Nitrogen uptake and net primary productivity in four forest FACE experiments

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FACE experiments provide valuable data for projecting future global carbon cycling

- Forests account for a large fraction of the exchange of C between the atmosphere and the terrestrial biosphere

- Net primary productivity of forests is expected to increase as the atmospheric $[\text{CO}_2]$ rises ("CO$_2$ fertilization")

- Ecosystem and coupled carbon-climate models require an accurate representation of the CO$_2$ fertilization effect

- Free-air CO$_2$ enrichment (FACE) experiments are the best source of data to inform models
Objectives:

- Quantify CO₂ effect on NPP in a manner that will inform ecosystem and global models
- Quantify N uptake, N-use efficiency, and related expressions of C-N interaction
- Look for general patterns of response that apply across diverse sites

Four experiments in which forest stands exposed to ~550 ppm CO₂ for 3-8 years

Closed-canopy

DukeFACE (NC) – loblolly pine

ORNL-FACE (TN) – sweetgum

Developing stands

AspenFACE (WI) – aspen/birch

PopEuroFACE (Italy) – poplars
Calculation of NPP

NPP = woody increment + leaf litter + fine-root production

**Wood increment**
- Allometry: $DM = f(BA, H, \text{taper, density})$
- Harvest

**Leaf**
- Litter traps

**Fine root**
- Minirhizotrons and in-growth cores
- Sequential coring

NPP calculated for all plots and years after canopy development was complete
Calculation of N Uptake

\[
N \text{ uptake} = N \text{ content of current year wood} + N \text{ content in live canopy} - \text{amount resorbed from previous year} + \text{amount used in fine-root production}
\]

Peak N content = amount in all wood + N content of canopy at peak mass + N content of fine roots at peak mass

Data
Concentration of N in green leaves, leaf litter, fine roots, and wood

\([N]\) combined with biomass data to calculate N content

\[
\text{NUE} = \frac{\text{NPP}}{\text{N uptake}}
\]

\[
\text{N productivity} = \frac{\text{NPP}}{\text{N content}}
\]

\[
\text{MRT} = \frac{\text{N content}}{\text{N uptake}}
\]

\[
\text{NUE} = \text{Nprod} \times \text{MRT}
\]
NPP increased in elevated CO₂ across a wide range of NPP

- Regression is significantly different from 1:1 line
- Regression defines a median response of 23% enhancement
- Basis of response was increased light absorption at low LAI and increased light-use efficiency at high LAI

Norby et al. (2005) *PNAS* 102: 1805
This analysis does not resolve all issues about forests in a CO$_2$-rich world

- The median response masks spatial and temporal variability
- Interactions with other global change factors may be significant
- The analysis did not include tropical or boreal forests
- C partitioning patterns may determine the ultimate fate of the additional C
- Will responses persist in more mature forests?
- N feedbacks might limit response over the long term

It’s time to look below ground!
To support increased NPP, the trees must either take up more N from soil or use N more efficiently

- **Increased N uptake**
  - Availability in soil
  - Root exploration
  - Sustainable?

- **Increased efficiency**
  - Biochemical
  - Allocation and retranslocation
  - Tissue quality feedbacks?
Nitrogen-use efficiency describes the relationship between NPP and N uptake

- Within a site, both NPP and N uptake are generally higher in elevated CO₂
- Exception: N uptake was not increased in the irrigated, fast-growing Euro-PopFACE experiment
- Within a site, data generally align along a constant NUE isopleth
- NUE is greater in the older stands
Nitrogen uptake is the first point of interaction between soil N and plant N

- N uptake increased significantly in elevated CO$_2$
- Increased uptake was not associated with any measured effect on microbial N metabolism
- Increased root exploration is indicated

**Graph:**
- $N_{uptake} = 1.19 \times N_{uptake}^{current} + 0.96$
- $E/C = 1.34$

**Legend:**
- Populus tremuloides
- P. tremuloides/B. papyrifera
- L. styraciflua
- Pinus taeda
- P. alba
- P. x euramericana
- P. nigra
Nitrogen-use efficiency is often assumed to increase in elevated CO₂ -- not supported by our data

- There was no response of NUE to elevated CO₂
- Understanding and predicting N uptake should be a key objective for modeling NPP response to elevated CO₂
Photosynthetic N-use efficiency *did* increase in elevated CO₂

- Stimulation ranged from 26 to 44%
- Leaf-level PNUE at the whole-tree scale is N productivity
Nitrogen productivity describes the relationship between NPP and peak N content

- N productivity increased significantly and consistently
- N productivity is not often used in models
- Discrepancy between NUE and N productivity is explained by MRT

\[ N_{prod-e} = 1.12 \times N_{prod-a} + 4.15 \]

\[ E/C = 1.18 \]
Mean residence time describes relationship between content and uptake

- MRT is a function of partitioning, organ longevity, and retranslocation
- MRT was reduced in elevated CO₂ in the more mature forests that are more dependent on recycling of N
- Lower MRT reflected increased partitioning of N to fine roots
- Partitioning to fine roots necessary for increased uptake
Conclusions....

• The response of forest NPP to ~550 ppm CO₂ was highly conserved across a broad range of productivity, with a stimulation at the median of 23%

• The surprising consistency of response across diverse sites is providing a benchmark to evaluate predictions of ecosystem and global models

• Increased NPP was usually associated with increased N uptake rather than increased N-use efficiency

• Increased N productivity reflected increased leaf-level photosynthetic N-use efficiency

• Reduced MRT offset increased N productivity

• A “cost” associated with increased foraging for N is partitioning of N to fine roots

• These results emphasize the continuing importance of unresolved questions about C and N partitioning, and controls on N uptake from soil
Good fellowship....

....good science