Agricultural Sustainability and Nitrous Oxide (N$_2$O) Markets

How Long-Term Ecological Research Informs Sustainability Science and Action

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Interacting Dimensions of Sustainability for Agriculture

Sustainable Agricultural Practices require

Economic incentives for producer acceptance
  • Profitability
  • Economic well-being (wealth)

Social benefit for public acceptance
  • Food and energy security
  • Rural community health
  • Human health & nutrition

Environmental benefit to mitigate burdens
  • Climate security
  • Biogeochemical health
  • Biodiversity benefits
U.S. Average Yields for Major Grain Crops from 1930

The graph shows the average yield (Mt/ha) for Major Grain Crops from 1920 to 2010. The crops are represented as follows:

- **Corn**: Blue line
- **Wheat**: Green line
- **Soybean**: Red line

The yields for Corn and Wheat have shown a steady increase over the years, with Corn having a more significant increase. The Soybean yield has also increased but at a slower rate compared to Corn and Wheat.
Environmental Signals of Agricultural Intensification

Inland Phosphorus

Coastal Nitrate

Habitat loss
U.S. Average Yields for Major Grain Crops from 1930

Sources of information used by Michigan farmers to determine nitrogen fertilizer application rates to corn

<table>
<thead>
<tr>
<th>Source</th>
<th>% Getting Information From Source</th>
<th>% Using as Most Important Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer dealers</td>
<td>69.6</td>
<td>36.5</td>
</tr>
<tr>
<td>Seed company agronomist</td>
<td>44.7</td>
<td>17.9</td>
</tr>
<tr>
<td>University recommendations</td>
<td>31.1</td>
<td>15.8</td>
</tr>
<tr>
<td>Other farmers</td>
<td>33.1</td>
<td>7.9</td>
</tr>
<tr>
<td>Magazines</td>
<td>23.3</td>
<td>3.4</td>
</tr>
<tr>
<td>Private consultant</td>
<td>18.7</td>
<td>7.4</td>
</tr>
<tr>
<td>Other</td>
<td>12.9</td>
<td>10.2</td>
</tr>
</tbody>
</table>

D. Stuart et al. 2012 (submitted)
MSU-EPRI Nitrous Oxide Reduction Protocol

Partner Utilities

- American Electric Power
- Detroit Edison Co.
- Duke Energy
- Hoosier Energy Rural Electric Coop
- Oglethorpe Power Corporation
- PNM Resources Inc.
- Salt River Project
- Southern California Edison
- Tri-State Generation and Transmission Coop
Atmospheric $\text{N}_2\text{O}$ is increasing at rates similar to the other 2 major biogenic gases.

From IPCC (2001, 2007)
# Global Warming Potential (GWP)

## Biogenic Gases

<table>
<thead>
<tr>
<th>Gas</th>
<th>Lifetime (yr)</th>
<th>Global Warming Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 yr</td>
<td>100 yr</td>
</tr>
<tr>
<td>$\text{CO}_2$</td>
<td>variable</td>
<td>1</td>
</tr>
<tr>
<td>$\text{CH}_4$</td>
<td>12</td>
<td>62</td>
</tr>
<tr>
<td>$\text{N}_2\text{O}$</td>
<td>114</td>
<td>275</td>
</tr>
</tbody>
</table>

Source: IPCC 2002; 2007
The contemporary N$_2$O increase is largely due to agricultural intensification

- with a total annual impact $\sim 1.2$ Pg C$_{\text{equiv}}$
  \[ \text{(compare to fossil fuel CO}_2\text{ loading} = 4.1 \text{ PgC per year)} \]

- Industry is responsible for $\sim 16\%$ of the anthropogenic source

- Agriculture for the remainder

- with most of the agricultural increase ($\sim 60\%$) from cropped soils

Source: IPCC 2001, 2007; Prinn 2004; Robertson 2004
# KBS Long-Term Ecological Research (LTER) Site

<table>
<thead>
<tr>
<th>Ecosystem Type</th>
<th>Management Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual Grain Crops (Corn - Soybean - Wheat)</strong></td>
<td></td>
</tr>
<tr>
<td>Conventional tillage</td>
<td>High</td>
</tr>
<tr>
<td>No-till</td>
<td></td>
</tr>
<tr>
<td>Low-input with legume cover</td>
<td></td>
</tr>
<tr>
<td>Organic with legume cover</td>
<td></td>
</tr>
<tr>
<td><strong>Perennial Biomass Crops</strong></td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td></td>
</tr>
<tr>
<td>Hybrid poplars</td>
<td></td>
</tr>
<tr>
<td><strong>Unmanaged Communities</strong></td>
<td></td>
</tr>
<tr>
<td>Early successional old field</td>
<td>Low</td>
</tr>
<tr>
<td>Mid successional old field</td>
<td></td>
</tr>
<tr>
<td>Late successional forest</td>
<td></td>
</tr>
</tbody>
</table>
N$_2$O Measurements are relatively simple but labor intensive

- Seasonality and environmental events are important
Nitrous Oxide Fluxes at KBS are related to the amount of N cycling in the system

- **IPCC 2006**
  - Tier 1 Linear Emission Factor
  - EF = 1.0% (0.25 – 2.25%)

Bouwman et al. 1996

Robertson et al. 2000; Bouwman et al. 1996; IPCC 2006

Gelfand et al. in prep.
Sources of $N_2O$ in soil

Terrestrial N Cycle

- $NO_x$ Fire
- Human-N Harvest
- N-Mineralization
- Soil organic N
- Erosion
- Sediment-N
- N-immobilization
- Fertilizer-N
- Precipitation-N
- N-Mineralization
- N-fertilization
- Microbial N
- $NH_4^+$ Nitrification
- $NO_3^-$ Leaching
- Groundwater-N

$N_2$, $N_2O$

$N_2$ Fixation

Plant - N

Plant N-uptake

Denitrification
KBS corn yields at different N rates (2008)
\( \text{N}_2\text{O} \) fluxes across different N rates (KBS 2010 wheat)

- Emissions factors vary with N-rate – especially above crop optimum

\[ \text{N}_2\text{O} \text{ emissions} = 9.6 + 0.24 \times e^{(0.021 \times \text{N rate})} \]
$N_2O$ flux $\times$ crop yield

- $N_2O$ fluxes accelerate at N-fertilizer rates greater than yield response
- Implication – $N_2O$ savings can be substantial where fertilizer rate exceeds crop needs

Cross-state test of non-linear N$_2$O response to N-fertilizer

Fairgrove, MI

N$_2$O emissions = 0.67 * exp (0.0067 * N rate)

Hoben et al., 2011, Global Change Biology
Implications for $\text{N}_2\text{O}$ reductions for a given $\text{N}$ rate reduction

For a given $\text{N}$ rate reduction, very different $\text{N}_2\text{O}$ outcomes

N rate reduction (50 kg N)
Trading and Offsets

Offset traded

Baseline

Practice Change

Offset provided

GHG emissions

Before After

Before After

Regulated entity
Electric Power Plant

Offset provider
Agriculture

Carbon Offset Credits

Our Sense of Carbon Dividends

Science, policy and economic solutions for the mitigation of climate change under the United Nations Framework Convention on Climate Change.
Emerging Offset Opportunities

Benefits

- Reduce agricultural GHGs
- Reduce reactive N release to the environment
- Incentivize conservation using current technology
- Incentivize new technology

Market Issues

- Baseline establishment
- Permanence
- Additionality
- Leakage
How to reduce N-fertilizer rates without affecting yields

Calculators are available for better economic estimates

Mean Return to Nitrogen (MRTN) Calculator

http://extension.agron.iastate.edu/soilfertility/nrate.aspx
Conclusions

1. Reactive nitrogen escaping to the environment is a major and recalcitrant problem challenging the sustainability of row-crop agriculture

2. Nitrous oxide is the most important source of greenhouse gas impact in fertilized crops
   - Fluxes can be reduced with closer attention to crop needs and adoption of technology that maximizes crop uptake
   - Carbon market payments may be sufficient to incentivize conservation efforts

3. Reducing N$_2$O loss through better fertilizer management will provide co-benefits related to the loss of other forms of nitrogen – nitrate, ammonia, and nitric oxides, in particular