Process-Based Models for Estimating Nitrous Oxide Emissions in Agricultural Crop Production

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JGCRI Joint Global Change Research Institute

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Models to estimate N_2O: Results of a bibliographic search

- Web of Science search
  - "denitrification models": ~2,800 citations
  - "denitrification models" and "agriculture": 131 citations
  - "((nitrous oxide) or (n2o))" and "models" and "agriculture": 209 citations
- Process-based models identified based on "model_name" and "((nitrous oxide) or (n2o))"
  - DNDC (Li et al. 1992): 139 citations
  - DayCent (Parton et al. 1996): 33 citations
  - *ecosys* (Grant et al. 2001): 23 citations
  - APSIM (Thorburn et al., 2010): 3 citations

N_2O-emission features that we would like to capture with process-based models

- Temporal trends
  - Interannual
  - Seasonal
  - Event-driven (e.g. fertilization)
- Spatial trends
  - Soil variability
  - Landscape controls
  - Cropping system – soil – landscape interactions
- N sources
  - Synthetic fertilizers
  - Organic amendments
  - Biological fixation
- N rates
- N timing
- N placement
  - Broadcast
  - Banding
- Nitrification inhibitors

Objective

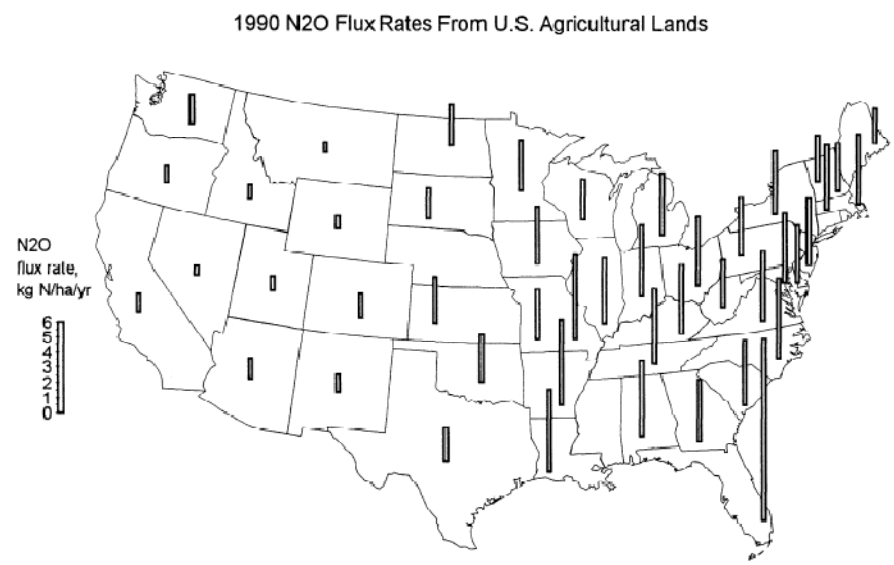
To review and exemplify process-based models for estimating nitrous oxide emissions in agricultural production systems

Outline

- Review model features and provide examples for
  - DNDC
  - DAYCENT
  - *ecosys*
  - APSIM
  - EPIC with new denitrification submodel
- Summarize model features, performance, and applications

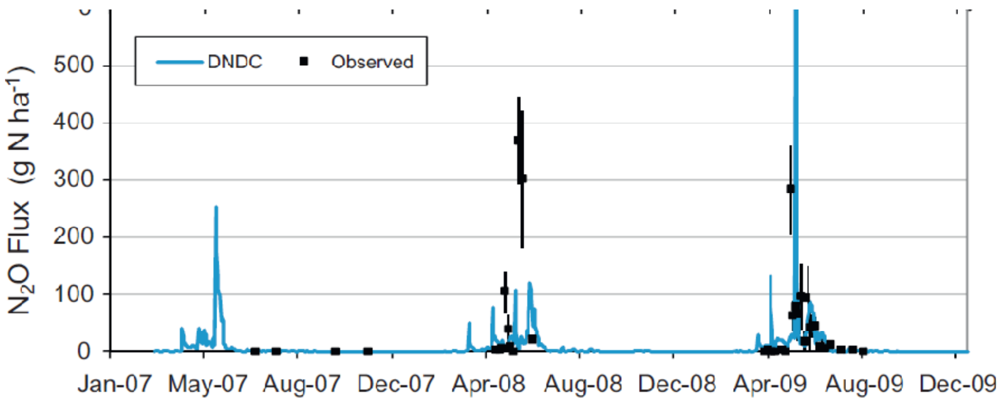
DNDC, a biogeochemical model to simulate soil carbon dynamics and trace gases in agriculture
Li et al. (1992a,b) J. Geophys. Res. 97

- Denitrification in DNDC occurs under oxygen-deficient conditions (e.g., wet soils following rain events)
- Nitrates are converted to NO_2^- and then to N_2O and N_2
- Nitrous oxide production and denitrification are functions of carbon decomposition, soil pH, soil water content, and soil temperature
- Uses of “anaerobic balloon” concept
- Li et al. (1996) produced generalized estimates of N_2O fluxes across U.S. agricultural lands



Li et al. (1996) Global Biogeochem. Cycles 10:297-306

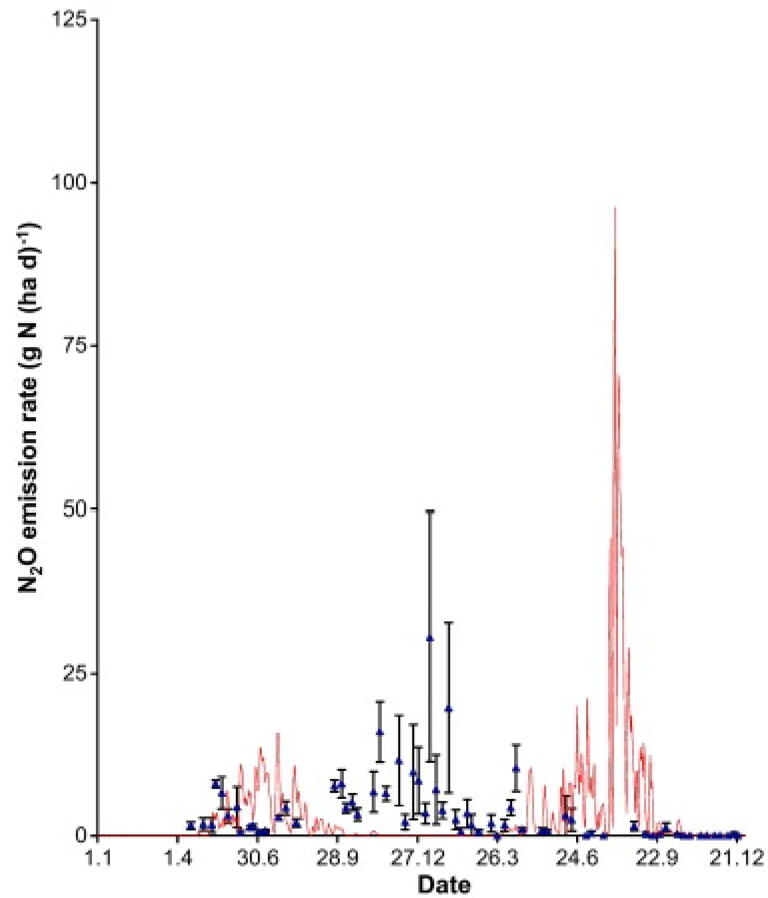
Capturing temporal distribution of N_2O fluxes with the DNDC model



DNDC-modeled (lines) and measured (symbols) N_2O emissions from soils under reduced tillage in Italy (Lugato et al. 2011. Agric. Ecosys. Environ. 139:546–556)

Year	Measurement period	Casselman[a]	Morewood[a]	DNDC[b]
		kg N_2O-N ha^{-1}		
2000	March 21–April 10	0.53	0.33	0.34
2001	March 19–April 27	0.55	0.52	0.76
2003	March 27–April 25 and May 15–June 12	1.87	1.34	1.44
2004	March 29–June 4	1.77	1.29	1.11

Aircraft-based measured and DNDC modeled N_2O emissions in Canada (Desjardins et al. 2010. Agric. For. Meteor. 150:817–824).



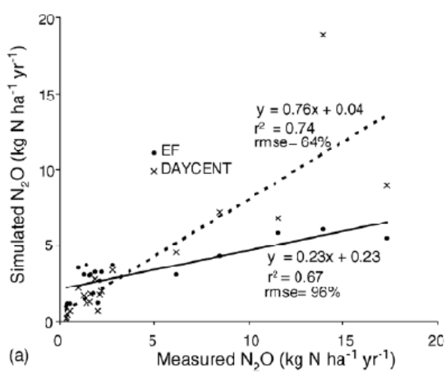
DNDC-modeled (lines) and measured (symbols) N_2O emissions from soils under conventional tillage in Germany (Ludwig et al. 2011. Soil Tillage Res. 112:114–121)

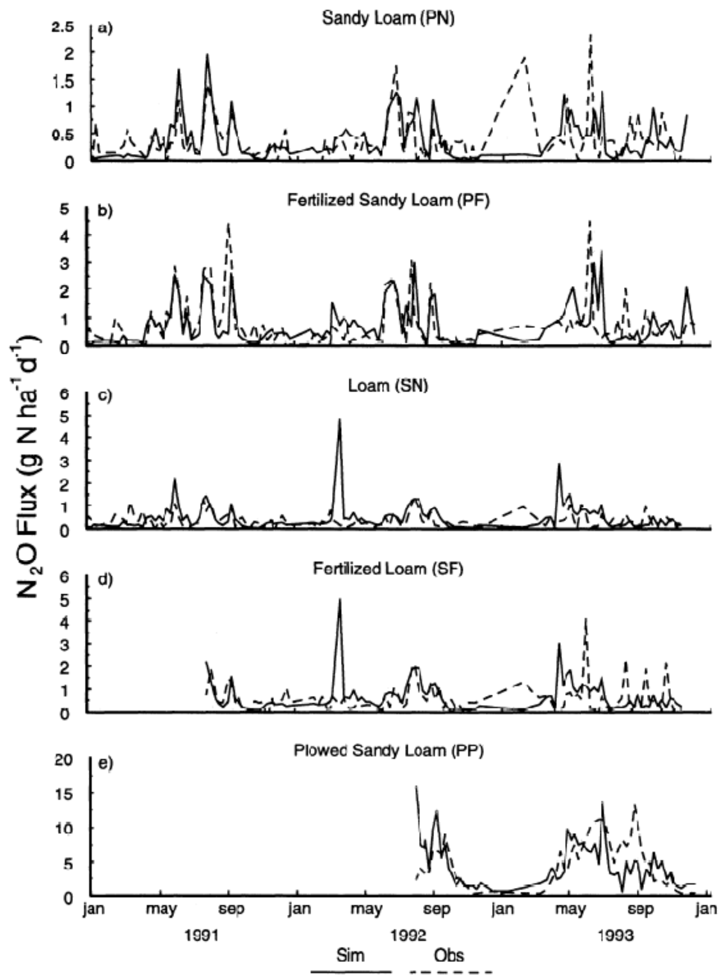
Modeling N_2O and N_2 production generated from denitrification and nitrification process

Parton et al. (1996) Global Biogeochem. Cycles 10:401-412

- Daily time step process-based model developed on the basis of the Century model
- Models nitrification as a function of soil pH, soil water content, soil temperature, and soil NH_4^+ level
- N_2O formation during nitrification is a direct function of nitrification rate
- N_2O and N_2 formation during denitrification is modeled as a function of heterotrophic respiration, soil NO_3^- level, and water-filled pore space (WFPS)

IPCC estimated and DNDC modeled comparisons against observed N_2O emissions in 5 US states and 1 Canadian province (Del Grosso et al. 2005. Soil Tillage Res. 83:9–24).





Parton et al. (1996) Global Biogeochem. Cycles 10:401-412.

Comparison of DAYCENT modeled and IPPC estimated global N_2O emissions (Tg CO_2eq) for corn, wheat, and soybean (Del Grosso et al. 2009)

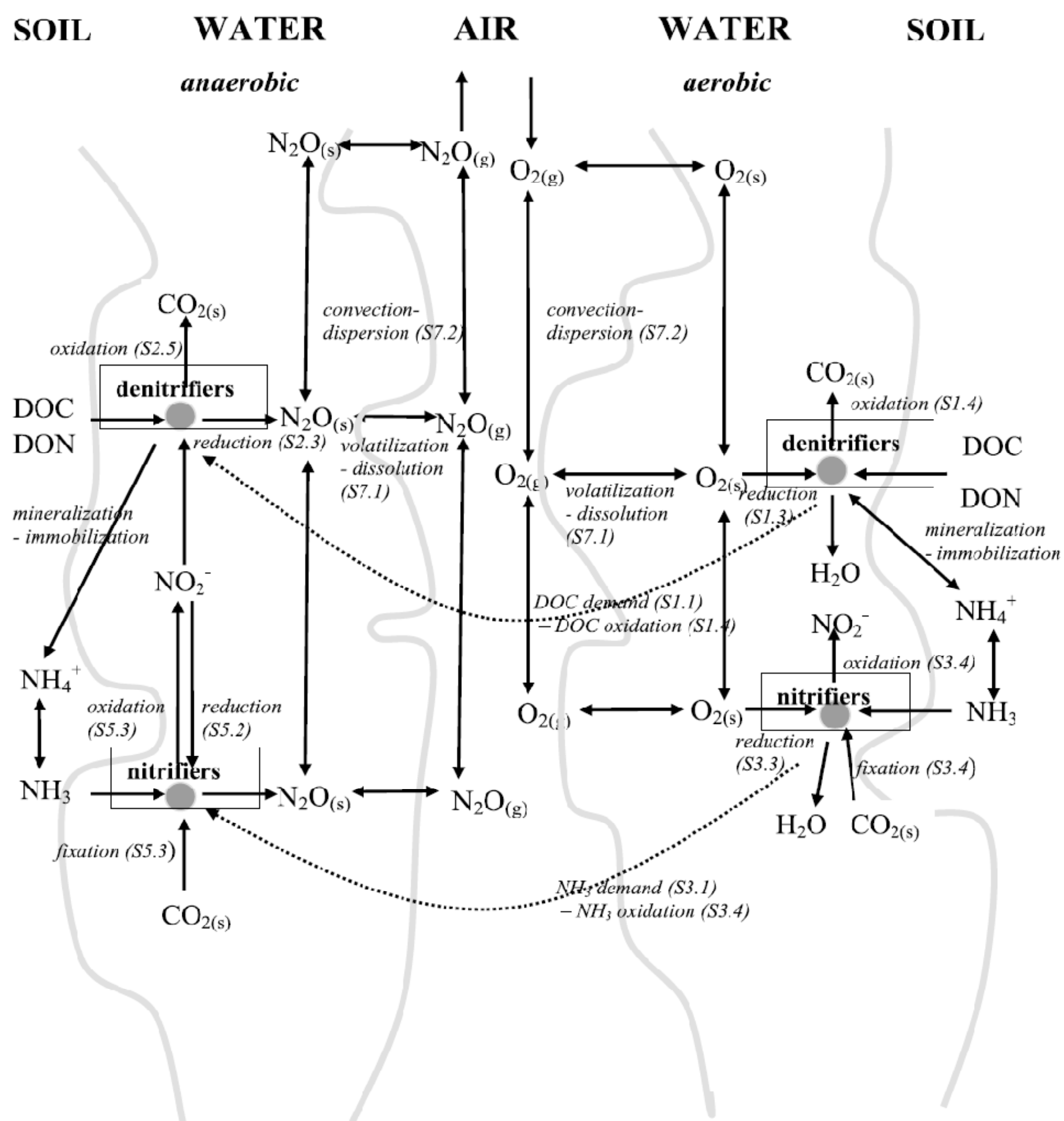
	N_2O direct		N_2O indirect		Total N_2O		% delta total N_2O
	IPCC	DAYCENT	IPCC	DAYCENT	IPCC	DAYCENT	(DAYCENT−IPCC)/IPCC
IPCC (1997) methodology							
Corn	183	118	110	115	293	233	−20.6
Wheat	284	274	171	225	454	500	10.0
Soybean	119	38	8	36	127	73	−42.1
Sum	586	430	289	377	875	806	−7.8
IPCC (2006) methodology							
Corn	146	118	48	37	195	154	−20.7
Wheat	227	274	75	71	302	345	14.5
Soybean	36	38	9	12	46	50	8.8
Sum	410	430	132	120	542	549	1.4

Modeled vs. observed growing season N_2O emissions ($kg\ N_2O\text{-}N\ ha^{-1}$) at two sites in Canada

	Observed	DNDC	DAYCENT
Quebec site			
Fertilizer, 150 kg N	0.23	0.74	0.66
Pig slurry, 60 Mg	1.21	2.04	0.82
Pig slurry, 120 Mg	3.08	1.81	1.28
Woodlsee site			
Conv. tillage	1.03	0.86	0.57
No tillage	1.04	0.86	0.55
Zone tillage	0.92	0.96	0.54

Smith et al. 2008. Can. J. Soil Sci. 88:251-260

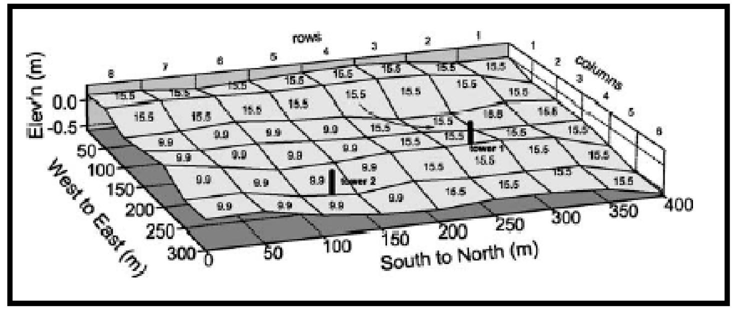
Reactions, products, and gas transport in gaseous and aqueous phases in *ecosys* (Grant et al. 2001)



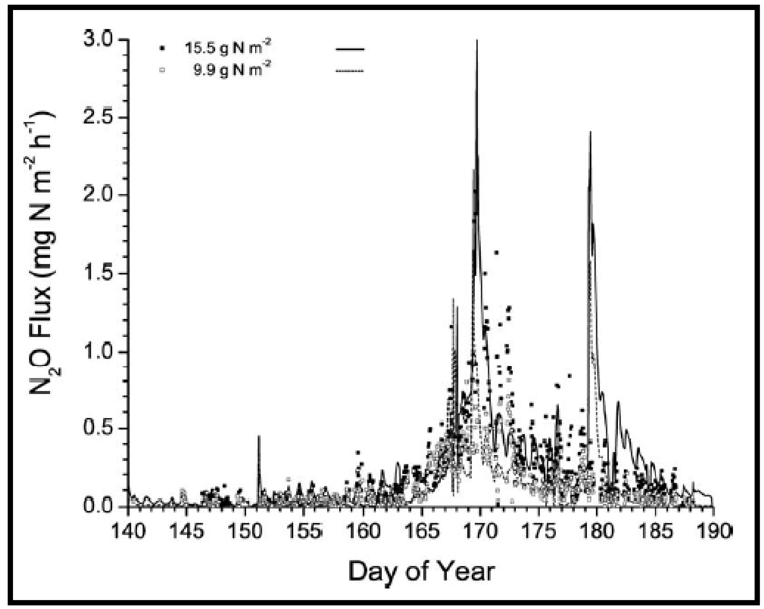
Modeling N_2O fluxes at the field scale with *ecosys*

Grant and Pattey. (2003) Soil Biol. Biochem. 35:225-243

- The model *ecosys* was run in 3D mode to simulate N_2O fluxes from a fertilized field with topographic variations
- Modeled data were compared with field scale measurements made using eddy covariance towers and a tunable diode laser trace gas analyzer
- Large spatial and temporal variability of N_2O emissions were modeled and measured
- Aggregation of N_2O flux measurements to regional scales should be based upon
  - sub-daily measurements at representative landscape positions,
  - rather than upon less frequent measurements at individual sites



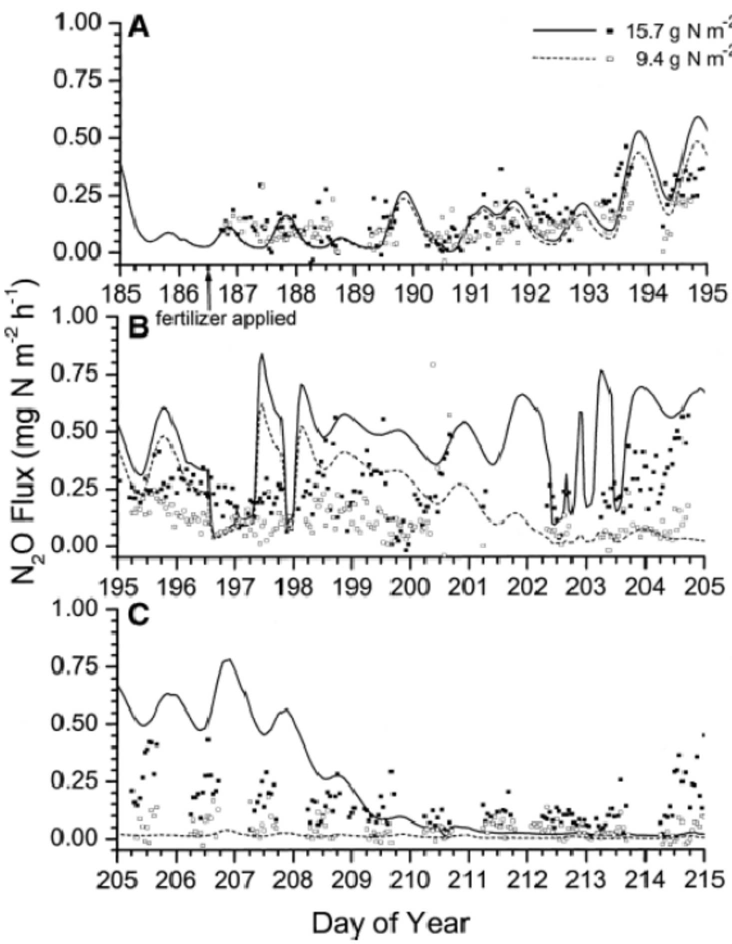
N application and TDL towers



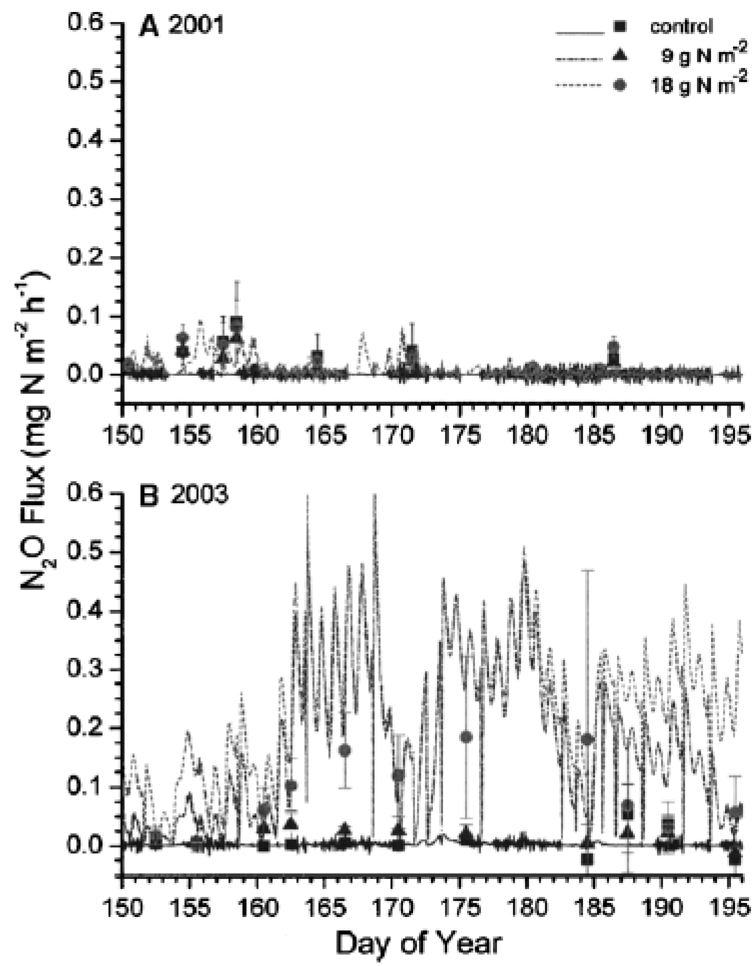
Observed (symbols) and modeled (lines) N_2O fluxes

Modeling effects of N rate on N_2O flux with *ecosys*

Ottawa, Ontario



Edmonton, Alberta

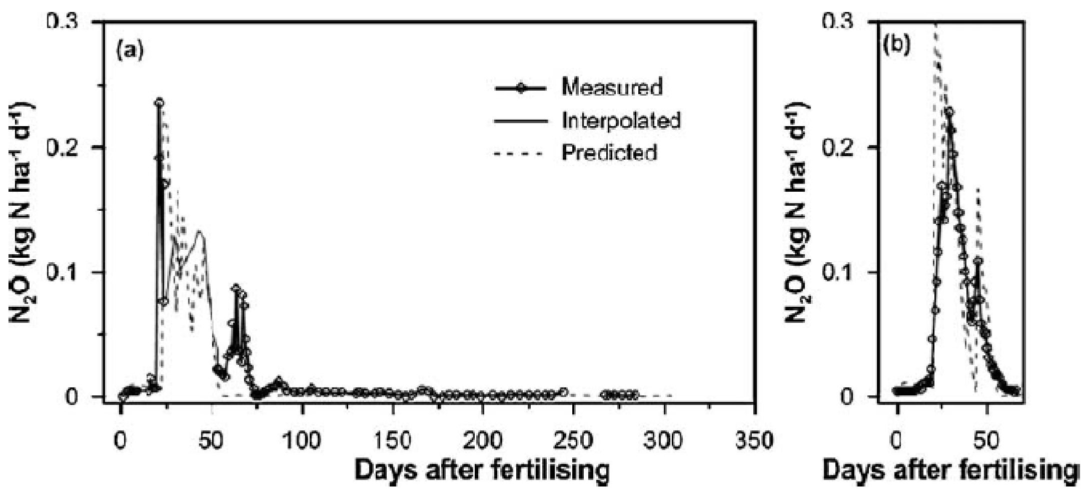


Grant et al. 2006. Soil Sci. Soc. Am. J. 70:235–248.

Modeling N_2O fluxes at the field scale with the APSIM model

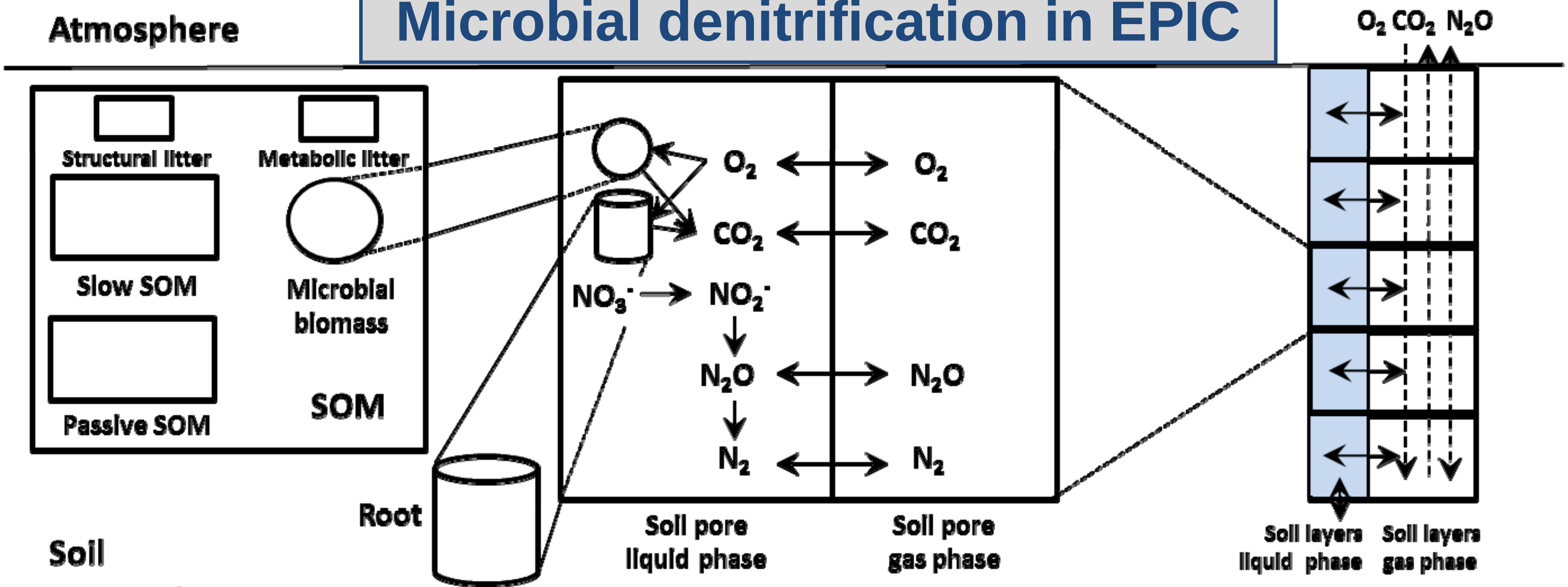
Thorburn et al. 2010. Agric. Ecosys. Environ. 136:343–350.

- Denitrification, a function of
- $R_{denit,i} = k_{denit}\ NO_{3,i}\ C_{A,i}\ F_{moist,i}\ F_{temp,i}$
- N_2O algorithms adapted from DAYCENT
- Tested under Australian conditions (sugarcane, subtropical cropping systems)



APSIM predicted and observed N_2O emissions in two sugarcane crops in Australia (Thorburn et al. 2010. Agric. Ecosys. Environ. 136:343–350).

Microbial denitrification in EPIC



Soil organic matter decomposition (daily)

- Potential C / N decomposition
  - Temperature
  - Water
  - Tillage
- Potential electron supply from microbial respiration
- Actual C / N decomposition based on electron and mineral N availability

Denitrification (hourly)

- Potential electron supply
- Habitable pore space
- Oxygen diffusion to microbial and root surfaces
- Oxygen uptake based on Michaelis - Menten kinetics
- Electrons not accepted by O_2 to denitrification
- Competitive inhibition approach to decide electrons accepted by NO_3^-, NO_2^-, and N_2O

Gas transport (hourly)

- Gas diffusion coefficients adjusted for tortuosity
- Initial partition of gases in gas and liquid phases based on solubility
- Numerical solution of gas transport equation
- Gas concentrations in gas and liquid phases recalculated each hour
- Surface gas flux; closed lower bound

Gas transport (daily) in liquid phase

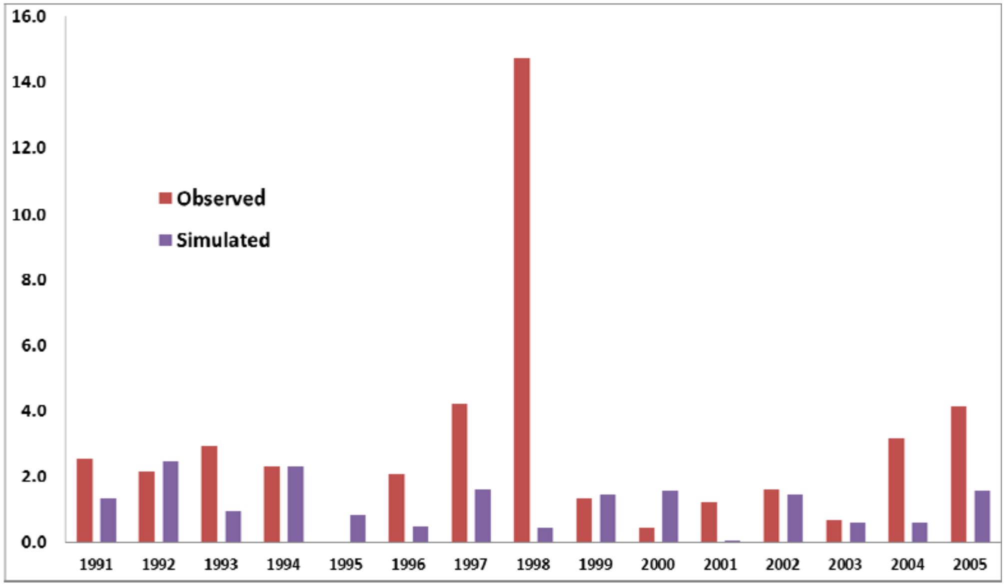
- Runoff
- Subsurface flow
- Percolation

Izaurralde, McGill, Williams, Link, Manowitz, Schwab

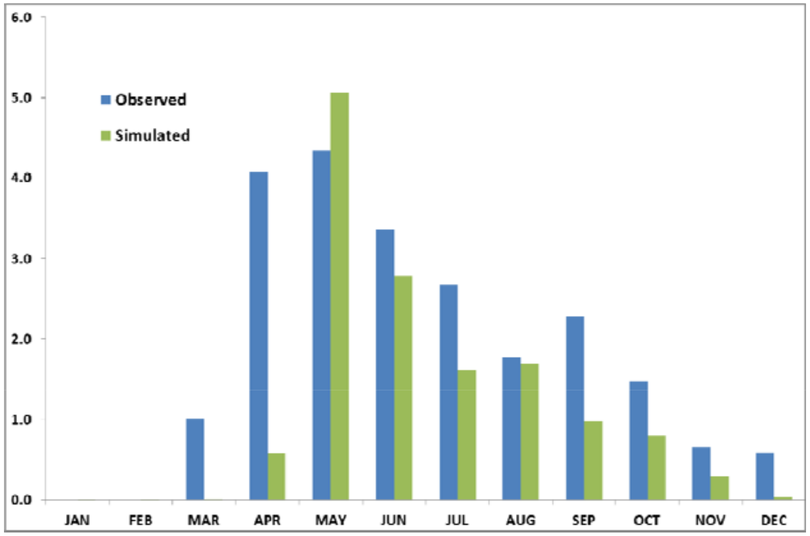
EPIC-simulated vs. observed N_2O flux in a corn-soy-wheat rotation at KBS, MI (g N_2O-N ha^{-1} d^{-1})

KBS Plots

Annual



Seasonal



Summary

- Models reviewed contain sufficient mechanistic-level representation to capture N_2O dynamics in agriculture production as affected by
  - Cropping practices
  - Fertilizer rates
- Improvements needed on
  - Temporal resolution (annual, seasonal, daily)
  - Fertilizer placement and source
  - Nitrification inhibitors
- Opportunities for model intercomparisons like
  - Soil Organic Matter models – Rothamsted Workshop 1995
  - AgMIP (climate change) – ongoing

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GP Robertson	Kellogg Biological Station LTER Michigan St. Univ.

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