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Nitrogen and Climate

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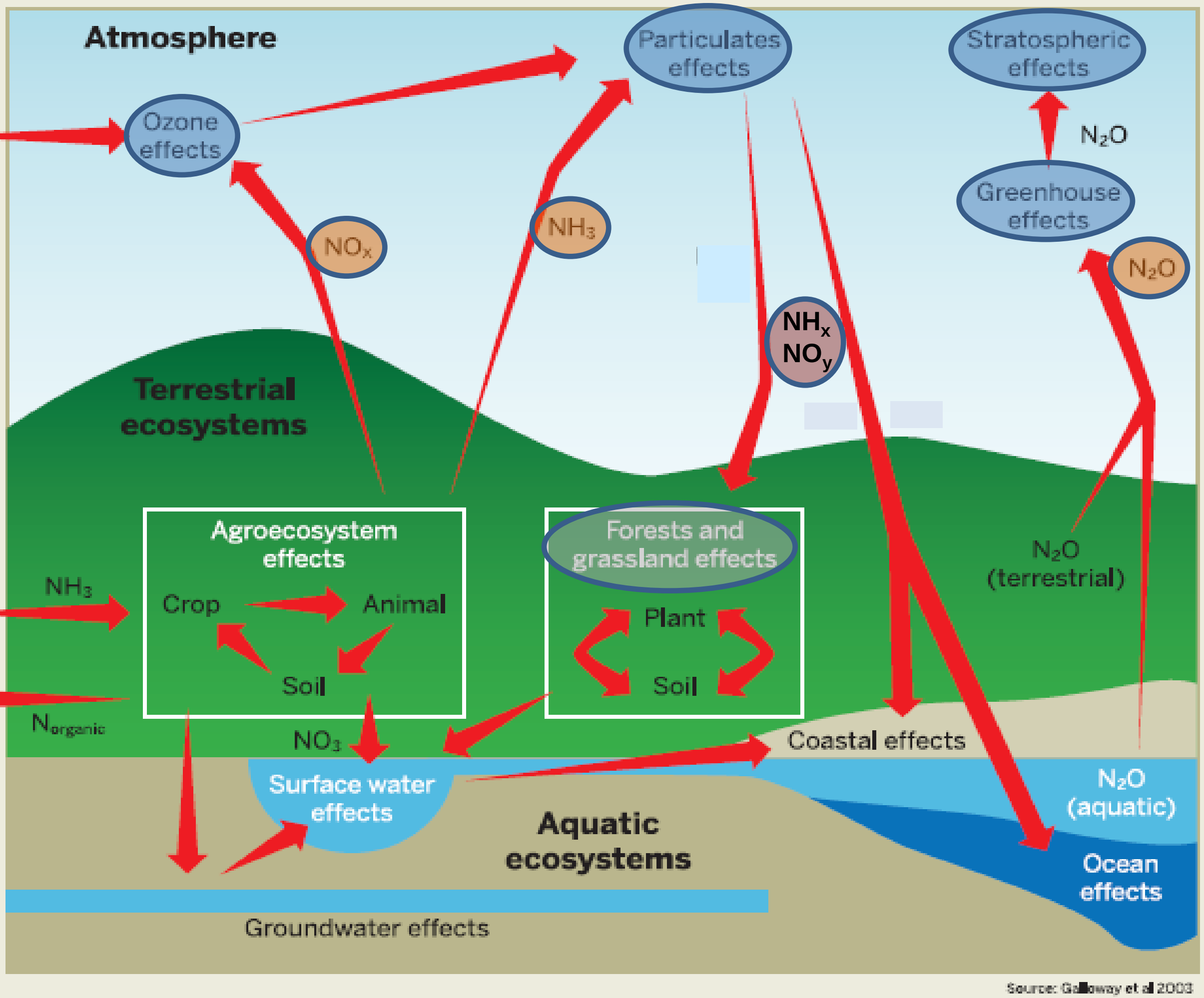
United States Senate
Washington, DC

Nitrogen cascade and climate



Science

Increasing emissions of nitrogen oxides (NO_x), ammonia (NH_3), and nitrous oxide (N_2O) alter atmospheric composition and chemistry

- ❑ N_2O, O_3, CH_4, and aerosols

Deposition of NH_x and NO_y on land alters ecosystems

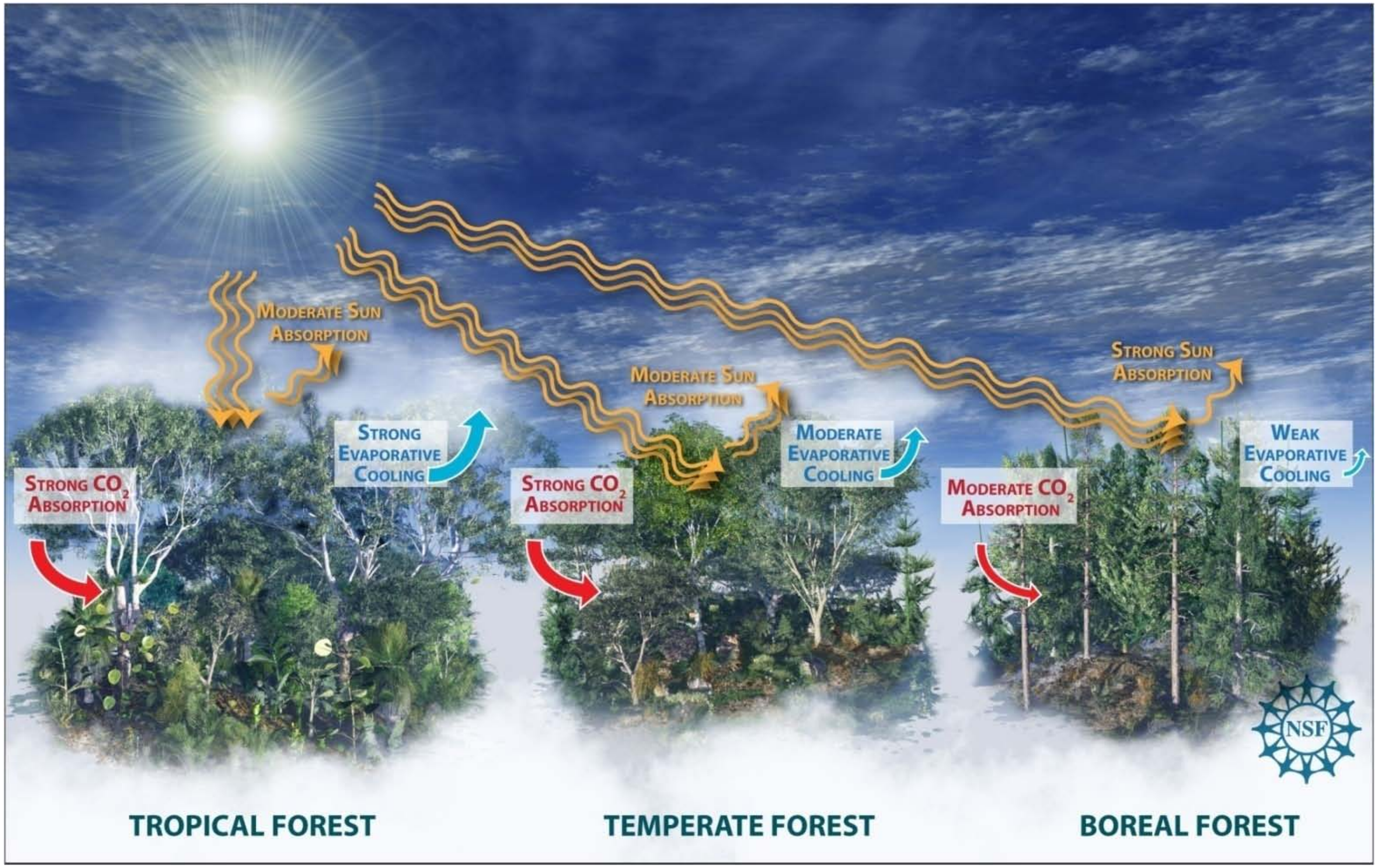
- ❑ Carbon storage, biodiversity

Indirect effects, e.g., higher surface O_3 reduces plant productivity

Policy

Nitrogen management strategies for global climate change mitigation, and concomitant benefits to society through the N cascade

Broader context: Terrestrial ecosystems influence climate



Bonan (2008) Science 320:1444-1449

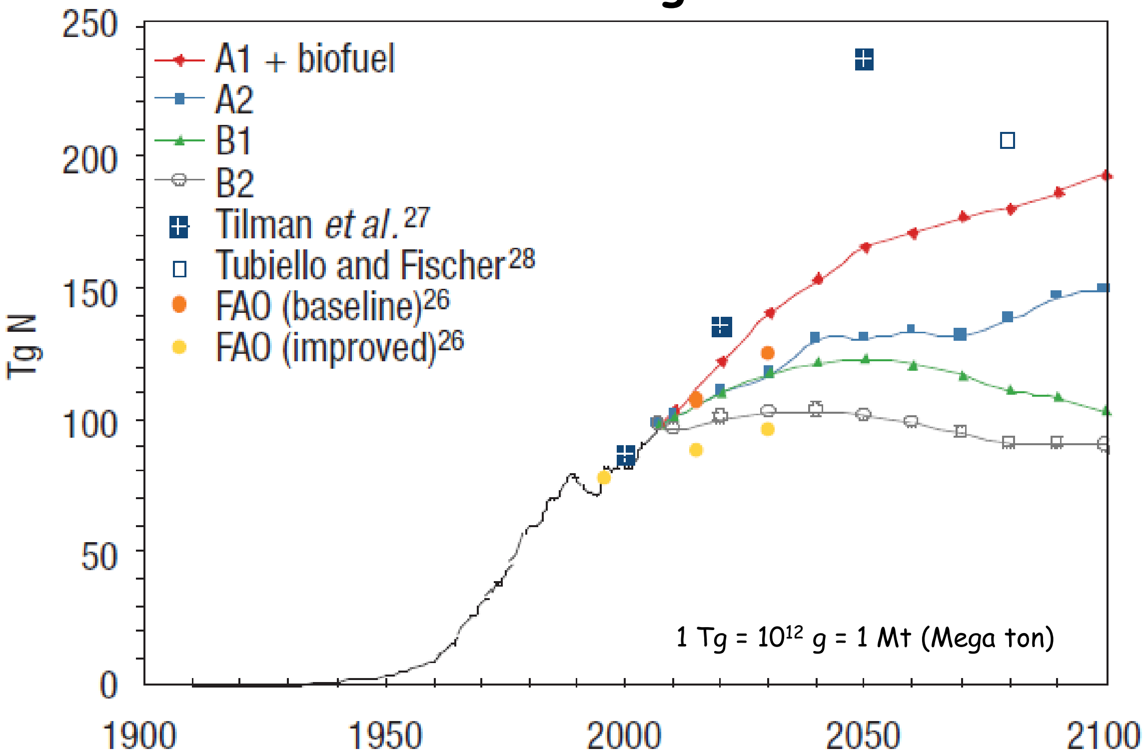
Credit: *Nicolle Rager Fuller, National Science Foundation*

- ❑ Absorption of solar radiation
- ❑ Evaporation of water
- ❑ CO_2 and carbon storage
- ❑ CH_4, N_2O, and many other processes

Nitrogen regulates this ecosystem-climate coupling. Nitrogen surplus increases carbon storage, increases N_2O emission, and reduces CH_4 uptake by soils. *Can ecosystems be managed for climate change abatement?*

Fertilizer use increases N_2O emissions

Global annual nitrogen fertilizer use



Erisman et al. (2008) Nature Geoscience 1:636-639

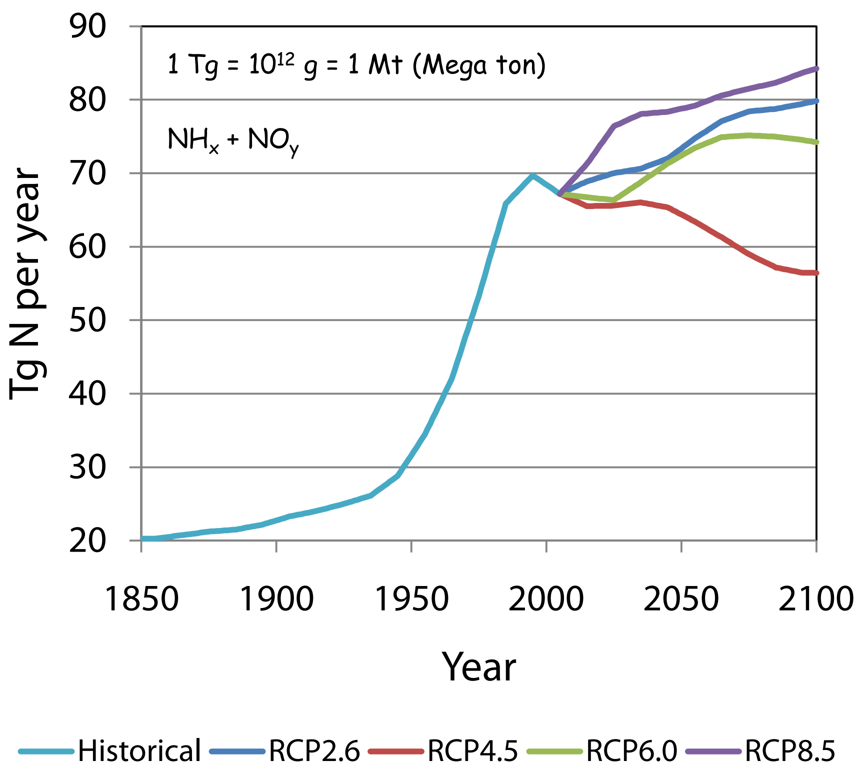
One consequence is increased N_2O emission, which leads to higher atmospheric N_2O

	1750	2005	Global warming potential (100-yr)
CO_2	278 ppm	379 ppm	1
CH_4	715 ppb	1774 ppb	25
N_2O	**270 ppb**	**319 ppb**	**298**

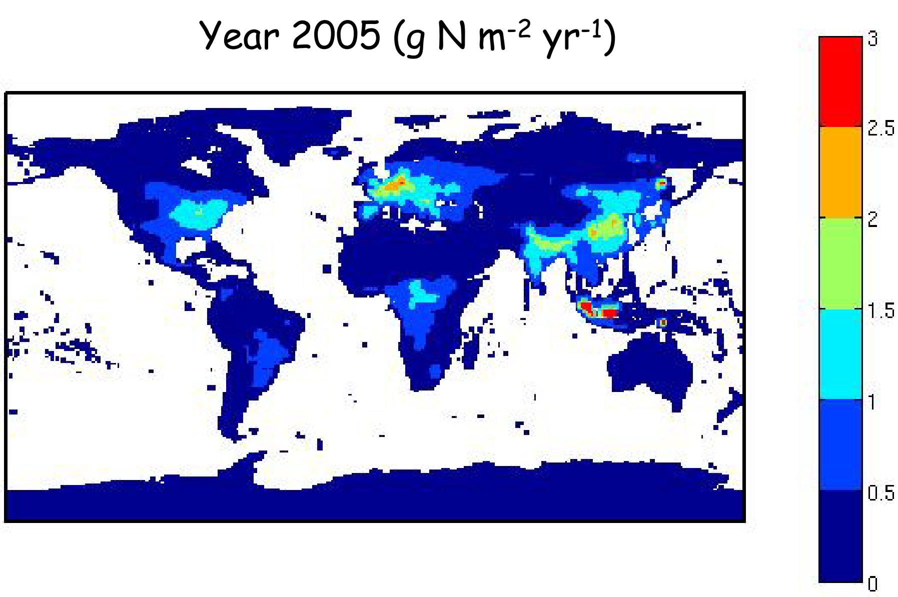
Forster et al. (2007) in *Climate Change 2007: The Physical Science Basis,* Solomon et al., Eds., 129-234

Global annual atmospheric nitrogen deposition

Surface emissions of NO_x and NH_3 are deposited on land. Atmospheric N deposition over land increased by 3x from 1850 to 2005

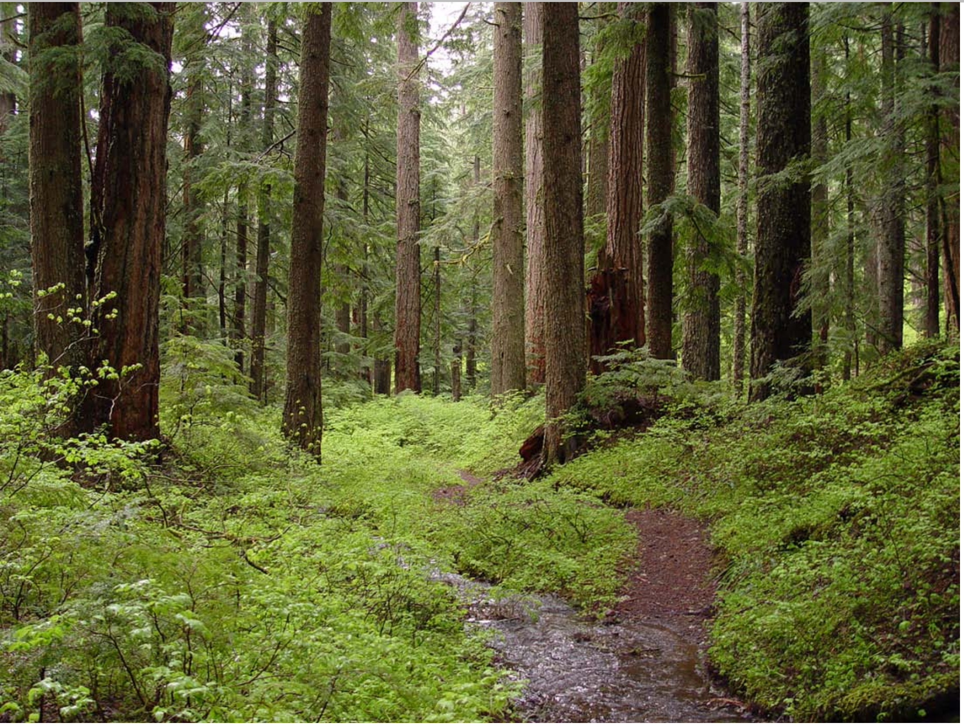


Most atmospheric N deposition occurs over industrialized regions

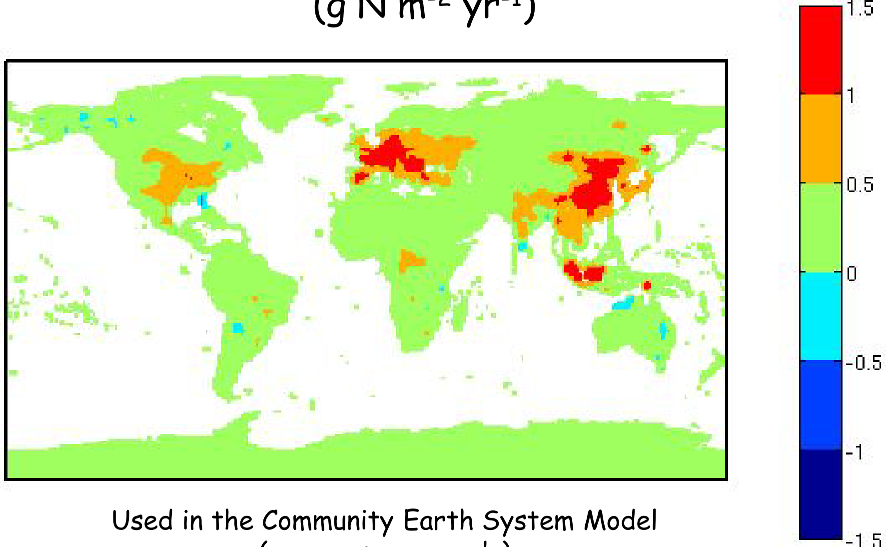


Used in the Community Earth System Model (www.cesm.ucar.edu)
Lamarque et al. (2010) Atmos Chem Phys 10:7017-7039

Carbon storage and nitrogen deposition



Atmospheric N deposition increase, 1850 to 2005
(g N m^{-2} yr^{-1})



Used in the Community Earth System Model
(www.cesm.ucar.edu)
Lamarque et al. (2010) Atmos Chem Phys 10:7017-7039

Plants and soils sequester carbon. Increased N from atmospheric deposition can enhance terrestrial carbon storage in N limited systems, up to a certain point.

Nitrogen enhances terrestrial carbon storage

N deposition increases terrestrial carbon storage by 0.25 Pg C yr^{-1}

(Fossil fuel combustion averaged 7.7 Pg C yr^{-1} during 2000-2008)

Nadelhoffer et al. (1999) Nature 398:145-148

Ecosystem pool	dC/dN_{dep} (g C/g N)
Non-woody plant biomass	4 (29 together with woody plant biomass)
Woody plant biomass	25
Forest floor and soil	21
Total	49

More recent studies all show a carbon gain of similar magnitude, but there is uncertainty

Liu & Greaver (2009) Ecology Letters 12: 1103–1117

Forest carbon gain

dC/dN_{dep} = 24 g C/g N

Thomas et al. (2010) Nature Geoscience 3:13-17

Aboveground tree carbon gain

dC_{tree}/dN_{dep} = 61 g C/g N

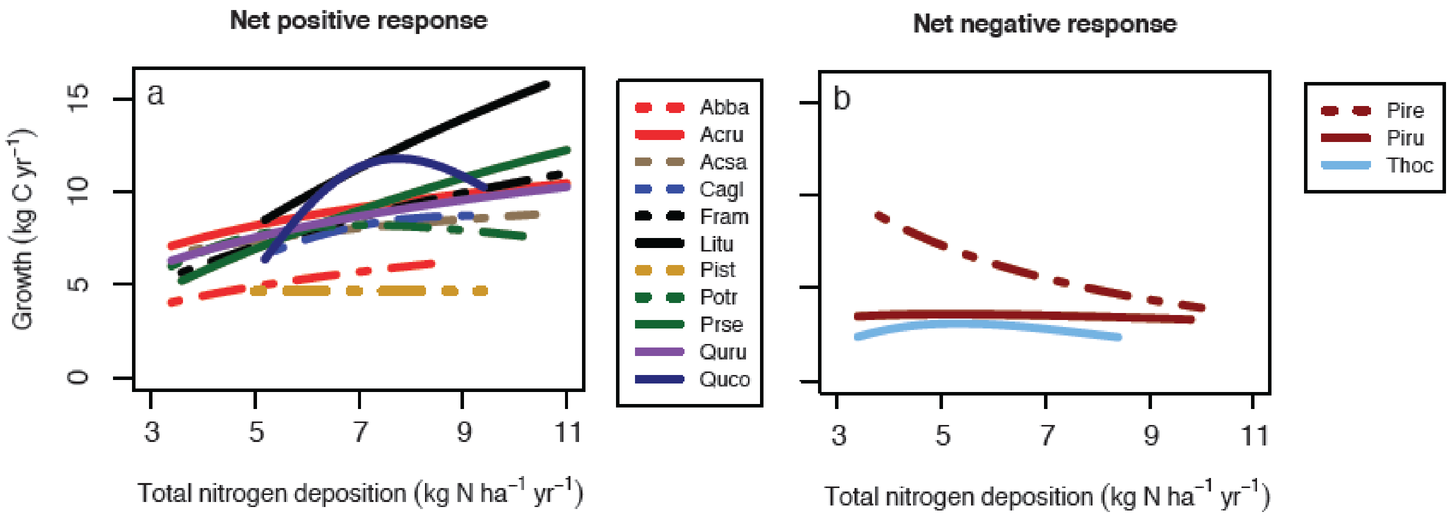
Janssens et al. (2010) Nature Geoscience 3:315-322

Soil carbon gain

dC_{soil}/dN_{dep} = 19 g C/g N

The nitrogen cascade and biodiversity

In northeast and north-central US, N deposition differentially affects tree growth

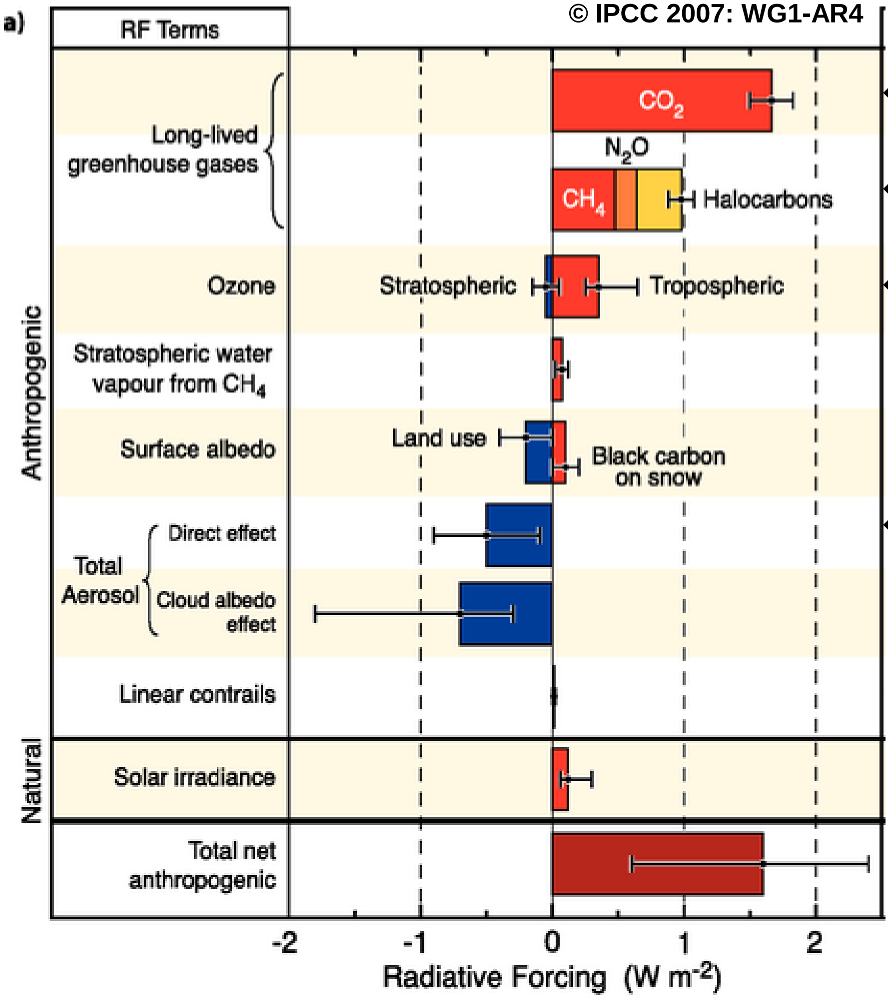


- *Enhanced* growth for 11 of 24 species
- *Reduced* growth for 3 of 24 species
- *No effect* for 10 of 24 species

Thomas et al. (2010) Nature Geoscience 3:13-17

Increased N deposition is likely to change the biotic composition and biodiversity of forest communities

Effect of nitrogen on global mean radiative forcings



Cooling **Warming**

Nitrogen addition:	**Change in radiative forcing**
Increases land CO_2 uptake	(-)
N_2O emission: Increases N_2O	(+)
NO_X emission: Decreases CH_4	(-)
NO_X emission: Increases tropospheric O_3	(+)
N_2O emission: Decreases stratospheric O_3	(+)
NH_3 emission: Increases aerosols	(-)

Nitrogen addition alters the composition and chemistry of the atmosphere, and changes the radiative forcing. The net radiative forcing varies regionally.

Take Away Message #1

Science

- Nitrogen impacts on CO_2 may reduce the radiative forcing (*global-scale*)
- Net nitrogen impacts on atmospheric N_2O, O_3, CH_4, and aerosols may increase the radiative forcing (*regional-scale*)

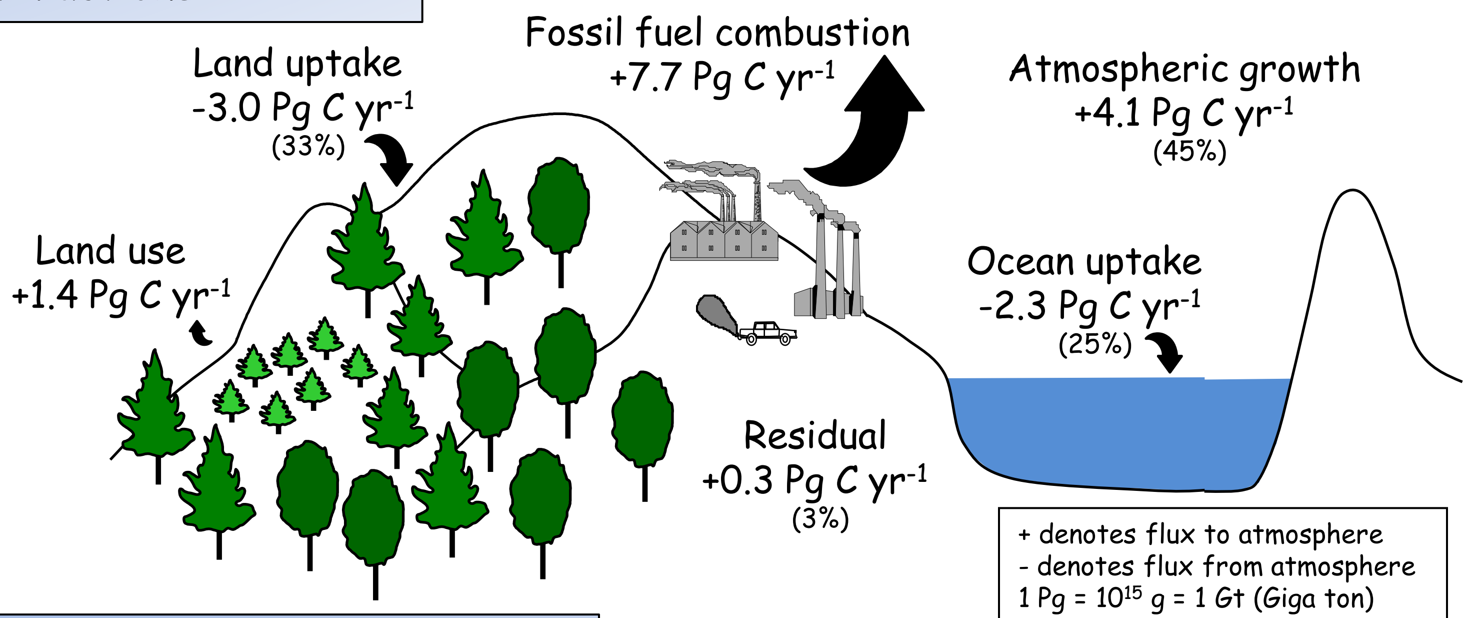
Policy

Nitrogen management strategies for global climate change mitigation, and concomitant benefits to society through the N cascade

Nitrogen and the carbon cycle

Policy
Fossil fuel CO_2 emission targets to stabilize atmospheric CO_2 may not be sufficient, because they do not include carbon-nitrogen interactions

Global carbon cycle, 2000-2008



Science
The capacity of the terrestrial biosphere to gain carbon in the future (i.e., land uptake) depends on nitrogen

- ❑ N deposition enhances land uptake
- ❑ Low N restricts CO_2 fertilization
- ❑ Soil warming enhances N in soil

Le Quéré (2010) Current Opinion in Environmental Sustainability 2:219-224

Data from Global Carbon Project

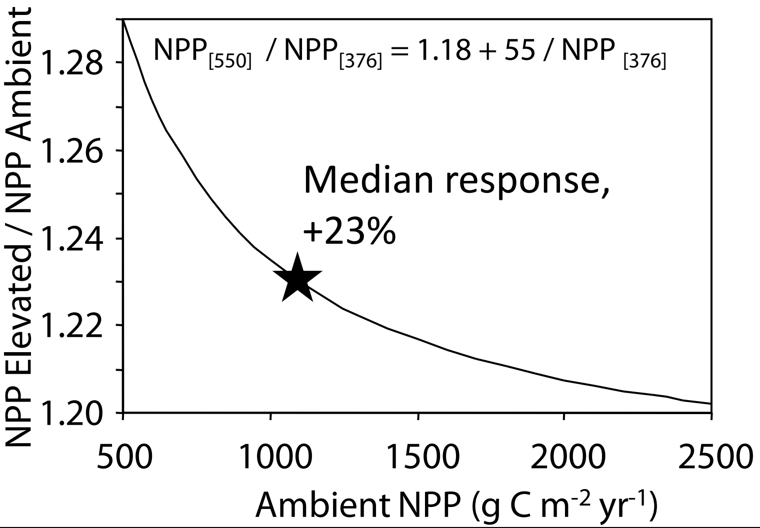
CO_2 fertilization

CO_2 enrichment,
Duke Forest, NC

Ambient CO_2, 376 ppm
Elevated CO_2, 550 ppm

Known
Rising atmospheric CO_2 concentration enhances carbon uptake in plant growth and terrestrial carbon storage

Response of net primary production (NPP) to elevated CO_2 in four forest FACE experiments

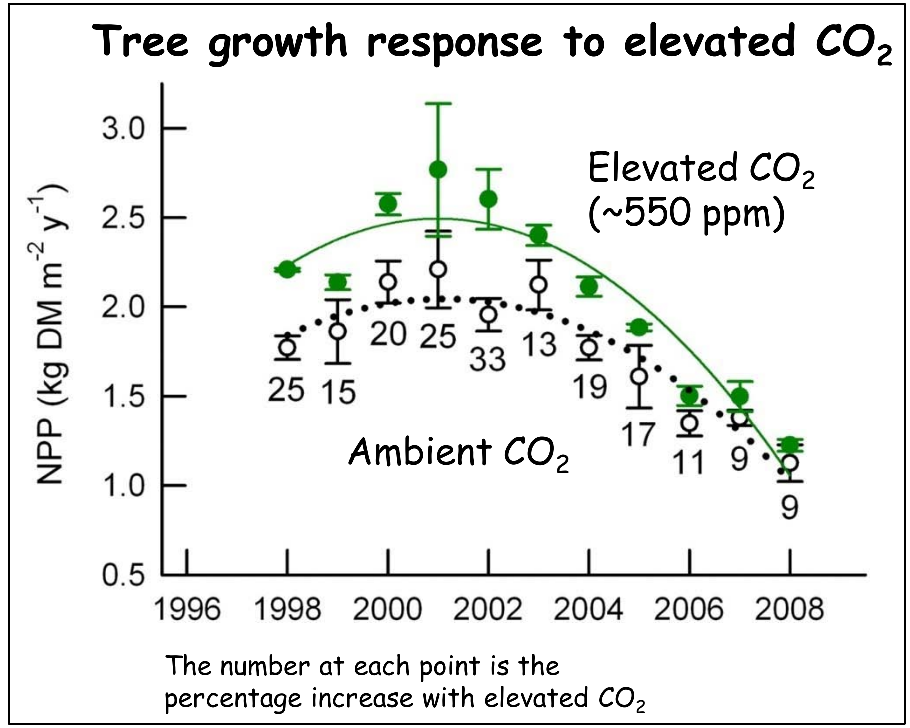


Norby et al. (2005) PNAS 102:18052-18056

Unknown
What is the long-term response?
Does nitrogen limitation restrict the CO_2 enhancement?

Nitrogen x CO_2 interaction

CO_2 enrichment, sweetgum forest, ORNL, TN



Norby et al. (2010) PNAS 107:19368-19373

- Elevated CO_2 enhanced net primary production (NPP) by 24% early in the study (2001-2003)
- The enhancement of NPP under elevated CO_2 declined to 9% in 2008

Declining N availability constrains the tree response to elevated CO_2

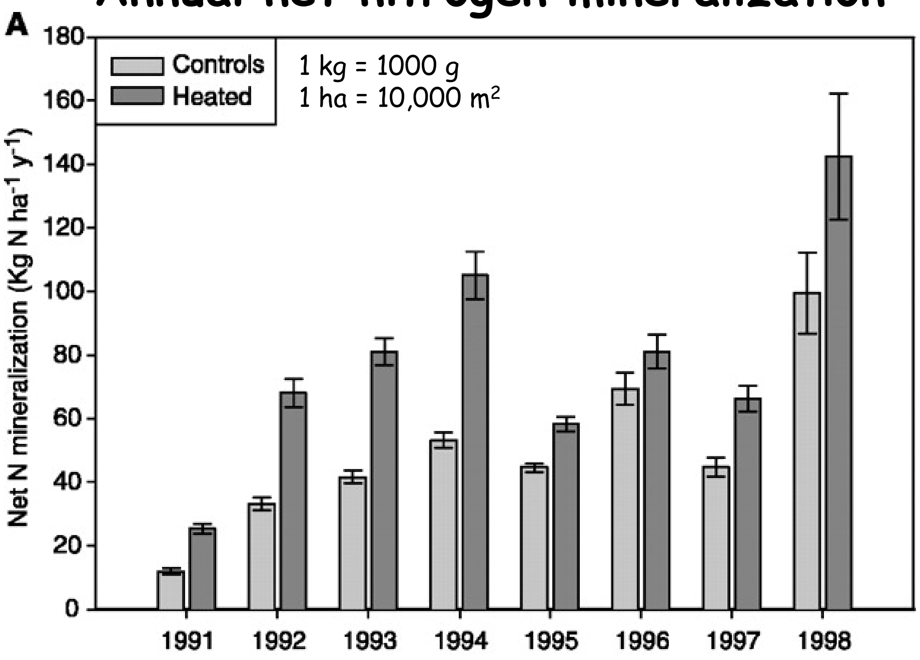
Nitrogen x warming interaction

Soil warming, Harvard Forest, MA

Heated soil has increased net nitrogen mineralization rates compared with unheated control soil

Soil warming increases decomposition rates (soil carbon loss), which can enhance N availability and stimulate plant growth

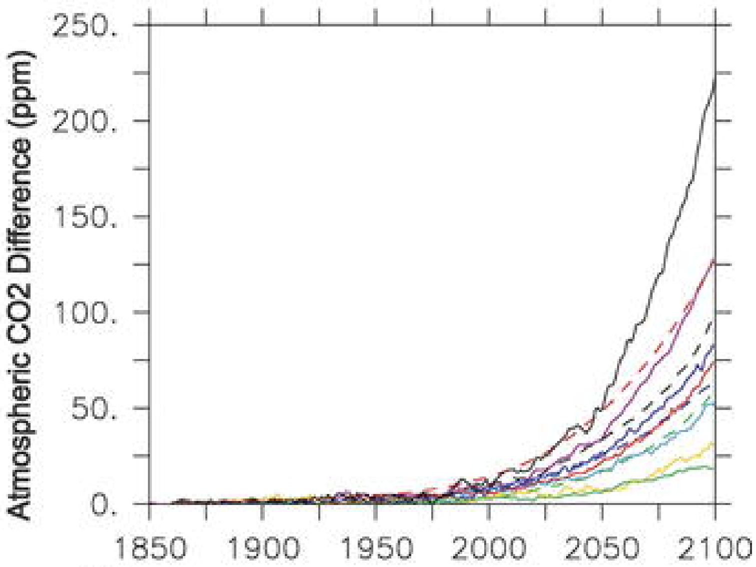
Annual net nitrogen mineralization



Melillo et al. (2002) Science 298:2173-2176

How will land carbon uptake change in the future?

Effect of climate change on carbon cycle



Friedlingstein et al. (2006) J Climate 19:3337–3353

A positive carbon cycle feedback

- 11 carbon cycle-climate models of varying complexity
- All models have a positive carbon cycle feedback with climate change (20 ppm to >200 ppm)
- Atmospheric carbon increases, because land carbon storage decreases

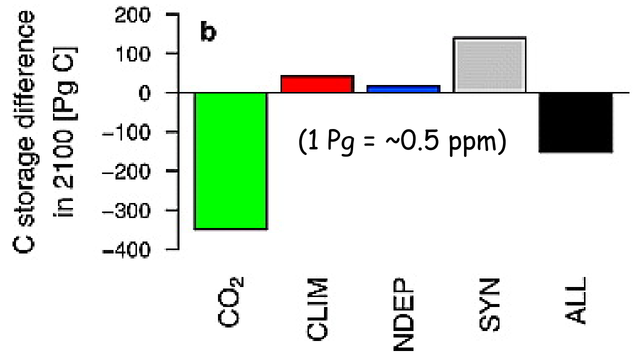
Prevailing paradigm
CO_2 fertilization enhances carbon uptake, diminished by decreased productivity and increased soil carbon loss with warming so that atmospheric CO_2 increases in a positive carbon cycle-climate feedback

Carbon-nitrogen interactions reduce land carbon uptake

Effect of nitrogen on land carbon storage

- Reduced carbon uptake with CO_2 fertilization
- Increased plant productivity with warming, resulting in reduced net carbon loss
- Increased carbon uptake with N deposition
- Net reduction in terrestrial carbon uptake

Effect of nitrogen on land carbon storage, 1860-2100



Zaehle et al. (2010) GRL, 37, doi:10.1029/2009GL041345

See also:
Sokolov et al. (2008) J Climate 21:3776-3796
Thornton et al. (2009) Biogeosci 6:2099-2120
Jain et al. (2009) GBC, 23, doi:10.1029/2009GB003519
Bonan & Levis (2010) GRL, 37, doi:10.1029/2010GL042430

The net capacity of the terrestrial biosphere to gain carbon decreases when carbon-nitrogen interactions are accounted for, and therefore the overall positive carbon cycle feedback increases

Take Away Message #2
Anthropogenic emissions and CO_2 stabilization

Global carbon budget

Source

Atmospheric = Fossil fuel + Land use
CO_2 increase - Land uptake – Ocean uptake

Sink

To stabilize atmospheric CO_2 at some specified concentration

- ❑ Reduce land use emission (e.g., reforestation, afforestation, avoided deforestation)
- ❑ Increase land uptake (e.g., ecosystem management, agricultural practices)
- ❑ Increase ocean uptake (e.g., iron fertilization)
- ❑ Reduce fossil fuel emission

If the capacity of the terrestrial biosphere to gain carbon in the future (i.e., land uptake) is less than we expect, then the reduction in fossil fuel emission needed to stabilize atmospheric CO_2 must increase

Nitrogen and climate: Concluding thoughts

Human activities have intensified the nitrogen cycle, with effects on the physics, chemistry, and biology of Earth's systems

Excess nitrogen has positive and negative effects on climate change, as well as terrestrial ecosystems and people

Nitrogen management strategies can be devised for global climate change mitigation, and concomitant benefits to society through the nitrogen cascade

How terrestrial ecosystems respond to climate change, and their capability for climate change abatement, depends not only on changes in physical climate but also on changes in the nitrogen cycle

The Earth system