Nitrogen Limitation is Reducing the Enhancement of NPP by Elevated CO₂ in a Deciduous Forest

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Summary

• Coupled carbon cycle-climate models are sensitive to the negative feedback to atmospheric CO₂ resulting from stimulation of terrestrial productivity by rising CO₂.
• The representation of the so-called CO₂ fertilization effect has been consistent with experimental evidence from four free-air CO₂ enrichment (FACE) experiments, which indicated that net primary productivity (NPP) of forests was increased by 23% in response to CO₂ enrichment of the atmosphere to 550 ppm.
• Although it is hypothesized that feedbacks through the nitrogen cycle will reduce the CO₂ 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 CO₂ concentration.

ORNL FACE Experiment

• The experiment uses free air CO₂ 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 CO₂ (eCO₂), averaging 545 ppm, continuously during daylight hours from April to November. There are three ambient CO₂ control (aCO₂) 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 mineralization analysis of fine-root production.
• N content of leaves from throughout the canopy, wood, fine roots, and litter is measured annually.

Mechanistic basis for N effect

• Leaf-level photosynthesis was less in 2008 than in 1999, and the effect of eCO₂ was lost.
• Reductions in Pn reflect differences in foliar Narea and in the parameters of photosynthetic biochemistry, J₅₀, and V₁₅₅.

Foliar N is declining

• Foliar N concentration (mass-based) has been declining steadily, and is less in eCO₂.
• Leaf mass per unit area increased with time and in eCO₂, explaining much of the decline in N (not shown).
• Uptake to aboveground pools has recently declined.
• There has been no effect of eCO₂ on N mineralization, but ¹⁵N analysis (CT Garten Jr., pers. comm.) suggests N availability has been declining over time.

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.

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 CO₂ enhancement of NPP will continue to decline or have reached a new steady state indicative of long-term forest response to eCO₂.
• 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.

ORNL FACE Enhanced NPP 1999 2008