Global pattern of nitrogen limitation: Confronting two global biogeochemical models with observations

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Nitrogen limitation determines carbon response to environmental charge
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- Nitrogen deposition increasing carbon storage
  (Thomas et al. 2010 Nature Geoscience)
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- Less CO$_2$ fertilization and smaller increase in carbon storage
  (Norby et al. 2010 PNAS; Oren et al. 2001 Nature)
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What are the patterns of nitrogen limitation in global biogeochemical models?
Test of nitrogen limitation in two global biogeochemical models

CLM-CN 4.0  
(Thornton et al. 2009 Biogeosciences)

O-CN  
(Zaehle et al. 2011 Nature Geoscience)
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Carbon-nitrogen interactions regulate climate-carbon cycle feedbacks: results from an atmosphere-ocean general circulation model


Carbon benefits of anthropogenic reactive nitrogen offset by nitrous oxide emissions

Sönke Zaehle¹*, Philippe Ciais², Andrew D. Friend¹ and Vincent Prieur²
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Buffering capacity of C to changes in N →
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By terrestrial ecosystems between 1996 and 2005, and for the increase in radiative forcing resulting from nitrous oxide emissions over the coming century, attributable in part to a steady decline in the ocean.

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P. E. Thornton¹, S. C. Doney², K. Lindsay³, J. K. Moore⁴, N. Mahowald⁵, J. T. Randerson¹, I. Fung⁶, J.-F. Lamarque²,³, J. J. Feddema⁴, and Y.-H. Lee³

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Fixed Vegetation C:N

Variable Vegetation C:N

Fixed Soil Organic Matter C:N

Variable Soil Organic Matter C:N

Differing mechanisms governing N loss
Global nitrogen fertilization experiment

- 25 year simulations (1985-2009)
- Nitrogen applied globally at five levels continuously
  - Low application to parallel plausible changes in nitrogen deposition (0.5 g N m$^{-2}$ yr$^{-1}$)
  - Higher applications to parallel field experimental additions of nitrogen fertilizer to terrestrial ecosystems (2.0, 4.0, 10.0 g N m$^{-2}$ yr$^{-1}$)
  - High application to test nitrogen saturation (30.0 g N m$^{-2}$ yr$^{-1}$)
- Same climate inputs and land-use history
Global nitrogen fertilization response: High addition (30.0 g N m\(^{-2}\) yr\(^{-1}\))

\[ \Delta \text{Net Primary Productivity (CLM-CN)} \]
Global nitrogen fertilization response: High addition (30.0 g N m$^{-2}$ yr$^{-1}$)

\[ \Delta \text{Net Primary Productivity (O-CN)} \]

CLM-CN more responsive to nitrogen than O-CN

Model comparison to data: Model response compared to observations

- Nitrogen fertilization experiments
- $^{15}$N tracer studies
- Plot/small catchment nitrogen budgets

Model comparison to data: NPP response to N fertilization

ANPP response ratio (fertilization / control)

- Grasslands: N = 39
- Temperate/Boreal Forests: N = 23

Model comparison to data: $^{15}$N Tracer studies (temperate and boreal forests)

Observations from Templer et al. in revision. *Ecology*

Thomas *et al.* In prep. *Glob. Ch. Biol.*

- Study length = 3 months - 2 yrs
  - Vegetation (n = 17)
  - Soil (n = 19)
  - Not recovered (n = 16)
Model comparison to data: 
$^{15}$N Tracer studies (temperate and boreal forests)

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% of nitrogen added to ecosystem

Observations
CLM-CN
OCN

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Model comparison to data:
Plot/Small Catchment Nitrogen Budgets

Temperate and boreal forests
n = 209

Observations from NiRENA project: Goodale et al.


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- Observations
- CLM-CN
- OCN

Background leaching from nitrogen fixation inputs
Leaching from nitrogen deposition inputs

Observations from NiRENA project: Goodale et al.
Conclusions and Implications
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• CLM-CN and O-CN have dramatically different responses to added nitrogen
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    • Are the buffering mechanisms too strong?
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  • CLM-CN: NPP too responsive to nitrogen
Conclusions and Implications

• CLM-CN and O-CN have dramatically different responses to added nitrogen

  • O-CN: NPP not responsive enough to nitrogen
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  • CLM-CN: NPP too responsive to nitrogen
    • Potential GPP is too high
Conclusions and Implications

• CLM-CN and O-CN have dramatically different responses to added nitrogen
  
  • O-CN: NPP not responsive enough to nitrogen
    • N limitation is too weak
    • Are the buffering mechanisms too strong?
  
  • CLM-CN: NPP too responsive to nitrogen
    • Potential GPP is too high
    • N retention is too low - NPP does not saturate even at 30 g N m$^{-2}$ yr$^{-1}$
Conclusions and Implications (cont’d)
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• Nitrogen fertilization experiments, $^{15}$N tracer studies, and nitrogen budgets
Conclusions and Implications (cont’d)

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  • Differentiate among models
Conclusions and Implications (cont’d)

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  - Provide insights into the nature of nitrogen limitation in global biogeochemical models
Conclusions and Implications (cont’d)

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- Guide model development
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• Current research is focused on developing buffering mechanisms in the CLM-CN (variable C:N tissue ratios)
Conclusions and Implications (cont’d)

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  • Provide insights into the nature of nitrogen limitation in global biogeochemical models
  
  • Guide model development

• Current research is focused on developing buffering mechanisms in the CLM-CN (variable C:N tissue ratios)

• Future research will focus on testing additional models and expanding the observational data set
Questions?
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- National Science Foundation
- Cornell Biogeochemistry and Environmental Biocomplexity Program
- Discussion with participants at the 2011 INTERFACE Research Coordination Network meeting in Florida
- Sam Levis and Gordon Bonan at the National Center for Atmospheric Research
Global nitrogen fertilization response (5 yr): High addition (10.0 g N m\(^{-2}\) yr\(^{-1}\))
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\(\Delta\) Net Primary Productivity (O-CN)

Global biogeochemical models coupled to climate models: overview
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[Diagram of biogeochemical cycles and climate interactions]

Zaehle and Dalmonech 2011 Curr. Opin. Env. Sust.
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Zaehle and Dalonech 2011 *Curr. Opin. Env. Sust.*