陆地生态系统N₂O排放研究方法

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Contents

- Atmospheric N\textsubscript{2}O & its effects
- Global budget & uncertainties
- Key questions
- Process study
- Field measurement
- Model simulation

Research methodologies
Ozone Hole

Environmental N enrichment due to anthropogenic activity

$	ext{N}_2\text{O}$ effects

Source: IPCC, 2001

Present vs. late 19th century: $+0.4\sim +0.8 \, ^\circ\text{C}$
<table>
<thead>
<tr>
<th></th>
<th>N₂O</th>
<th>CH₄</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-industrial era con. (ppbv):</td>
<td>~275</td>
<td>~700</td>
<td>~280000</td>
</tr>
<tr>
<td>Present con. (ppbv):</td>
<td>319</td>
<td>1774</td>
<td>379000</td>
</tr>
<tr>
<td>Annual increase (%/yr⁻¹):</td>
<td>0.25</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Life time (yr):</td>
<td>114</td>
<td>12</td>
<td>50-200</td>
</tr>
<tr>
<td>Specific GWP (100 yr):</td>
<td>298</td>
<td>25</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: IPCC, 2007

$\text{N}_2\text{O}$: a long-lived greenhouse gas in troposphere
Warming effect of N$_2$O

Net radiative forcing of N$_2$O (since 1750): 0.16 w m$^{-2}$
(~ 6% of long-lived GHG’s radiative forcing)

Source: IPCC, 2007
N$_2$O -induced O$_3$ depletion in stratosphere

Photolysis-induced O$_3$ destruction in stratosphere

Diagram showing the cycle of N$_2$O and O$_3$ depletion in the stratosphere.
N$_2$O release: the primary anthrop. emission of O$_3$-depletion matter

Source: Ravishankara et al. (2009, Science)
Global budget & contributions of individual sources (%)

<table>
<thead>
<tr>
<th>Natural sources</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>21%</td>
</tr>
<tr>
<td>Soils under natural vegetation</td>
<td>37%</td>
</tr>
<tr>
<td>Atmospheric chemistry</td>
<td>3%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Anthropogenic sources</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>16%</td>
</tr>
<tr>
<td>Aquatic ecosystem</td>
<td>10%</td>
</tr>
<tr>
<td>Combustion &amp; industrial processes</td>
<td>4%</td>
</tr>
<tr>
<td>Biomass and bio-fuel burning</td>
<td>4%</td>
</tr>
<tr>
<td>Atmospheric deposition</td>
<td>3%</td>
</tr>
<tr>
<td>Human excreta</td>
<td>1%</td>
</tr>
</tbody>
</table>

Uncertainty of estimates for $\text{N}_2\text{O}$ emission of different source categories

<table>
<thead>
<tr>
<th>Sources</th>
<th>Tg N yr$^{-1}$ Range</th>
<th>Mean (Uncert.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural soils</td>
<td>3.3 ~ 9.7</td>
<td>6.6 (-50 ~ 47%)</td>
</tr>
<tr>
<td>Agriculture</td>
<td>1.7 ~ 4.8</td>
<td>2.8 (-39 ~ 71%)</td>
</tr>
<tr>
<td>Aquatic ecosys. (Rivers, estuaries, coastal zones)</td>
<td>0.5 ~ 2.7</td>
<td>1.7 (-71 ~ 59%)</td>
</tr>
<tr>
<td>Other anthrop. sources</td>
<td>0.8 ~ 5.0</td>
<td>2.2 (-64 ~ 127%)</td>
</tr>
</tbody>
</table>

Source: IPCC, 2007
Key questions

- How to reduce the uncertainties?
- How to mitigate the anthrop. emissions?

Accurate quantification

• Process study
• Field study
• Model simulation
& upscaling
Microbial nitrification

- Autotrophic nitrifiers
- Heterotrophic nitrifiers
Microbial denitrification

Oxidation: $\text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{NO} \rightarrow \text{N}_2$  
Reduction: $\text{N}_2 \rightarrow \text{N}_2O$  

Nitrogen oxidation states

Denitrifiers: heterotrophic
Microbial DNRA & ANAMOX

Reduction

Nitrogen oxidation states

Oxidation

Microbial nitrification
Microbial denitrification
Chemo-denitrification
ANAMOX
DNRA

NH₃

NH₂OH

NOH

NO₂⁻

NO₃⁻

N₂

N₂O

Microbial nitrification
Microbial denitrification
Chemo-denitrification
ANAMOX
DNRA
Non-microbial process

Reduction

-3 $\text{NH}_3$
-1 $\text{NH}_2\text{OH}$
0 $\text{NOH}$
+1 $\text{NO}$
+2 $\text{NO}_2^-$
+3 $\text{NO}_3^-$

N2O
N2

Oxidation

Nitrogen oxidation states

Microbial nitrification
Microbial denitrification
Chemo-denitrification
ANAMOX
DNRA

Non-microbial process
Processes producing N₂O in soil/water

Measured N₂O from a soil may result from multiple processes
Needs of process study

➢ To know the importance of individual processes in overall soil/water $N_2O$ emission: nitrification, denitrification, nitrifiers denitrification, dissimilatory nitrate reduction to ammonium (DNRA), anaerobic ammonium oxidation (ANAMOX), chemo-denitrification

➢ To understand the effects of key factors on $N_2O$ production in individual processes: microbes, substrates, environmental conditions (temperature, moisture, soil properties)

➢ To quantify the ratios of $N_2O$ production rate to rates of nitrogen turnover processes (e.g. denitrification or gross nitrification)
Techniques for process study

- **Molecular biology techniques:** to detect and count functional microbes responsible for individual processes of N$_2$O production in soil/water.
- **Isotopic signature techniques:** to quantify contribution of nitrification and denitrification, using site preference and isotopologue enrichment factors
- **$^{15}$N pool dilution techniques:** to measure gross nitrification rate, ammonization rate, and NH$_4^+$ and NO$_3^-$ immobilization
- **Gas-flow-soil-core/C$_2$H$_2$/O$_2$ inhibition techniques:** to measure denitrification/nitrification and its production ratios
Molecular biology techniques

\[ \text{NO}_2^- \xrightarrow{\text{NirK, NirS}} \text{NO} \xrightarrow{\text{NirS}} \text{N}_2 \]

\[ \text{NO}_3^- \xrightarrow{\text{NarG, NapA}} \text{NO}_2^- \xrightarrow{\text{NirS}} \text{NO} \xrightarrow{\text{NirS}} \text{N}_2 \]

\[ \text{NO} \xrightarrow{\text{Hao}} \text{NH}_2\text{OH} \xrightarrow{\text{AmoA}} \text{NH}_4^+ \]

\[ \text{NO}_3^- \xrightarrow{\text{nXR}} \text{NO}_2^- \xrightarrow{\text{NirS}} \text{NO} \xrightarrow{\text{NirS}} \text{N}_2 \]

\[ \text{NH}_2\text{OH} \xrightarrow{\text{AmoA}} \text{NH}_4^+ \]

\[ \text{Hao} \text{NH}_2\text{OH} \xrightarrow{\text{AmoA}} \text{NH}_4^+ \]

\[ \text{Nir} \text{NO} \xrightarrow{\text{NirS}} \text{N}_2 \]

\[ \text{Nir} \text{NO} \xrightarrow{\text{NirS}} \text{N}_2 \]

\[ \text{Nir} \text{NO} \xrightarrow{\text{NirS}} \text{N}_2 \]
Molecular biology techniques

DNA或RNA提取（DNA/RNA extraction）

宏基因组学（Metagenomics）

系统发育分析（Phylogenetic analysis）

聚合酶链式反应（PCR amplification）

定量聚合酶链式反应（Real-time PCR）

末端限制性片段多态性分析（T-RFLP analysis）

DNA或RNA提取（DNA/RNA extraction）
Isotopic signature techniques

\[ SP = \delta^{15}N_\alpha - \delta^{15}N_\beta \]

Isotopomer

Bond order = 1.61
Bond order = 2.73

\[ \alpha = 1 - \frac{1}{2} \times \frac{\text{bond order}}{1.61} \]

Isotope fractionation factors (‰)

SP (‰)

Nitrification fraction (%)

Denitrification by bacteria

Nitrification by bacteria

$\frac{15}{30}$
$^{15}$N pool dilution techniques

Gross ammonization rate

$\Delta$ NH$_4^+$ between t = 0 and 40 h

NH$_4^+$ immobilized by microbes

Gross nitrification rate

$\Delta$ NO$_3^-$ between t = 0 and 40 h

NO$_3^-$ immobilized by microbes

Source: Klaus Butterbach-Bahl
C$_2$H$_2$ / O$_2$ inhibition techniques

- Denitrification rates (10% C$_2$H$_2$): NO$_3^-$ $\rightarrow$ NO$_2^-$ $\rightarrow$ NO $\rightarrow$ N$_2$O $\rightarrow$ N$_2$
- Separation of N$_2$O production processes (C$_2$H$_2$ and O$_2$):

<table>
<thead>
<tr>
<th>Processes</th>
<th>Control</th>
<th>10 Pa C$_2$H$_2$</th>
<th>21% O$_2$</th>
<th>10 Pa C$_2$H$_2$</th>
<th>21% O$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Nitrification</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>Denitrification</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>Nitrifier denitrification</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>Other processes</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

(3) - (4): nitrification
(2) - (4): denitrification
(1) - (2) - (3) + (4): nitrifier denitrification
(4): other processes

Source: e.g. Wrage et al., 2004
Gas-flow-soil-core technique

<table>
<thead>
<tr>
<th>Gas</th>
<th>Accuracy (μmol mol⁻¹)</th>
<th>Detection Limit (μg N h⁻¹ kg⁻¹ ds)</th>
<th>Detection Limit (μg N m⁻² h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂</td>
<td>0.2</td>
<td>0.23</td>
<td>8.6</td>
</tr>
<tr>
<td>N₂O</td>
<td>5 × 10⁻³</td>
<td>0.02</td>
<td>0.6</td>
</tr>
<tr>
<td>NO</td>
<td>1 × 10⁻³</td>
<td>0.08</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Source: Wang et al., 2011, EST
Gas-flow-soil-core technique

Denitrification potential measurement

Daily measurements of $\text{NH}_4^+$, $\text{NO}_3^-$, $\text{NO}_2^-$, DOC, and microbial carbon and nitrogen during incubation are necessary to link laboratory study with field $\text{N}_2\text{O}$ flux and its model simulation.

Source: Wang et al., 2012, Plant Soil
Techniques for measuring field N$_2$O fluxes

- Static chamber technique
- Eddy covariance technique

Overall N$_2$O fluxes, which integrate emissions of multiple processes occurring in field conditions.
Static chamber-based field measurement

Gas chromatography-electron capture detector (GC-ECD) is usually used to analyze (online or offline) air samples from chamber (automatic, manual) headspace.

Researchers start recently to use laser/FTIR detectors.
Static chamber-based field measurement

Static chamber technique

\[ F = \frac{(dC/dt)V}{A} \]

- \(F\): field \(\text{N}_2\text{O}\) flux
- \(dC/dt\): initial change rate of \(\text{N}_2\text{O}\) concentration during enclosure
- \(V\): headspace volume
- \(A\): measured land area

Nonlinear relationship occurs between \(\text{N}_2\text{O}\) concentration and sampling time, as chamber enclosure:

a) reduces concentration gradient \((\partial C/\partial z)\), and
b) prevents air mass flow driven by wind.
Chamber-based measurement: Con. → flux

\[ F = (dC/dt) \cdot V/A \cdot \rho_{N_{2}O} \cdot P/P_{0} \cdot T_{0}/T \]

Linear model:
\[ \frac{dC}{dt} = a \]
\[ C_{t} = a \cdot t + b \]
(used almost for all available dataset)

Nonlinear model:
\[ \frac{dC}{dt} = a - b \cdot C_{0} \]
\[ C_{t} = \frac{a}{b} + \left( C_{0} - \frac{a}{b} \right) \cdot e^{-b \cdot t} \]
(seldom used, yet)

Source: Kroon et al., 2008, NCA; Valente et al., 1995, JGR; Wang et al., 2012, AFM
Chamber-based measurement: flux bias

- **Linear model has to be used in case nonlinearity detection fails** (offline concentration analysis or usage of GC, as a slow-response detector, prevent high-frequency concentration measurements during enclosure; usually using only 5 observations to detect nonlinearity in GC-based measurement).

- **Flux bias**: using of wrong model and failure in nonlinearity detection could underestimate annual $\text{N}_2\text{O}$ fluxes by $0 \sim 30\%$ (for a fertilized cotton case).

Source: Wang et al., 2012, AFM
Chamber-based measurement: flux bias

AC: automatic chamber fluxes (nonlinear model was used for detected nonlinearity cases)

EC: eddy covariance (TDL) fluxes with wind from chamber location

Result from comparison between chamber and EC data:

\[ y = 1.21 \times \]

\[ R^2 = 0.91 \]

\[ p < 0.01 \]

Source: Wang et al., 2012, AFM
Chamber-based measurement: flux bias

Flux bias due to wrong GC method

- Argon-methane mixture (5-10% CH₄ in Ar) is better to be used as carrier (AM method);
- If Ar-CH₄ mixture is substitute with N₂ alone (DN method), ascarite (which may lead to negative flux for marginal emission) is not recommended to use as filter of CO₂ (DN-Ascarite method). Instead, we recommend to let 10% CO₂ in pure N₂ flow through ECD cell at ~2 ml min⁻¹ as a buffer gas (DN-CO₂ method).

Source: Zheng et al., 2008, Plant Soil; Wang et al., 2010, AAS
Chamber-based measurement: flux bias

Flux bias due to wrong GC method

N$_2$ as carrier gas in GC-ECD (DN method)

Source: Zheng et al., 2008, Plant Soil
Chamber-based measurement: flux bias

Flux bias due to wrong GC method

<table>
<thead>
<tr>
<th>GC-ECD method</th>
<th>Precision for 300 ppbv N$_2$O (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DN</td>
<td>1.6 - 2.3</td>
</tr>
<tr>
<td>DN-CO$_2$</td>
<td>0.2 - 0.7</td>
</tr>
</tbody>
</table>

Not able to detect low fluxes

Source: Wang et al., 2010, AAS
Chamber-based measurement: flux bias

Gas-flow system in GCs for simultaneous analysis of N₂O, CH₄ and CO₂, using DN-CO₂ for N₂O

- Precision of each gas: 0.2 ~ 0.7% for ambient air samples.
- > 90% of GCs in China using this method.

Source: Wang et al., 2010, AAS
Chamber-based measurement: flux bias

Flux bias due to wrong GC method

Source: Zheng et al., 2008, Plant Soil
**Chamber-based measurement: flux bias**

### Case study of a rice-wheat rotation ecosystem (relative to six measurements d\(^{-1}\))

<table>
<thead>
<tr>
<th>Fixed frequency</th>
<th>Annual flux bias (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once every 3 d</td>
<td>-19 ± 10</td>
</tr>
<tr>
<td>Once every 4 d</td>
<td>-23 ± 15</td>
</tr>
<tr>
<td>Once every 5 d</td>
<td>-24 ± 12</td>
</tr>
<tr>
<td>Once every 7 d</td>
<td>-30 ± 18</td>
</tr>
<tr>
<td>Once every 10 d</td>
<td>-30 ± 13</td>
</tr>
</tbody>
</table>

Source: Zheng et al., 2004

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**Daily N\(_2\)O fluxes**

Most field measurements: Frequency-related biases are variable with ecosystems.
Chamber-based measurement: advantages

a) **High sensitive**: detection limit could be $1 \sim 11$ (mean: \textit{4.6} $\mu g \text{ N m}^{-2} \text{ h}^{-1}$ for 50 cm chamber height (95\% confidence interval), being more sensitive than other approaches by \textit{1-2} order of magnitude.

b) **Flexible applicability**: applicable for all field plot sizes of uniform or non-uniform land surface.

c) **Very practical**: simple principle, easy operation, and low cost.

Source: Wang et al., 2012, AFM
Chamber-based measurement: disadvantages

a) **Negative bias:** due to failure in nonlinearity detection and prevent of mass flow.

b) **Low temporal resolution** (manual) and **poor representativeness for spatial variability** (automatic).

c) **Very labor-consuming.**

Source: Wang et al., 2012, AFM
Chamber-based measurement: avoiding bias

a) Using AM or DN-CO$_2$ if GC has to be adopted.

b) Enlarging sample size of concentration measurements during chamber enclosure.

c) Using high-precision, fast-response detectors for online concentration analysis.

d) Using **flexible measurement schedule**: daily measurement for a few days to a few weeks following flux-stimulating events (e.g., fertilization, irrigation, rainfall, …), but weekly otherwise.
中国陆地CH$_4$和N$_2$O排放通量箱法观测网

制定并采用了统一的测定方法与数据质控规范，为过程规律与模型研究提供具有可比性的高质量通量数据。

行业（农业）科研专项项目（首席邱建军）的大部分站点
中科院先导（碳）专项项目（首席蔡祖聪）和973项目（首席郑循华）的所有站点

Network for Observing Land CH$_4$ and N$_2$O Emissions (2012-2015)
观测网数据质量控制：中科院大气所数据质控人员及时收集和处理各站点气体通量数据，诊断存在问题，提出问题解决方案，并负责或协助解决。

海北严重退化高寒草甸的通量数据的有效率（n = 300）：

- CH₄ 97%
- N₂O 65%

箱高：40 cm; 采样时间：80′; GC精度：0.2% ~ 0.8%
Eddy covariance measurement of N$_2$O fluxes

30′ average flux: $F = \rho_c' \cdot w'$

Requiring fast response sensors (10 - 20 Hz) to simultaneously measure N$_2$O concentration (TDL, QCL or LGR) and vertical wind velocity, and large uniform land surface (10 - 30 ha) to meet similarity theory for turbulence

Source: Wang et al., 2012, AFM
Eddy covariance measurement of N$_2$O fluxes

- **Corrections** and quality control to determine 30-min fluxes:
  - a) Coordinate rotation for two-dimension wind velocity;
  - b) Detrending vertical wind velocity & N$_2$O concentration;
  - c) Correcting lag time between N$_2$O concentration & wind velocity;
  - d) Correcting flux loss at high-frequency.
  - e) Using friction velocity ($u^*$) filter to reject fluxes from area beyond footprint of the EC mast.

Source: Wang et al., 2012, AFM
Eddy covariance measurement of N$_2$O fluxes

- **N$_2$O flux detection limit** of eddy covariance technique (TDL): $36 \sim 108$ μg N m$^{-2}$ h$^{-1}$ (95% confidence interval).
  Versus chamber: $1 \sim 11$ μg N m$^{-2}$ h$^{-1}$

- **Hourly flux uncertainty**: ±676 and ±569 μg N m$^{-2}$ h$^{-1}$ during the high and low emission periods, respectively (95% confidence interval).
  Versus chamber: -62 ~ 15 (high) & -6 ~ 3 (low) μg N m$^{-2}$ h$^{-1}$

- **Applicability of eddy covariance** technique is still questionable for low to moderate levels of N$_2$O fluxes.

- Source: Wang et al., 2012, AFM
Eddy covariance measurement of N₂O fluxes

➢ Advantages:
   a) Good representativeness of spatial variability for the area within footprint fetch.
   b) Easy operation in situ & labor-saving.

➢ Disadvantages:
   a) Low sensitivity, yielding not reliable fluxes from low emission sources.
   b) Not applicable for manipulation field experiment with small plots & non-uniform land surface.
   c) Complexity in principles and data processing
   d) Expensive detectors.

➢ Promising application: 1) long-term observation; and, 2) developing correction factors for chamber flux biases

Source: Wang et al., 2012, AFM
Field measurements: never sufficient in terms of N$_2$O emission management; 
Process-oriented modeling approach: necessary way to link process understandings at molecular/microsite scales, field measurements at site scale, and management decision at regional scale.
Process-oriented modeling approach

DNDC (US)
Daycent (US)
PaSim (EU)
WNMM (Australia)
Landscape DNDC (EU)

Models are designed to describe the nitrogen/carbon cycling processes from site to regional/catchment scale, so as to predict management effects of given scenarios.
DNDC9.5 model (1D process)

**Soil climate**
- Mean annual temperature
- Soil moisture profile
- Oxygen profile
- Water movement in the soil
- Transpiration
- Evaporation
- Daily evapotranspiration

**Nitrate denitrifiers**
- NO
- NO
- NO
- N2O
- N2

**Nitrite denitrifiers**
- Nitrit denitrifier

**Denitrification**
- Exchange of NO, N2O, NO2

**Nitrification**
- N2O
- NO
- NO3
- NH4+
- DOC

**Crop growth**
- Root respiration
- Water uptake
- Water stress
- N-uptake
- Daily growth

**Nitrate**
- NO
- NO
- NO3

**Nitrite**
- Nitrit denitrifier

**Anaerobic balloon**

**Mineralisation**
- Very labile
- Labile
- Resistant
- Degradable organic matter

**Effect of temperature and moisture on mineralisation**

**Soil environment**
- Temperature
- Moisture
- pH

**Emission of CO2, NO, N2O, N2, NH3 and CH4**

**Human impact**
- LAI depending on albedo
- Soil T-profile

**Ecological driver**
- Mean annual temperature
- Soil moisture profile
- Oxygen profile
- Water movement in the soil
- Transpiration
- Evaporation
- Daily evapotranspiration

**Predicted gas fluxes**
- Methanogenesis
- Methanogenic bacteria
- Methane oxidation
- CH4 oxidation
- Methanotrophic bacteria
- Diffusion
- Gas bubbles
- Plant transport

**Predicted soil environmental forces**
- Water movement
- Oxygen profile
- Water stress
- N-uptake
- Daily growth

**Crop growth**
- Root respiration
- Water uptake
- Water stress
- N-uptake
- Daily growth

**Soil mineralisation**
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- Labile
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**Predicted soil environmental forces**
- Water movement
- Oxygen profile
- Water stress
- N-uptake
- Daily growth
Modeling approach: scaling up and scenario study

- Process studies
  - parametrisation of N$_2$O production processes
  - identification of the dominating microbial process
  - correlation of microbial parameters with N$_2$O fluxes

- Field measurements
  - Soil-atmosphere exchange N$_2$O
    - at various sites
    - Effects of regulating factors and key disturbances on N-emissions

Source: Klaus Butterbach-Bahl
Modeling approach: scaling up and scenario study

Challenges

1) Long-term (replicated years) flux validation of multiple carbon- and nitrogen-gases including N$_2$O, NH$_3$, NO, CO$_2$ and CH$_4$ with multiple field treatments of site scale: no successful case so far.

2) Simultaneous simulation of multiple gas emissions, hydrology and productivity at catchment scale: model development is undergoing, e.g. Landscape DNDC, WNMM.

3) Available measurement dataset for model test, calibration, and validation in terms of simultaneously measured variables and/or parameters: not sufficient.
Modeling approach: scaling up and scenario study

Close cooperation of experimental and model scientists are strongly required to integrate the studies from site, ecosystem to catchment scales!
Modeling approach: scaling up and scenario study

DNDC-SCS-MULSE model application

Slope runoff (SCS curve):

\[ Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \]

\[ S = 25.4 \left( \frac{1000}{CN} - 10 \right) \]

Erosion (MUSLE):

\[ sed = 11.8 \cdot (Q_{surf} \cdot q_{peak} \cdot area_{hru})^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG \]

N retention and runoff in stream:

\[ orgN_{surf} = 0.001 \cdot conc_{orgN} \cdot \frac{sed}{area_{hru}} \cdot \varepsilon_{N:sed} \]

(Deng et al., 2011, JGR; 2011, Biogeosciences)
Modeling approach: scaling up and scenario study

DNDC-SCS-MULSE model application

41% fertilizer nitrogen lost from the catchment by NH₃ emission and leaching or run-off

<table>
<thead>
<tr>
<th>Land types</th>
<th>N₂O (kg N yr⁻¹)</th>
<th>NO</th>
<th>N₂</th>
<th>TN</th>
<th>NH₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry cropland</td>
<td>27.0</td>
<td>4.5</td>
<td>7.5</td>
<td>525</td>
<td>1350</td>
</tr>
<tr>
<td>Rice-based rotation</td>
<td>4.5</td>
<td>0.8</td>
<td>29.5</td>
<td>48</td>
<td>93</td>
</tr>
<tr>
<td>Winter-flooded paddy</td>
<td>0.2</td>
<td>0.2</td>
<td>5.9</td>
<td>31</td>
<td>34</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Forest</td>
<td>2.2</td>
<td>0.0</td>
<td>8.8</td>
<td>121</td>
<td>0</td>
</tr>
<tr>
<td>Residence area</td>
<td></td>
<td></td>
<td>52</td>
<td>904</td>
<td>1479</td>
</tr>
<tr>
<td>Total</td>
<td><strong>34</strong></td>
<td><strong>6</strong></td>
<td><strong>52</strong></td>
<td><strong>904</strong></td>
<td><strong>1479</strong></td>
</tr>
</tbody>
</table>

Source: Deng et al, 2011, JGR; Deng et al., 2011, Biogeosciences
Thank you for your attention!

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