Global change effects and feedbacks on N$_2$O and CH$_4$
emissions from natural and managed land

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Why to look at soils when talking about atmospheric C and N-trace gases and global change?

Forster et al., 2007, In: Climate Change 2007

Diagram showing concentrations of greenhouse gases from 0 to 2005 with CO₂, CH₄, and N₂O emissions from different sources:
- Fossil fuel burning
- Land use change
- Industrial sources
- Rice paddies, wetlands, ruminants
- Agriculture, forests, oceans

Soils: 60-70%
Global Changes and soil N\textsubscript{2}O and CH\textsubscript{4} exchange

**Land use**
- Change
- Manag.

**Climate change**
- Temp.
- Precip.

**Atmospheric Compos.**
- CO\textsubscript{2}
- N-Dep. (O\textsubscript{3}, ...)

**Physico-chemical environment**
- Soil C and N turnover
- Soil microbial community
- Plant litter (QA/QN) & Exudation

**Plant Physiology**
- Plant species composition

**Biosphere-Atmosphere Exchange of CH\textsubscript{4} & N\textsubscript{2}O**
- Nitrification
- Denitrification
- CH\textsubscript{4}-Prod.
- CH\textsubscript{4}-Oxid.
CH$_4$-exchange is the result of simultaneous microbial production and consumption processes.

\[
\text{CH}_4\text{-flux} = \text{CH}_4\text{-Production} - \text{CH}_4\text{-Oxidation}
\]

Dunfield, 2007, Cabi.org
$\text{N}_2\text{O}$-exchange is the result of simultaneous microbial production and consumption processes.

\begin{align*}
\text{NH}_2\text{OH} &\quad \text{DNRA, ANAMMOX} \\
\text{NH}_3 &\quad \text{Abiological} \\
\text{NO}_3^- &\quad \text{Nitrification} \\
\text{NO}_2^- &\quad \text{Denitrification} \\
\text{NO}_2 &\quad \text{Denitrification} \\
\text{NO} &\quad \text{Denitrification} \\
\text{N}_2\text{O} &\quad \text{Denitrification} \\
\text{N}_2 &\quad \text{Denitrification}
\end{align*}

Tilled versus no-tilled systems

Land use

Change

Manag.

Climate change

Temp.

Precip.

Atmospheric Compos.

$\text{CO}_2$

N-Dep. ($\text{O}_3, \ldots$)

$\Delta \text{SOC} \ (\Rightarrow \text{cult.})$

$\Delta \text{SOC} \ (\Rightarrow \text{no-till})$

Time [yr]
Tilled versus no-tilled systems

No-till - tilled [kg N_2O-N ha^{-1} yr^{-1}]

-10
-5
0
5
10
15
20
25

Years

humid climate

dry climate

Holdridge Lifezones

- Polar and tropical zones
- Dry zones
- Humid zones

CO2
N2O
CH4

Six et al., 2004, Global Change Biol
Understanding the coupling between C and N cycling

- Increased SOC
  - +soil microbial activity
  - +soil N-cycling
  - -O₂ avail.
  - +DOC avail.
  - Increased N₂O

Li et al., 2005, Climatic Change
Feedback of SOC increase on total GHG balance

Li et al., 2005, Climatic Change
Feedback of SOC increase on total GHG balance

Li et al., 2005, Climatic Change

Change in net-GHG emissions, alternative - standard
(kg CO₂-equivalents ha⁻¹ yr⁻¹)

Iowa  Hebei  Bavaria

Iowa: CH₄, N₂O, C-sequestration in soil
Hebei: CH₄, N₂O, C-sequestration in soil
Bavaria: CH₄, N₂O, C-sequestration in soil

Total: CH₄, N₂O, C-sequestration in soil
Grazed versus non-grazed steppe systems

Land use
- Change
- Manag.

Climate change
- Temp.
- Precip.

Atmospheric composition
- CO$_2$
- N-Dep. (O$_3$, ...)

Kit – die Kooperation von Forschungszentrum Karlsruhe GmbH und Universität Karlsruhe (TH)
Grazed versus non-grazed steppe systems: $\text{N}_2\text{O}$
Grazed versus non-grazed steppe systems: N$_2$O

Extremely high N$_2$O-fluxes during freeze-thaw from ungrazed steppe

→ >70% of annual fluxes
Do natural steppe systems emit more \( \text{N}_2\text{O} \) than grazed systems?

Not always – On a regional scale nutrient management may override site scale effects.
Grazed versus non-grazed steppe systems: CH$_4$

<table>
<thead>
<tr>
<th></th>
<th>UG</th>
<th>WG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture</td>
<td>sL</td>
<td>sL</td>
</tr>
<tr>
<td>pH</td>
<td>6.8±0.3</td>
<td>6.7±0.3</td>
</tr>
<tr>
<td>SOC [%]</td>
<td>2.5±0.6</td>
<td>2.6±0.5</td>
</tr>
<tr>
<td>Bulk dens. [g cm$^{-3}$]</td>
<td>1.09±0.1</td>
<td>1.09±0.1</td>
</tr>
<tr>
<td>Gas Perm. -30kPa [cm d-1]</td>
<td>99.6±67</td>
<td>55.5±38</td>
</tr>
</tbody>
</table>
Do natural steppe systems take up more CH$_4$ than grazed systems?

<table>
<thead>
<tr>
<th>Source/sink</th>
<th>Base unit for flux calculations</th>
<th>Mean flux [µg CH$_4$-C m$^{-2}$ h$^{-1}$]</th>
<th>Total CH$_4$ emission/uptake [tons C GS$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upland steppe</td>
<td>286592 ha</td>
<td>-28.3±5.3</td>
<td>78±56</td>
</tr>
<tr>
<td>Riparian area</td>
<td>4069 ha</td>
<td>678±168</td>
<td>232±145</td>
</tr>
<tr>
<td>Summer sheepfold</td>
<td>2.7 m$^2$ per sheep</td>
<td>107±56</td>
<td>2.7±0.7</td>
</tr>
<tr>
<td>Winter sheepfold</td>
<td>0.6 m$^2$ per sheep</td>
<td>107±56</td>
<td>0.1±0.0</td>
</tr>
<tr>
<td>Faeces dropped at steppe</td>
<td>45 kg FDW GS$^{-1}$ sheep$^{-1}$</td>
<td>1344±219 $^a$</td>
<td>34.6±5.6</td>
</tr>
<tr>
<td>Sheep</td>
<td>400685 capita</td>
<td>12.6±1.8 $^b$</td>
<td>770±108</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>741±315</td>
</tr>
</tbody>
</table>

$^a$ NO – CH$_4$ emission from riparian areas and from sheep are more important as CH$_4$ uptake by steppe soils.

\[ x0.98 = -1.96 \text{ kg C ha}^{-1} \quad X0.02 = 1.4 \text{ kg C ha}^{-1} \quad X2 = 2.2 \text{ kg C ha}^{-1} \]
Nitrogen cycling changes during the past two centuries

1860

NO<sub>y</sub> → N<sub>2</sub> → NH<sub>x</sub>

Change

Land use

Manag.

Temp.

Precip.

Atmosph. Compos.

N-Dep. (O<sub>3</sub>, …)

mid-1990s

Nitrogen cycling changes during the past two centuries

Nitrogen cycling changes during the past two centuries

Galloway et al., 2003, Biogeochemistry

NO → N<sub>2</sub> → NH<sub>x</sub>

mid-1990s

Nitrogen cycling changes during the past two centuries

Nitrogen cycling changes during the past two centuries

Galloway et al., 2003, Biogeochemistry

Nitrogen cycling changes during the past two centuries

Nitrogen cycling changes during the past two centuries
Nitrogen deposition – past and present

Holland et al., 1999, Biogeochemistry, EMEP, 2002
Nitrogen oxide emissions from Forests in Europe (NOFRETETE)

Mean: 98.0 ± 4.7 µg N m\(^{-2}\) h\(^{-1}\)
Mean: 28.8 ± 2.5 µg N m\(^{-2}\) h\(^{-1}\)
Nitrogen oxide emissions from Forests in Europe (NOFRETETE)

Stimulation of N-oxide emissions from soils at sites with high N-deposition and narrow C/N ratios

Pilegaard et al., 2006, Biogeosciences
Nitrogen oxide emissions from Forests in Europe (NOFRETETE)

Kesik et al., 2005, Biogeosciences

15% of agricultural soils

K. Butterbach-Bahl | IMK-IFU | November 2008
Forest management, N deposition and N$_2$O fluxes (Höglwald)

- Land use
- Change
- Manag.
- Land use changes
- Climate change
- Temperature
- Precipitation
- Atmospheric composition
- CO$_2$
- N deposition (O$_3$, ...)

**Selective cutting 2000/2006**

**Clear cut 2000**

**Spruce control**

**Forest management, N deposition and N$_2$O fluxes (Höglwald)**

- Forest management
- N deposition
- N$_2$O fluxes
- Höglwald
- Spruce control
- Selective cutting
- Clear cut
- CO$_2$
- N deposition
- Atmospheric composition
- Climate change
- Temperature
- Precipitation
Clear-cutting enhances N₂O emissions for years
Climate change and the variability of fluxes - Höglwald

Climate change and the variability of fluxes - Höglwald

Annual N$_2$O flux [kg N ha$^{-1}$ yr$^{-1}$]

- non-freeze/thaw fluxes
- freeze/thaw fluxes

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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flux</td>
<td>0.0</td>
<td>0.5</td>
<td>3.0</td>
<td>0.5</td>
<td>n.d.</td>
<td>n.d.</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Note: n.d. = not determined
Summary

1) **Human perturbation of N cycle may override climate effect**
   - Additional Nr creation
   - Management largely feedback on soil N₂O emissions

2) **Emissions from “natural” sources most likely underestimated**
   - Freeze-thaw is hardly accounted for

3) **Long-term monitoring is required to understand variability of fluxes**
   - Landscape/ regional analysis of nutrient cycling and associated non-CO₂ and CO₂ GHG exchange at identified hotspots (e.g. China)

4) **CH₄ uptake is mostly negatively affected by human activity**
   - Effect not quantified yet