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

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Oak Ridge Experiment on CO_2 Enrichment of Sweetgum

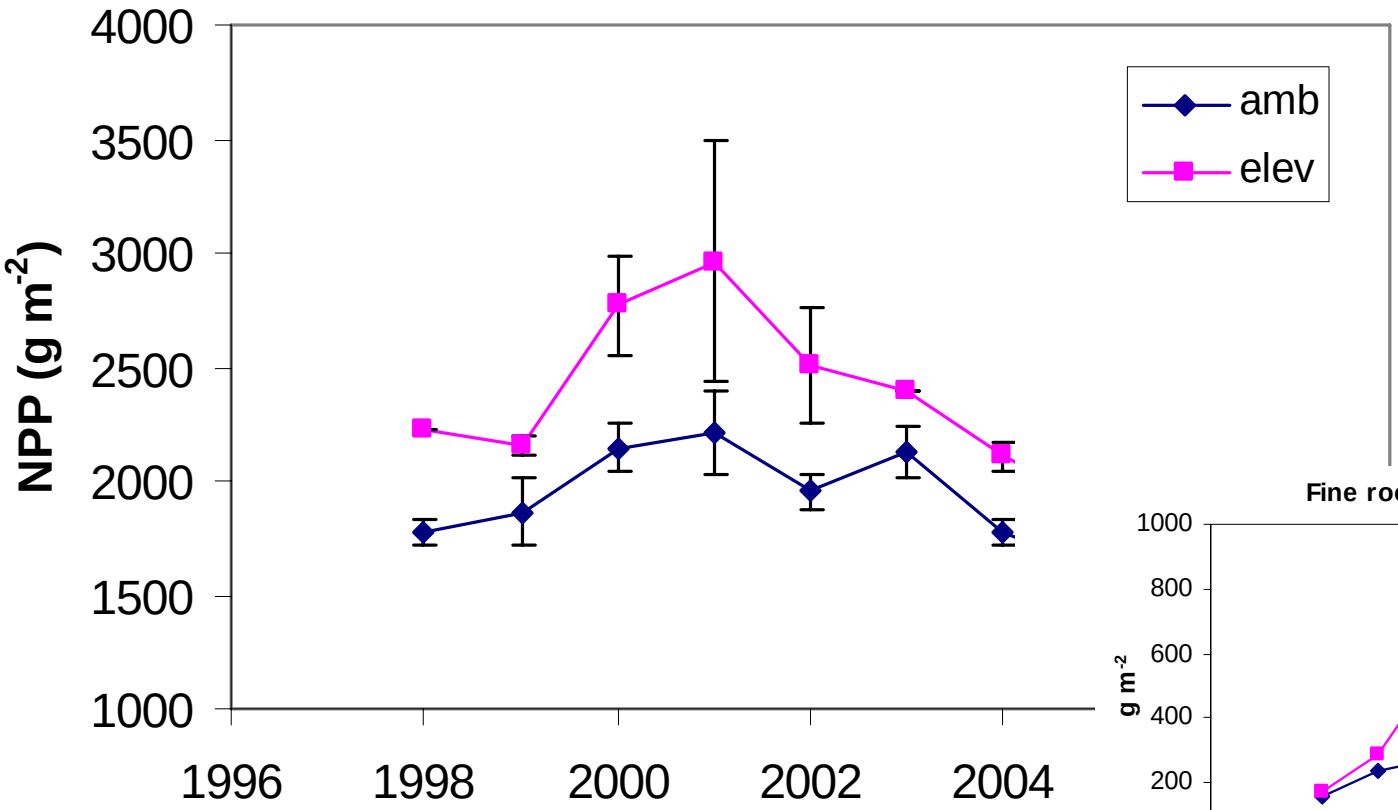
A FACE experiment in a deciduous forest

- ***Liquidambar styraciflua* plantation started in 1988**
- **Closed-canopy stand, linear growth rate**
- **2 elevated, 3 control plots (25 m diameter)**
- **CO_2 exposure (545 ppm) started in 1998**
- **N fertilizer experiment started in 2004**

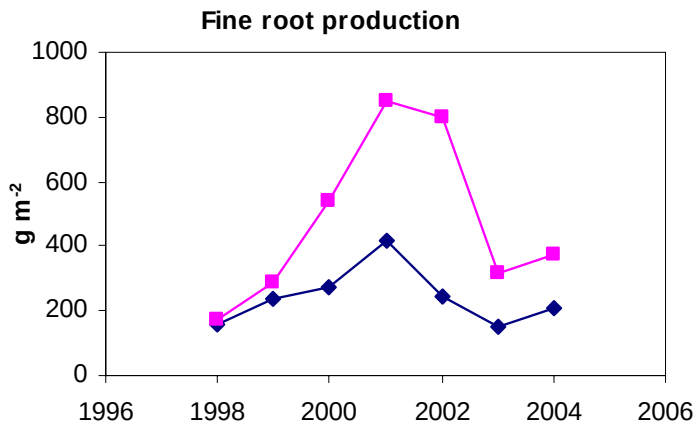
NPP = stem + coarse root increments + leaf litter + fine-root production

N uptake = N content in these components

We had been reporting that NPP showed a consistent response to elevated CO_2

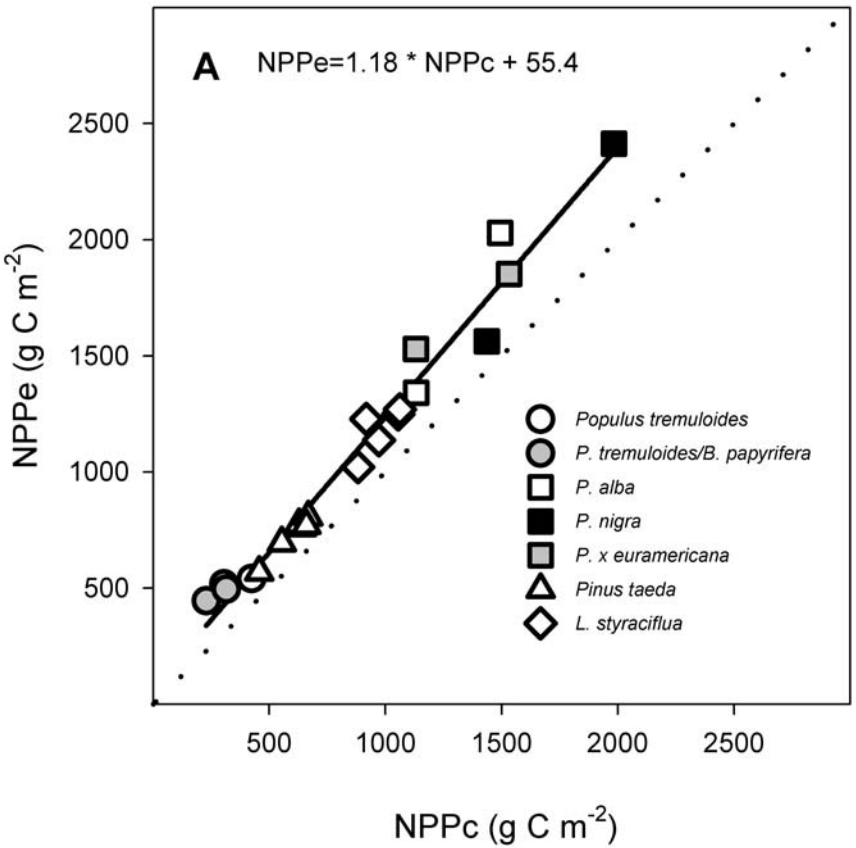


- **Average increase 23%**
- **Most of the increase was in fine-roots**

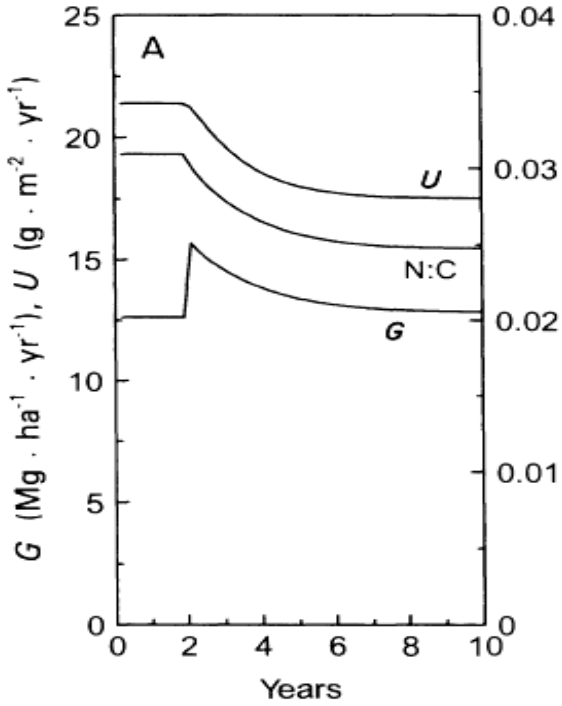


Our data contributed to a four-site forest FACE synthesis that indicated a 23% increase in NPP, consistent over a wide range of productivity

A benchmark for ecosystem and global models



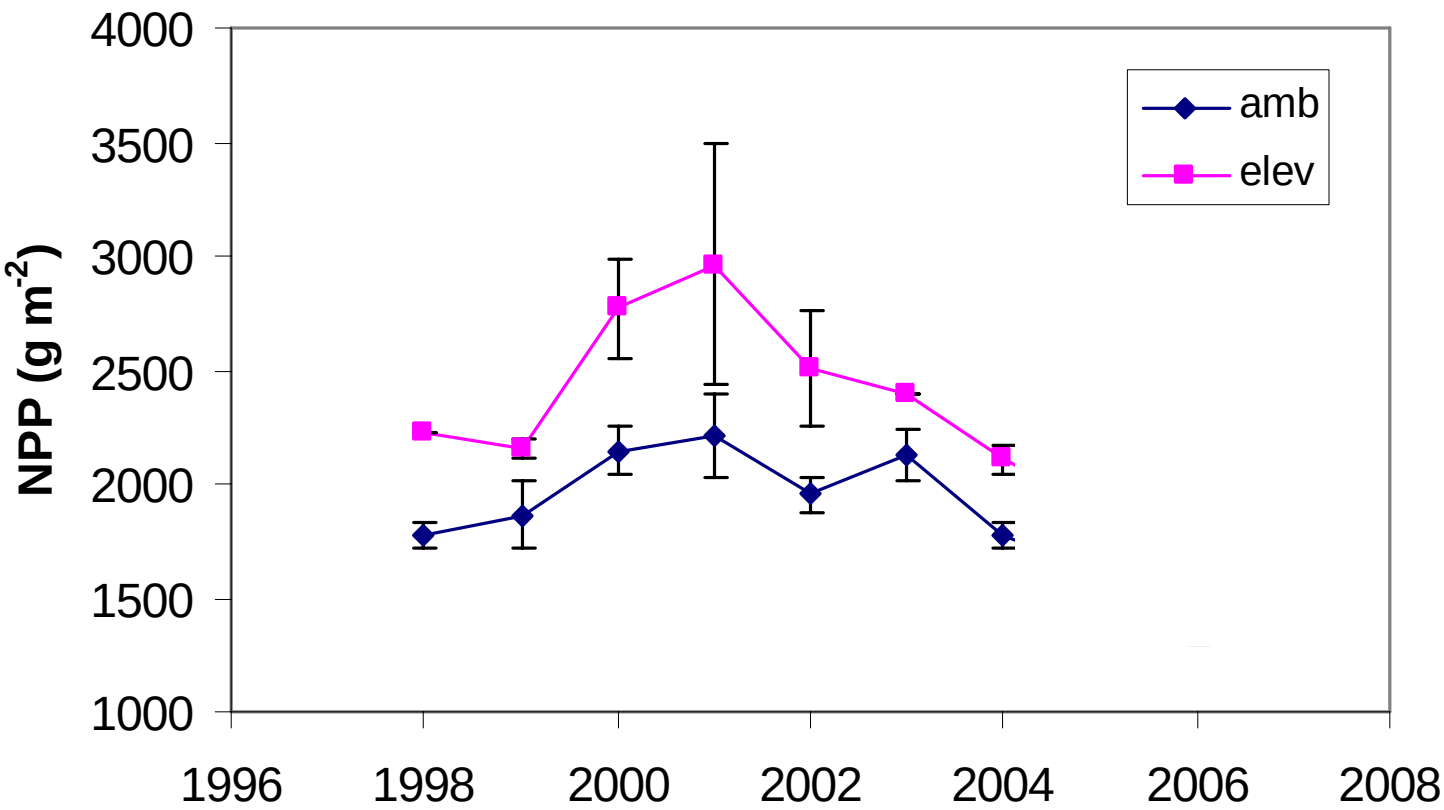
Norby et al. 2005. *PNAS* 102: 18052-18056.



Comins and McMurtrie 1993

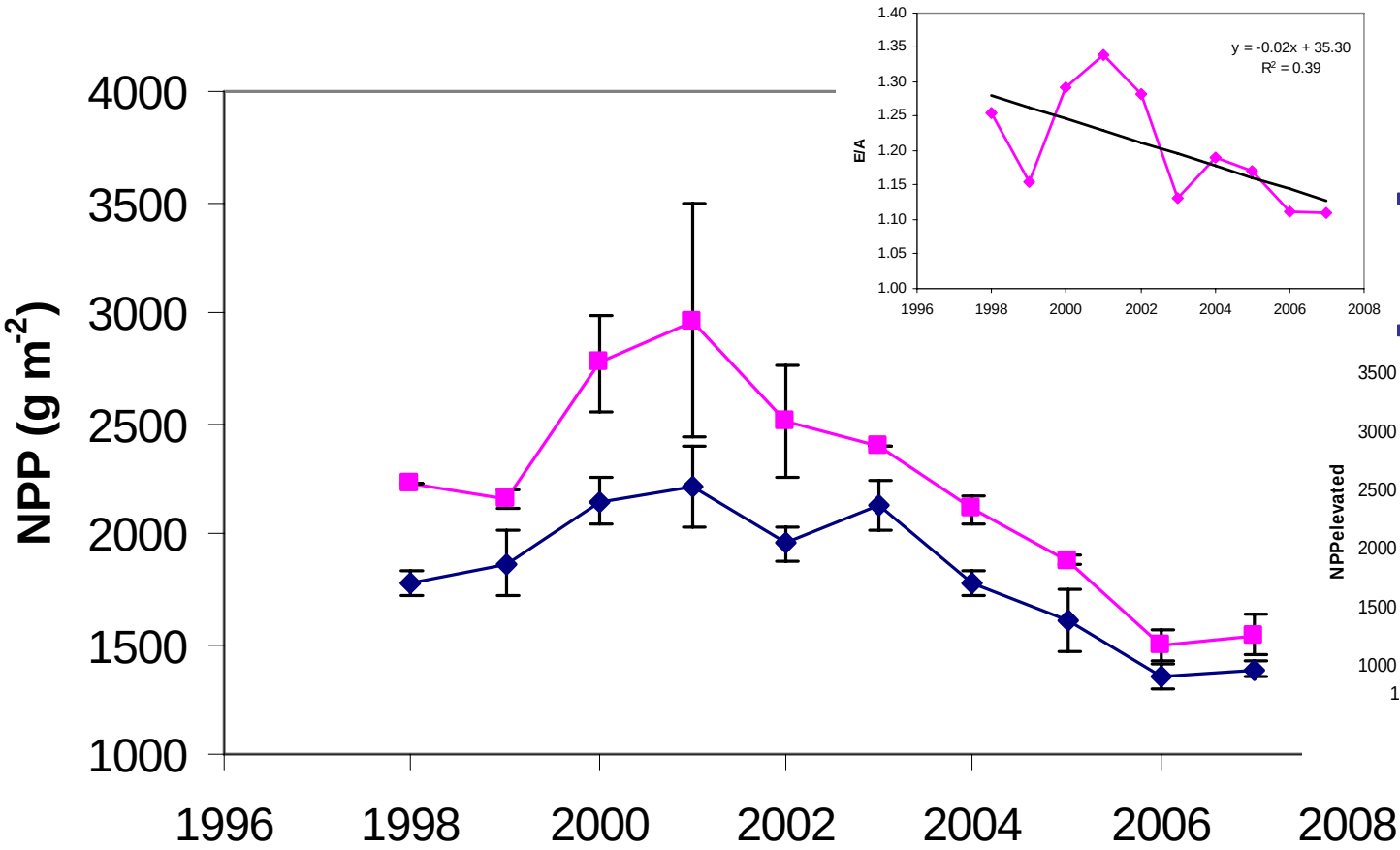
But models have suggested that the productivity response to eCO_2 would be transient

We had been reporting that NPP showed a consistent response to elevated CO_2

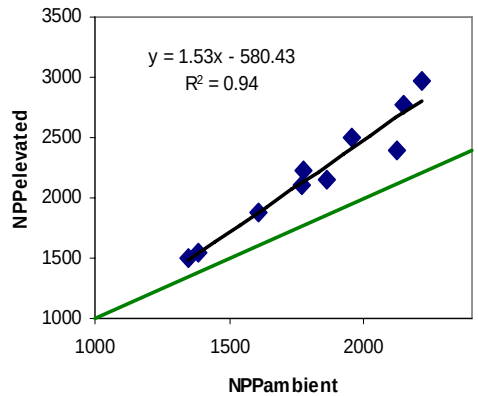


Have our experiments lasted long enough?

We now see that NPP has been declining in both ambient and elevated CO_2



- Decline leveling off in 2007?
- Relative



Can we explain these responses?

- Why is response to eCO_2 declining?
- Why is NPP declining in ambient CO_2?
- What do we project for the future?

C^{4}MIP models used in IPCC 4th assessment report matched (on average) FACE results, but with wide variation

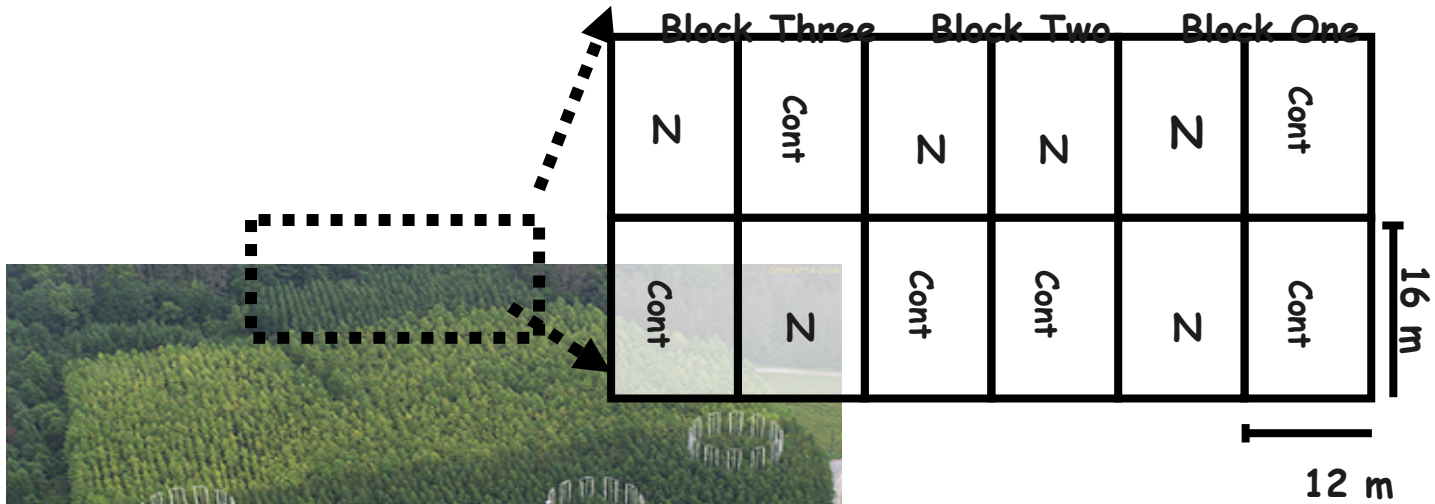
Both the models and experiments do not represent long-term N feedback

"Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests"

Free-air CO_2 studies in forests find that a ~50% increase in atmospheric CO_2 concentration sustained over several years enhances NPP by 23%, but the long-term outcome is unclear, especially when interactions with nitrogen availability are considered.

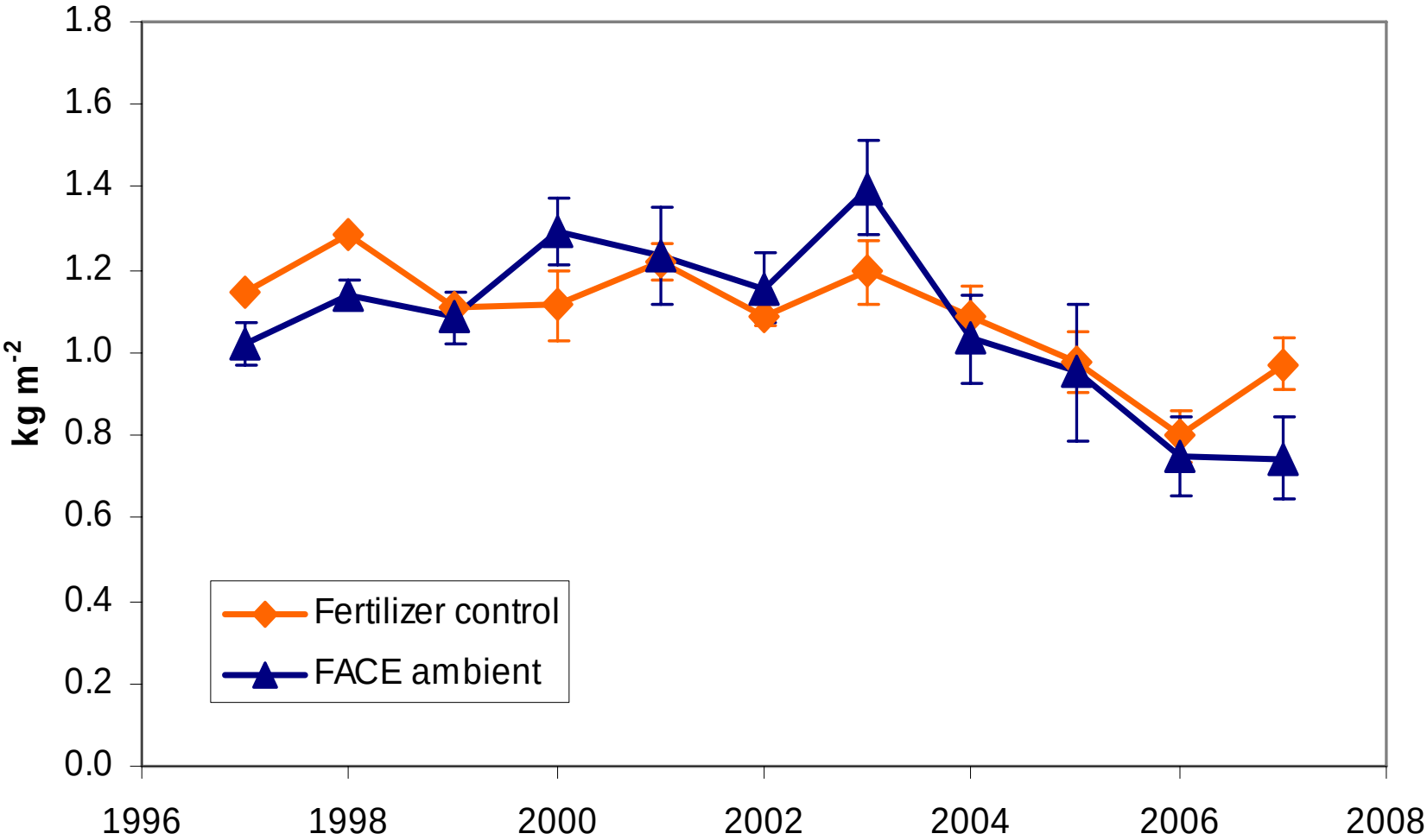
(Bonan, *Science*, 2008)

Is nitrogen limiting in this forest stand?

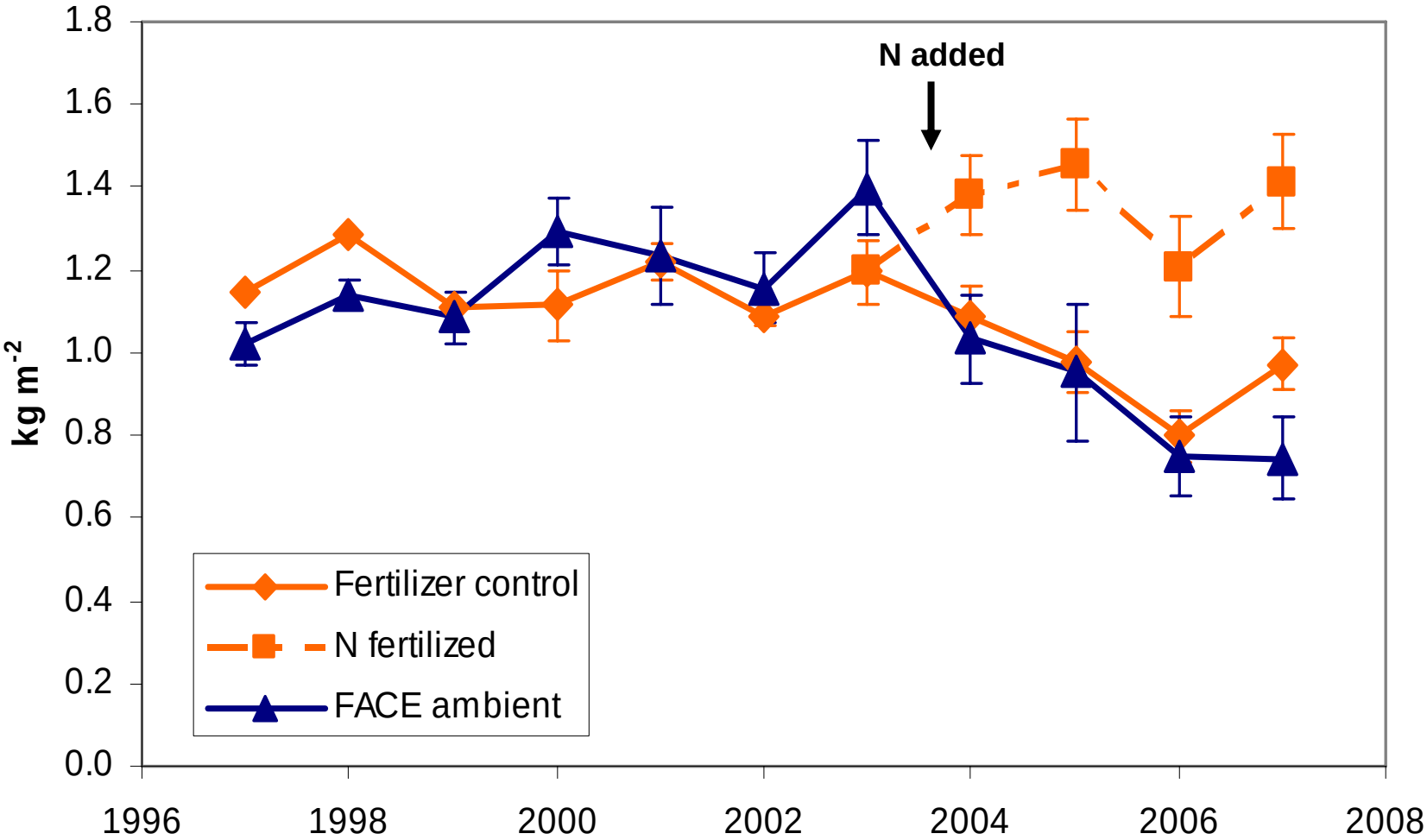


Iversen CM, Norby RJ. 2008. *Canadian Journal of Forest Research* 38: 1021-1032.

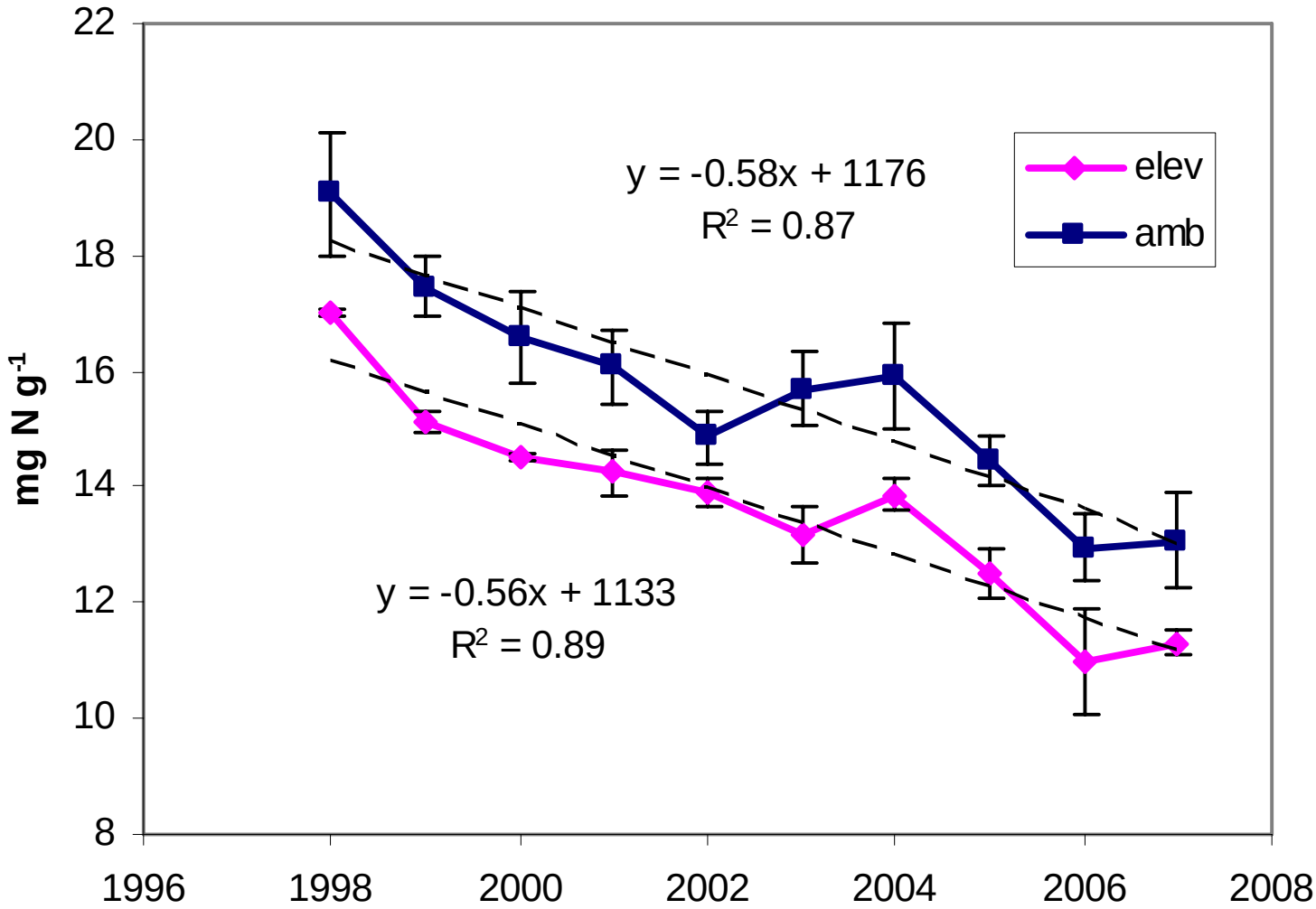
Aboveground dry matter increment in fertilizer control plots matches FACE controls



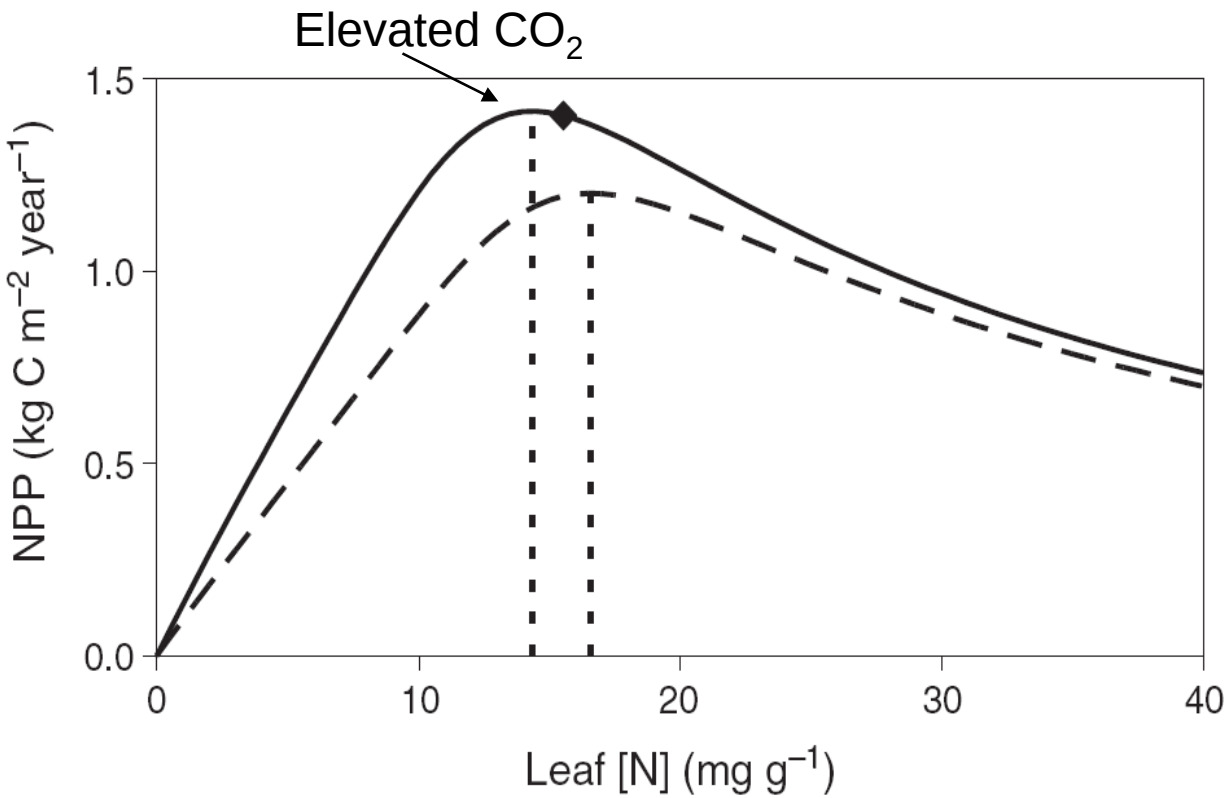
Aboveground growth was stimulated by N addition and the growth decline was avoided



Foliar nitrogen concentration has been declining steadily



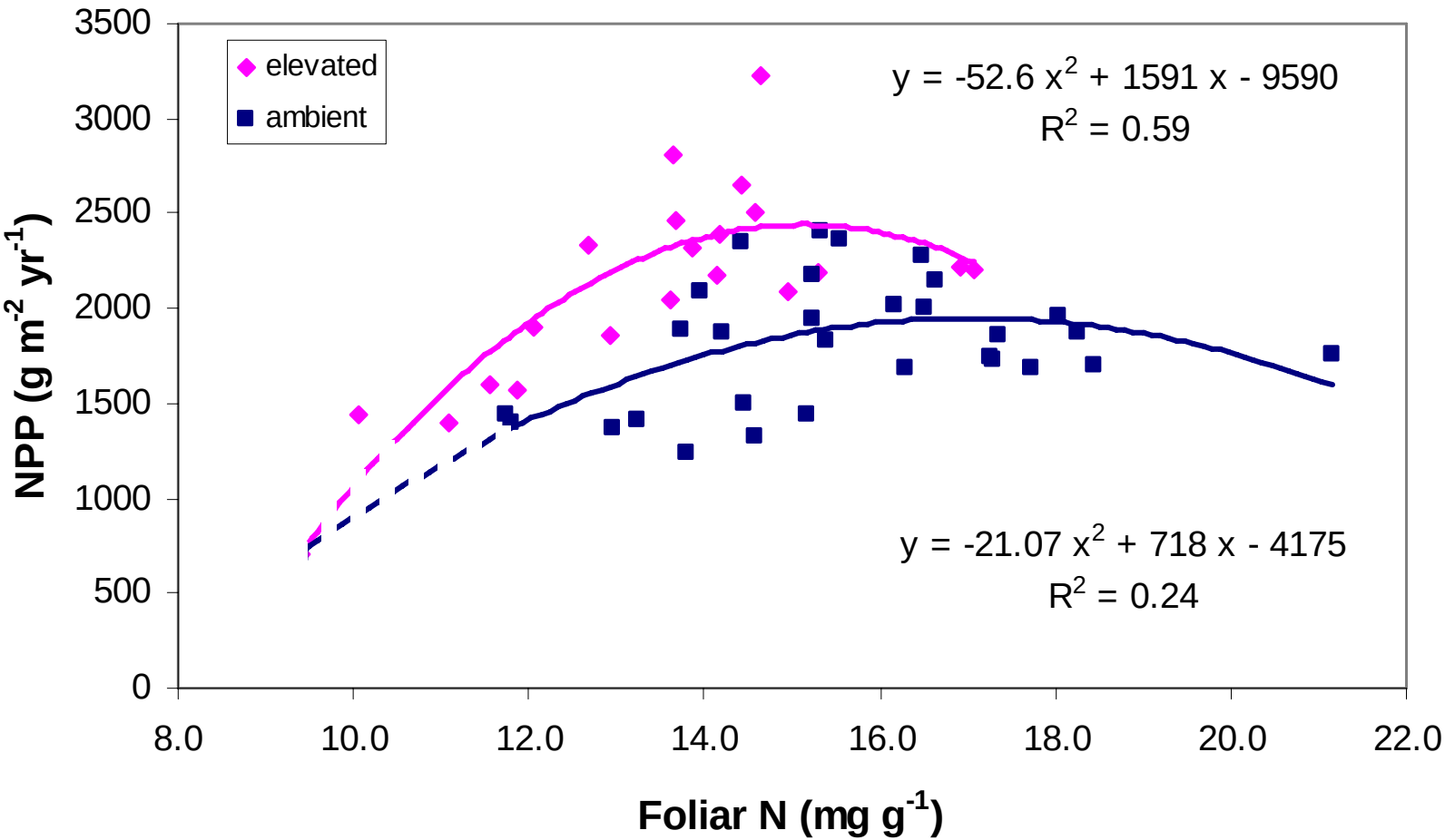
Optimization model suggests that NPP should decline faster with declining %N in eCO_2



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

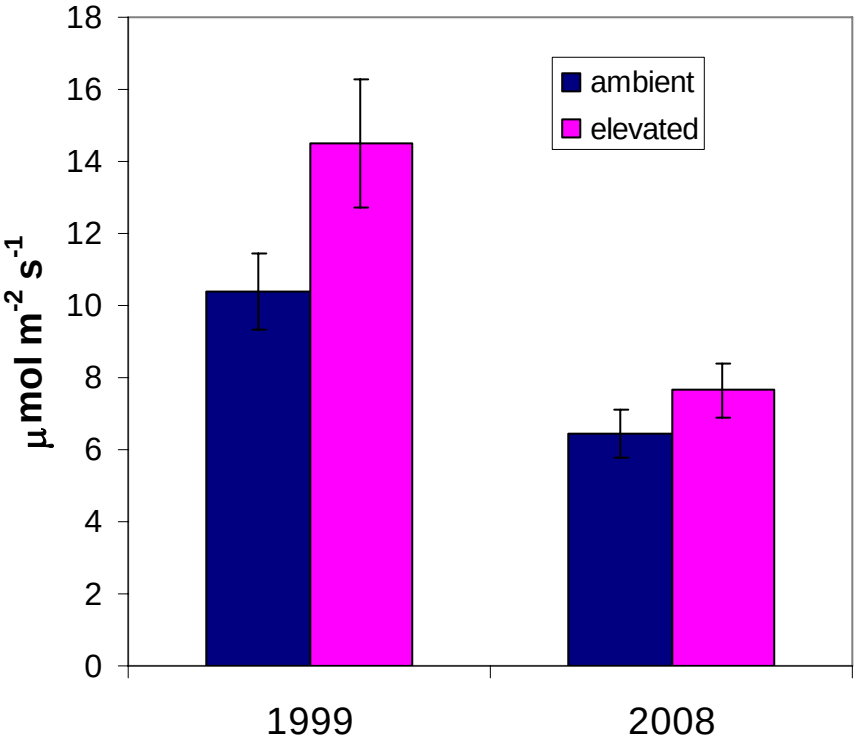
Experimental data match the prediction

-- *NPP declines more steeply in eCO_2 after 2004*

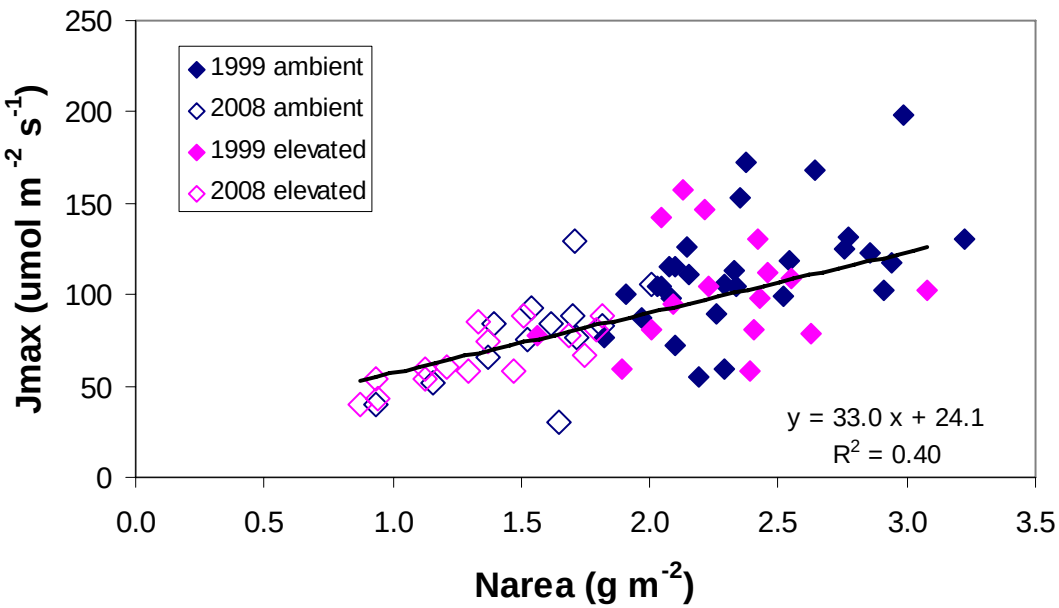


Implication: **no NPP response to eCO_2 when [N] < 9.4 mg g^{-1}**

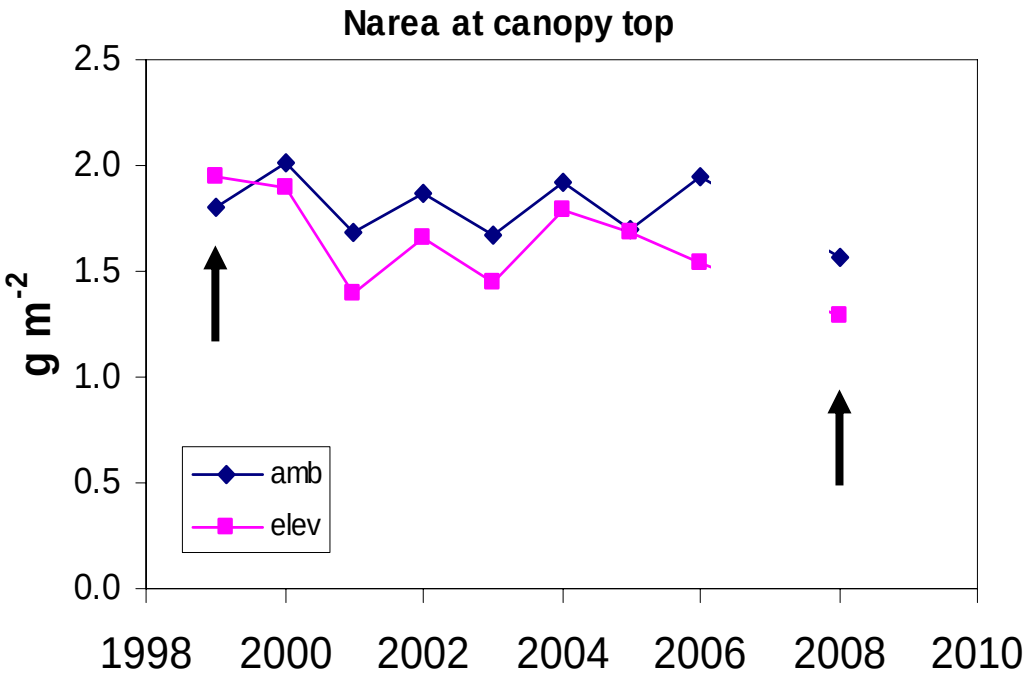
Mechanistic basis for decline in NPP resides in leaf-level photosynthesis



Sholtis et al., *New Phytologist*, 2004; Warren (unpublished)



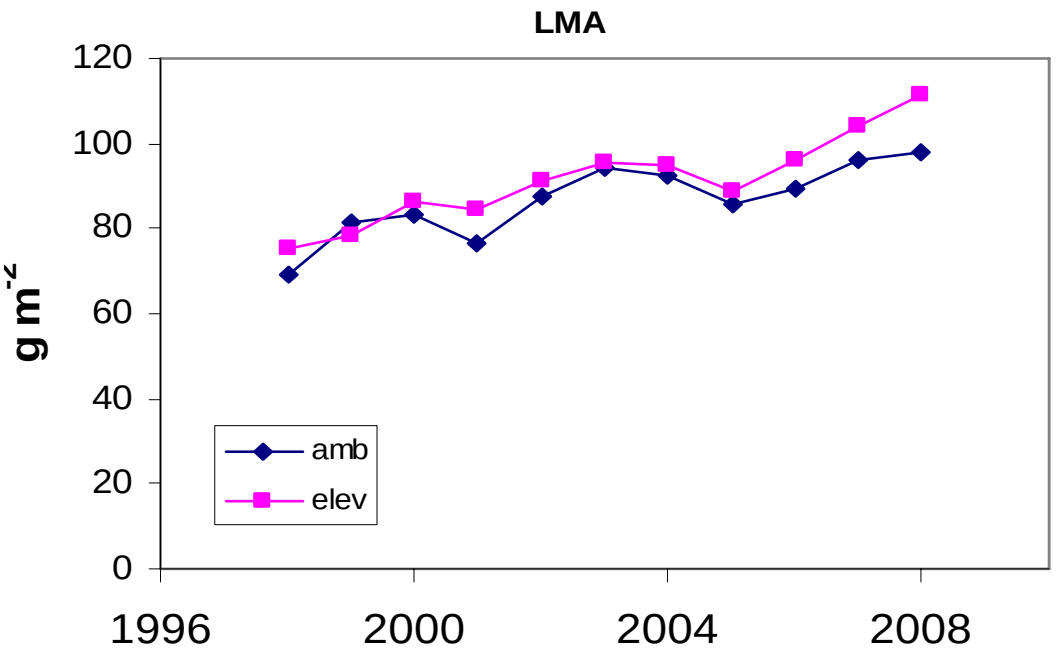
Medlyn and Warren, (unpublished)



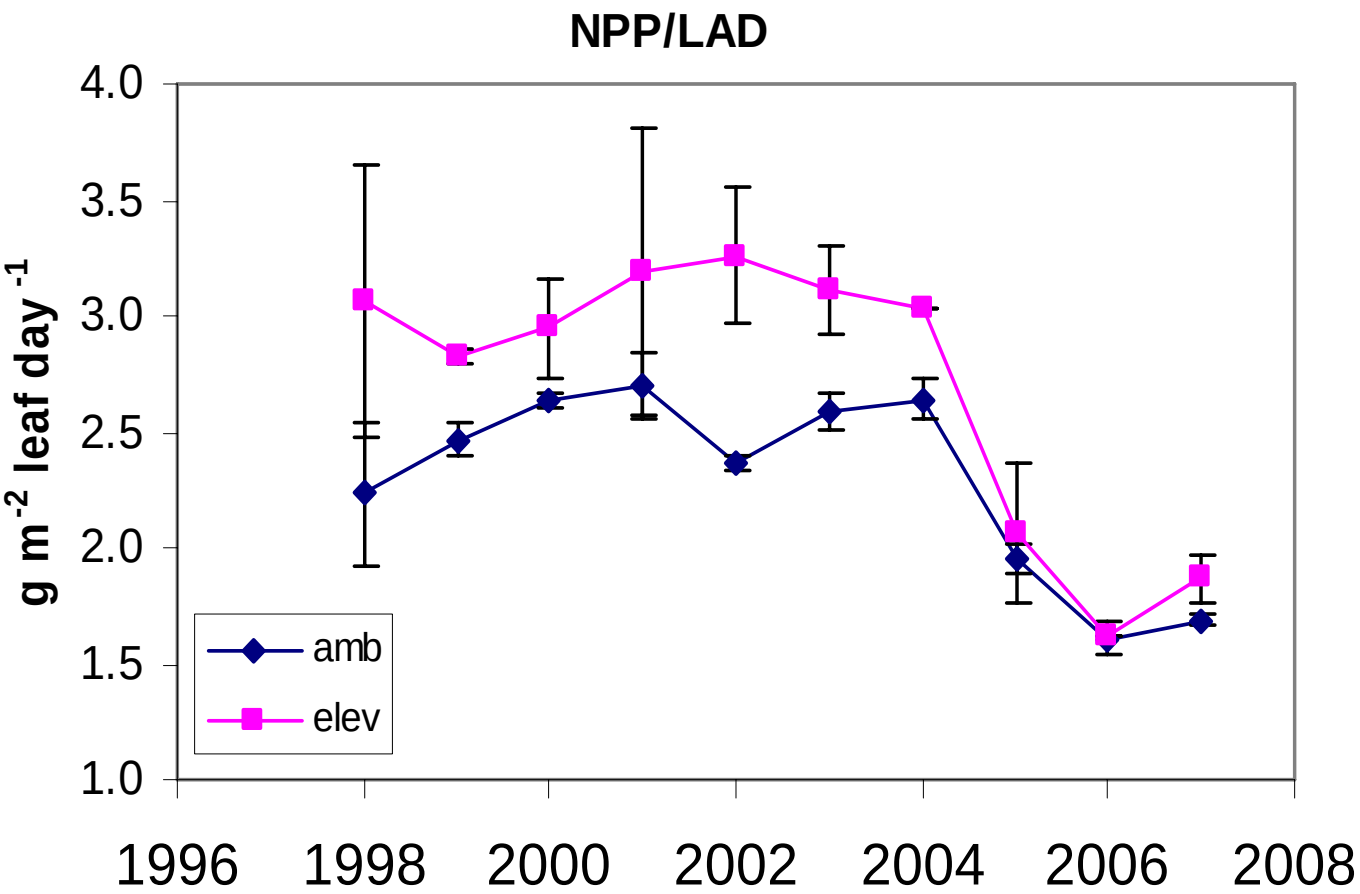
Photosynthetic enhancement is reduced because of lower N_{area}

Foliar %N is influenced by LMA…

sink limitation?



The leaf-level response scales to a stand-level response



- Year-to-year variation in LAD explains some of the NPP trend
- LAD does not explain decline over past several years
- N limitation implied, but soil moisture may be involved

Remaining challenges…

- What is the relationship between plant N and soil N?
- How do fine-root production, turnover, and distribution interact with N availability and uptake?
- Can CO_2 effect on fine-roots be captured in models?
- *Continued interaction between models and experiments is needed*

C-LAMP Results & Diagnostics

See Poster B51E-0447 Friday morning

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C-LAMP Free Air CO_2 Enrichment (FACE) Simulations

Forrest Hoffman and *Jim Randerson*
Updated September 9, 2008

Site Name	Longitude (°E)	Latitude (°N)	Measurement		CASA' Model		CN Model	
			NPP Increase	β_L	NPP Increase	β_L	NPP Increase	β_L
DukeFACE	-79.08333	35.96666	28.0%	0.69	16.4%	0.41	6.2%	0.15
AspenFACE	-89.61666	45.66666	35.2%	0.87	15.6%	0.39	12.4%	0.31
ORNL-FACE	-84.33333	35.90000	23.9%	0.59	17.3%	0.43	5.2%	0.13
POP-EUROFACE	11.80000	42.36666	21.8%	0.54	20.0%	0.49	5.7%	0.14
4 Site Mean			**27.2%**	**0.67**	**17.3%**	**0.43**	**7.4%**	**0.18**

- Simulations are for grid cells, not the experimental plantations
- Inclusion of N feedbacks in CN model reduces NPP response
- Important for experiments to inform these modeling efforts