Au delà de la photosynthèse, quels sont les impacts de la fertilisation du CO_2 pour le stockage de carbone dans les écosystèmes

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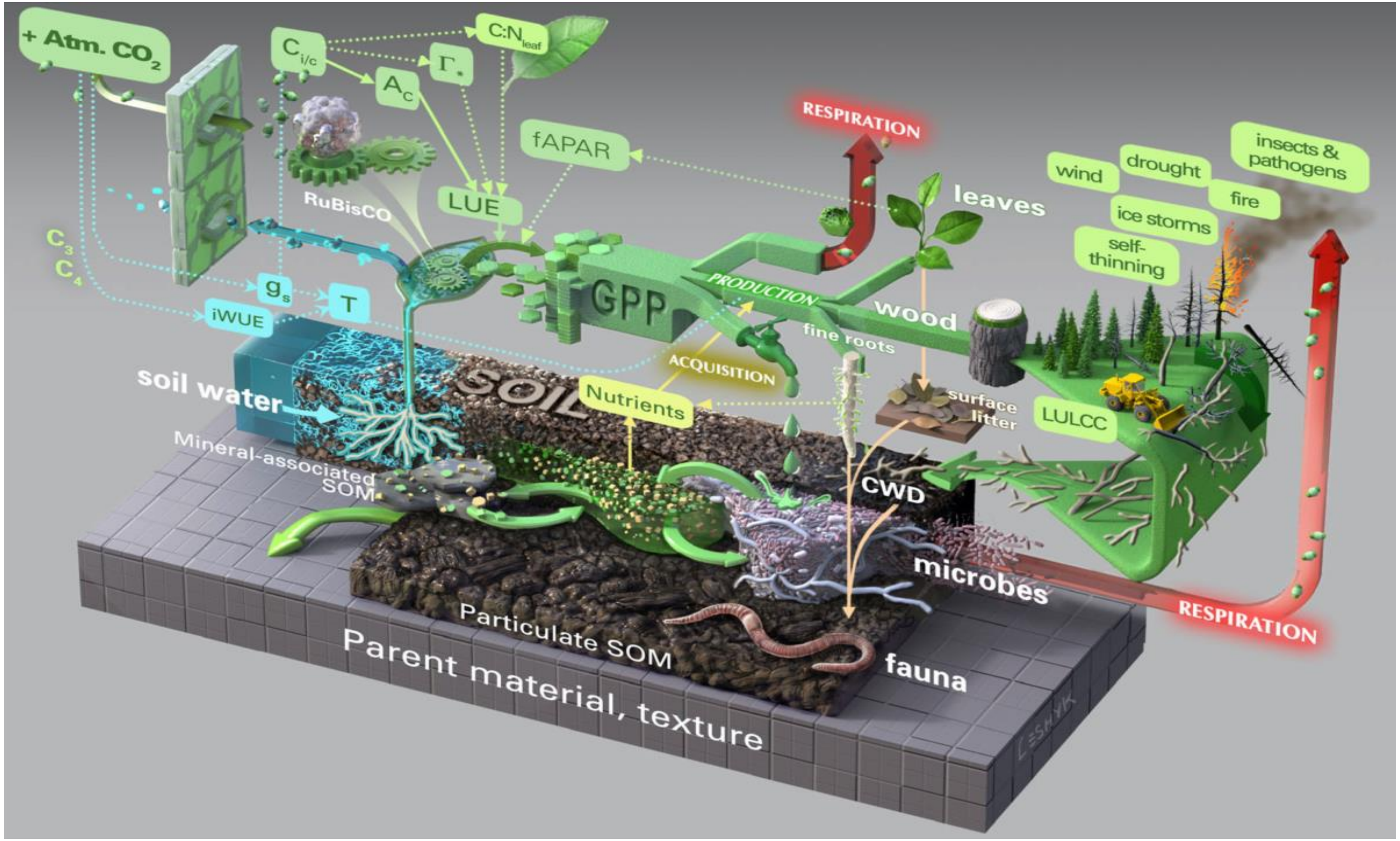
How ecosystems absorb CO_2 and store carbon



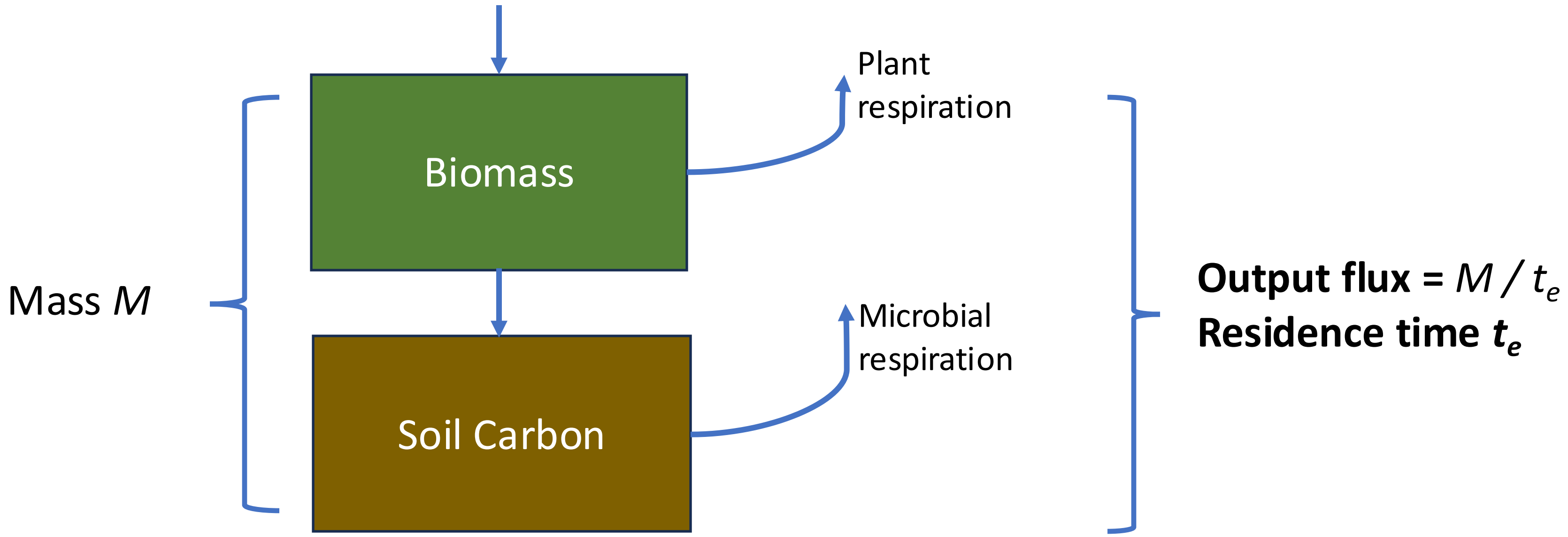
Ecosystem C storage depends on :

- Rate of increase of carbon inputs by photosynthesis
- Fate of C in ecosystems { tissues formation, death, dead carbon decomposition by soil microbes, emissions by fires } **= residence time**

Input flux

Photosynthesis N_p

N_p = f(climate, nutrients, vegetation type, CO_2)



Net balance = N_b = input – output

A very simple predicts net ecosystem C storage in response to elevated CO_2

Mass balance $$dM/dt = N_p - M/t_e$$

Photosynthesis response to CO_2 $$N_p(t) = N_p(t_0)\{1 + \beta[(C_a(t) - C_a(t_0)]/C_a(t_0)\}$$

CO_2 fertilization effect
The β factor

Historical CO_2 increase $$C_a = a + be^{t/ta}$$

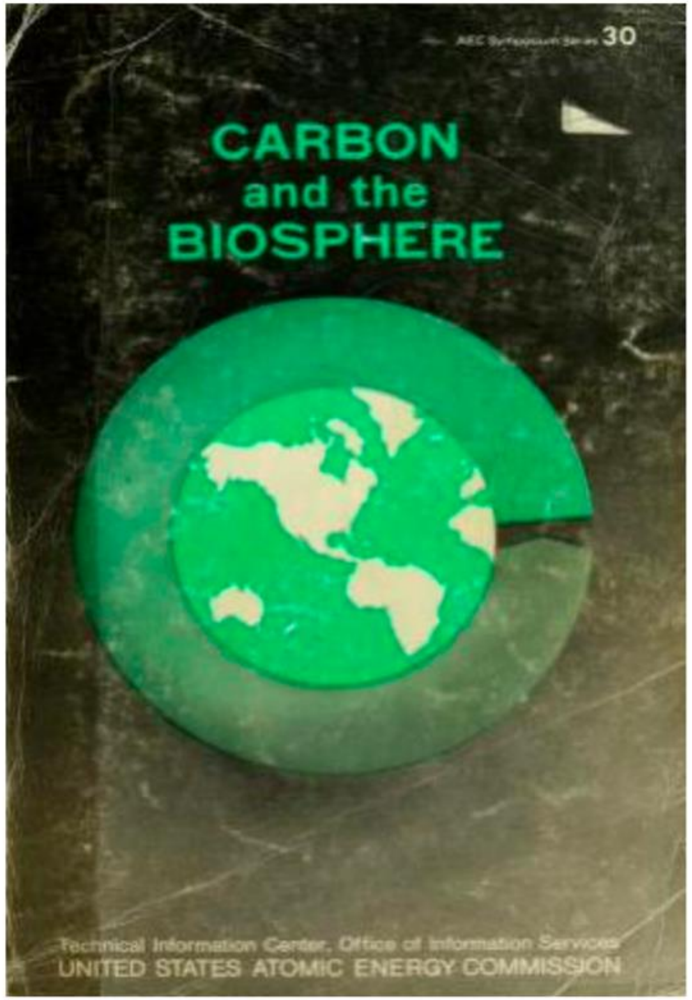
Net carbon balance $$N_b = [\beta/(1 + t_a/t_e)][(C_a - C_0)/C_a][N_p/(1 + \beta(C_a - C_0)/C_a)]$$

The net carbon balance response to high CO_2 is a rectangular hyperbolic function of the stimulation of photosynthesis by CO_2 : the β factor, and quasi proportional to the residence time of C in ecosystems : $\boldsymbol{t_e}$

Ciais et al. 2005

Complex models used for IPCC have a similar structure & can be understood with this equation

What is the value of the beta factor ?



Bacastow and Keeling, 1973

Introduces the biota growth factor (β) as an adjustable parameter that reflects the degree of CO_2 fertilization needed to balance global C budget

$$\beta = ((NPPe/NPPa) - 1)/\ln(\mathrm{eCO_2}/\mathrm{aCO_2})$$

"In our model we assume that the **land biota responds** to gaseous CO_2 approximately **as do individual plants grown in glass houses** with adequate light, water, and nutrients. If this assumption holds, the land biota may nearly double by 2070."

They recognize this is **unrealistic** and rather assumed that plant growth will not be able to keep pace with fossil fuel consumption.

They defined ß from net primary production which was easier to measure than ecosystem photosynthesis at that time, and used a log response ratio

Carbon cycling modeling in the 1970s were constrained in representation of CO_2 fertilization because of lack of relevant data

C. F. Baes, Jr., H. E. Goeller, J. S. Olson, and R. M. Rotty

Carbon Dioxide and Climate: The Uncontrolled Experiment

Possibly severe consequences of growing CO_2 releases from fossil fuels require a much better understanding of the carbon cycle, climate change, and the resulting impacts on the atmosphere

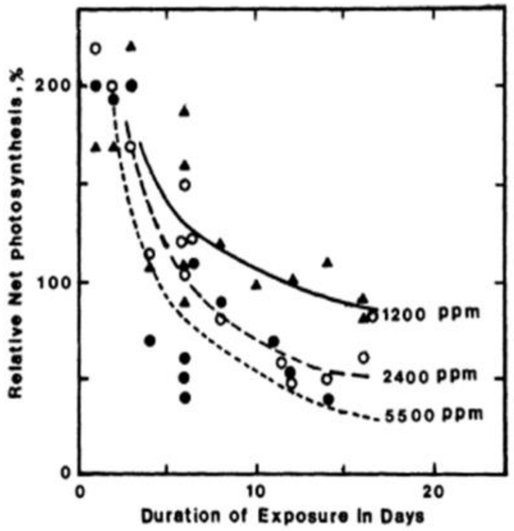
American Scientist (1977) 65: 310-320

"Another effect to be considered is the enhanced rate of photosynthetic production that might be caused by the increasing concentration of CO_2 in the atmosphere. Controlled studies of plant growth show that there is such an effect when other nutrients are not limiting; *however, its importance in the carbon cycle is presently unclear*."

Carbon Dioxide Concentration, Photosynthesis, and Dry Matter Production

Paul J. Kramer

BioScience 31:29-33 (1981)



"In nature, the rate of photosynthesis and biomass production probably is limited more often by water and nitrogen deficiency than by the low CO_2 concentration of the air."

"Increasing the CO_2 concentration will have little effect if … the use of photosynthate is limited by lack of nitrogen."

- Emphasized importance of forest responses, which are not addressed by current studies on crop plants
- Calls for a large, coordinated effort to address the role of forests in stabilizing the global CO_2 concentration

1982-1988

1989-2003

Free Air Carbon dioxide Enrichment Experiments FACE

1996-2009

What did they expect ?

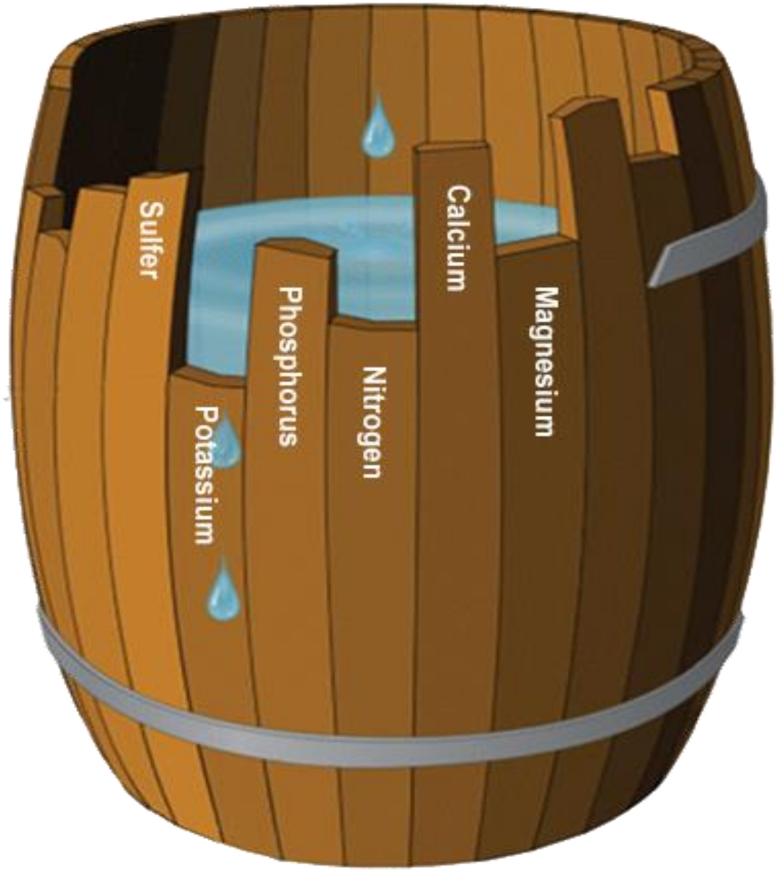


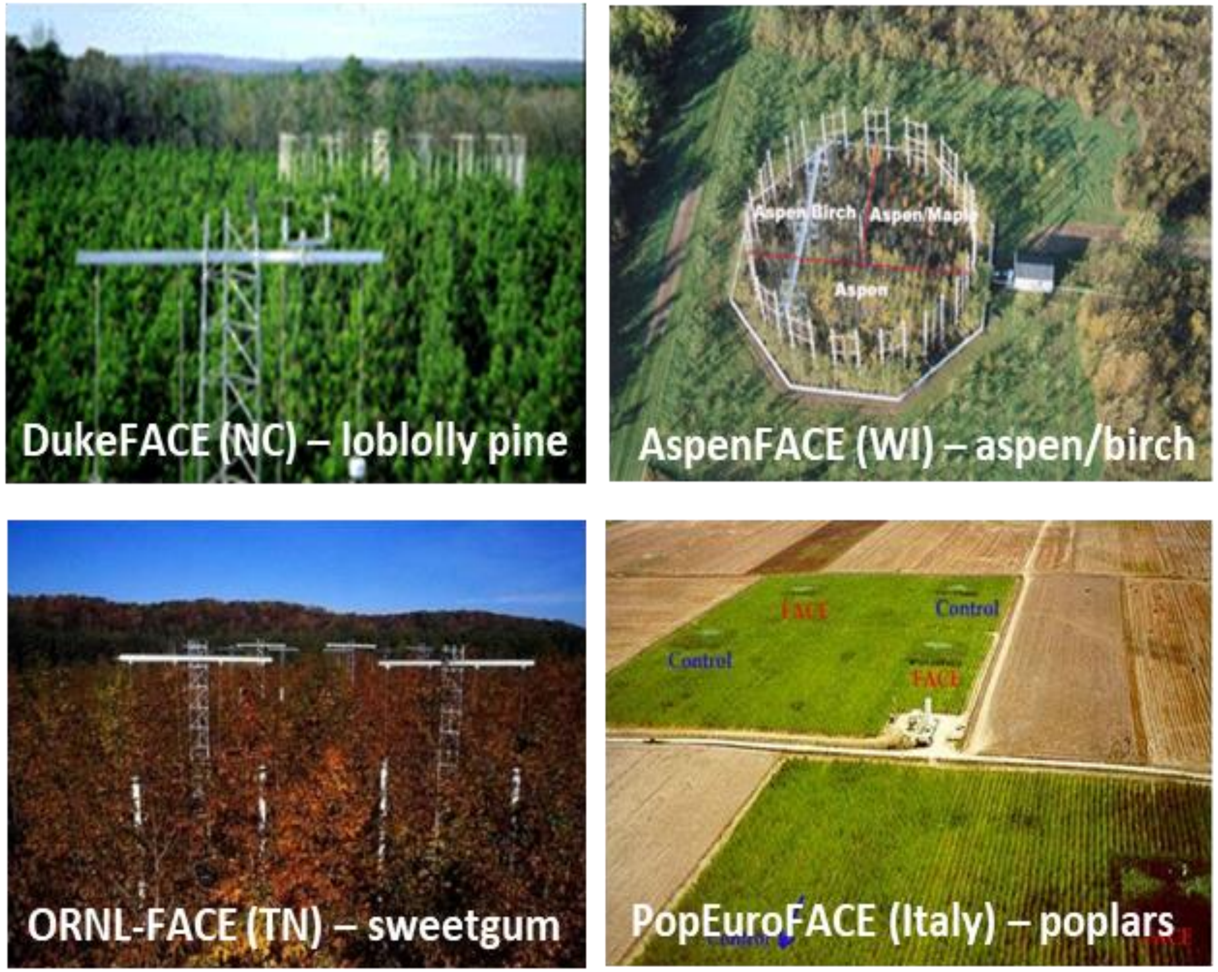
Figure 1. Liebig's law of the minimum illustrated using the barrel stave concept.

That nutrient availability would limit the effect of high CO_2 on beta

What did they find ?

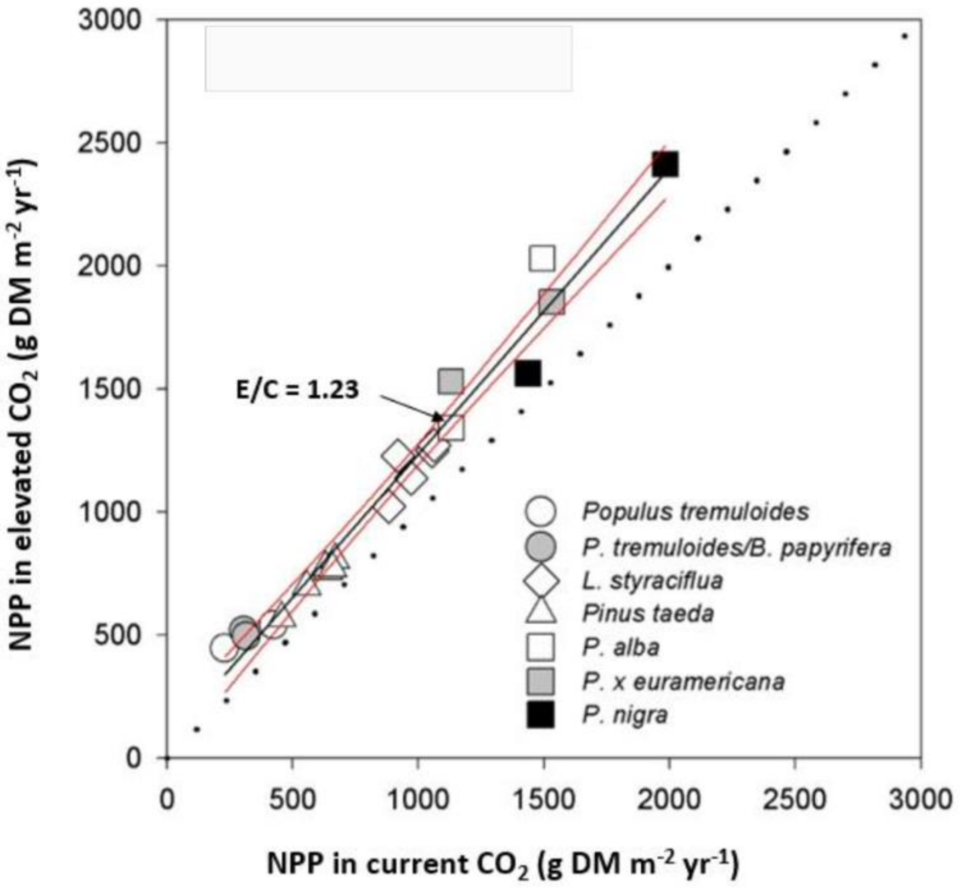
Rick Norby

Closed-canopy | Developing stands

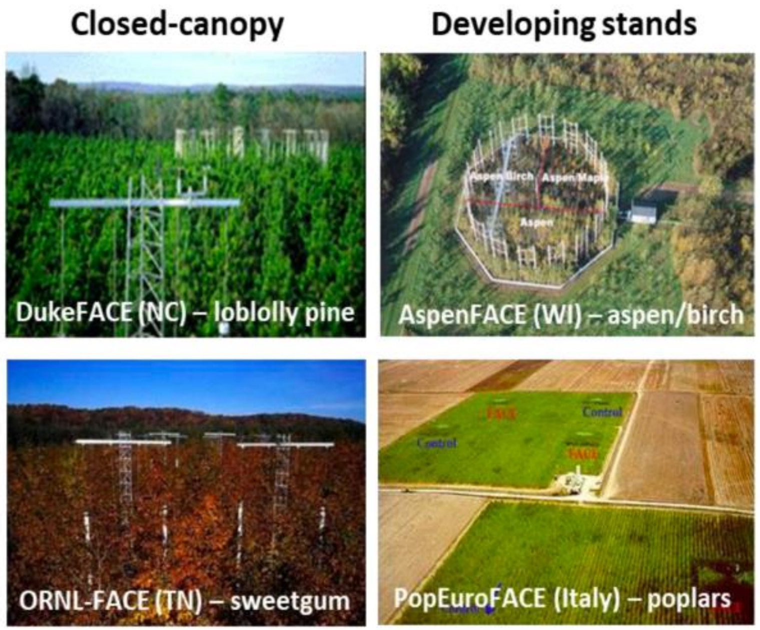


FACE
Iconic experiments where an entire forest is exposed to high CO_2 during several years

NPP was a robust response to elevated CO_2 in four temperate forest FACE experiments



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



- The median response (23%) masks spatial and temporal variability
- Interactions with other global change factors may be significant
- N feedbacks might limit response over the long term
- The analysis did not include tropical or boreal forests
- Will responses persist in older forests?
- C partitioning patterns may determine the ultimate fate of the additional C

New FACE experiments are expanding the inference space

EucFACE
Eucalyptus forest
New South Wales, Australia

Jiang *et al*., 2020, *Nature*

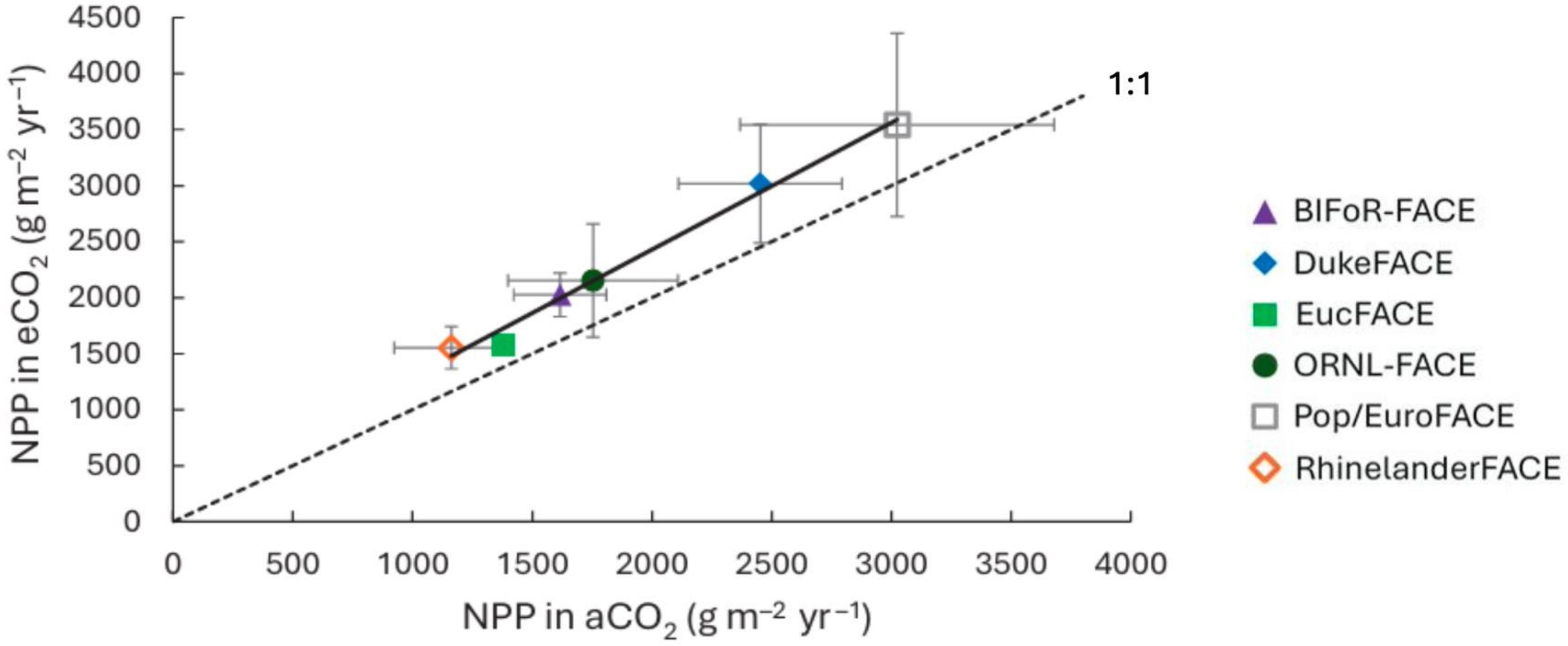
BIFoR-FACE
Old oak woodland
Central England

Norby *et al*., 2024, *Nature Climate Change*

AmazonFACE
Primary tropical forest
Manaus, Brazil

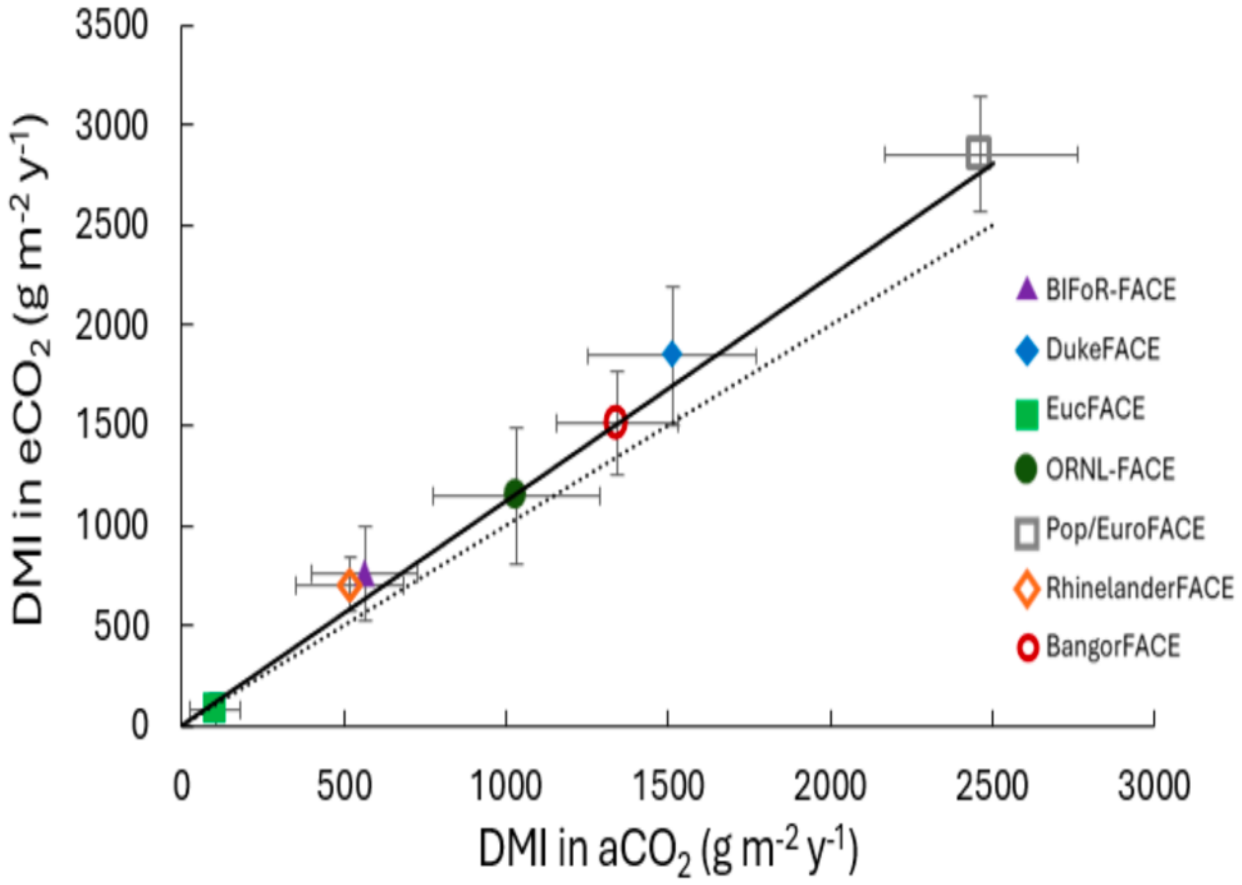
Fleischer *et al*., 2019, *Nature Geoscience*

New analysis:
NPP response to a 41% increase in CO_2 is 21.8%



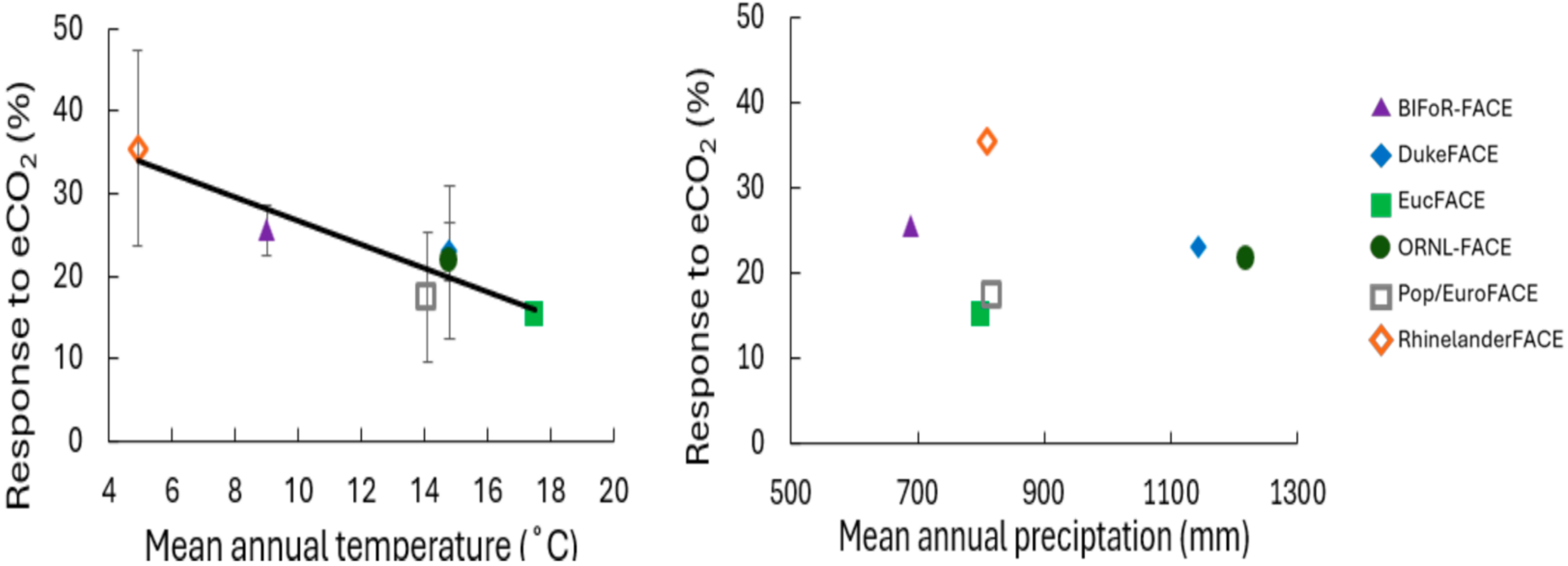
Corresponds to a β of 0.57

Aboveground wood biomass increased 18.2%



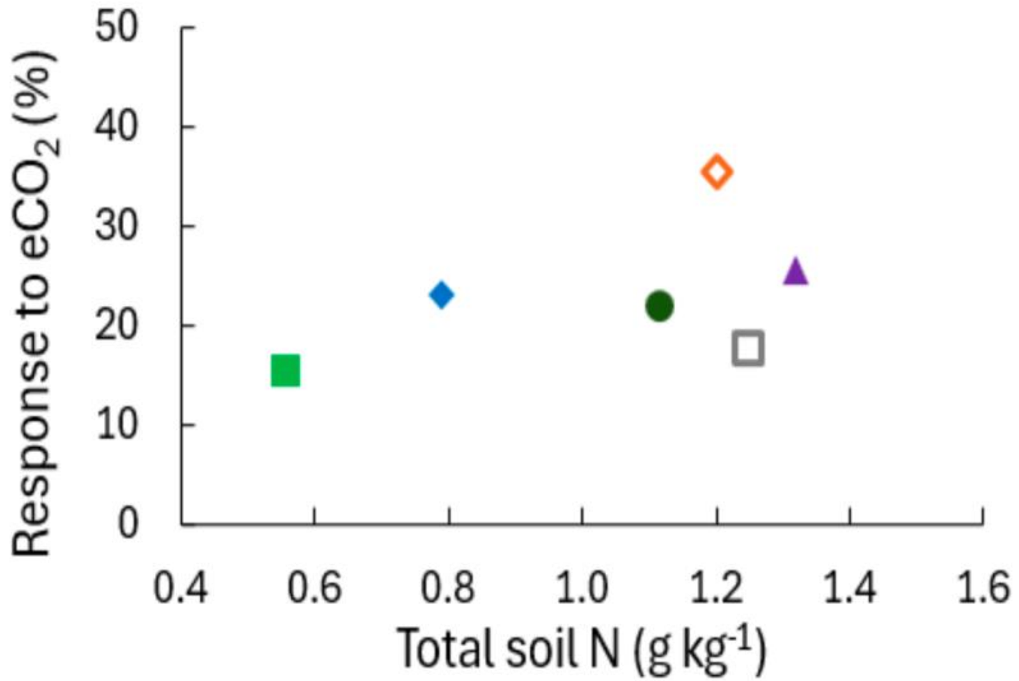
- Duke: shift in allocation toward wood
- BIFoR: Increased wood production
- ORNL: increase in NPP primarily to fine roots
- EucFACE: No increase in wood
- Overrall: wood fraction was 58% in aCO_2, 56% in eCO_2

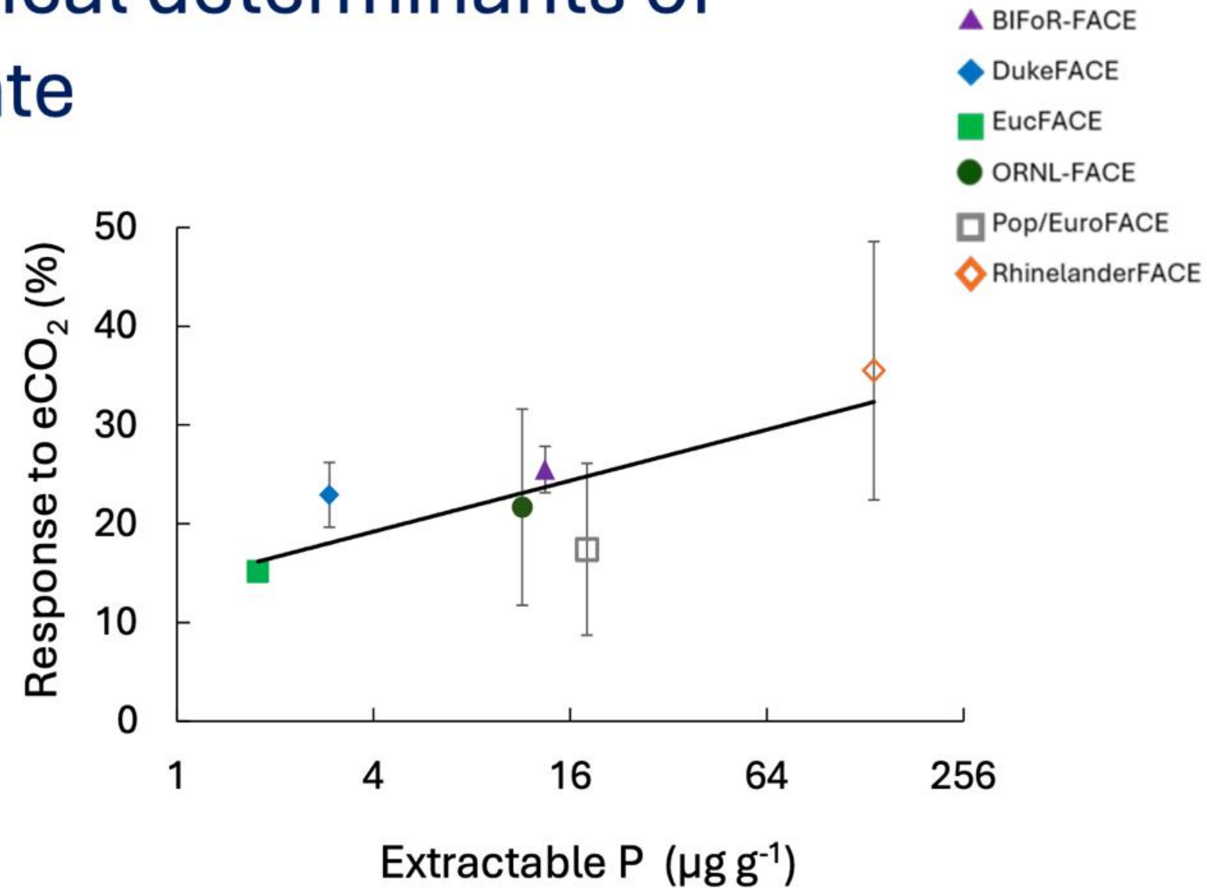
Norby et al. New Phytologist 2025



- Response was less in warmer sites
- No effect of mean annual precipitation or various climate indices
- Temperature effect different from model projections
- Confounded with site fertility

Nutrient interactions are critical determinants of response, but hard to evaluate





- Total N is not the best metric for evaluating CO_2 × N interactions
- Progressive N limitation documented in ORNL-FACE
- Growth response in BIFoR-FACE sustained by high N deposition

- Relationship dominated by Rhinelander
- P limitation in EucFACE primary reason for lack of response

In plants or in soils : nutrient limitation in fact determine where does the carbon go under high CO_2

Article

A trade-off between plant and soil carbon storage under elevated CO_2

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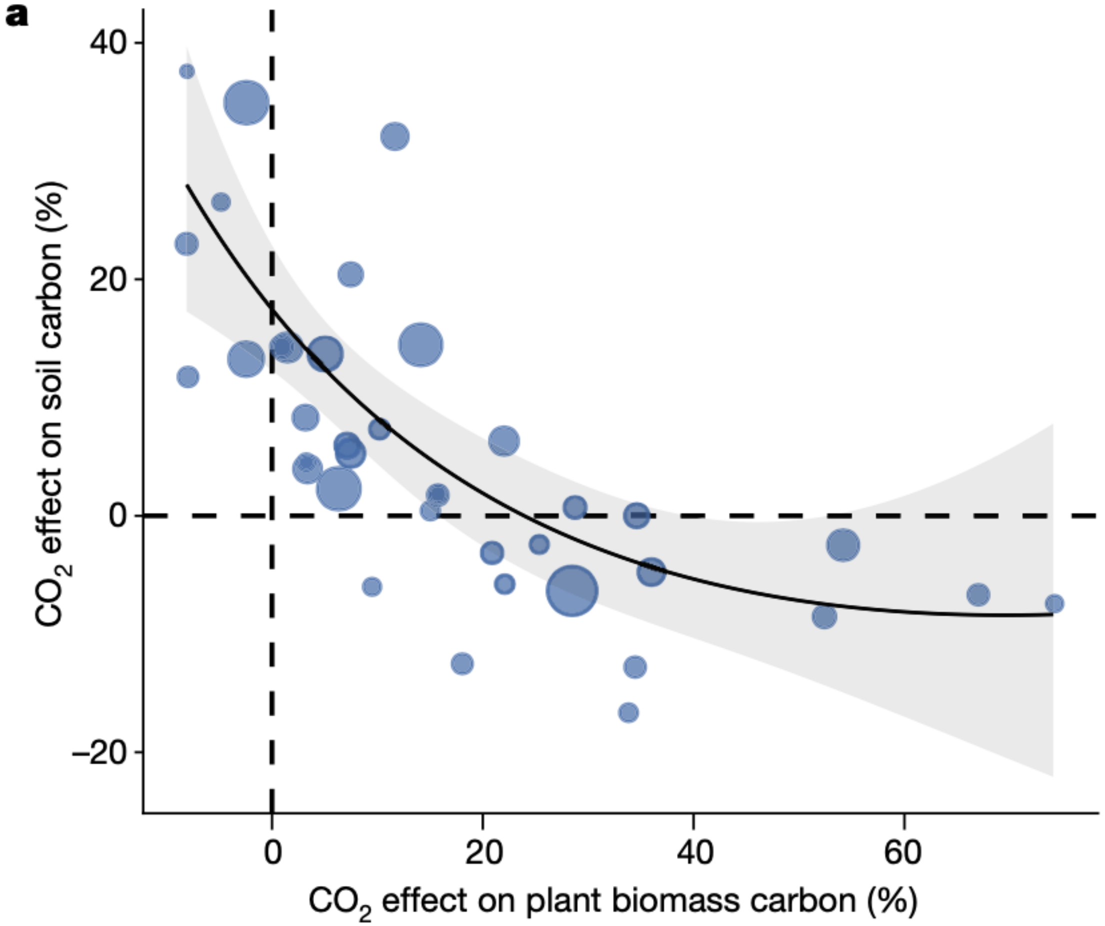
Where does the carbon go under elevated CO_2?

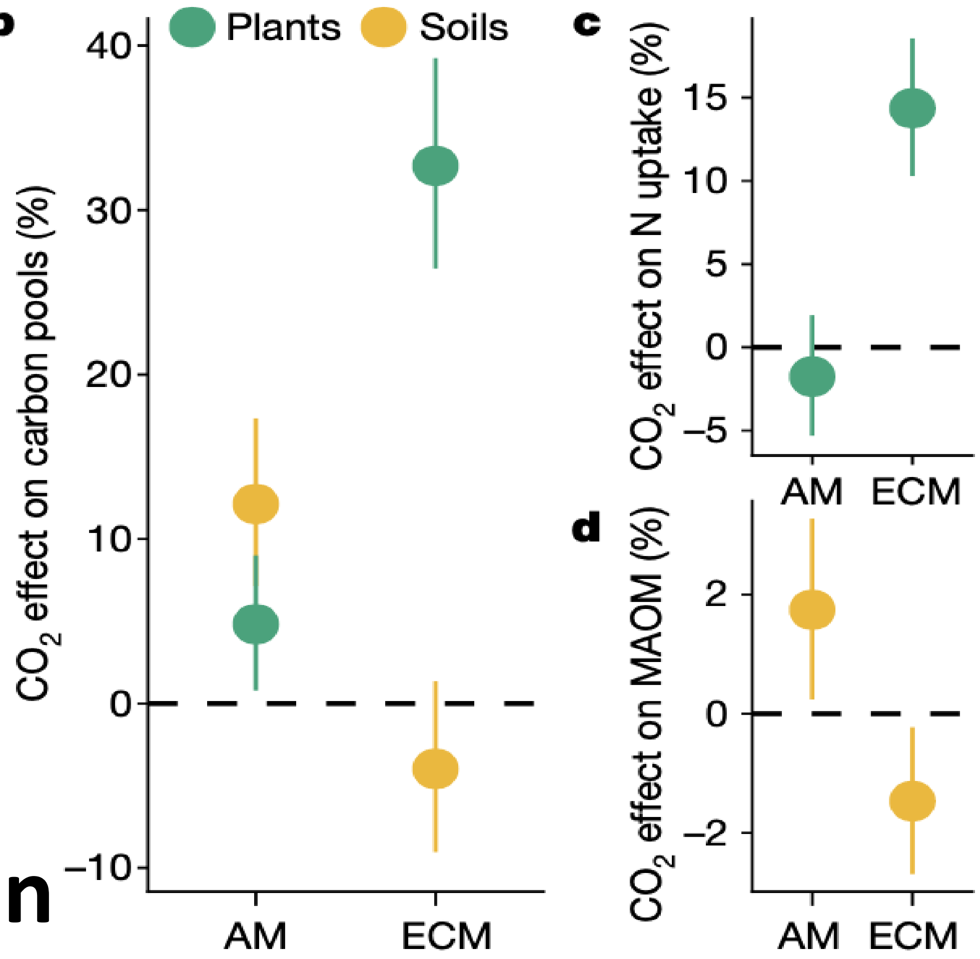


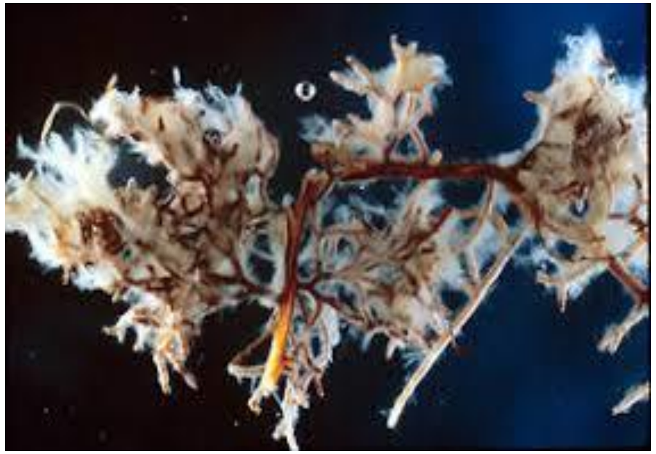
Trade off : when more goes to biomass, less goes to soils

It’s the micorrhizea !

Arbuscular types AM
go inside the root
Take C from plants

Favor C storage in soils





Ecto types ECM
Live around the root
Take C but give nutrients

Favor C storage in plants

Morzine : un réseau italien venait piller les cèpes de la forêt pour les revendre à prix fort

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1 min

Cèpe is an ecto-miccorhizae increasing wood storage under high CO_2