

Photosynthetic acclimation through the lens of optimality

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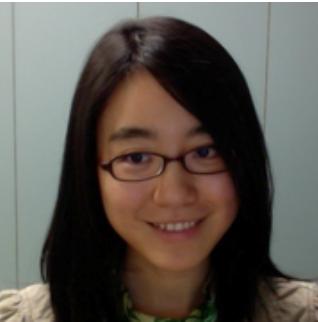
Helen Scott
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Trevor Keenan
Berkeley Lab



Wang Han
Tsinghua U.

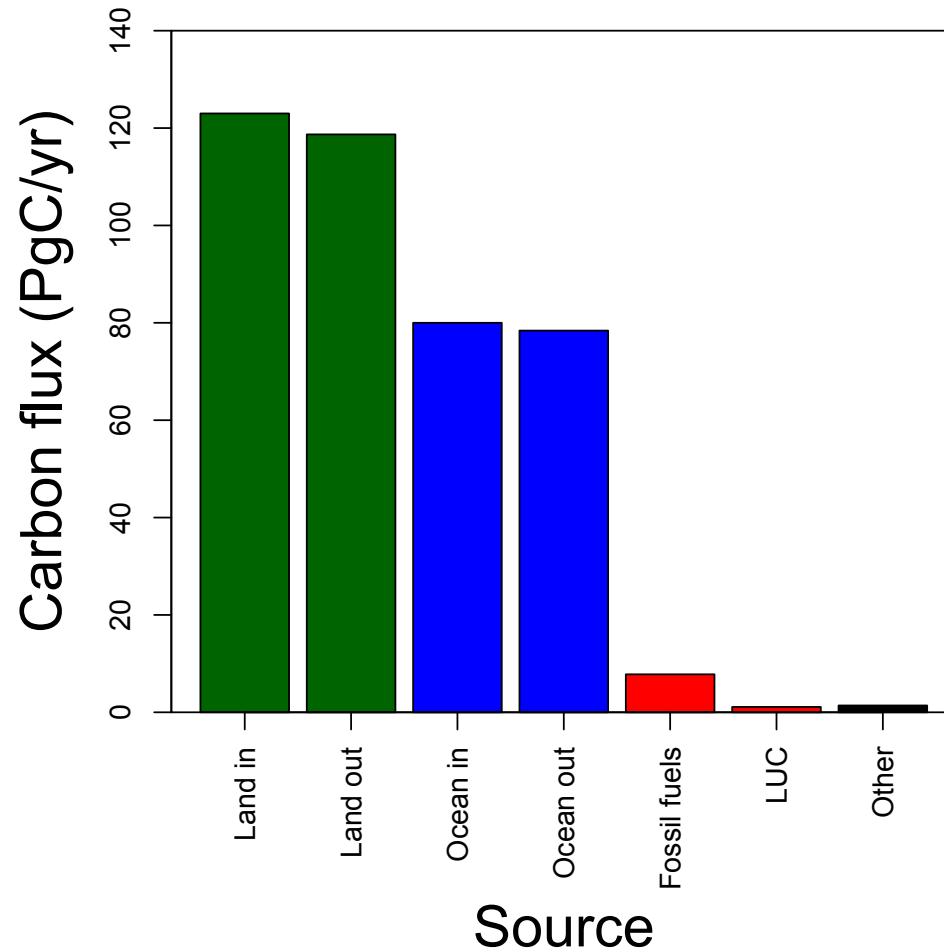


Colin Prentice
Imperial College

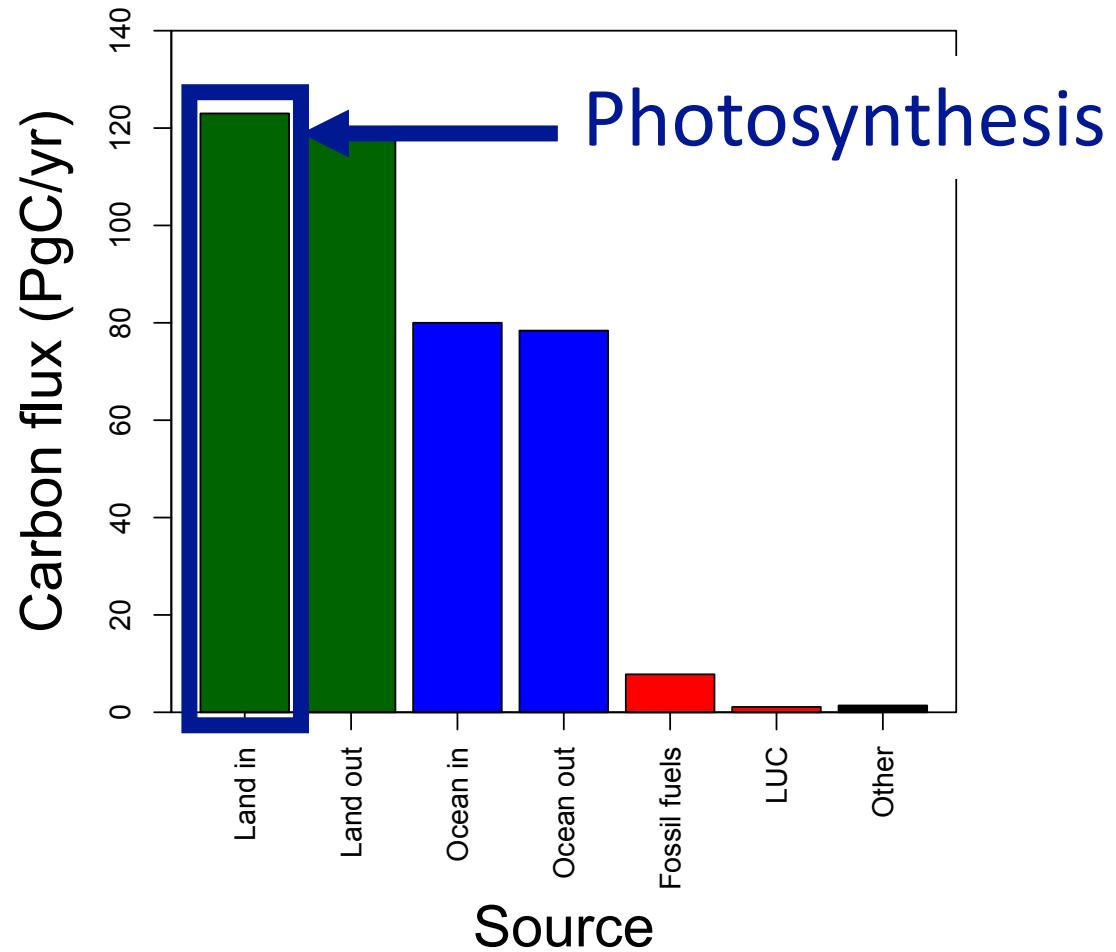


Photosynthesis is important!

Photosynthesis is important!



Photosynthesis is important!



Theoretical models for photosynthesis exist

Planta 149, 78–90 (1980)

Planta
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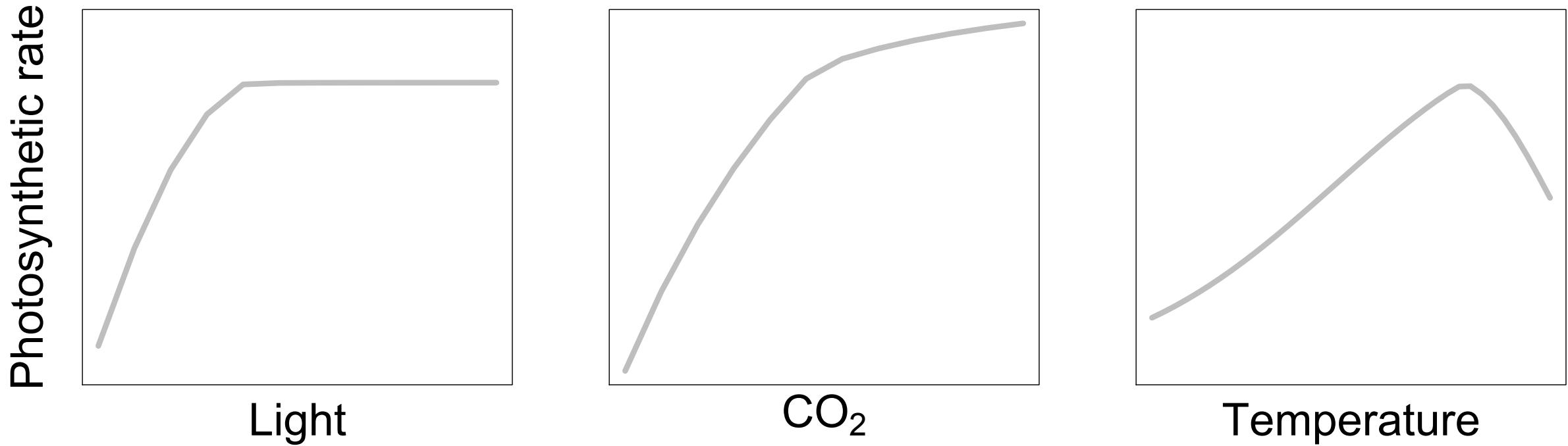
A Biochemical Model of Photosynthetic CO₂ Assimilation in Leaves of C₃ Species

G.D. Farquhar¹, S. von Caemmerer¹, and J.A. Berry²

¹ Department of Environmental Biology, Research School of Biological Sciences, Australian National University, P.O. Box 475, Canberra City ACT 2601, Australia and

² Carnegie Institution of Washington, Department of Plant Biology, Stanford, Cal. 94305, USA

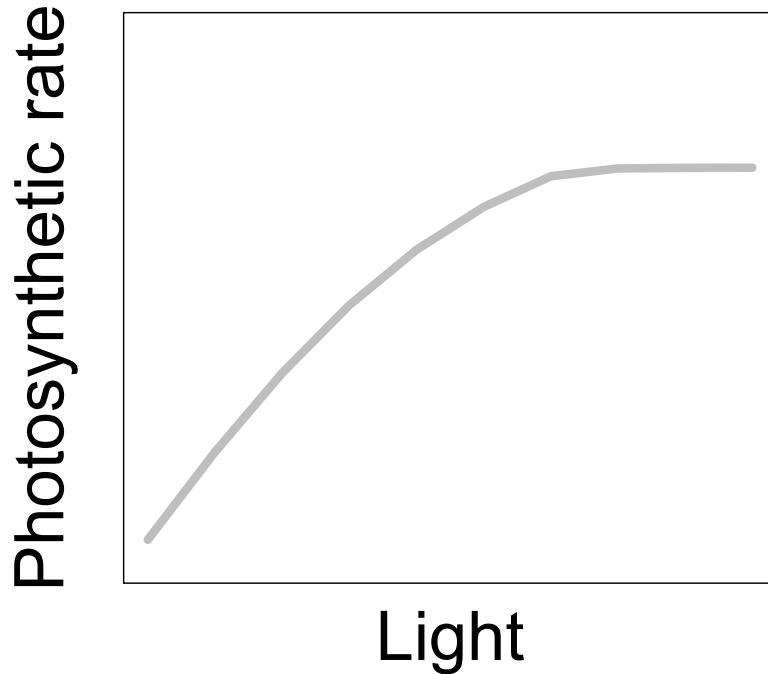
And short-term responses are well known!



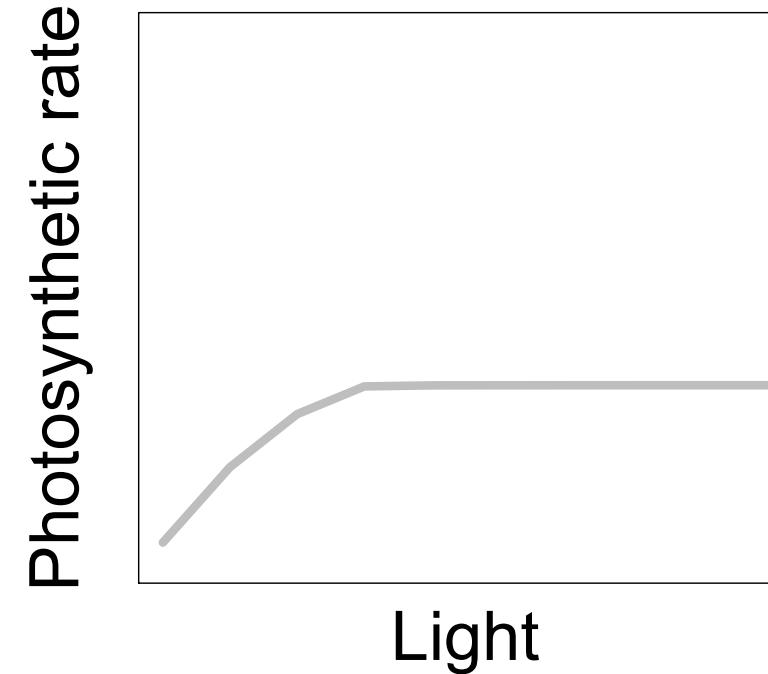
Long-term responses can differ from short-term responses due to acclimation

Long-term responses can differ from short-term responses due to acclimation

Acclimated to high light



Acclimated to low light



Acclimation is ubiquitous and well known...

CO₂: Bazzaz (1990)

Ann. Rev. Ecol. Syst. 1990, 21:167–96
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THE RESPONSE OF NATURAL ECOSYSTEMS TO THE RISING GLOBAL CO₂ LEVELS

F. A. Bazzaz

Light: Boardman (1977)

Ann. Rev. Plant Physiol. 1977, 28:355–77
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COMPARATIVE PHOTOSYNTHESIS OF SUN AND SHADE PLANTS

N. K. Boardman
Division of Plant Industry, CSIRO, Canberra City, A.C.T. 2601, Australia

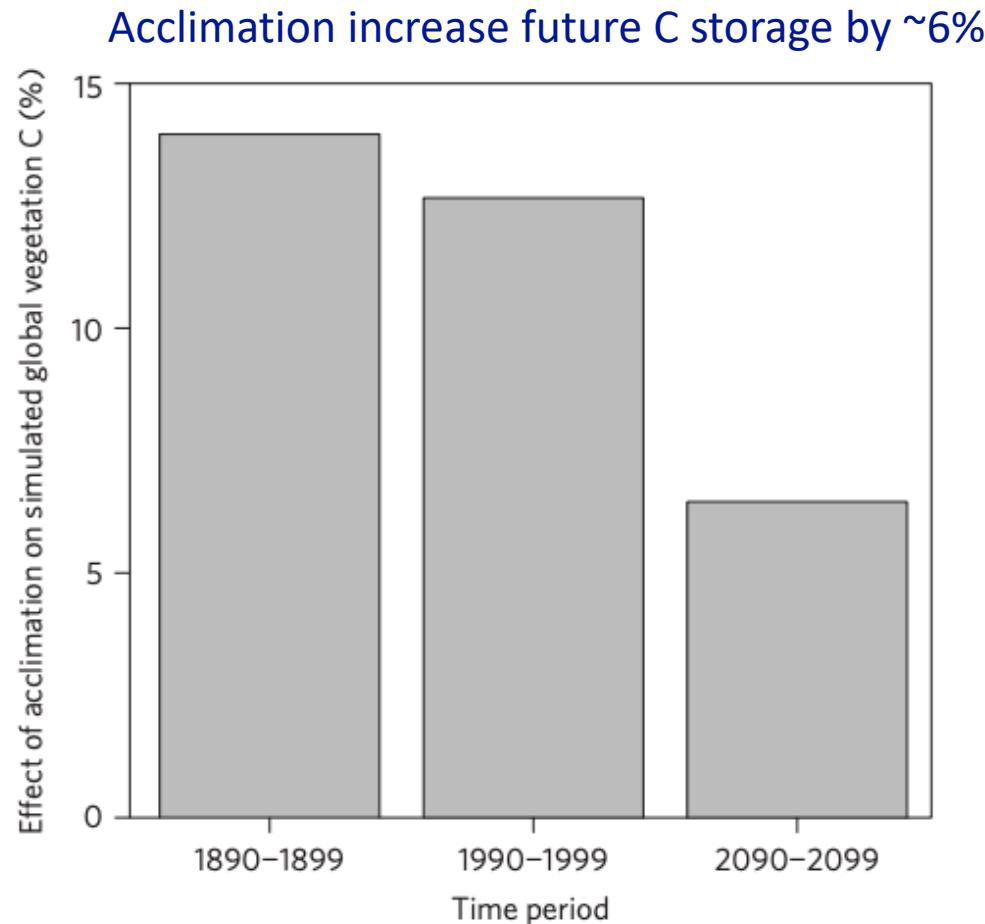
Temperature: Berry & Björkman (1980)

Ann. Rev. Plant Physiol. 1980, 31:491–543
Copyright © 1980 by Annual Reviews Inc. All rights reserved

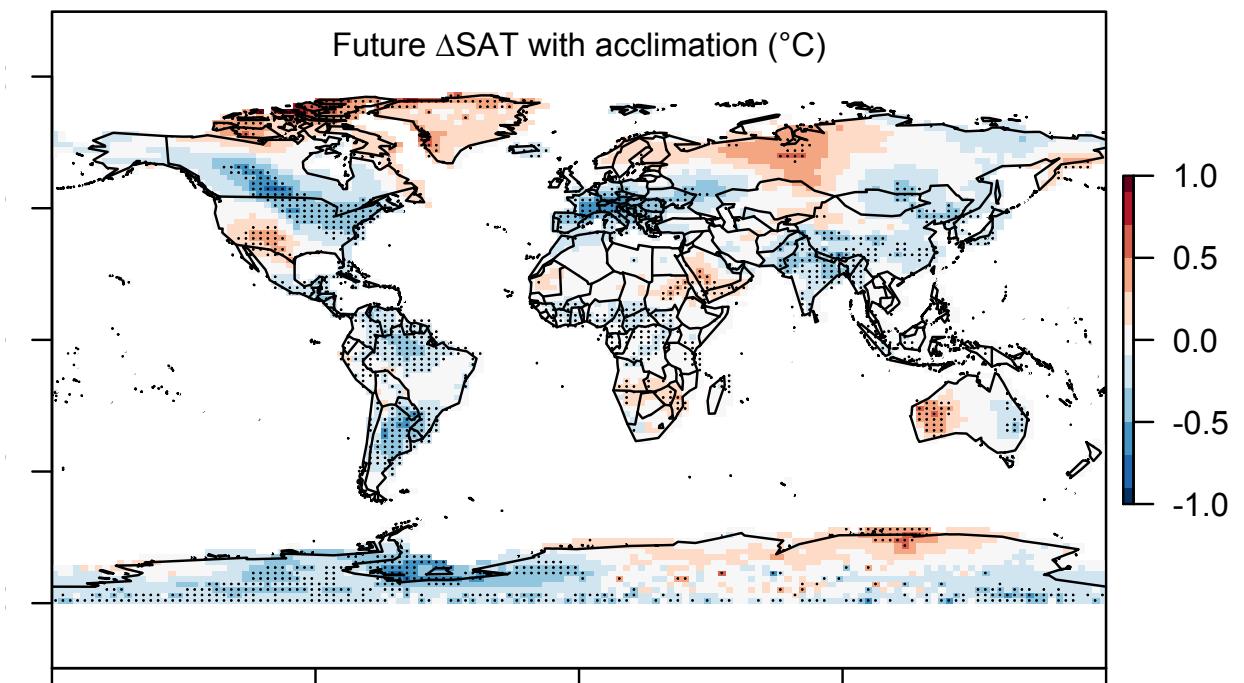
PHOTOSYNTHETIC RESPONSE AND ADAPTATION TO TEMPERATURE IN HIGHER PLANTS

Joseph Berry and Olle Björkman¹

...and can impact carbon cycling and climate...



Acclimation alters future temperature by >1°C



...but the mechanisms underlying
photosynthetic acclimation are
not well known

Solution: A testable, theoretical model!

Least cost theory

Maintain fastest rate of photosynthesis at the lowest cost (water and nutrient use)

Biochemistry optimization: Coordination hypothesis

Photosynthesis may be limited by
multiple processes

Biochemistry optimization: Coordination hypothesis

Photosynthesis may be limited by multiple processes

Optimally, plants will coordinate their
biochemistry to be equally limited by
these processes

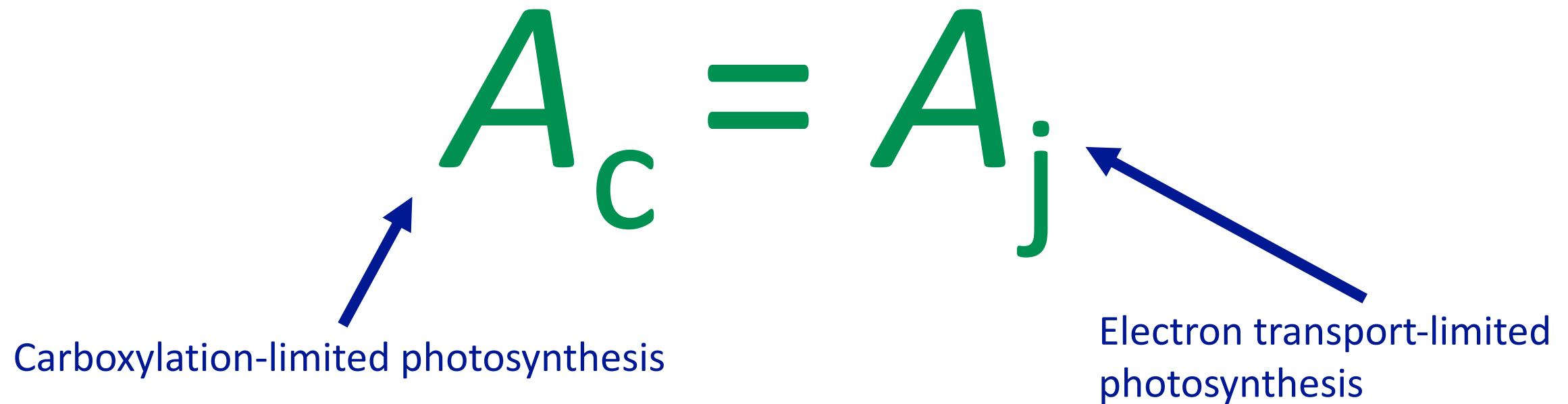
Coordination of photosynthesis

Optimally...

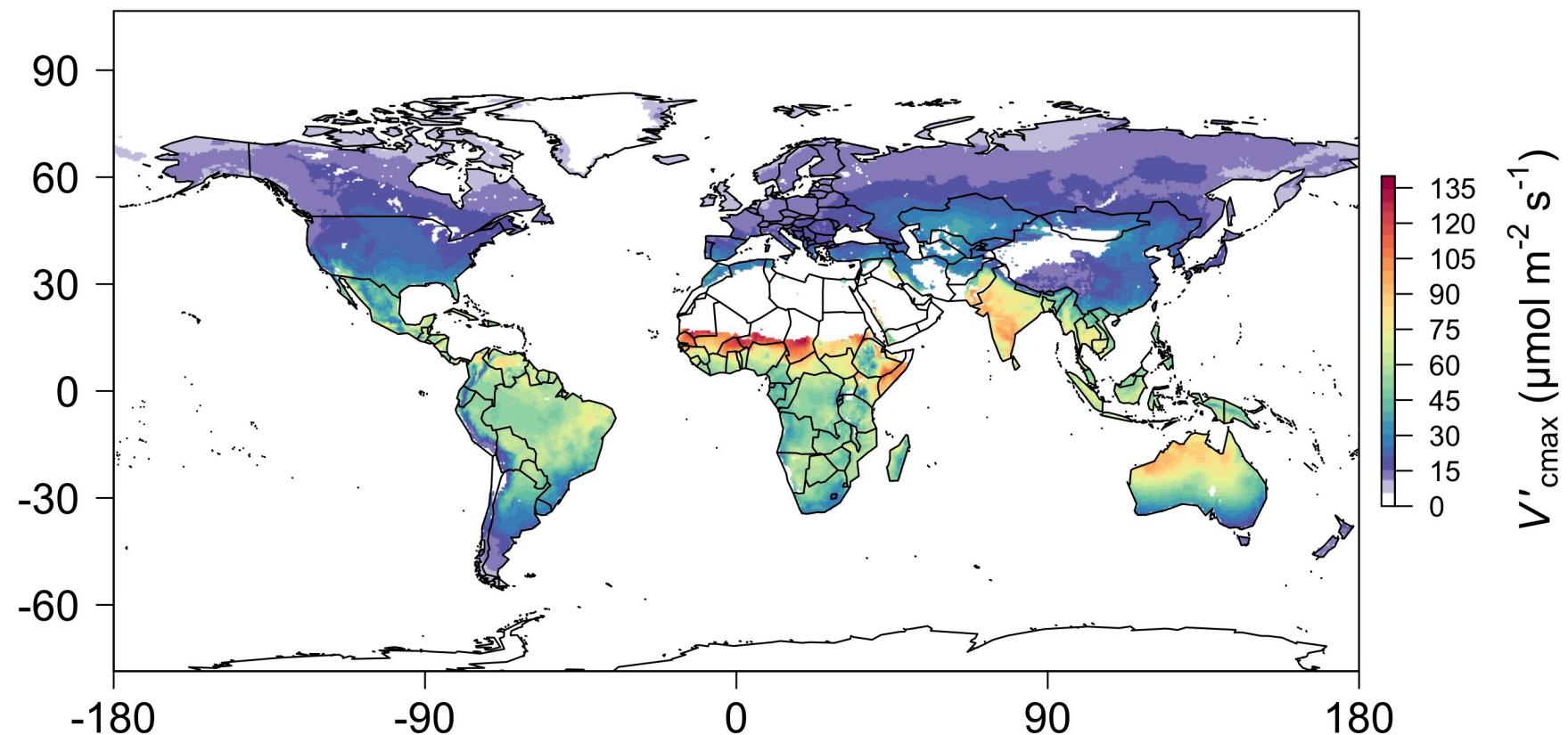
$$A_c = A_j$$

Carboxylation-limited photosynthesis

Electron transport-limited photosynthesis



We can predict optimal traits in different environments

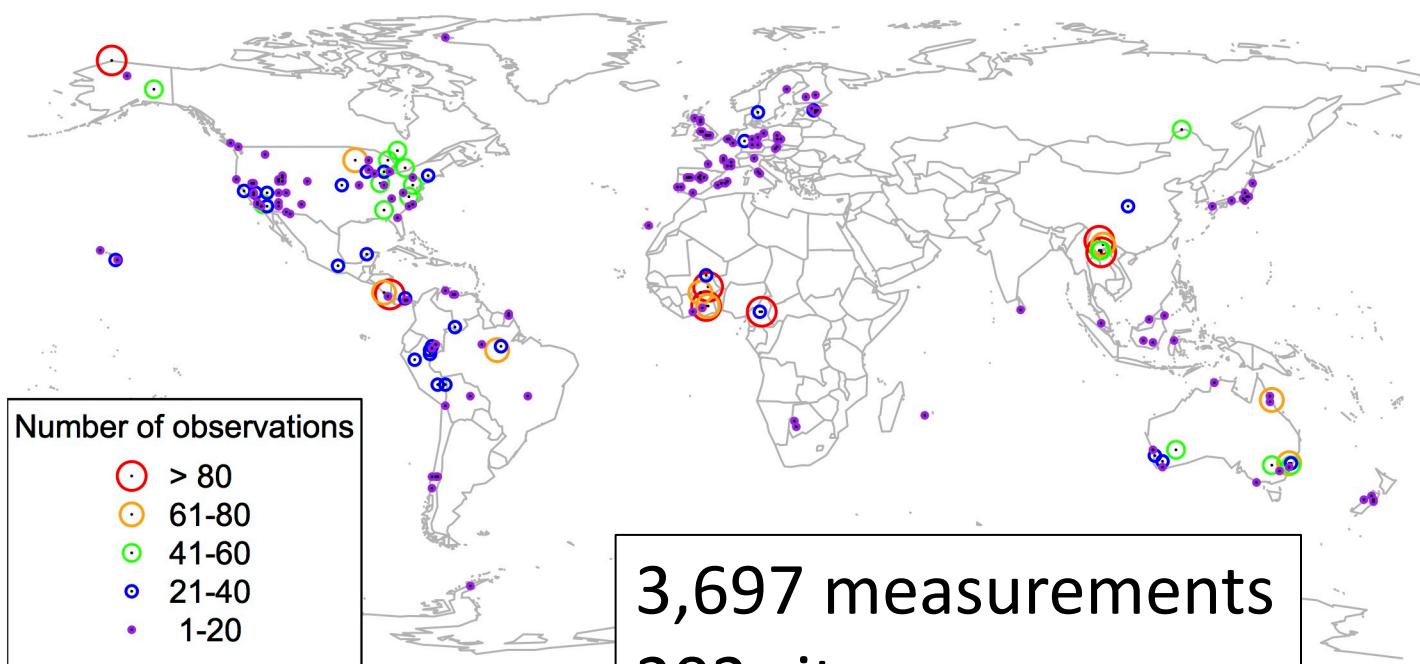


Ok, great, but now what?

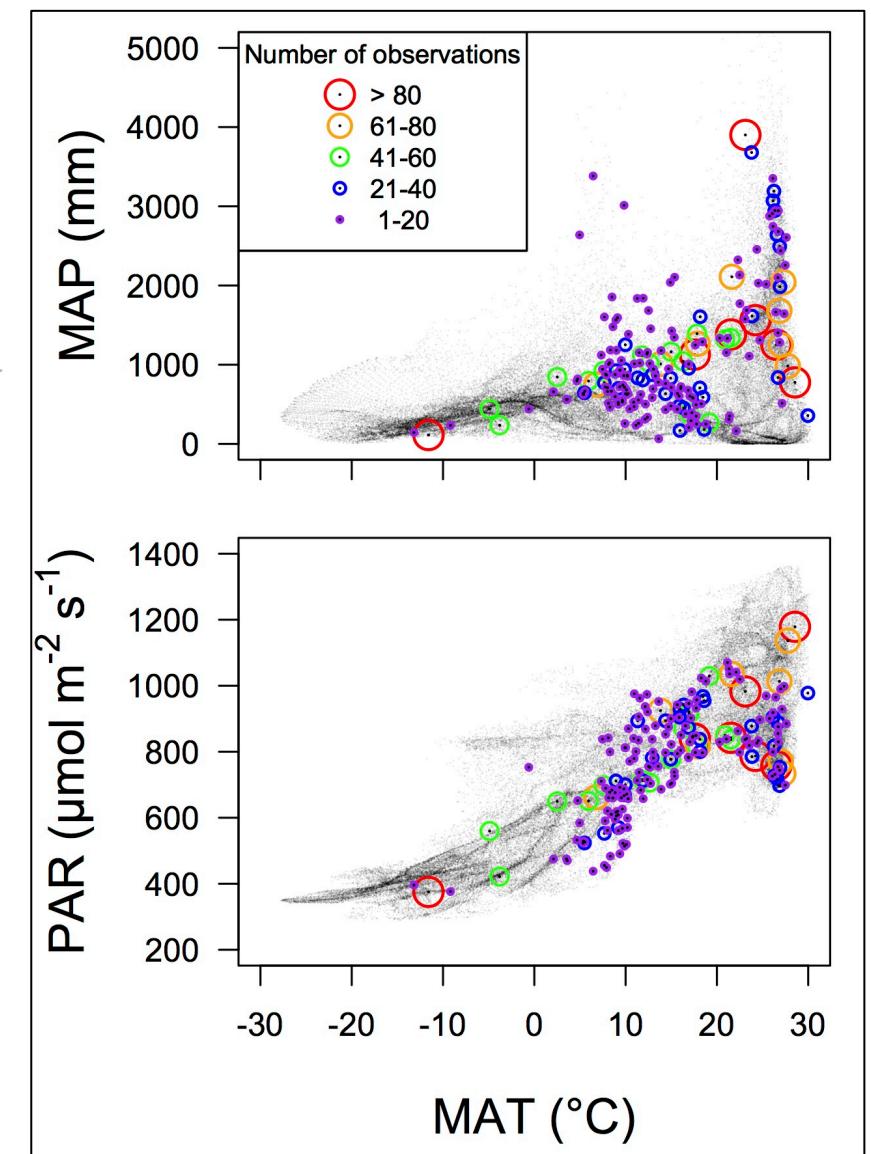
Let's tackle some big questions in
plant ecophysiology!

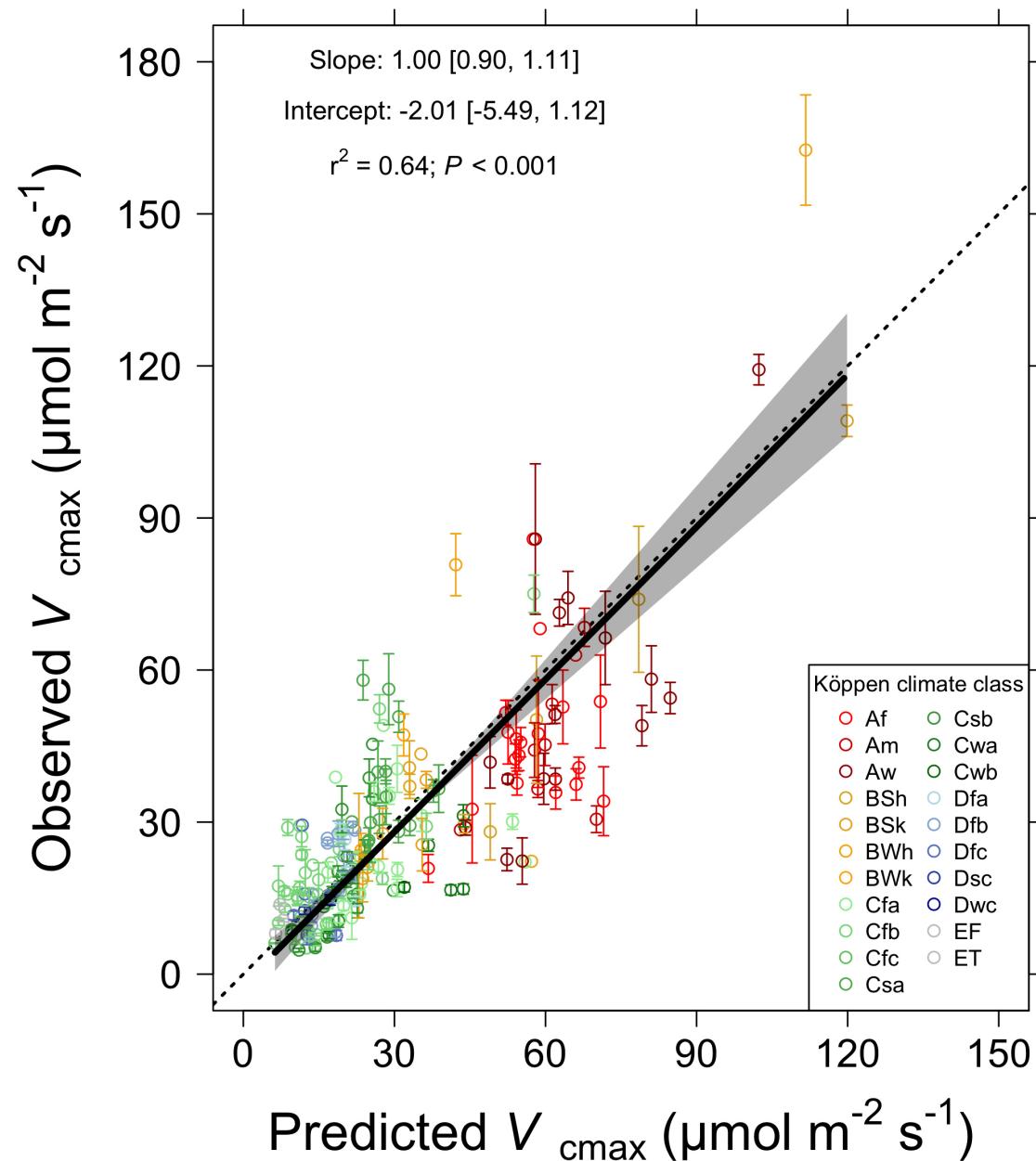
Question 1: Is photosynthesis
optimized to the environment?

Global V_{cmax} dataset



3,697 measurements
202 sites
> 600 genera





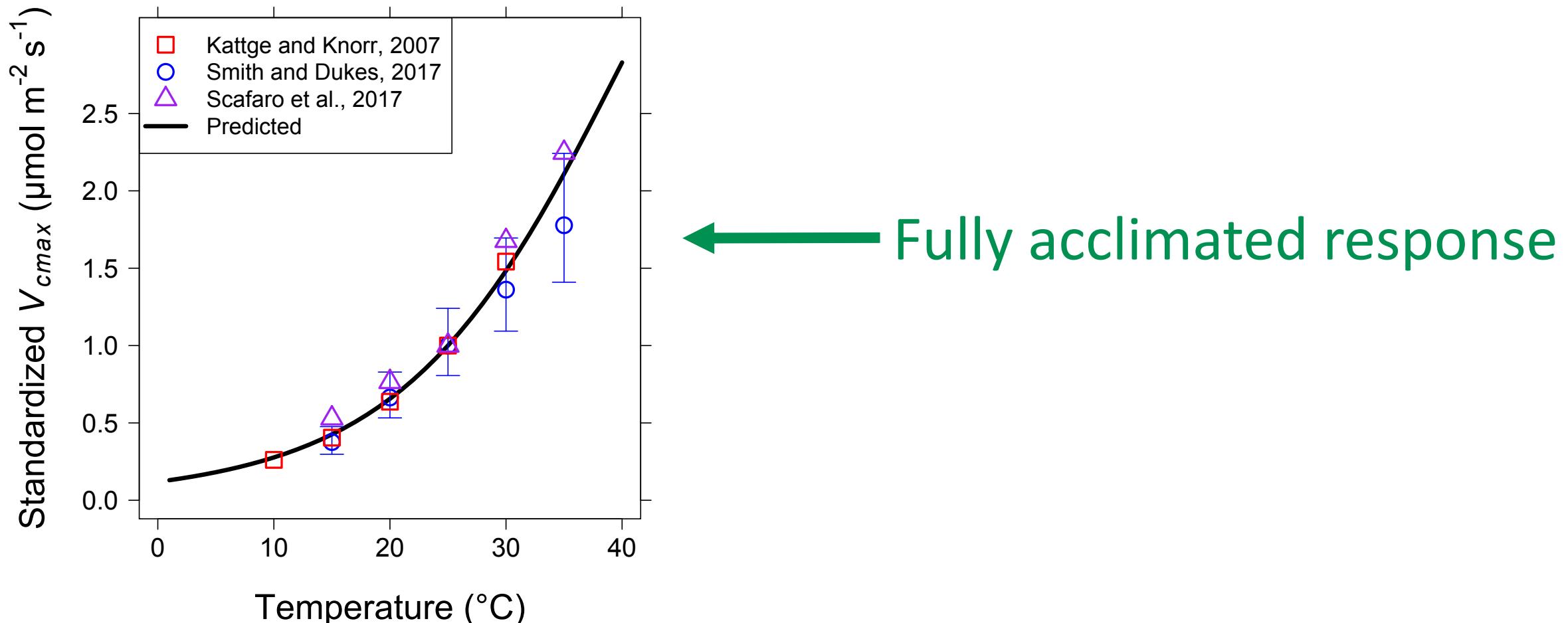
Question 1: Is photosynthesis optimized to the environment?

YES! Photosynthesis acclimates spatially as expected from optimization

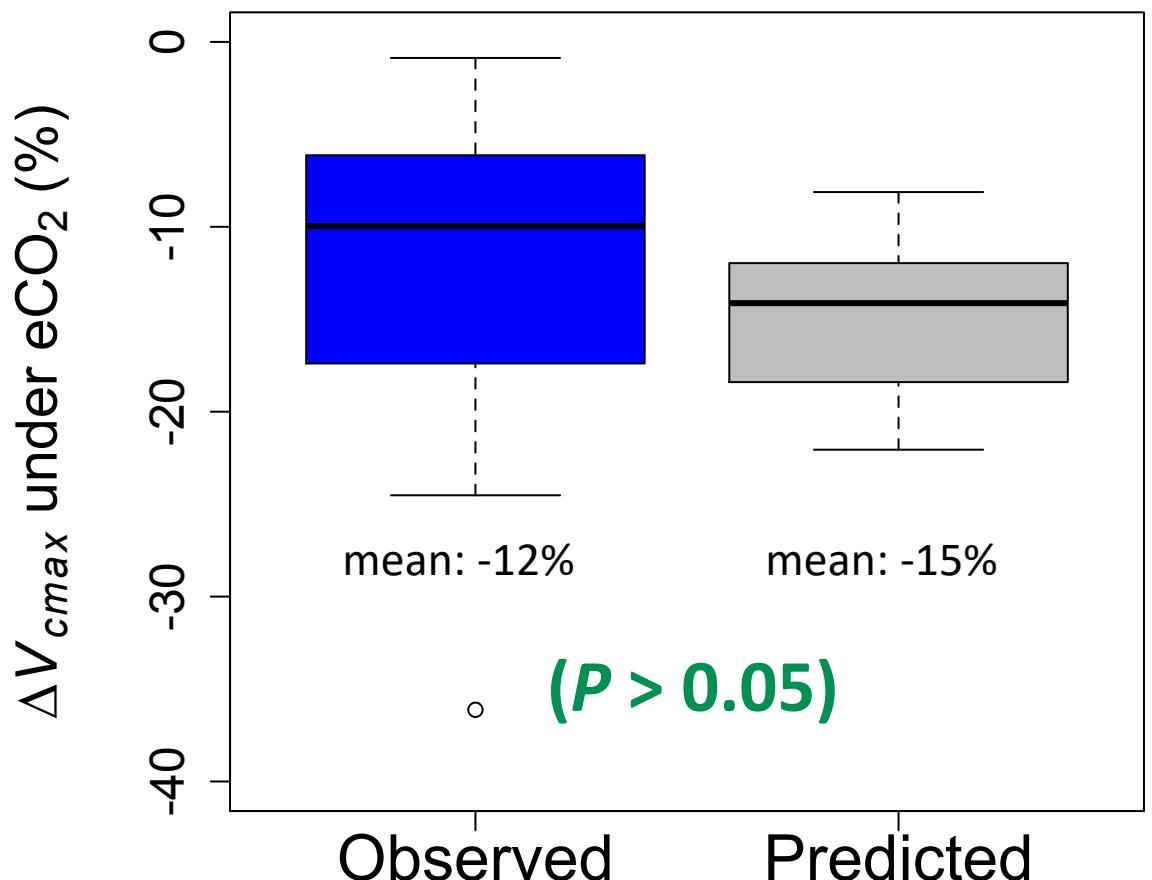
Question 2: How will
photosynthesis acclimate to
future conditions?

Photosynthetic traits change with temperature
and CO₂ in ways expected from optimization

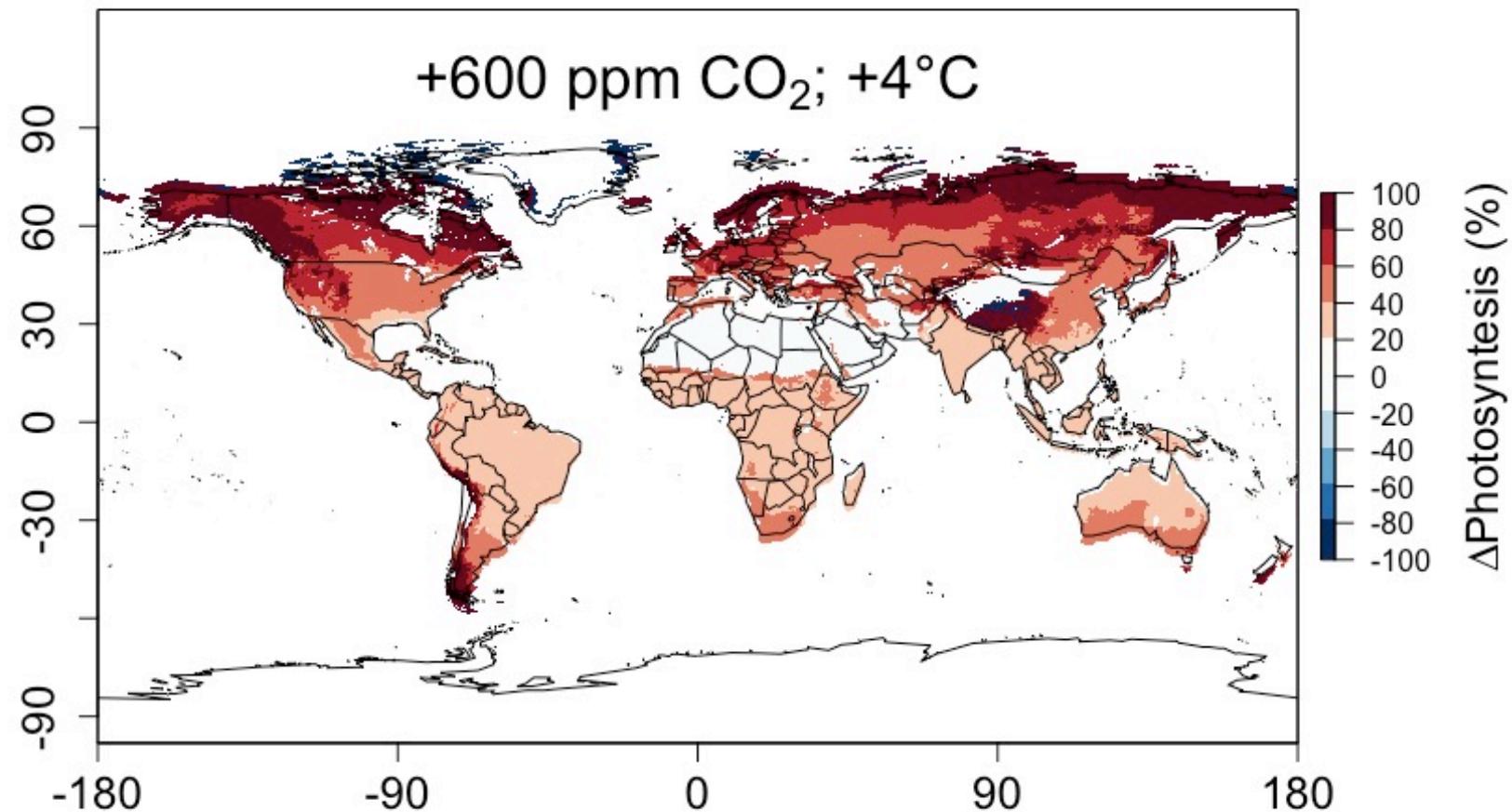
Photosynthetic traits change with temperature and CO₂ in ways expected from optimization



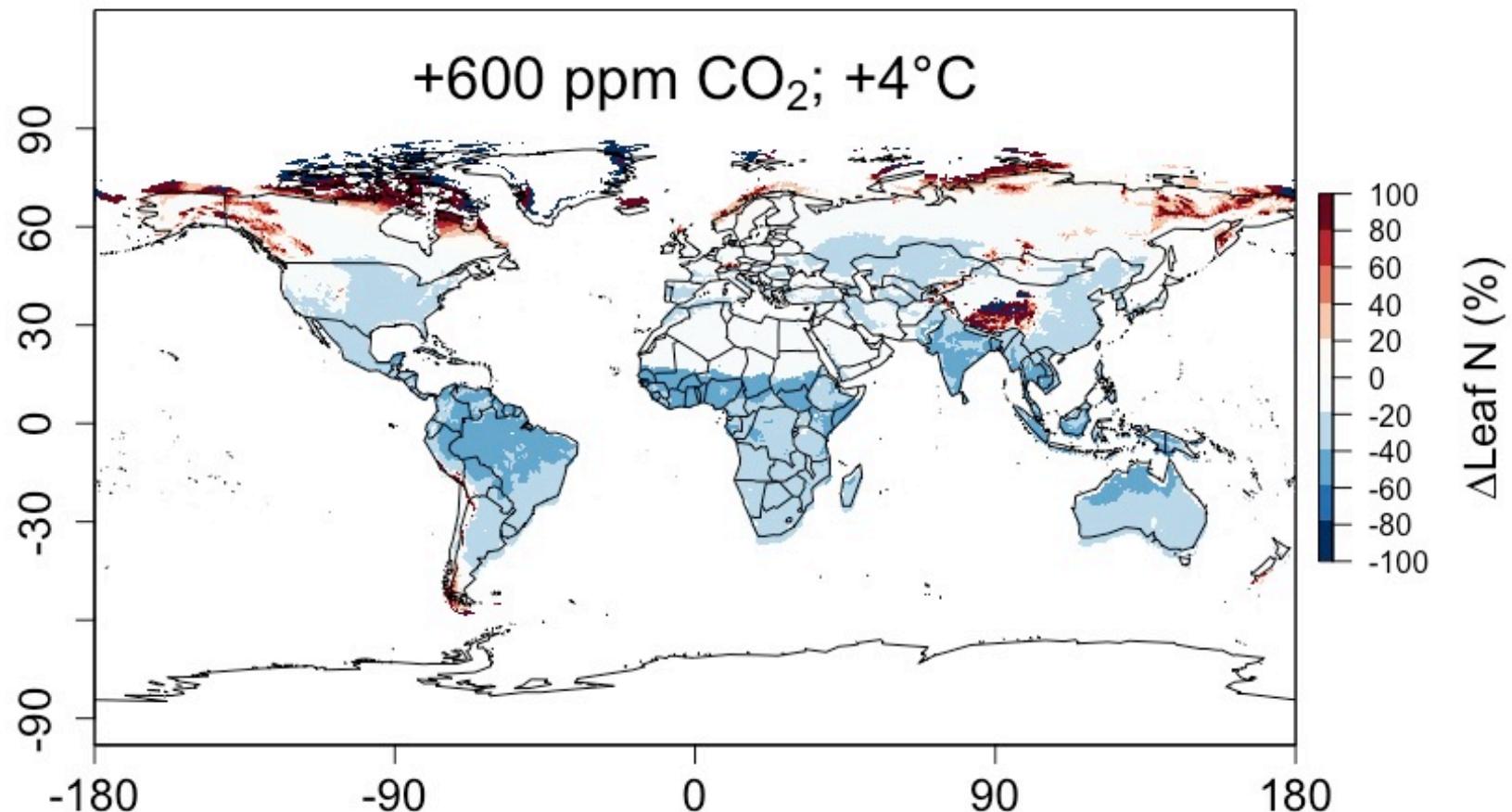
Photosynthetic traits change with temperature and CO₂ in ways expected from optimization



Higher CO₂ and increased temperatures increase future photosynthesis



Higher CO₂ and increased temperatures increase future photosynthesis (at lower nutrient use)



Question 2: How will photosynthesis
acclimate to future conditions?

Photosynthesis will increase and per-
leaf-area nutrient use will decrease

Question 3: Does photosynthesis respond to nutrient addition?

Lizz Waring
TTU



From the least cost hypothesis...

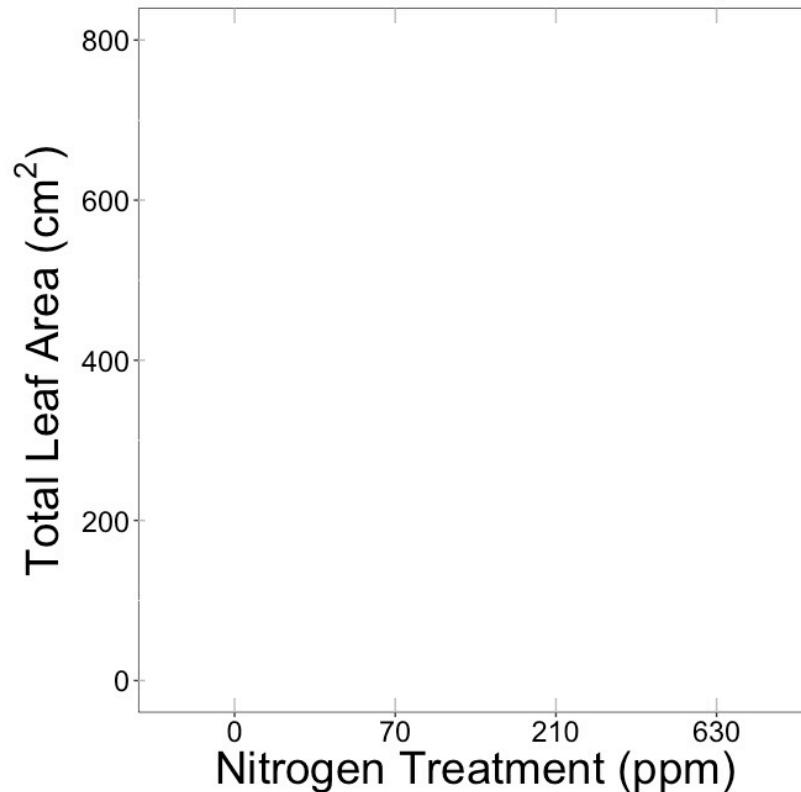
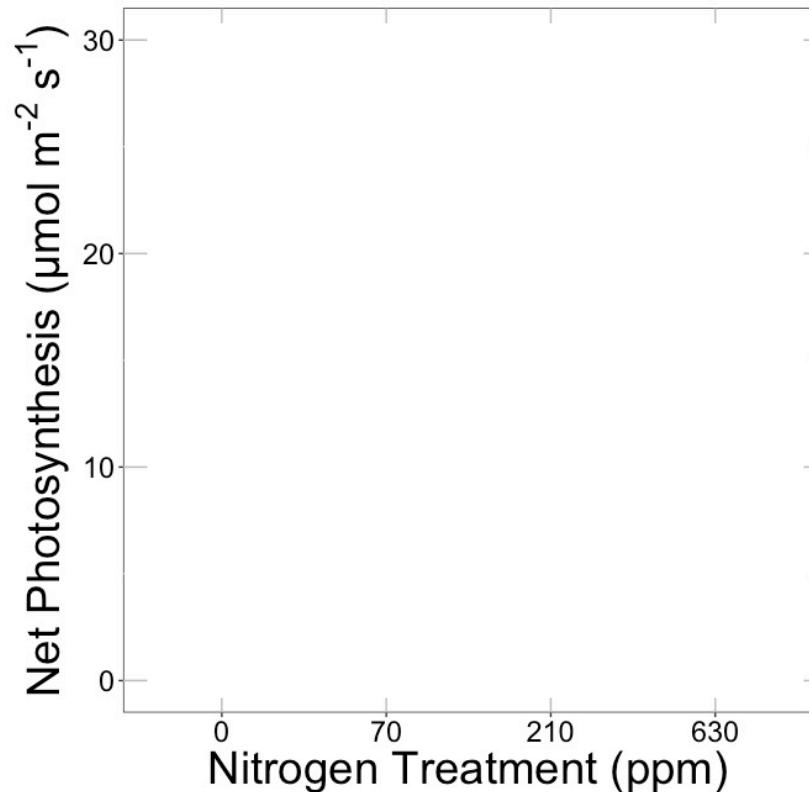
Added nutrients will not increase photosynthesis
because light limitation will kick in

From the least cost hypothesis...

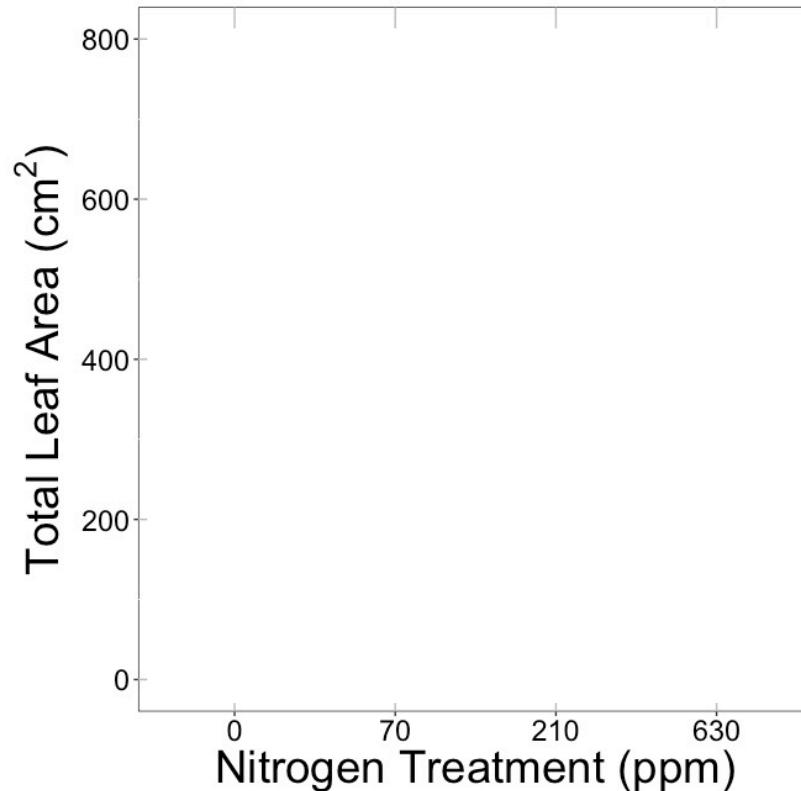
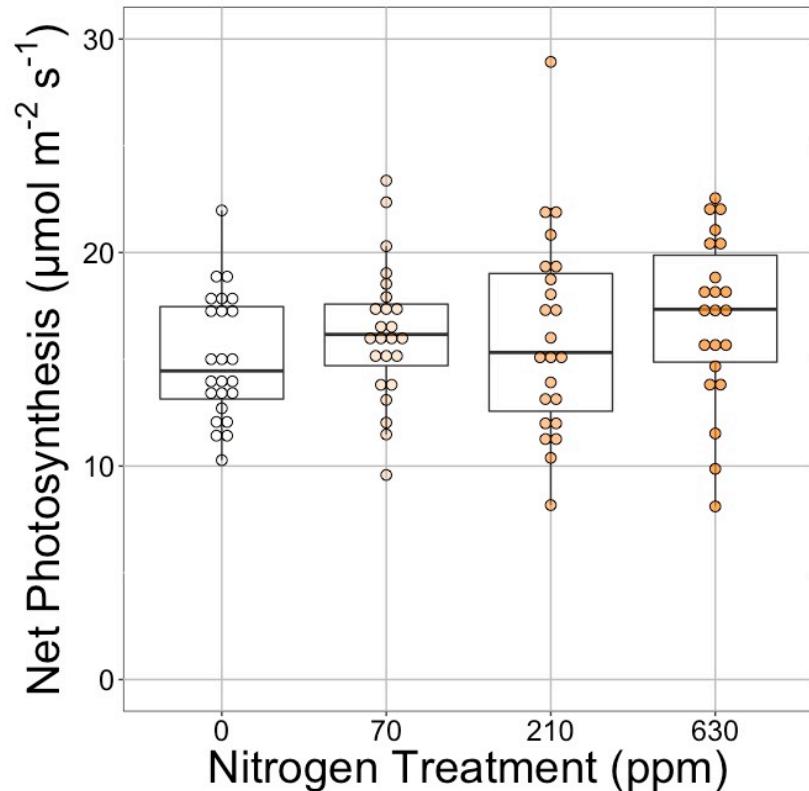
Added nutrients will not increase photosynthesis
because light limitation will kick in

**Optimal response would be to
increase leaf area**

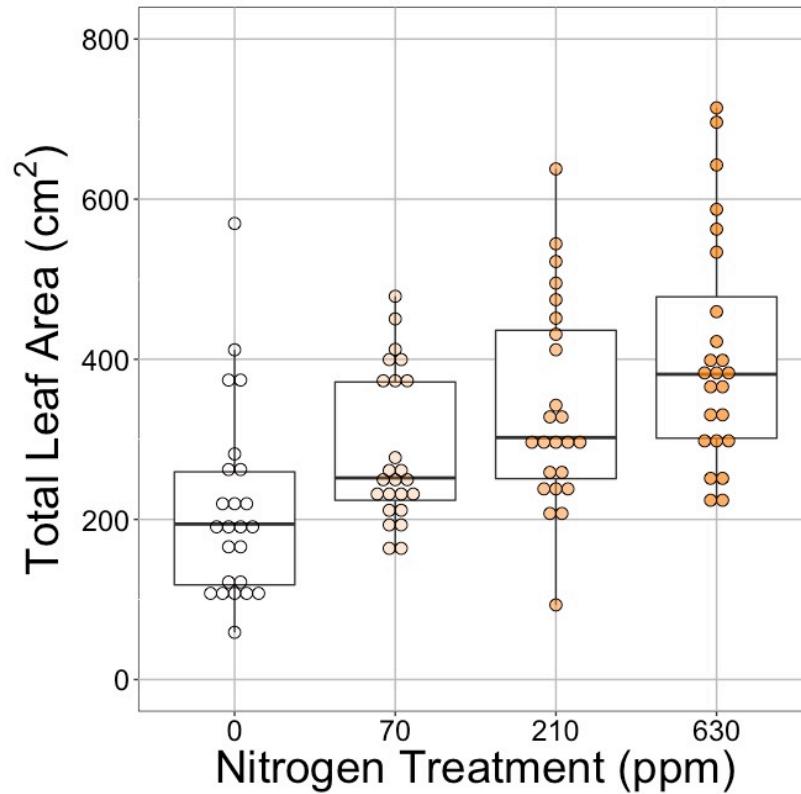
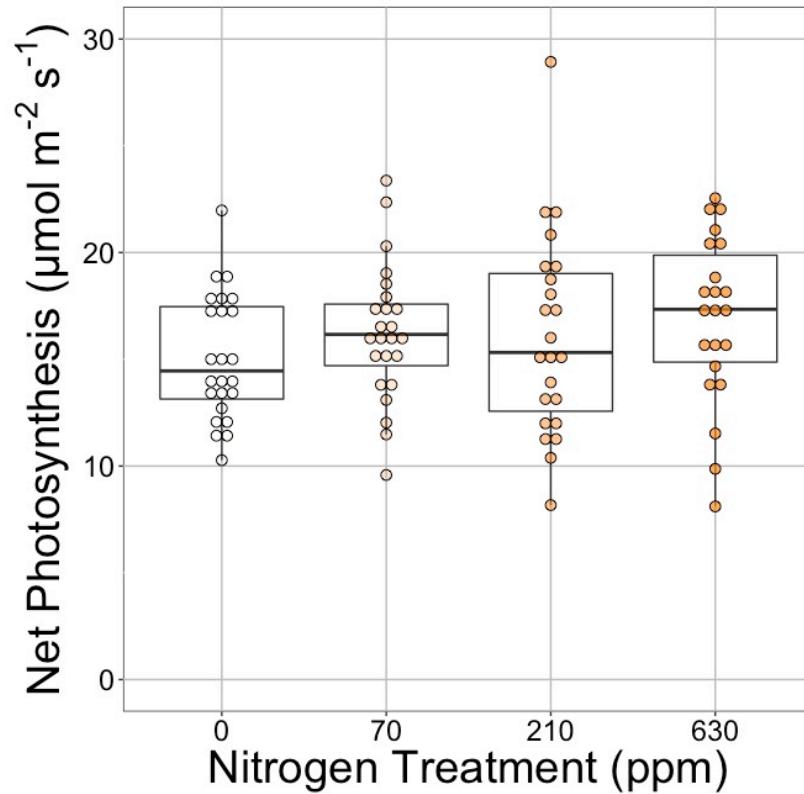
Leaf area, but not photosynthesis increases with N addition



Leaf area, but not photosynthesis increases with N addition



Leaf area, but not photosynthesis increases with N addition



But do greenhouse experiments
translate to the field?



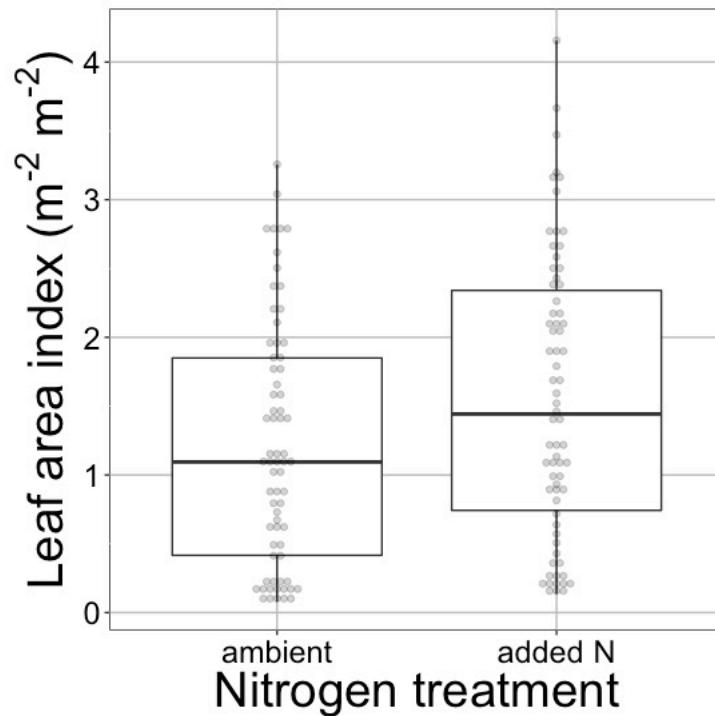
nutrient
network

Grassland soil nutrient addition network:

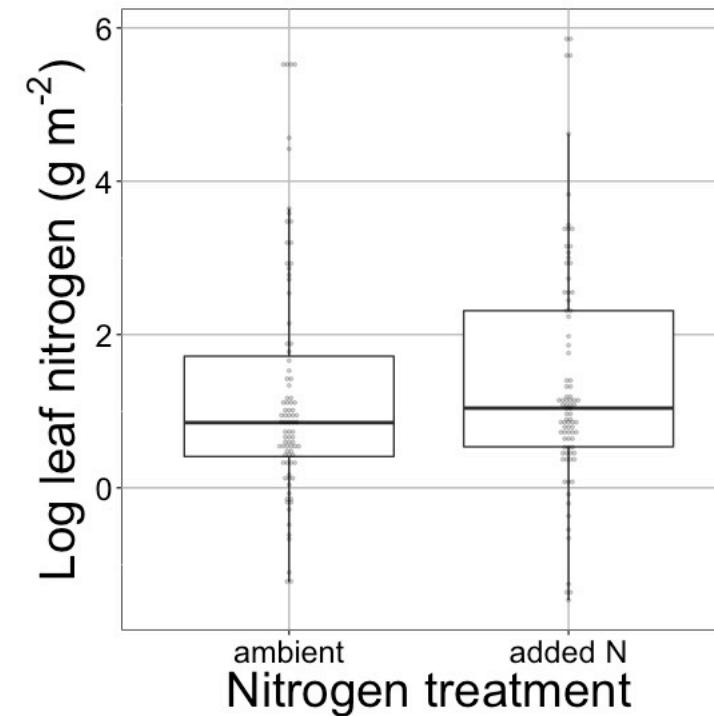
1. Leaf area index
2. Per-leaf-area nitrogen (photosynthetic proxy)

Globally, N addition increases leaf area, not leaf N

41% increase ($P < 0.05$)



No change ($P = 0.42$)



Question 3: Does photosynthesis respond to nitrogen addition?

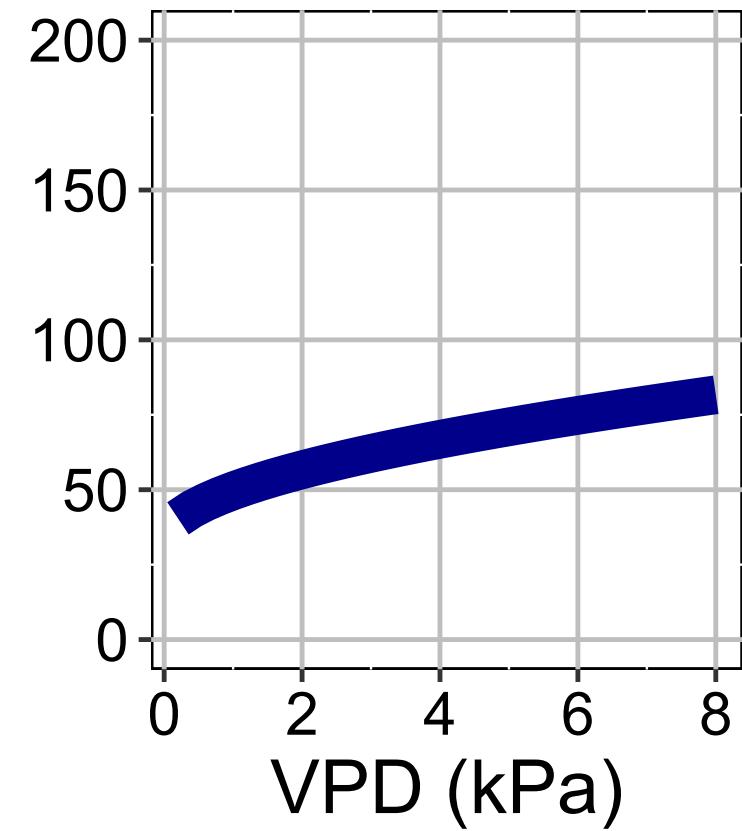
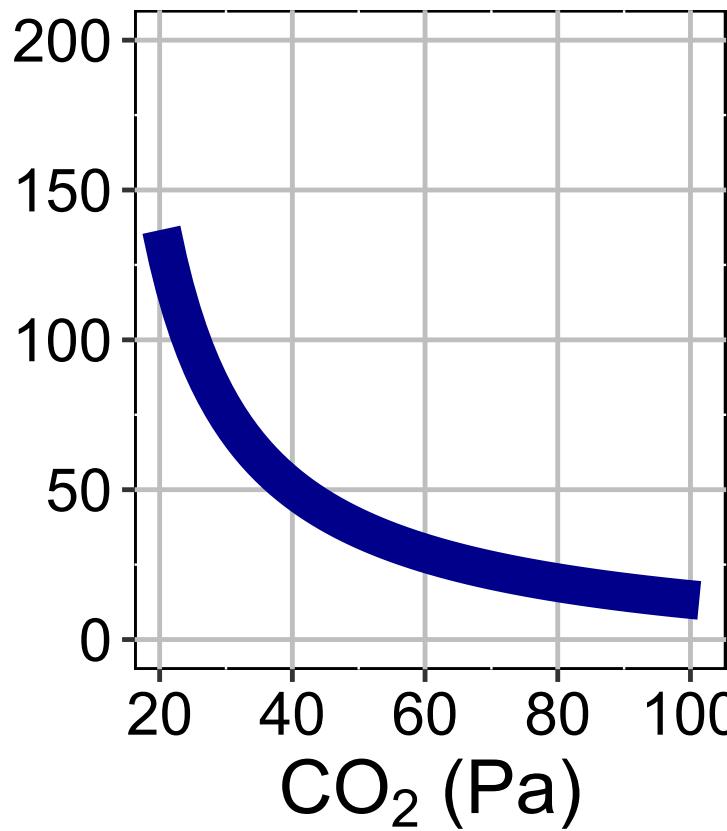
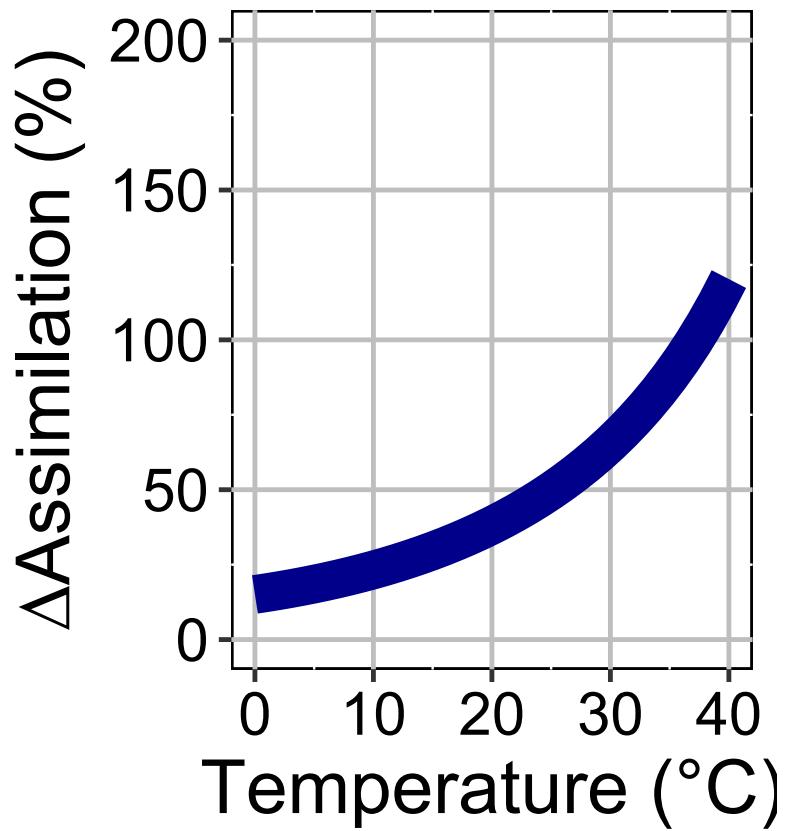
No, plants respond to added nitrogen by increasing leaf area, not photosynthesis

Question 4: Will C₄ be
advantageous in the future?

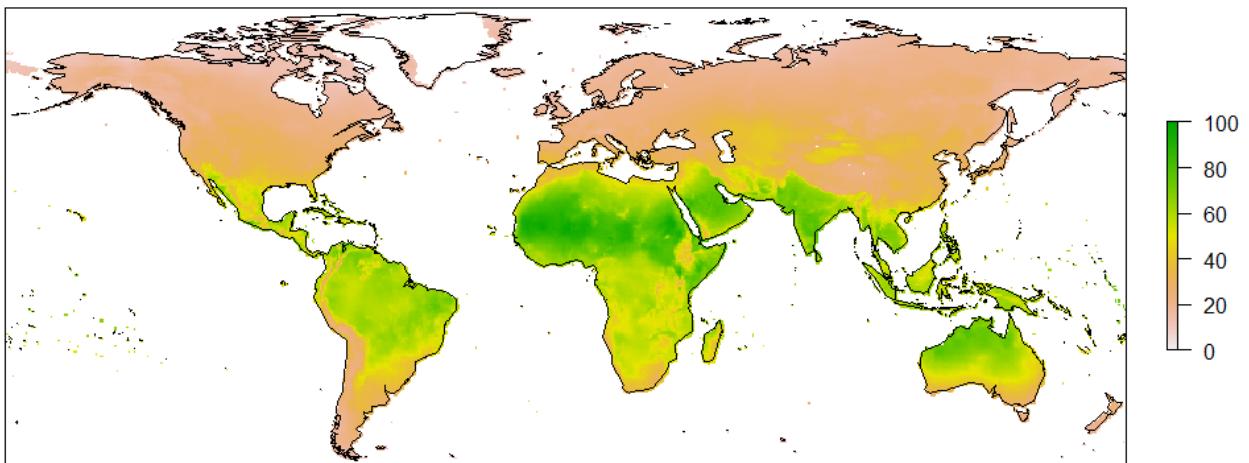
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TTU



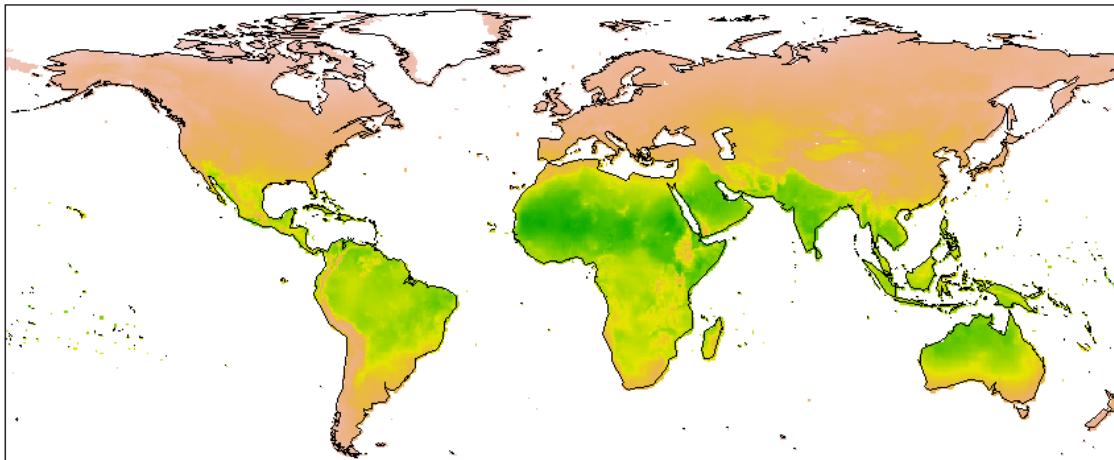
Relative advantage of C₄ physiology



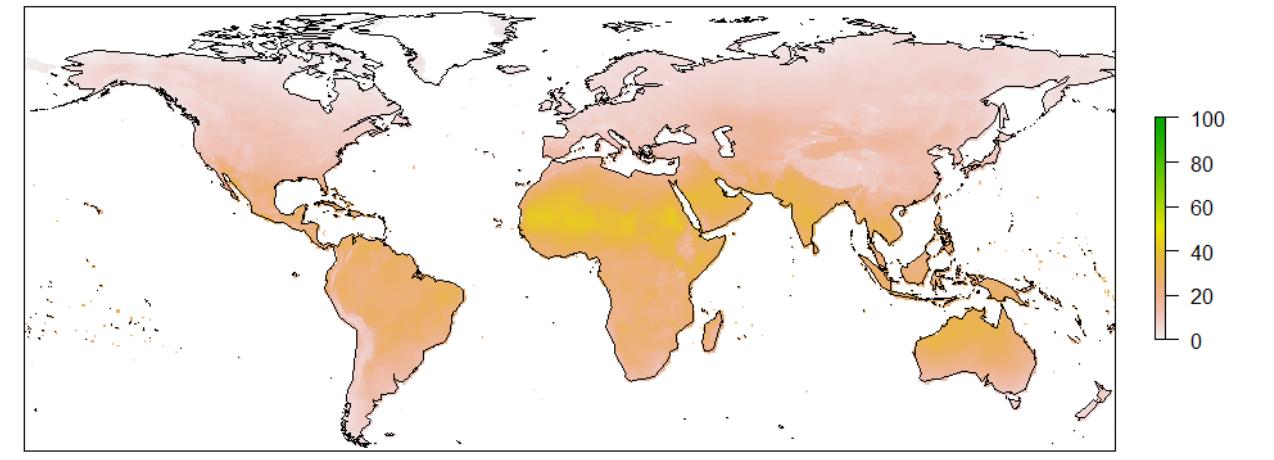
Current relative advantage of C₄ (%)



Current relative advantage of C₄ (%)



Future relative advantage of C₄ (%)



Question 4: Will C₄ be
advantageous in the future?

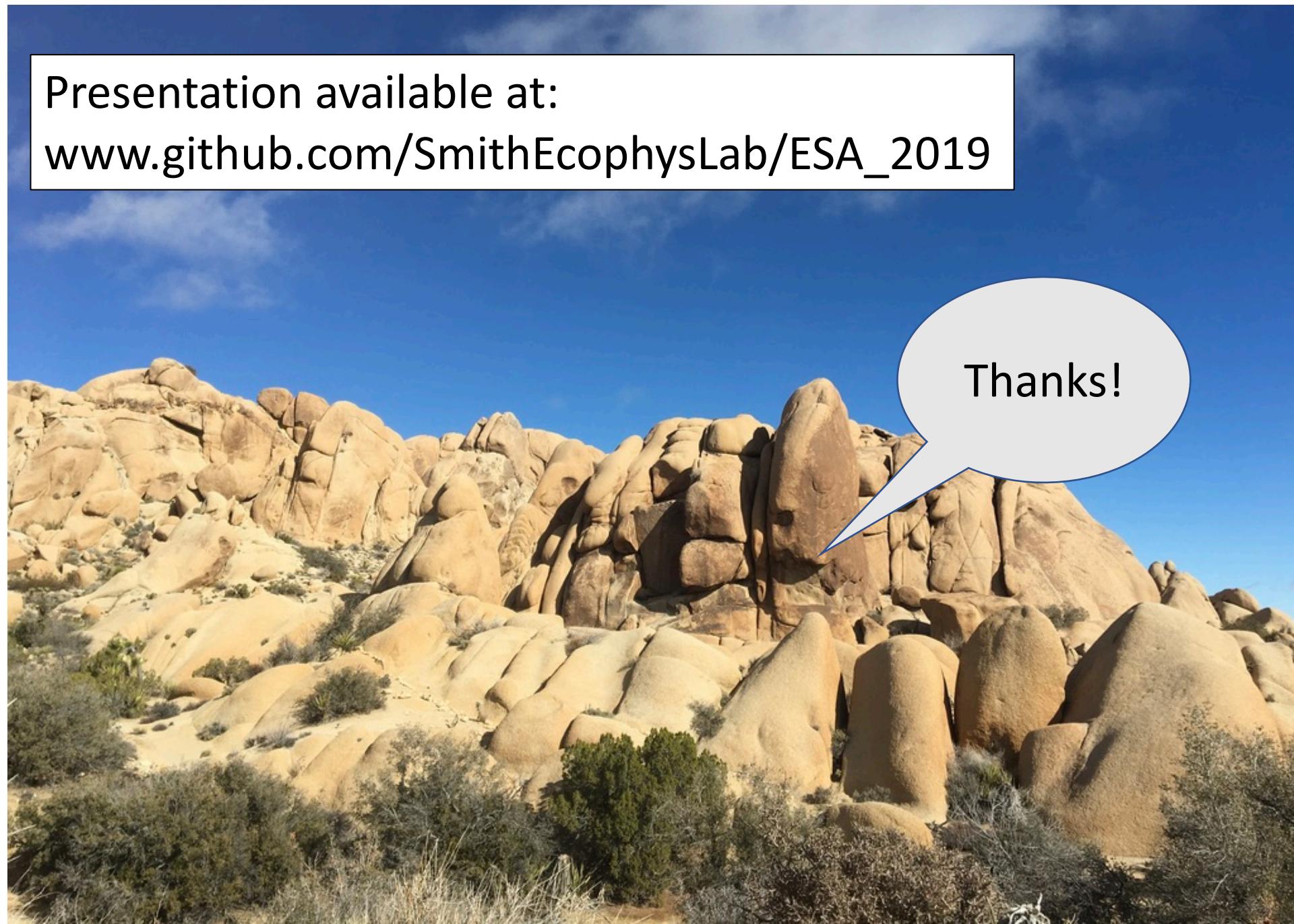
Elevated CO₂ will negate C₄
advantages in the future

Conclusions

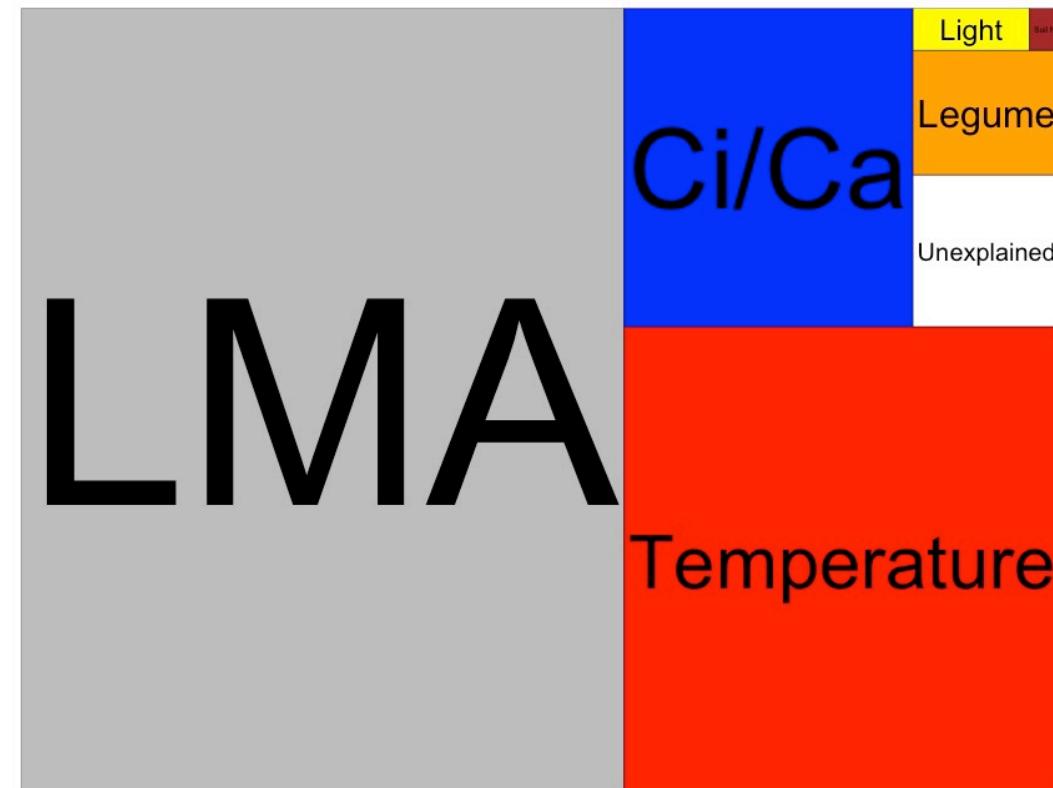
Theory can be useful!

- Improving the reliability of climate models
- Acting as a null model for understanding mechanisms

Presentation available at:
www.github.com/SmithEcophysLab/ESA_2019



Globally, N addition has no impact on leaf N



Each box is proportional to the variance in leaf N explained by each variable