University of New Hampshire

Understanding Greenhouse Gas Mitigation with Biogeochemical Models

Changsheng Li, University of New Hampshire

Background:

Production of greenhouse gases (GHGs) has long been a company of life on this planet since 4 billion years ago. When the primitive atmosphere and oceans turned from anoxic to oxic, the life shifted its respiration from anaerobic to aerobic to survive. Methanogens and denitrifiers, the anaerobic heterotrophes, yielded to the aerobic decomposers dominating the Earth ecosystems. However, all the genes or enzymes still co-exist in the contemporary bacteria even their expression is conditional, mainly depending on redox potential (Eh) of the environment. Nowadays, three major greenhouse gases (GHGs), methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2), are byproducts of survival of the bacteria activated by Eh and sustained by dual nutrients, electron donor (e.g., dissolved organic carbon) and electron acceptor (e.g., oxygen, nitrate etc.). If any of the three drivers is altered, the production of GHGs can be reduced or eliminated. As there are a lot of farming management practices (e.g., tillage, fertilization, irrigation, crop rotation) which can alter the soil Eh, electron donor or electron acceptor status, the potential for mitigating GHG emissions from agricultural land is large.

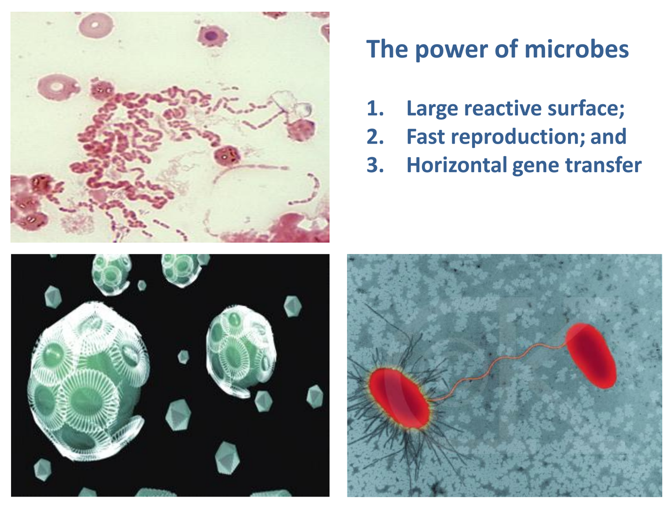
The invisible hand in universe: Thermodynamics
Microbes gain energy in the most efficient way

$C + O_2 \rightarrow CO_2$
(ΔG = -393.51 kJ/mol)

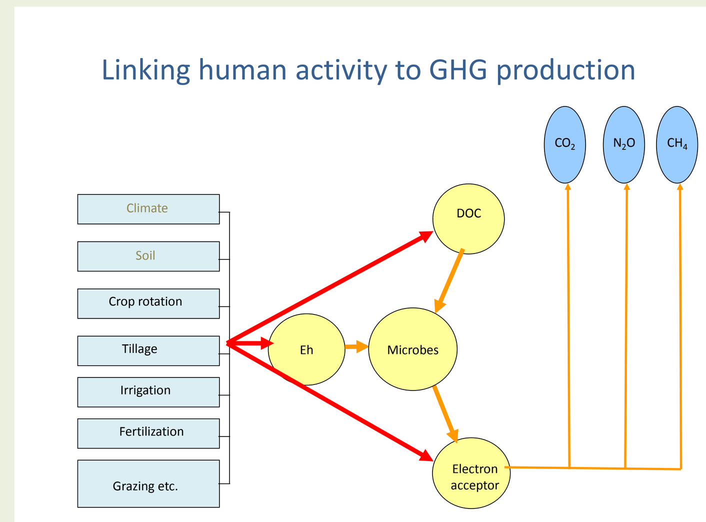
$2C + NO_3 \rightarrow NO_2 \rightarrow NO \rightarrow N_2O \rightarrow N_2$
(ΔG = -245.23 kJ/mol)

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$
(ΔG = -50.75 kJ/mol)

$CH_3COO^- + H^+ \rightarrow CH_4 + CO_2$
(ΔG = -36 kJ/mol)



The power of microbes
1. Large reactive surface;
2. Fast reproduction; and
3. Horizontal gene transfer



Two Equations Controlling Microbial Activity

- The **Nernst Equation** (thermodynamics):

$Eh = Eo + RT/nF \cdot \ln([OX]/[RE])$

- The **Michaelis-Menten Equation** (kinetics):

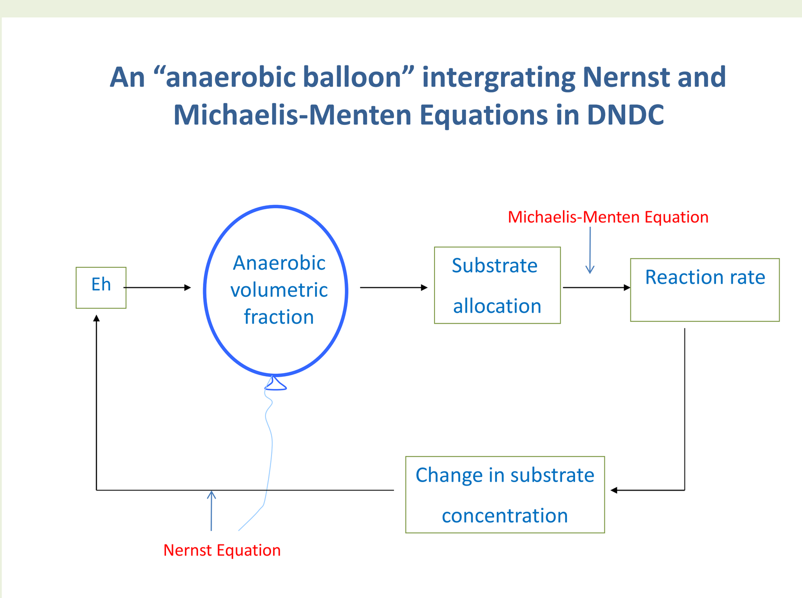
$R = Rmax \cdot DOC/(Ka+DOC) \cdot OX/(Kb+OX)$

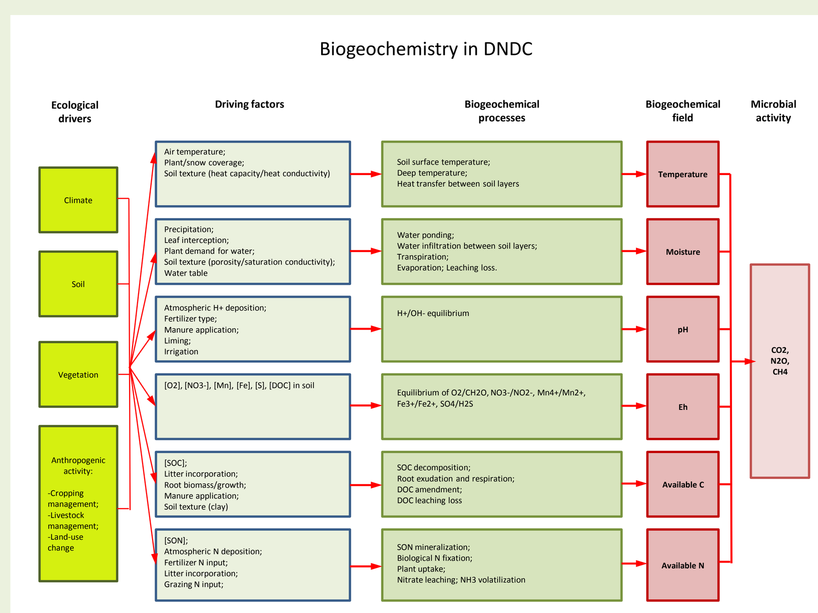
Hypotheses for modeling GHG production:

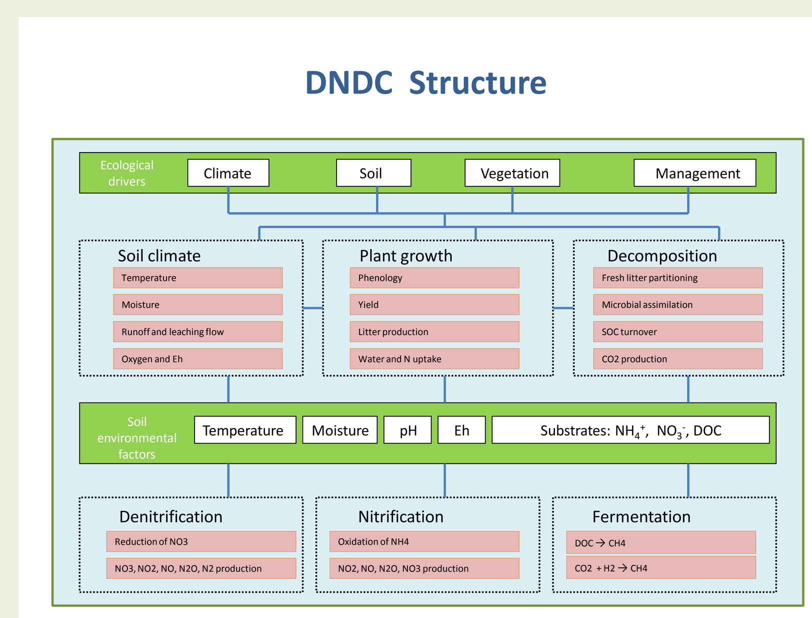
(1) CO_2, N_2O and CH_4 are products of reductive-oxidative (redox) reactions through electron exchange between electron donor and acceptor though mediated by microbes;
(2) Occurrence of electron exchange depends on redox potential (Eh) of the environment, which can be quantified by the Nernst Equation;
(3) When suitable Eh is established, the functional enzymes of bacteria will build up their full capacity within a short term due to their rapid reproduction and horizontal gene transfer; and
(4) When the microbial capacity is built up, the reaction rate will be in turn controlled by the availability of the relevant nutrient substrates based on the Michaelis-Menten Equation.

Model development:

A process-based model, Denitrification-Decomposition or DNDC, was developed based on the hypotheses to track the microbe-driven turnover of soil carbon (C) and nitrogen (N) in agro-ecosystems. The model consists of six sub-models to convert input parameters to biotic and abiotic reactions including decomposition, hydrolysis, nitrification, denitrification, ammonia volatilization and fermentation, which collectively determine production and consumption of CO_2, N_2O and CH_4 in soils.

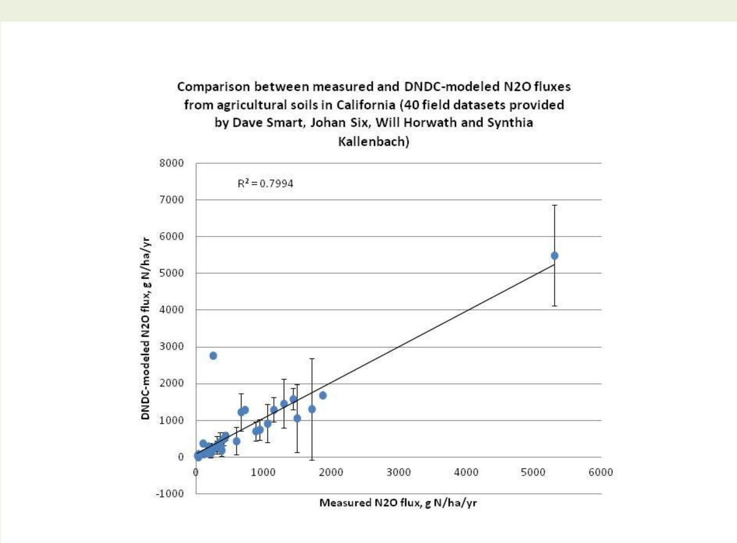


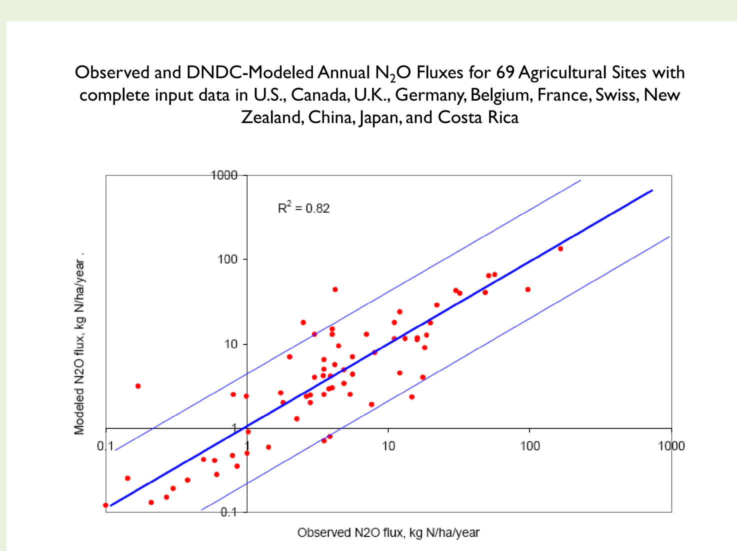




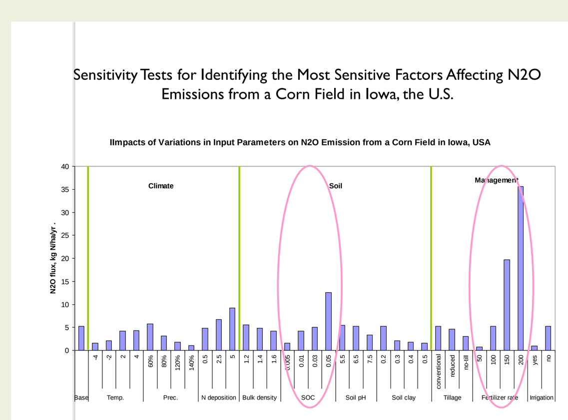
Model validation and sensitivity tests:

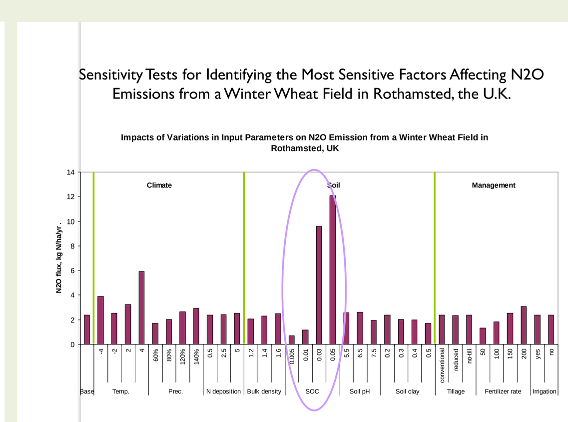
DNDC has been tested against N_2O datasets observed worldwide. Sensitivity tests were implemented to find out the most sensitive factors which determine the variation in N_2O emissions from agro-ecosystems.

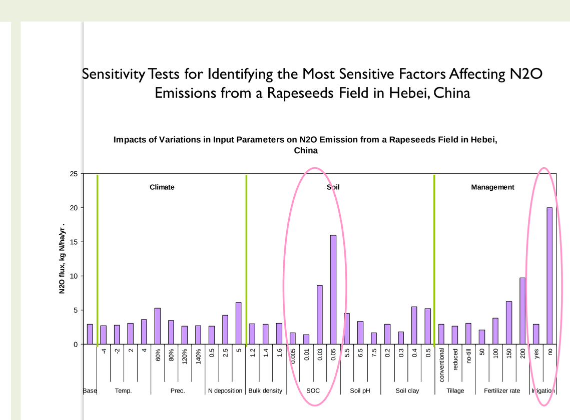




DNDC was validated against N_2O flux datasets measured in California, USA and other countries



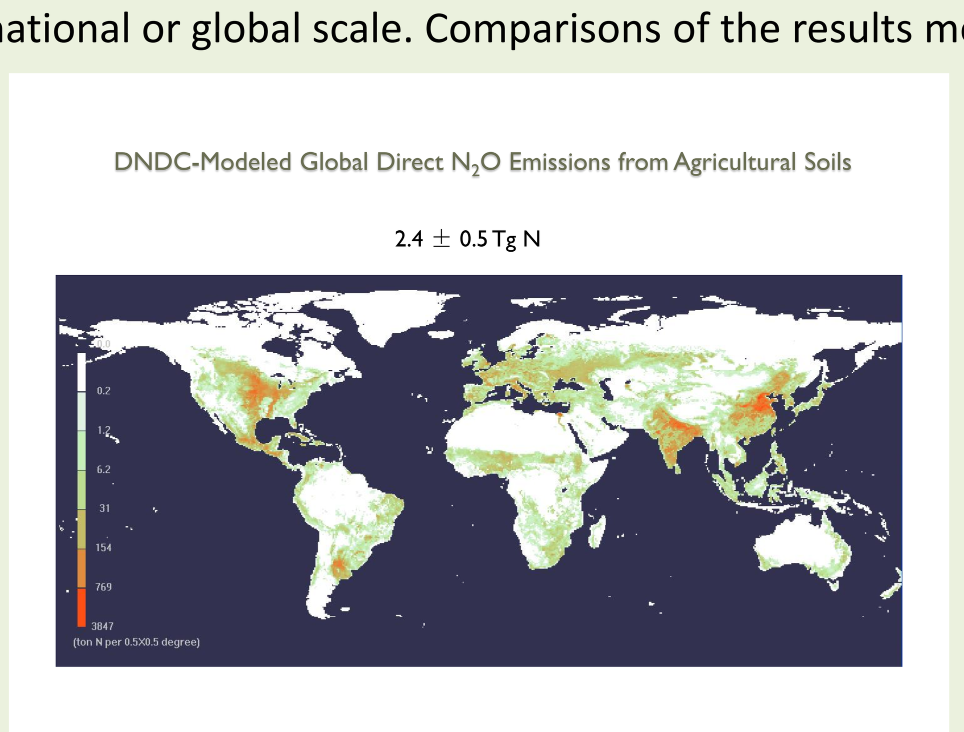




Sensitivity tests with DNDC indicated that the most sensitive factors affecting agricultural N_2O emissions are fertilizer rate and SOC content for a corn field at Iowa, USA, SOC for a winter wheat field at Rothamsted, UK, and irrigation, fertilizer rate and SOC for a rapeseeds field at Hebei, China.

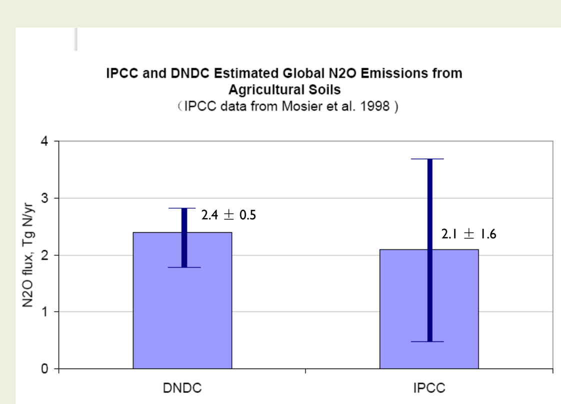
Model applications for mitigation at regional or global scale:

Linked to GIS databases which hold spatially differentiated input information of climate, soil and farming management, DNDC can be applied for quantifying N_2O emissions at regional, national or global scale. Comparisons of the results modeled with baseline and alternative input scenarios will enable to estimate effectiveness of mitigation strategies.



Top Ten World N_2O Emitters
(Accounting for 79% of world total)

Country	Direct N_2O emission from agricultural soils (tons N/yr)
China	0.65 ± 0.17
United States	0.46 ± 0.07
India	0.38 ± 0.05
Russia	0.11 ± 0.03
Argentina	0.09 ± 0.008
Mexico	0.07 ± 0.02
Canada	0.045 ± 0.01
France	0.037 ± 0.01
Brazil	0.036 ± 0.004
Ukraine	0.035 ± 0.006



DNDC and IPCC results are similar on global N_2O emission although the differences are great at smaller scales.

There is large potential for China to reduce N_2O emissions even only by optimizing fertilizer use.