Nutrient limitation reduces land C uptake in a model of combined C, N and P cycling

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• **Plants need nutrients to grow.**
  - This fact is neglected in most models used for climate projections. (some few account for N, but none for P)
CO$_2$ fertilization constrained by N

11 year FACE: Oak Ridge
Sweetgum plantation

Norby et al, PNAS, 2010
CO$_2$ fertilization constrained by N

11 year FACE: Oak Ridge
Sweetgum plantation

Norby et al, PNAS, 2010
Present day nutrient limitation

Wang et al, *Biogeosciences*, 2010
N and P cycles: main differences

“Leaky”:
Large inputs from the atmosphere

“Tight”:
- Only small inputs from bedrock
- Soil P sorption
- Biochemical mineralization (phosphatases)
MPI-M Earth System Model

- ECHAM5
- OASIS3
- JSBACH
- MPIOM
- HAMOCC

Fluxes
Surface Conditions
MPI-M Earth System Model

- Photosynthesis (Farquhar)
- Dynamical Phenology
- Soil Hydrology
- Fire
- Carbon, Nitrogen, and Phosphorus

V. Gayler
Experimental setup

- Transient simulation 1860 – 2500
- SRES A1B emission scenario ("business as usual")
- 4 nutrient setups:
  - **C**: Carbon only
  - **CN**: Carbon and Nitrogen
  - **CP**: Carbon and Phosphorus
  - **CNP**: Carbon, Nitrogen and Phosphorus
Results
Land C sink: 21\textsuperscript{st} century

A) Temperature [K]

B) CO\(_2\) [ppm]

C) Change in total C [Gt]

Goll et al, *Biogeosciences Diss.*, 2012
Land C sink: 21st century

Goll et al, *Biogeosciences Diss.*, 2012
Land C sink: Extension

Goll et al, *Biogeosciences* Diss., 2012
Land C sink

A

reduction in NPP [%]

30S 0 30N 60N

CN
CN_{dp}
CP
CP_{mo}
CP_{ox}

Goll et al, *Biogeosciences Diss.*, 2012
Land C sink

A) Temperature [K]

B) CO₂ [ppm]

C) Total C [Gt]

Goll et al, *Biogeosciences Diss.*, 2012
Conclusions

1. P constrains tropical C uptake during 21st century

2. P may become a constrain at high latitudes.

→ The omission of P (& N) in global C cycle models is problematic.

Goll et al., Nutrient limitation reduces land carbon uptake in simulations with a model of combined carbon, nitrogen and phosphorus cycling. Biogeosciences Discuss., 2012
Global C cycle

Reservoir sizes in GtC
- Surface Ocean: 900 + 18
- Intermediate & Deep Ocean: 37,100 + 100
- Marine Biota: 3

Fluxes and Rates in GtC yr\(^{-1}\)
- Weathering: 0.2
- Respiration: 120
- GPP: 119.6
- Atmosphere: 597 + 165
- Land sink: 2.6
- Land Use Change: 1.6
- Fossil Fuels: 3700 - 244
- Surface sediments: 150

Rivers: 0.8
Land uptake rates ($C^4$MIP)

Friedlingstein et al, *Journal of Climate*, 2006
- Photosynthesis (BETHY)
- Phenology
- Albedo
- Soil Hydrology

- Dynamic Vegetation
- Fire
- Carbon, Nitrogen, and Phosphorus
- Land Use
10 soil types

11 PFTs:
- Tropical evergreen trees
- Tropical deciduous trees
- Temperate broadleaf evergreen trees
- Temperate broadleaf deciduous trees
- Coniferous evergreen trees
- Coniferous deciduous trees
- Raingreen shrubs
- Deciduous shrubs
- C3 grass
- C4 grass
- Tundra

Stoichiometric parameterization:
- TRY data base (Kattge et al. 2011)

Dark grey: leaf N
Stoichiometry

Parameter perturbations
- 7 parameters
- Latin Hypercube Sampling
- 140 simulations

Nitrogen requirement:

Total ecosystem N:

\[ N_{eco} = \left( \frac{N}{C_{veg}} \cdot (1 - \alpha) + \frac{N}{C_{soil}} \cdot \alpha \right) \cdot C_{eco} \]

Vegetation N:C ratio

Soil N:C ratio

Fraction of $C_{eco}$ in soil

Total ecosystem N
Nitrogen discrepancy

Scenarios:
- Only CO2 increase
- CO2 increase + climate change

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Nitrogen discrepancy

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- Only CO2 increase
- CO2 increase + climate change

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Nitrogen discrepancy

Scenarios:
- Only CO2 increase
- CO2 increase + climate change

Wang et al, 2009 (dynamical model)

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