Improving SWAT for simulating N_2O emissions from three cropping systems

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Outline

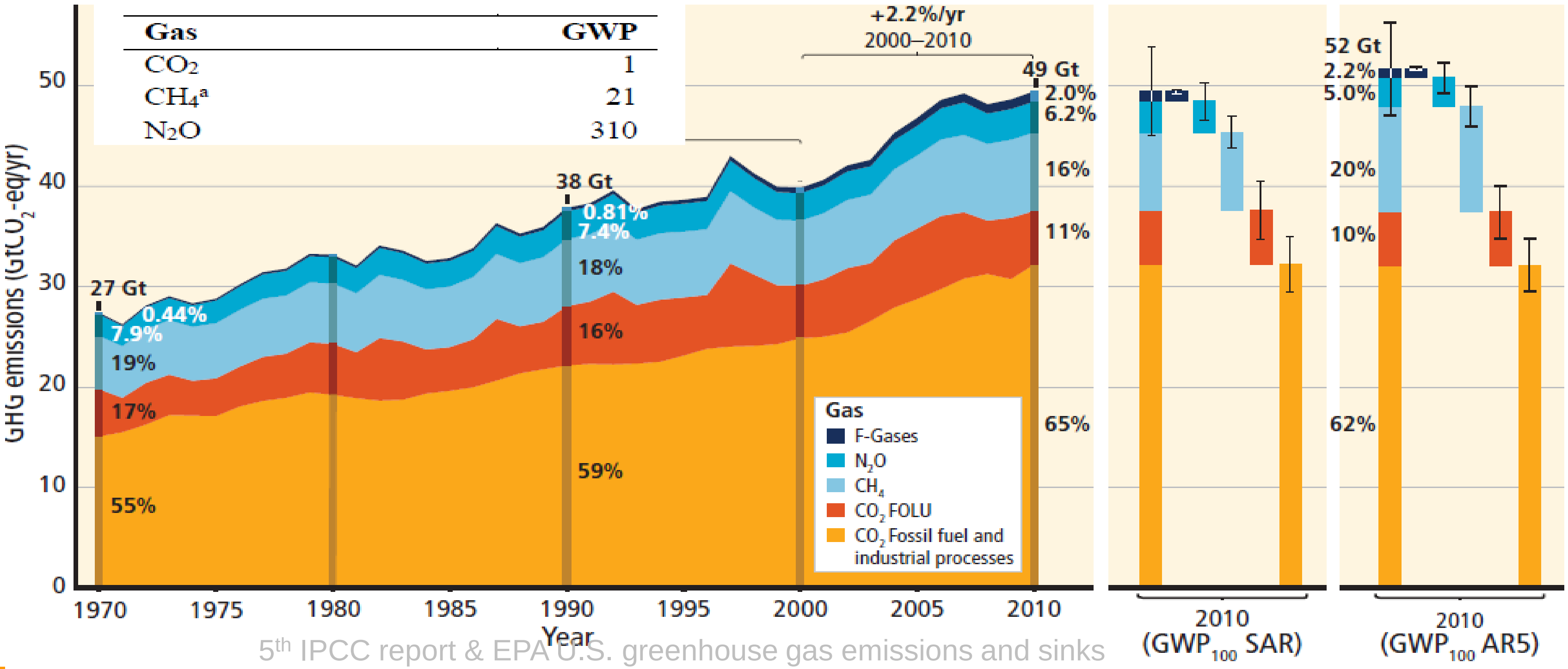
- **Background**
- **Objectives**
- **Model development**
- **Model performance evaluation**
- **Sensitivity analysis**
- **Summary**

Background

- Increasing evidences suggest that greenhouse gas (GHG) emission is a key driver of climate change.
- Nitrous Oxide (N_2O) is an important GHG due to its long lifetime and high global warming potential.

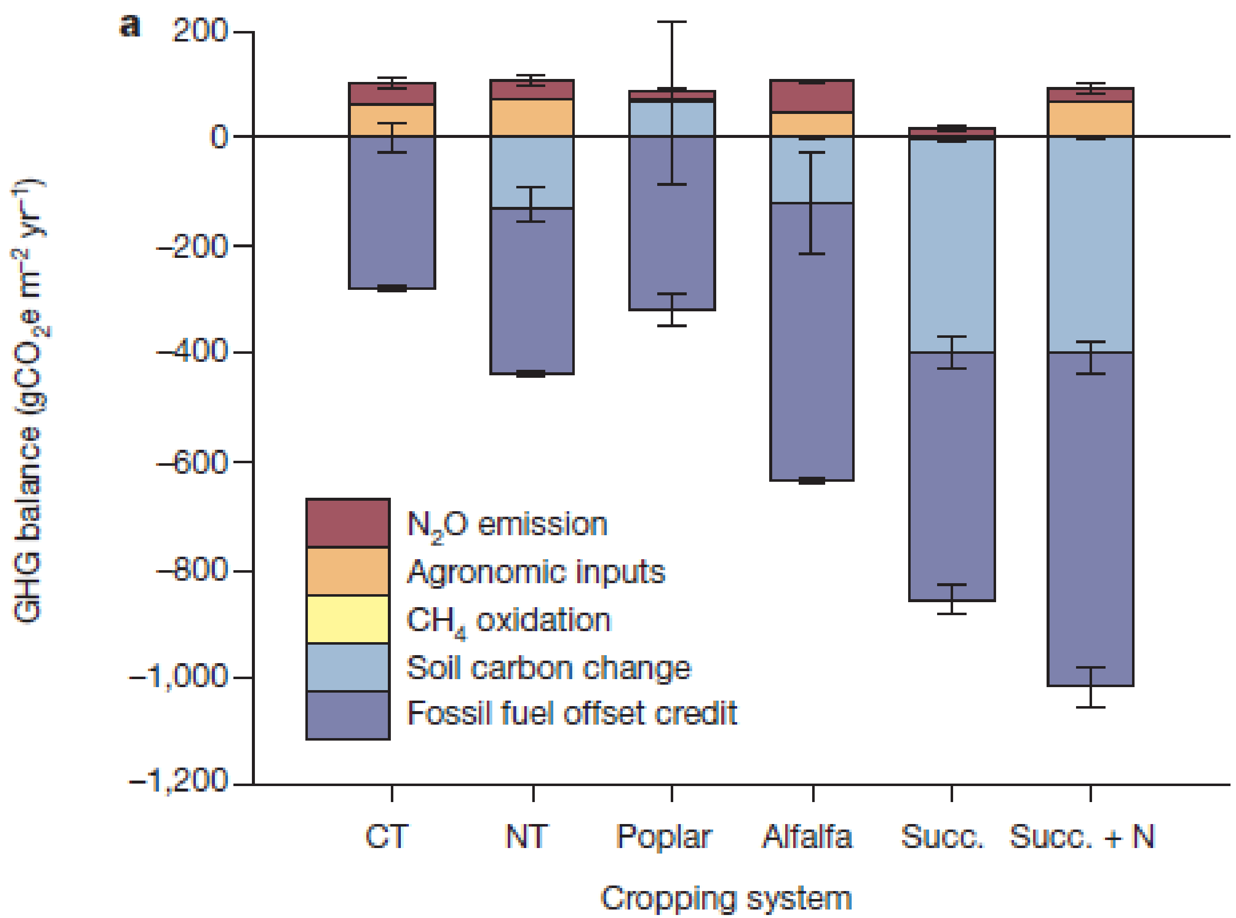
http://indianexpress.com/article/india/india-news-india/uttar-pradesh-flood-alert-2922703/
http://usatoday30.usatoday.com/weather/drought/2008-02-11-drought_N.htm

Gas	GWP
CO_2	1
CH_4[a]	21
N_2O	310



5th IPCC report & EPA U.S. greenhouse gas emissions and sinks

Green house gases (GHGs) balance of diverse cropping systems



Gelfand et al. 2013. Nature.

Background

- Agricultural system is the primary N_2O emitter in the U.S.

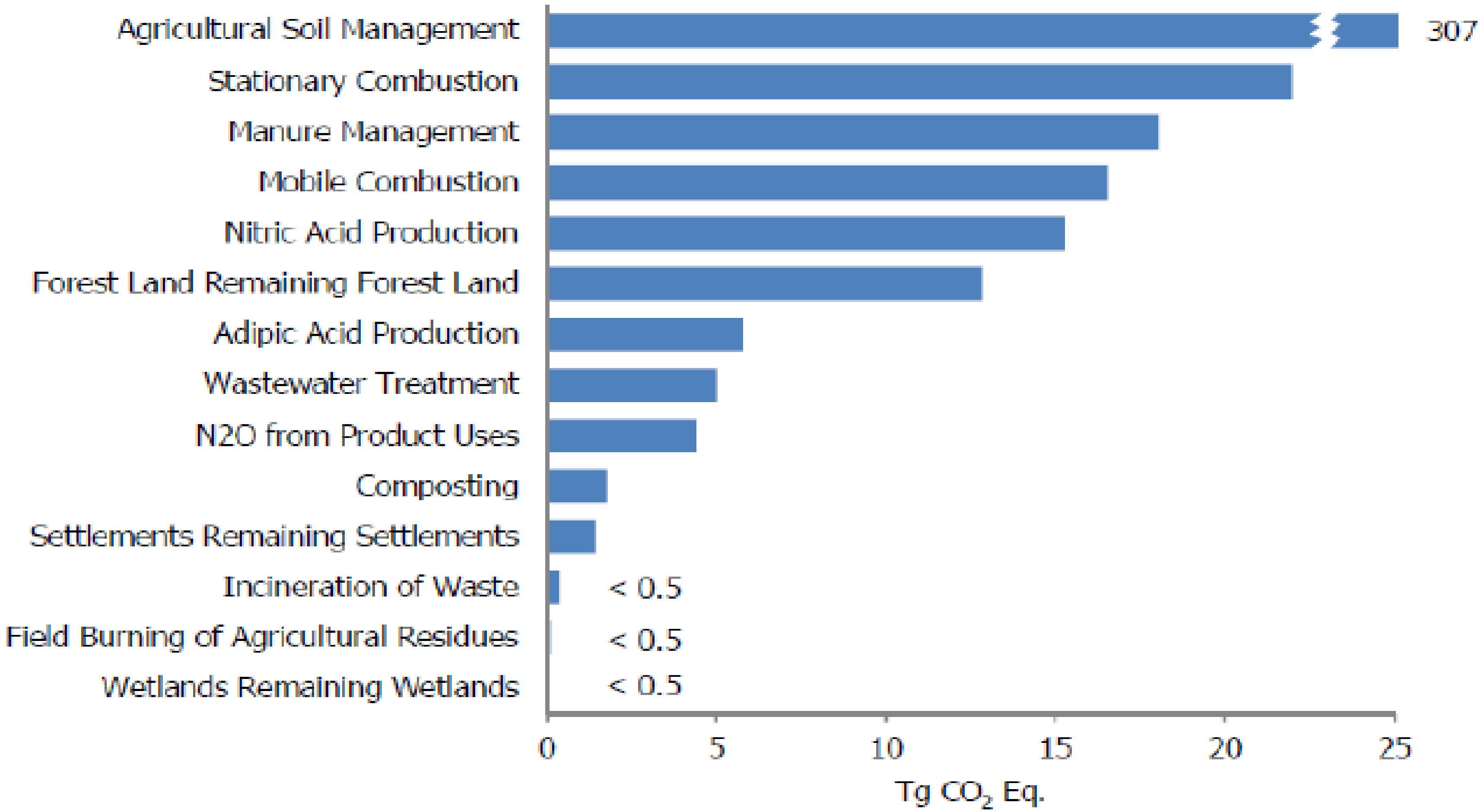


Table and the bottom figure from US EPA inventory of U.S. greenhouse gas emissions and sinks

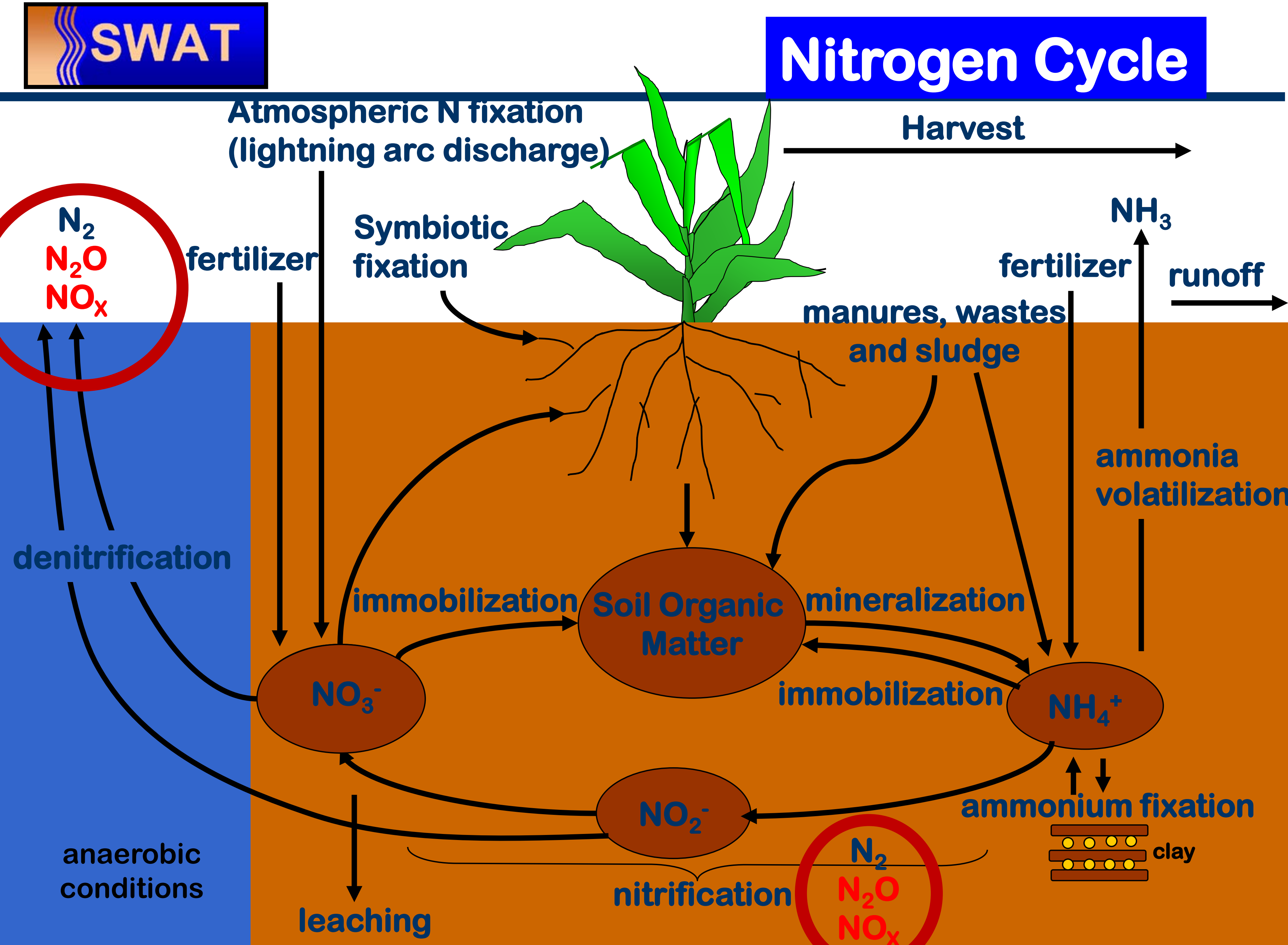
Objectives

- Develop a N2O emission module for SWAT
- Evaluate model performance with site-scale observational data
- Improve parameterization of the module
- Analyze sensitivity of N2O estimates to key parameters and input driving forces

Model development

- **Multiple numerical models have been developed to simulate N2O emission, including DAYCENT, DNDC, CLM, etc.**
- **Among these models, DAYCENT is the one that has been widely used and tested from site to global scales (Del Grosso et al, 2002, 2009)**
- **Current SWAT soil organic carbon processes were adopted from DAYCENT**

Nitrogen Cycle



Model development_nitrification

Nitrification

$NH_4 \rightarrow NO_2^- \rightarrow NO_3^+$

$NO_2^- \rightarrow NO \rightarrow N_2O$

$$N_{nit} = f_{moist} \times f_{st} \times f_{pH} \times N_{nit\_max} + N_{nit\_base}$$

Soil water impacts

$$f_{moist} = \frac{1}{1+30\times e^{-9\times rel\_wc}}$$

Soil T impacts

$$f_{st} = e^{\frac{4.5\times(1-(\frac{-5-ST}{-40})^{7})\times(\frac{-5-ST}{-40})^{4.5}}{7}}$$

Soil pH impacts

$$f_{pH} = 0.56 + \frac{1}{\pi} \times \operatorname{atan}(\pi \times 0.45 \times (SPH - 5))$$

http://bioenergyrus.blogspot.com/2008/05/nitrogen-cycle.html

Model development_denitrification

Denitrification

$NO_3^+ \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O$

$$E_{N2O\_den} = \frac{E_{den}}{1+Rn2n2o}$$

$$Rn2n2o = \mathrm{fRno3\_co2} \times \mathrm{fRwfps}$$

Soil diffusivity impacts

$$\mathrm{fRno3}_{\mathrm{co2}} = 0.16 \times \left(38.4 - 350 \times dD0_{fc}\right)$$

Soil water impacts

$$fRwfps = 1.5 \times wfps - 0.32$$

Soil texture impacts

$$E_{Nden} = Dtotflux \times fDwfps \times C_{unit} \times \rho_{soil}$$

Soil CO_2 impacts

$$Dtotflux = \min(fDco2, fDno3)$$

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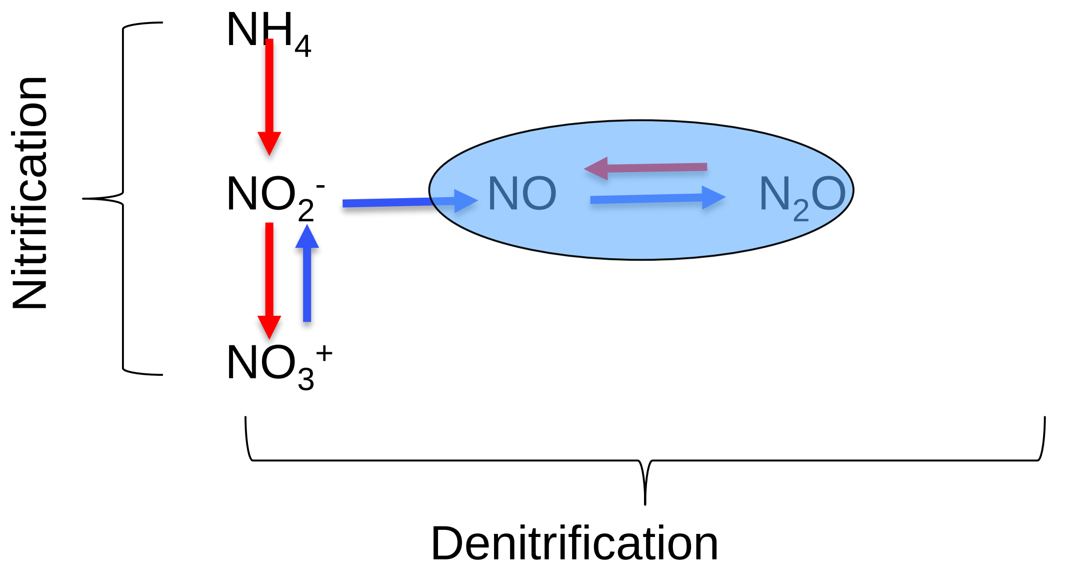
$$fDco2 = 0.1 \times \mathrm{co2}_{\mathrm{correction}}{}^{1.3} - min\_nit$$

Model development_N_2O oxidation



$$E_{NO\_N2O} = (E_{N2O\_den} + E_{N2O\_nit}) \times R_{no\_n2o}$$

Soil diffusivity

$$R_{no\_n2o} = 8 + \frac{18 \times \operatorname{atan}(0.75 \times \pi \times (10 \times dD0))}{\pi}$$

Model performance evaluation_site selection

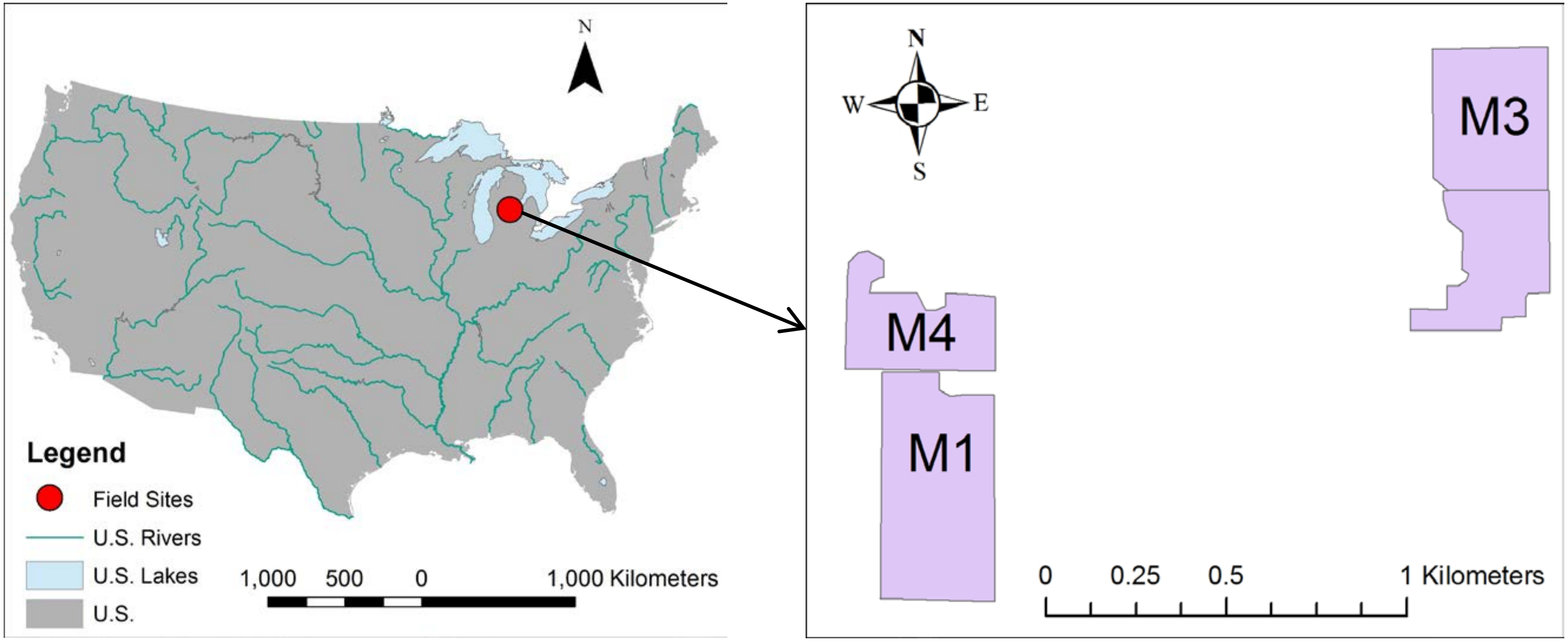
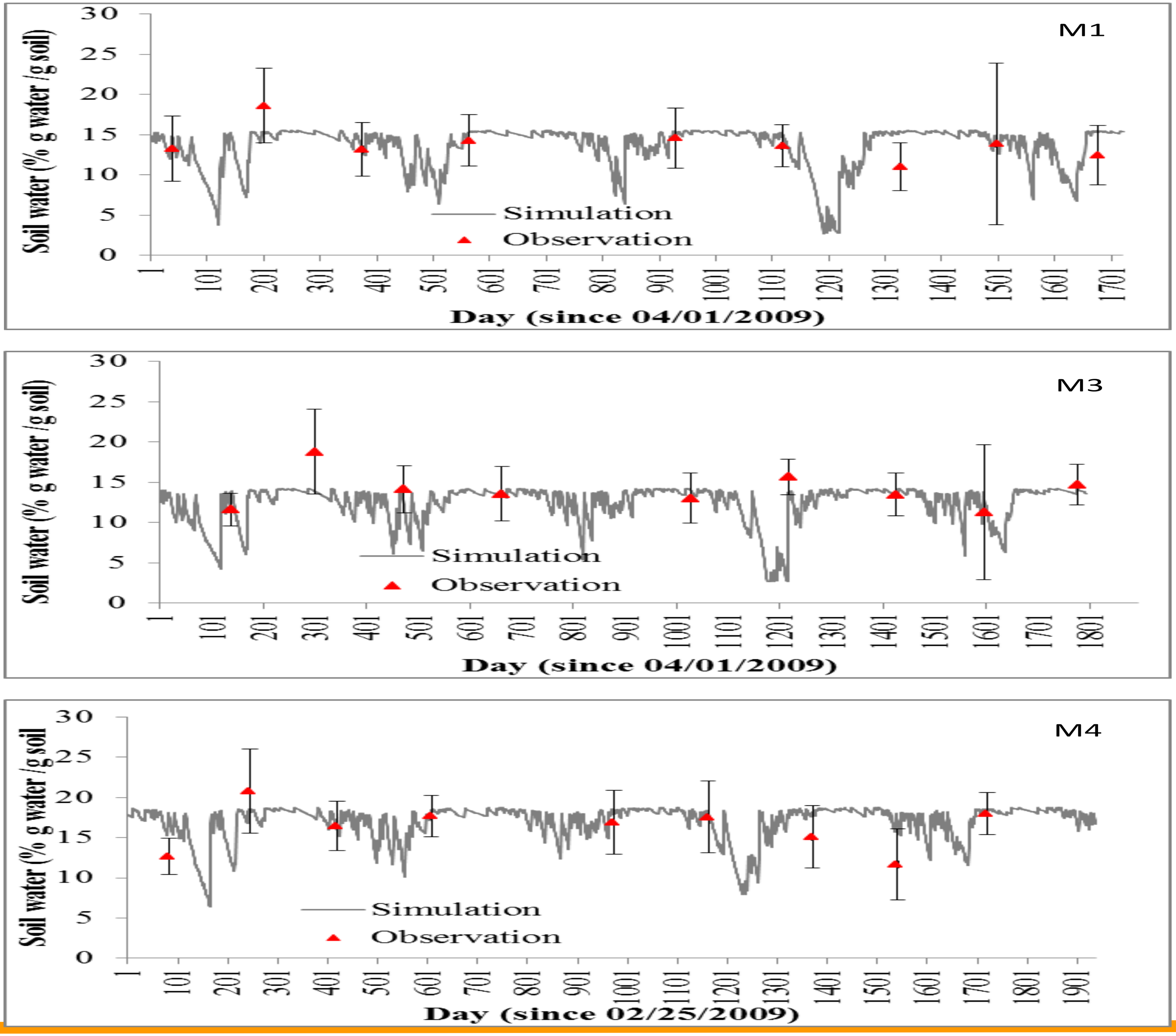


Figure 1. Locations of the three GLBRC scale-up experiment sites

A Corn site (M1), a switchgrass site (M3), and a reference site (M4) in the Marshall Farm Scale-up fields of GLBRC were selected for this study.

Model performance evaluation_soil water

- Soil water was sampled using the gravimetric method (original and dry weight difference)
- Sample were collected from the top 25 cm
- Simulated soil moisture was close to the average value of field data, or within one standard deviation of the average



Model performance evaluation_default simulation

- Default SWAT generally simulated well magnitude of N_2O fluxes
- Seasonal patterns of N_2O fluxes were reasonably simulated at M1 and M3, but not for the reference site (M4)

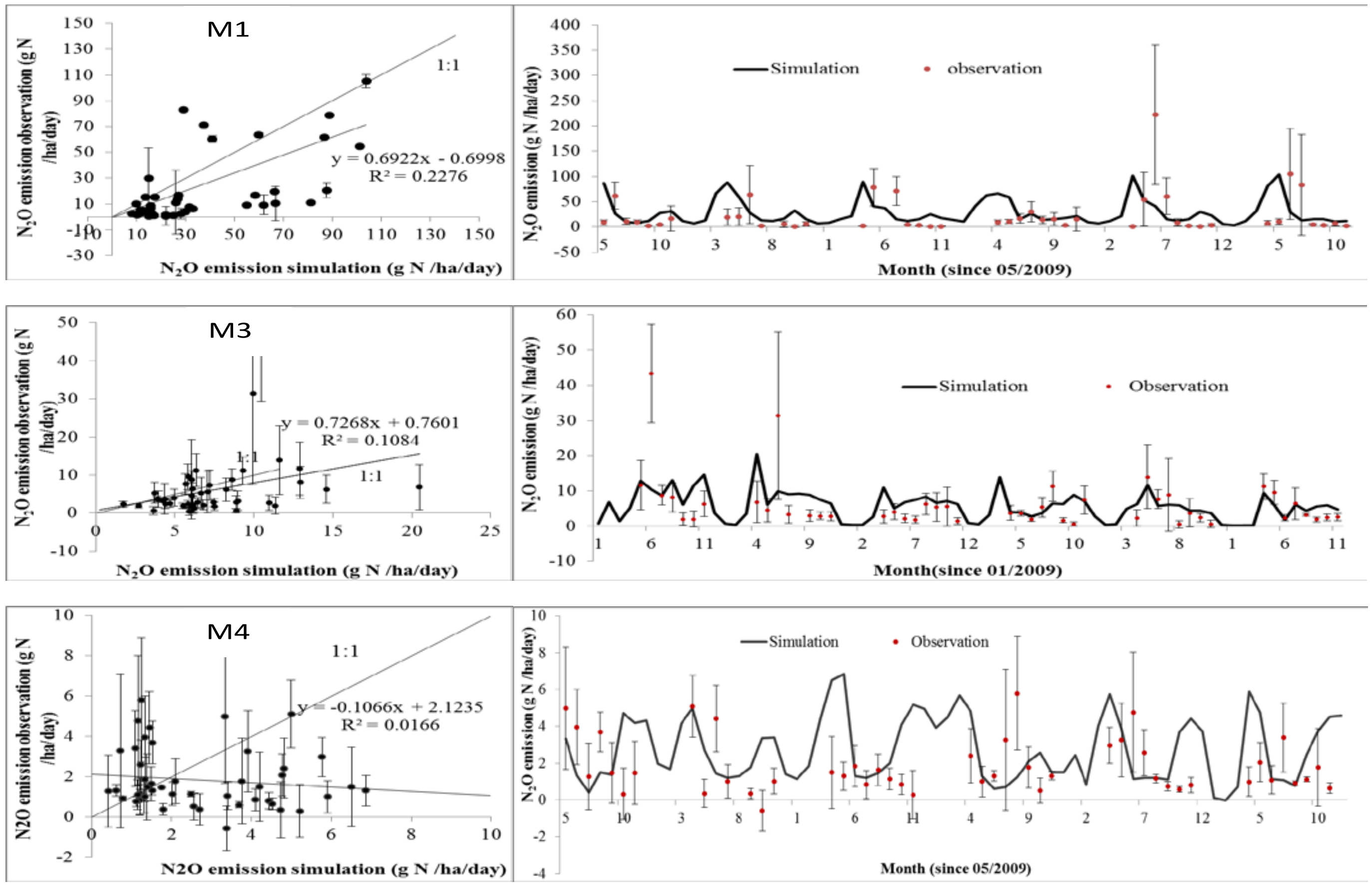


Figure 3. Model estimates of N_2O emission with default parameter values.at the three sites

Table 1 SWAT parameters controlling N_2O emission in nitrification and denitrification

Parameters	Unit	Default Values	Calibrated Values
adj_{fc}	unitless	0.015	0.012-0.018
adj_{wp}	unitless	0.002	0.0019-0.0022
$wfps\_adj$	day^{-1}	1	1.1-1.3
min_nit	unitless	0.1	0.1
f_{nit_max}	unitless	0.15	0.13-0.17

Note: adj_{fc} is the maximum fraction of N_2O to nitrified N at the field capacity; adj_{wp} is the minimum fraction of N_2O to nitrified nitrogen at the wilting point; min_nit N_{nit_base} is the minimum nitrate concentration required in a soil layer for trace gas calculation; $wfps\_adj$ is the adjustment on inflection point for water filled pore space effect on denitrification curve (unitless); f_{nit_max} is the maximum fraction of ammonia that is nitrified during nitrification (unitless).

we calibrated model parameters regulating N_2O production through nitrification and denitrification manually by adjusting parameter values to minimize the discrepancies between model estimates and field observation.

Model performance evaluation_improved simulation

- **The optimized parameter sets further reduced bias in estimated average N2O fluxes.**

- **Calibrated simulation also demonstrated better simulation of the seasonal patterns in N2O emission(P <0.05).**

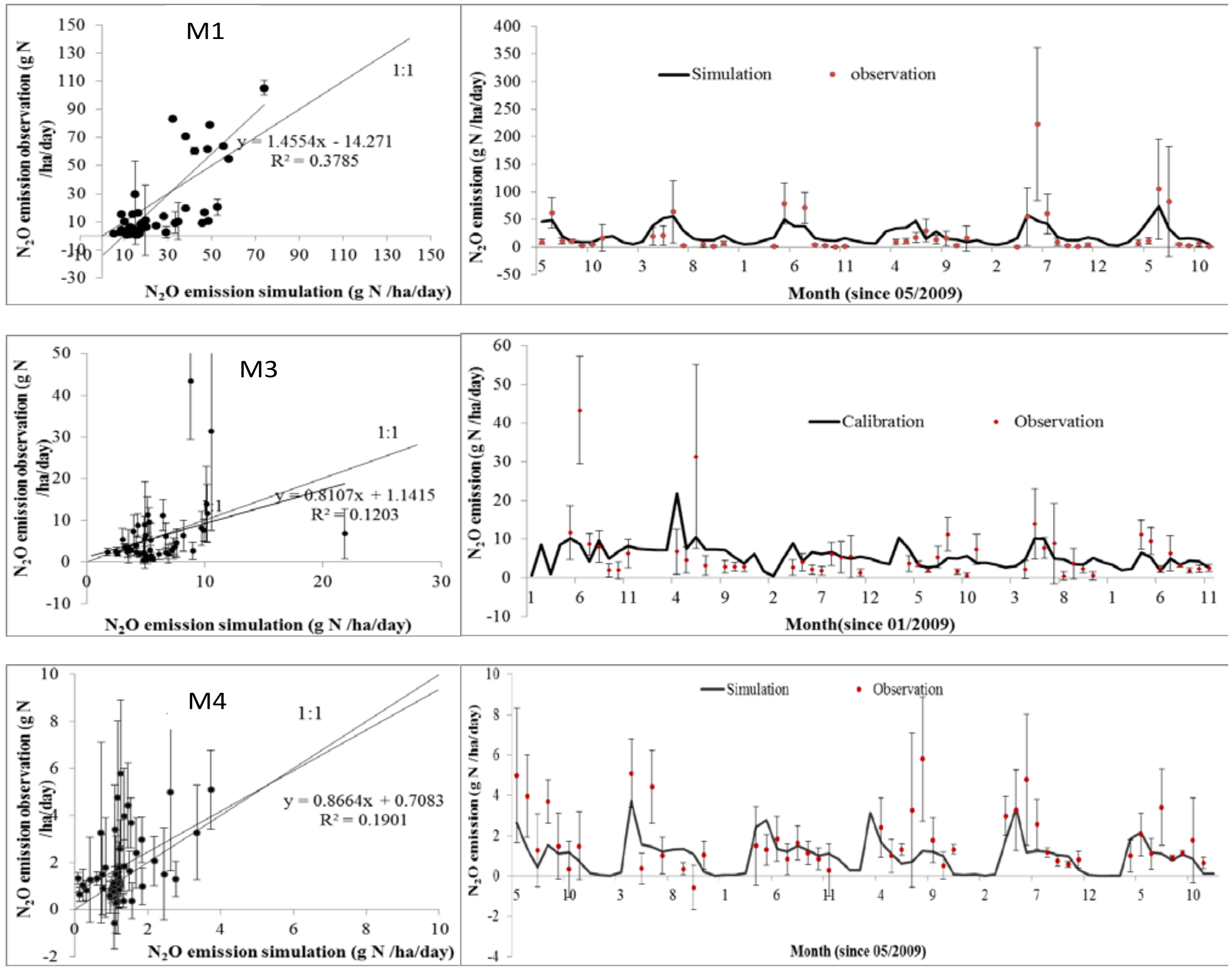
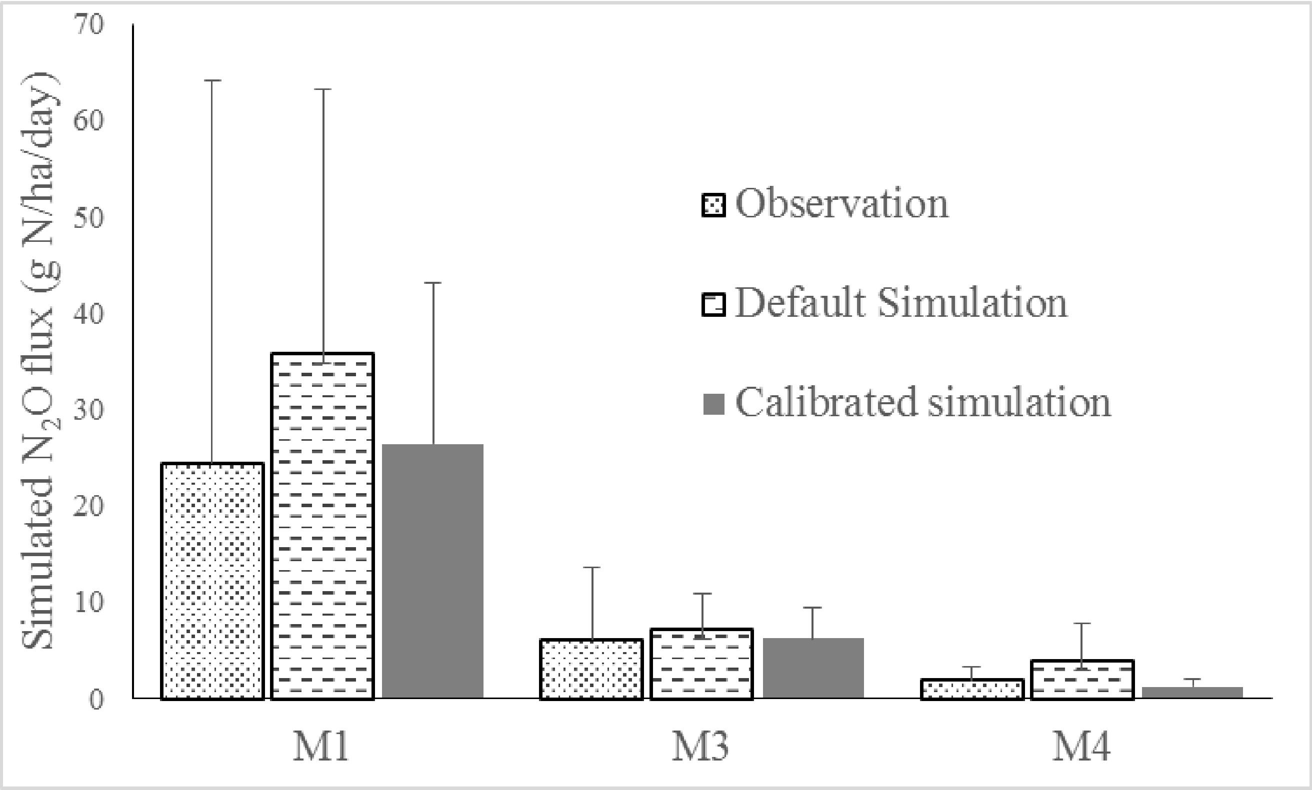


Figure 4. Model estimates of N_2O emission with calibrated parameter values.at the three sites

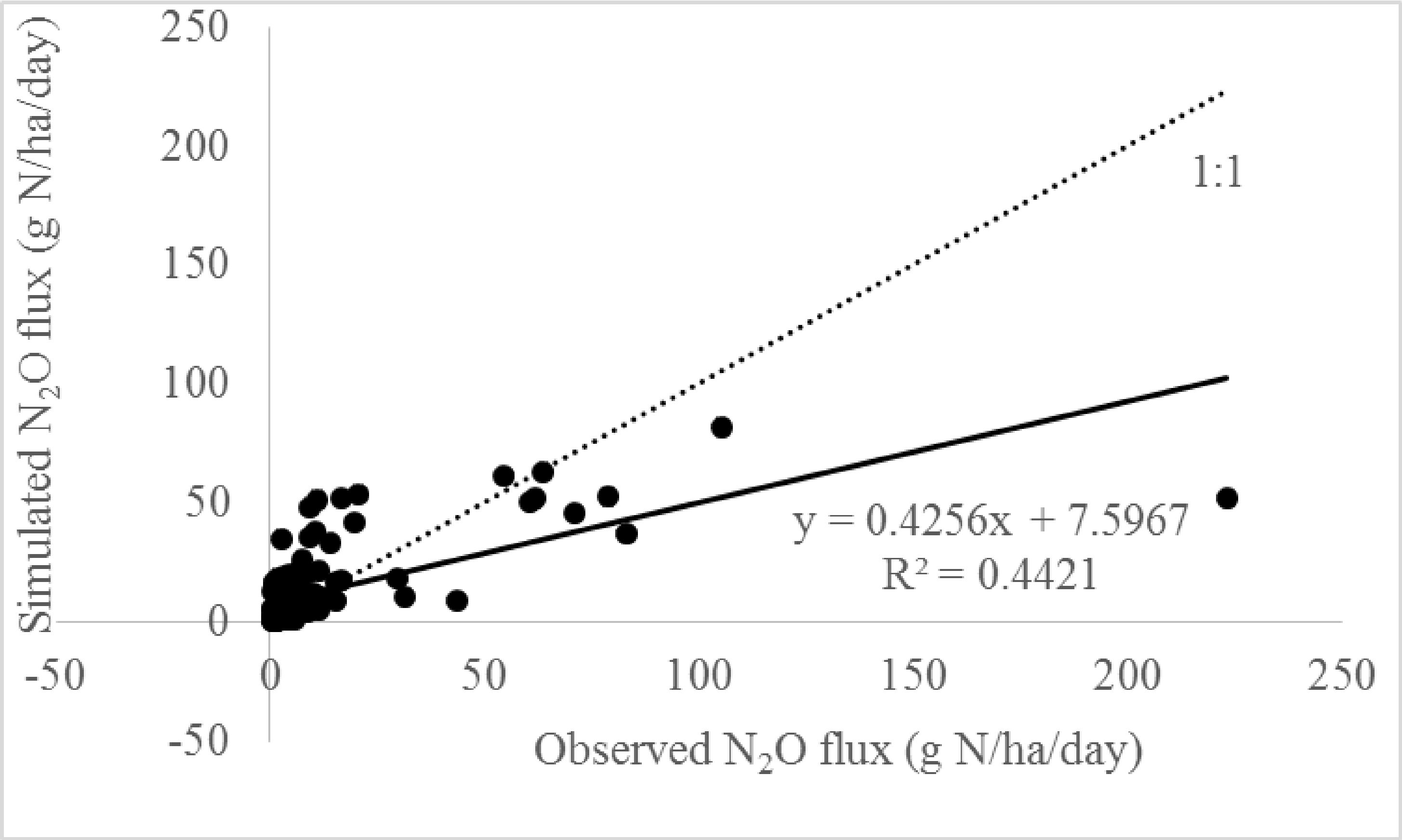
Comparison of default and calibrated simulations

Simulations	R^2			Bias		
	M1	M3	M4	M1	M3	M4
Default	0.23	0.11	0.02	48.6%	18.0%	117%
Calibrated	0.38	0.12	0.19	9.3%	2.4%	29%

Model performance evaluation



Model performance evaluation_improved simulation



The new SWAT model explained up to 44.21% of the spatial variability in the multi-year average N_2O emission over three sites that represent a broad range of management activities

Parameter sensitivity analysis

Table 2. Sensitivity response of N_2O emission to changes of key parameters

Parameters	Changes in Parameter (%)	Changes in N_2O emission M1 site (%)	M3 site (%)	M4 site (%)
adj_{fc}	-20	-9.41	-12.19	-12.68
	+20	+9.21	+12.14	+12.69
adj_{wp}	-20	-0.19	-0.38	-0.72
	+20	+0.17	-	+0.72
min_nit	-20	-	-	-0.72
	+20	-	-	+0.02
$wfps\_adj$	-20	+86.79	+18.14	+195.10
	+20	-40.48	-33.65	-3.9
f_{nit_max}	-20	-3.62	+0.18	-0.77
	+20	+2.35	-0.19	+0.53

Note: adj_{fc} is the maximum fraction of N_2O to nitrified N at the field capacity; adj_{wp} is the minimum fraction of N_2O to nitrified nitrogen at the wilting point; min_nit N_{nit_base} is the minimum nitrate concentration required in a soil layer for trace gas calculation; $wfps\_adj$ is the adjustment on inflection point for water filled pore space effect on denitrification curve (unitless); f_{nit_max} is the maximum fraction of ammonia that is nitrified during nitrification (unitless); '-' indicate changes less than 0.01%.

Sensitivity to input data

Table 3. Response of N_2O emission to changes in climate conditions and fertilizer use

Parameters	Changes in variable	Changes in N_2O emission M1 site (%)	M3 site (%)	M4 site (%)
Precipitation	-20%	-3.66	-3.12	-1.52
	+20%	+1.39	+1.50	+1.44
Temperature	+1ºC	+3.69	+1.94	+2.68
	+2ºC	+14.36	+0.59	+5.74
Fertilizer use	-20%	-16.25	-0.21	NA
	+20%	+21.01	+0.14	NA

Note: Negative signs indicate decreases whereas positive signs suggest increases; 'NA' indicates not applicable.

Our sensitivity analysis suggested that N_2O emission had positive correlations with changes in precipitation at the selected sites; Warmer temperatures (2ºC increase) would further increase N_2O emission; Responses of N_2O emission to changing fertilizer use highlighted the significant control of chemical fertilizer application on N_2O production, particularly at the corn site (M1).

Summary

- Developing N_2O emission module for SWAT is critical for strengthening the model's capability in simulating agricultural ecosystems.
- New algorithms provide reasonable estimates of average N_2O fluxes over the three sites, but did not simulate seasonal patterns well at the M4 site.
- Parameter calibration substantial reduce bias in model estimates, and improve simulation of seasonal changes in N_2O fluxes over the three sites.
- Sensitivity analysis is expected to provide valuable information for future application of the model
- Warmer and wetter climate scenarios tended to enhance N_2O emission over the study area.
- Sensitivity response of N_2O simulation to fertilizer use call for improved management practices to reduce fertilizer loss through N_2O emission.

Thanks