Climate, Water, and Ecosystems: A Future of Surprises

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Climate change is not uniform geographically

Average T for 2001-2005 compared to 1951-80, degrees C

And T is not the only factor that’s changing

Effect is not uniform; most places getting wetter, some getting drier.
Mitigation and Adaptation to Climate Change By Design

- Carbon dioxide is primary greenhouse gas, but methane, nitrous oxide, CFC’s, ozone, and black soot also contribute to climate change.

- Significant climate change mitigation benefits can be derived by reducing nitrous oxide and methane emissions from agriculture.
Climate forcing agents in the industrial era. “Effective” forcing accounts for “efficacy” of the forcing mechanism.

Source: Hansen et al., JGR, 110, D18104, 2005.
Inefficiencies in fertilizer nitrogen use offer important opportunities for mitigation of nitrous oxide emissions.

4% of the N produced in the Haber–Bosch process and used for animal production enters the human mouth.

Galloway JN and Cowling EB. 2C
DNDC: A Computer-aided Tool for Precision Land Management

DNDC Reveals the mechanisms that drive ecosystem change by tracking movement of chemical elements between life and its environment.

DNDC allows users to construct scenarios that benefit land managers and enhance environmental protection.

DNDC can stimulate innovation and information sharing relevant to creating better landscape management for people and nature.
Welcome to DNDC

http://www.dndc.sr.unh.edu
N inputs
HNO₃, etc

N₂

N₂O, N₂, NOₓ
gas losses

N distribution

NH₄⁺ → NO₃⁻

Microbial N

Soil N

Plant N

N losses

leaching
The DNDC Model

**Ecological drivers**
- Climate
- Soil
- Vegetation
- Human activity

**Soil climate**
- annual average temp.
- LAI-regulated albedo
- soil temp profile
- soil moist profile
- O₂ diffusion
- O₂ use

**Decomposition**
- CO₂
- NH₃
- DOC

**Plant growth**
- water demand
- water uptake
- water stress
- N-demand
- N-uptake
- root respiration
- grain
- stem
- roots

**Soil environmental factors**
- Temperature
- Moisture
- pH
- Eh

**Denitrification**
- NO
- NO₂⁻
- nitrate denitrifier
- NO₃⁻
- N₂O denitrifier
- N₂

**Nitrification**
- DOC
- nitrifiers
- NH₄⁺
- NH₃
- clay-NH₄⁺

**Fermentation**
- CH₄ production
- CH₄ oxidation
- CH₄ transport

Effect of temperature and moisture on decomposition

Substrates: NH₄⁺, NO₃⁻, DOC
DNDC bridges between inputs and outputs

**INPUT**
- Climate
  - Temperature
  - Precipitation
  - N deposition
- Soil properties
  - Texture
  - Organic matter
  - Bulk density
  - pH
- Management
  - Crop rotation
  - Tillage
  - Fertilization
  - Manure use
  - Irrigation
  - Grazing

**PROCESSES**
- DNDC
  1. Soil water movement
  2. Plant-soil C dynamics
  3. N transformation
- Availability of water, NH4, NO3, and DOC
- Competition

**OUTPUT**
- Emissions of N2O, NO, N2, CH4 and CO2
- N leaching
- Growth of crop biomass
- Used by soil microbes
- Used by plants
- Growth of crop biomass
DNDC
Simulating carbon in soils and ecosystems
160-year soil organic carbon dynamics at a winter wheat field with different treatments in Rothamsted Agricultural Station in UK from 1840-1990
86-year SOC dynamics at 3 plots with different crop rotations in the Morrow Plots, Urbana, IL, 1904-90

SOC, kg C/kg (0-10 cm)

Year

- Corn/oat/clover: model
- Corn/oat/clover: field
- Corn: model
- Corn: field
- Corn/oat+clover: model
- Corn/oat+clover: field
Model performance can be tested based on short- or long-term observations on C fluxes.

Observed and DNDC-modeled photosynthesis, ecosystem respiration and NEE fluxes from a cultivated peat soil in Linnansuo, Finland in 2005.
DNDC
Simulating nitrogen in soils and ecosystems
N2O Fluxes from a Organic Soil at Glades, Florida, 1979-80

![Graph showing N2O fluxes from a organic soil at Glades, Florida, 1979-80. The graph plots N2O flux in g N/ha/day against days from 106 to 353. The data points are represented as circles with a line model overlay.](image-url)
Observed and Modeled N$_2$O and NO Emissions from a Spruce Stand at Hoglwald Forest in Germany in 1995-1997
Observed and DNDC-Modeled N2O Fluxes from Agricultural Soils in the U.S., Canada, the U.K., Germany, New Zealand, China, Japan, and Costa Rica

\[ R^2 = 0.84 \]

Observed and modeled N2O flux in kg N/ha/year.
Sensitivity of N$_2$O flux to environmental factors
Goal: Predicting impacts of management alternatives on C and N dynamics in terrestrial ecosystems

A change in management

- Climate
- Vegetation
- Soil
- Other management

- Yield
- C storage
- N leaching
- Trace gas
A scenario of best management practices was composed with

(1) no-till, 
(1) increased depth of fertilizer application, 
(3) three splits of fertilizer application, and 
(4) non-legume cover crop.
Impacts of conventional tillage (CT), no-till (NT) and best management practices (BMP) for a crop field at Story County, Iowa

<table>
<thead>
<tr>
<th></th>
<th>CT</th>
<th>NT</th>
<th>BMP</th>
<th>Unit</th>
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<tr>
<td>Fertilizer use</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>kg N/ha</td>
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<tr>
<td>Crop yield</td>
<td>4188</td>
<td>3830</td>
<td>4138</td>
<td>kg C/ha</td>
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<td>dSOC</td>
<td>-86</td>
<td>415</td>
<td>996</td>
<td>kg C/ha</td>
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<td>N leaching</td>
<td>47</td>
<td>20</td>
<td>8</td>
<td>kg N/ha</td>
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<tr>
<td>N2O</td>
<td>19</td>
<td>28</td>
<td>16</td>
<td>kg N/ha</td>
</tr>
</tbody>
</table>
Summary

• Precision management of fertilizer use can provide significant reductions in nitrous oxide emissions while maintaining crop yields. Co-benefits can include reductions in water pollution that results from leaching of nitrate.

• Soil carbon and nitrogen must be treated as an integrated management issue to achieve maximum benefits.

• The DNDC precision management tool can also be applied to the management of timber, pastures, rice, and other landscapes.

• A market-based fertilizer reduction program could offer a fast-track approach to reductions in nitrous oxide emissions and nitrate pollution.
Summary

Uncertainties, unclear signals, and long time scales are characteristic of climate, water, and ecosystem interactions. We argue that there is a strong rationale for enhanced policy flexibility and innovation using a portfolio of reactive, adaptive, and precautionary land management strategies.