Nitrogen Limitation is Reducing the Enhancement of NPP by Elevated CO_2 in a Deciduous Forest

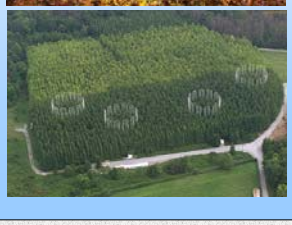
Richard J Norby[1], Jeffrey M Warren[1], Colleen M Iversen[1], Belinda E Medlyn[2], Ross E McMurtrie[3]

[1]Oak Ridge National Laboratory, Oak Ridge, Tennessee

[2]Macquarie University, Sydney, Australia; [3]University of New South Wales, Sydney, Australia

Summary

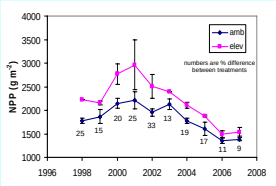
- Coupled carbon cycle–climate models are sensitive to the negative feedback to atmospheric CO_2 resulting from stimulation of terrestrial productivity by rising CO_2.
- The representation of the so-called CO_2 fertilization effect has been consistent with experimental evidence from four free-air CO_2 enrichment (FACE) experiments, which indicated that net primary productivity (NPP) of forests was increased by 23% in response to CO_2 enrichment of the atmosphere to 550 ppm.
- Although it is hypothesized that feedbacks through the nitrogen cycle will reduce the CO_2 stimulation of NPP, these feedbacks are not generally included in the models and to date have not been confirmed by experiments in forests.
- New evidence from the ORNL FACE experiment shows that N limitation has significantly reduced the stimulation of NPP by elevated atmospheric CO_2 concentration.



ORNL FACE Experiment

- The experiment uses free air CO_2 enrichment technology in a *Liquidambar styraciflua* (L.) plantation in Oak Ridge, Tennessee, USA.
- The trees were planted in 1988, and when the experiment began in 1998, canopy closure had occurred and the trees exhibited a linear growth rate.
- Two 25-m diameter plots receive elevated CO_2 (eCO_2), averaging 545 ppm, continuously during daylight hours from April to November. There are three ambient CO_2 control (aCO_2) plots.
- N fertilizer (200 kg ha^{-1}) has been applied annually since 2004 to replicated plots in a separate area of the plantation.
- NPP is calculated from allometric relationships, leaf litter collections, and minirhizotron analysis of fine-root production.
- N content of leaves from throughout the canopy, wood, fine roots, and litter is measured annually

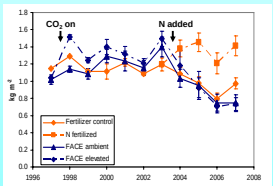
NPP enhancement is diminished



- From 1998 to 2004 NPP averaged 23% greater in eCO_2, and the response was consistent and sustained.
- NPP in both aCO_2 and eCO_2 has been declining since 2004.
- The relative response of NPP to eCO_2 has been declining since 2004.
- Most of the NPP response has been in fine-root production (47-98%).

Norby et al. 2005. *PNAS* 102: 18052-18056.
Iversen et al. 2008. *New Phytologist* 179: 837-847.

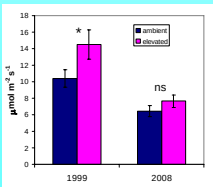
This forest is N limited



- An adjacent area of the plantation was fertilized with N in from 2004 to 2008.
- Aboveground growth was stimulated by N addition and the growth decline was avoided.
- This is strong evidence that tree growth at this site is N limited, but it does not address CO_2 x N interaction.

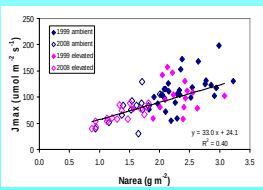
Iversen & Norby. 2008. *Canadian Journal of Forest Research* 38: 1021-1032.

Mechanistic basis for N effect



- Leaf-level photosynthesis was less in 2008 than in 1999, and the effect of eCO_2 was lost.

Sholtis et al. 2004. *New Phytologist*, 162: 343-354.

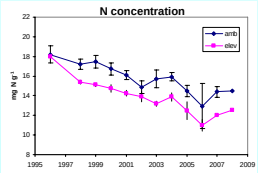


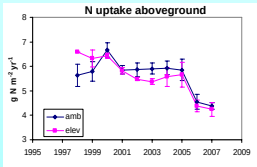
- Reductions in Pn reflect differences in foliar N_{area} and in the parameters of photosynthetic biochemistry, J_{max} and V_{cmax}.

Foliar N is declining

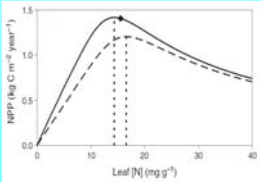
- Foliar N concentration (mass-based) has been declining steadily, and is less in eCO_2.
- Leaf mass per unit area increased with time and in eCO_2, explaining much of the decline in [N] (*not shown*).
- Uptake to aboveground pools has recently declined.
- There has been no effect of eCO_2 on N mineralization, but ^{15}N analysis (CT Garten Jr., *pers. comm.*) suggests N availability has been declining over time.

Norby & Iversen. 2006. *Ecology* 86:5-14;
Finzi et al. 2007. *PNAS* 104: 14014-14019.





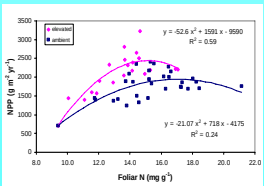
Optimization model explains response



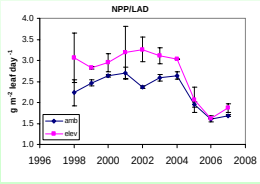
- An optimization model provides explanation for lack of effect of declining [N] on NPP until 2004.
- The model suggests that NPP should decline faster with declining [N] in eCO_2.

McMurtrie et al. *Functional Plant Biology* 35: 521-534.

- The data match the model prediction – NPP declines more steeply in eCO_2 after 2004.
- The analysis suggests that there will be no effect of eCO_2 on NPP when [N] = 9.4 mg g^{-1}.
- Model prediction of N uptake to aboveground pools also closely matches data (*not shown*).



Are there other possible causes of declining NPP?



- Variation in leaf area duration (LAD) accounts for some variability in NPP, but cannot explain declining NPP after 2004.
- Soil moisture at 20 cm was generally lower in 2004-2007, but these trees have access to deep water.
- These results do not support Progressive N Limitation (N limitation caused by eCO_2), but rather reflect changes in N economy during stand development.
- Linking tree responses to soil C and N dynamics remains a critical challenge.

Implications

- Continuation of this experiment for 12 years was necessary to reveal the interactions between C and N cycles, but it is not yet clear whether foliar [N] and CO_2 enhancement of NPP will continue to decline or have reached a new steady state indicative of long-term forest response to eCO_2.
- These results provide a strong rationale and process understanding for incorporating N limitation and N feedback effects in ecosystem and global models used in coupled carbon cycle–climate change assessments.
- Failure to characterize these interactions and incorporate suitable algorithms into models will lead to unreliable predictions of the response of the terrestrial biosphere to atmospheric and climatic change.

Oak Ridge National Laboratory

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