Acid deposition impacts on wetland methane emission: brake or accelerator?

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Does atmospheric deposition of reactive S and N change the emission of CH$_4$ from wetlands?
Microbial Competition:
NO$_3^-$ and SO$_4^{2-}$ suppress CH$_4$ production

$O_2$  $NO_3^-$ $SO_4^{2-}$ $CO_2$

$C(H_2O)$

$CO_2$
$H_2O$  $N_2O$ $H_2S$  $CH_4$
CH$_4$ suppression by SO$_4^{2-}$: Summary of peatland experiments

Dise and Verry (2001), Minnesota
Granberg et al (2001), Sweden
Gauci et al (2004), peat monoliths, Scotland
Gauci et al (2002), Scotland

Gauci et al. PNAS 2004
SO$_4^{2-}$ suppression of CH$_4$ emission - rice

Denier van der Gon et al. 2001
Role of Trophic Status

Suppression of CH$_4$ flux (%)

$SO_4^{2-}$ deposition rate (kg-SO$_4$-S ha yr$^{-1}$)

Sphagnum - dominated

Vascular plant – dominated (e.g. rice)

Gauci et al. 2004

Denier van der Gon et al. 2001
CH₄ suppression by SO₄²⁻:
Summary of field manipulation experiments

- **Vascular plant-dominated**
- **Sphagnum-dominated**

CH₄ emission (% change)

kg S/ha/y
Sulfate in acid rain could decrease CH₄ emission in wetlands if...

- Acid rain delivers concentrations of sulfate sufficient to stimulate sulfate reduction
- Concentrations of other electron acceptors are low
- There is little input of sulfate from other sources
Nitrogen is complicated.

At the community scale

NO$_3^-$ in acid rain could *decrease* CH$_4$ production and emission through increasing redox potential, suppressing methanogenesis and favouring denitrification.

But…
Nitrogen (NO$_3^-$ or NH$_4^+$) added to N-limited plants could increase vascular plant biomass, and increase DOC from root exudates, both of which could increase CH$_4$ emission.

Schimel, 2000, Nature 403: 376-7
At the biochemical scale….

Adding NH$_4^+$ could *increase* CH$_4$ emission by inhibiting the activity of methane monoxygenase (CH$_4$-oxidizing enzyme).

But, the degree of inhibition is proportional to the ratio NH$_4^+$:CH$_4$. In high CH$_4$-producing, N-limited wetlands…

Schimel, 2000, Nature 403: 376-7
Adding N could decrease CH$_4$ by stimulating N-limited methanotrophs (population-scale) (Bodelier et al. 2000)
Summary of N-addition experiments to peatlands

(10 sites, N. America & Europe, 10-200 kg N ha$^{-1}$ y$^{-1}$; 1-3 years)

(Dise, unpub.)

- First 2 years: either no change or a slight (NS) enhancement of CH$_4$ emission

- Year 3+: sometimes significant increase in CH$_4$ at higher levels of treatment

- No difference between effect of NH$_4^+$ or NO$_3^-$ (but only 1 study)

- Impact always attributed to indirect effects on vegetation
Sphagnum ‘filter’ becomes saturated at ~20 kg N ha\(^{-1}\) y\(^{-1}\)
Meta-analysis: Effects of N addition on CH$_4$ emission from peatlands and rice

For N additions of 20-120 kg N/ha/y:

**Peatlands:**
mean = 23\% increase
~dose-dependent
(3 sites, 5 experiments)

**Rice:**
mean = 37\% increase
(2 sites, 5 experiments)

Liu and Greaver 2009
Effects of simulated S,N deposition on wetland CH$_4$ emission (BOE)

- **Vascular plant-dominated**
- **Sphagnum-dominated**

**CH$_4$ emission (% change)**

- **+N**
- **+S**

**kg/ha/y N or S**
N deposition will remain ~ constant for northern wetlands, increase for tropical/subtropical wetlands.
S deposition will continue to decline for northern wetlands, increase for tropical/subtropical wetlands.
Net Effect

Northern wetlands:
• N-dep constant, S-dep declining $\rightarrow$ increasing CH$_4$

Tropical /subtropical wetlands:
• N-dep increasing, S-dep increasing $\rightarrow$ ?
  – Will depend on:
    • Wetland type
    • Relative levels S and N
    • Length of exposure
    • etc
The effects of S and N in acid deposition on CH$_4$ emission from nutrient-poor wetlands probably **counteract** each other.

Release of the sulfate inhibition in northern wetlands, and increasing N deposition in vascular plant-dominated tropical/subtropical wetlands **suggests** that net global effect of N+S is **enhanced** CH$_4$ emission.

**Climate change** will exert a **positive feedback** if it shifts wetlands toward more vascular plant-dominated types.

**More research** is needed!
- Function development and upscaling of experiments (esp. N)
- Gradient surveys
- Multi-factor experiments: pollution, climate, other GHGs
Thanks to...

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NASA Goddard Institute for Space Studies
European Science Foundation
Thank You!
Nitrogen limited → Nitrogen saturated

*Sphagnum* dominated

NH$_4$, NO$_3$

Vascular plant dominated

NH$_4$, NO$_3$

Nitrogen limited

Nitrogen saturated

no Δ CH$_4$
**Estimating Global Impact**

+ *Sulfate deposition model*

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**Global wetland CH$_4$ emission model +GCM**

- **Scenario b**
  - (step function at 15 kg S/ha/yr)

  - S deposition (kg-S/ha/yr)
    - 0
    - 10
    - 20
    - 30
    - 40
    - 50

  - % suppression of CH$_4$ flux
    - 0
    - 10
    - 20
    - 30
    - 40
    - 50

- **Scenario c**
  - (linear increase in S-effect with no change in excess of 15 kg S/ha/yr)

  - S deposition (kg-S/ha/yr)
    - 0
    - 10
    - 20
    - 30
    - 40
    - 50

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**Models:**
- Matthews and Fung, 1987
- NASA GISS GCM
- Walter and Heimann, 2000
- Koch et al. 1999

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**Gauci et al. PNAS 2004**

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**Scenario c**

- (linear increase in S-effect with no change in excess of 15 kg S/ha/yr)

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**15 Tg CH$_4$ decline (ca 8%)**
S: 32% suppression of CH$_4$ flux

N: No significant effect on CH$_4$ flux, but 11% higher trend

Dise and Verry 2001
Effects of N addition on biological CH4 uptake

(a) Overall
   Mean (78)

(b) Vegetation
   Agriculture (aerobic) (31)
   Coniferous (18)
   Deciduous (11)
   Grassland (8)
   Wetland (drained) (6)

(c) N form
   NH₄NO₃ (30)
   NH₄⁺ (5)
   NO₃⁻ (8)
   Urea (11)
   UAN (5)

(d) Experimental length
   Short term (38)
   Long term (38)

Liu and Greaver 2009