

Using optimization to better understand leaf-to-whole plant acclimation

Nick Smith

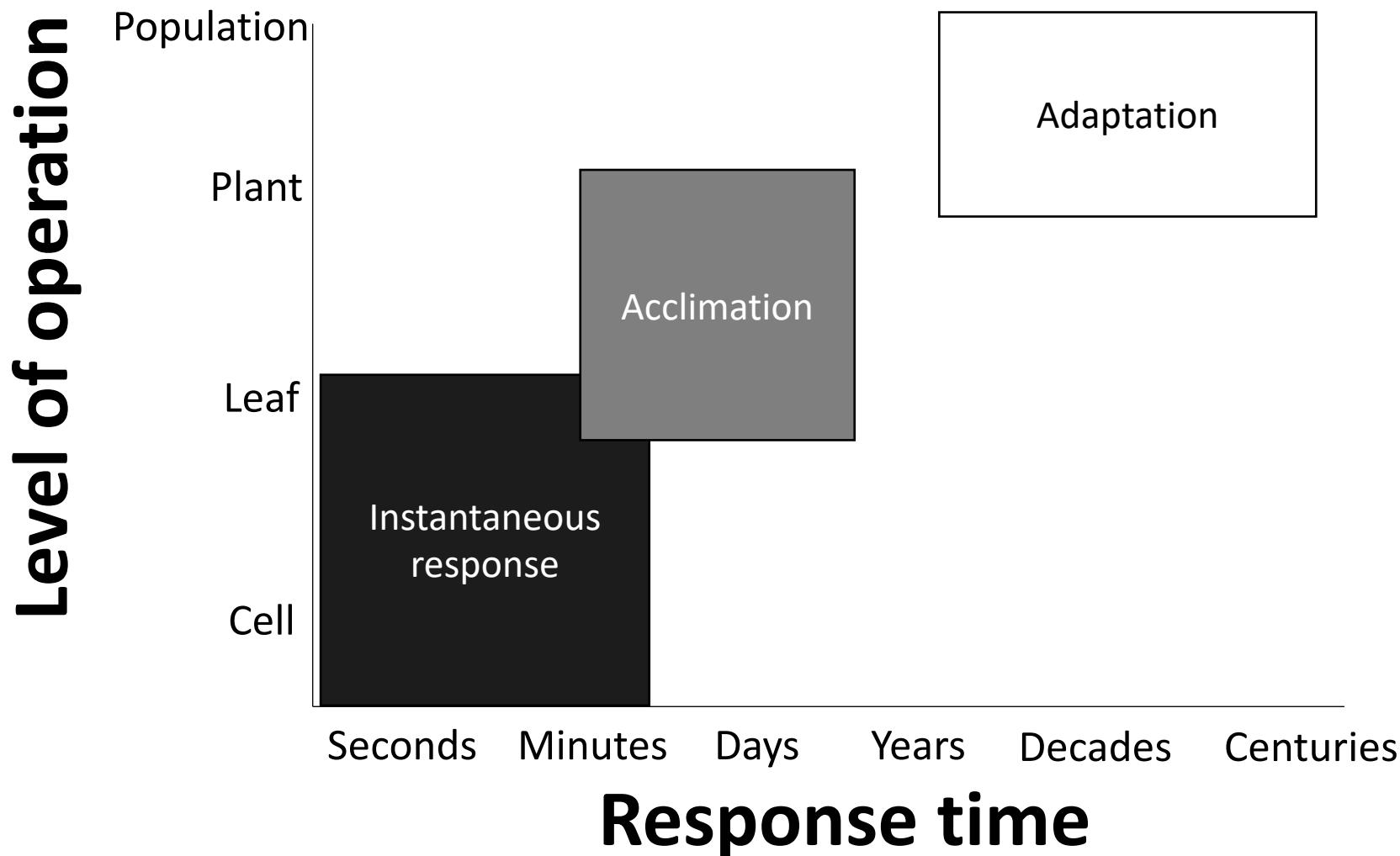
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Lizz Waring (Northeastern State U)
Helen Scott (TTU)
Trevor Keenan (UC-Berkeley)



Plants acclimate to environmental conditions



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)

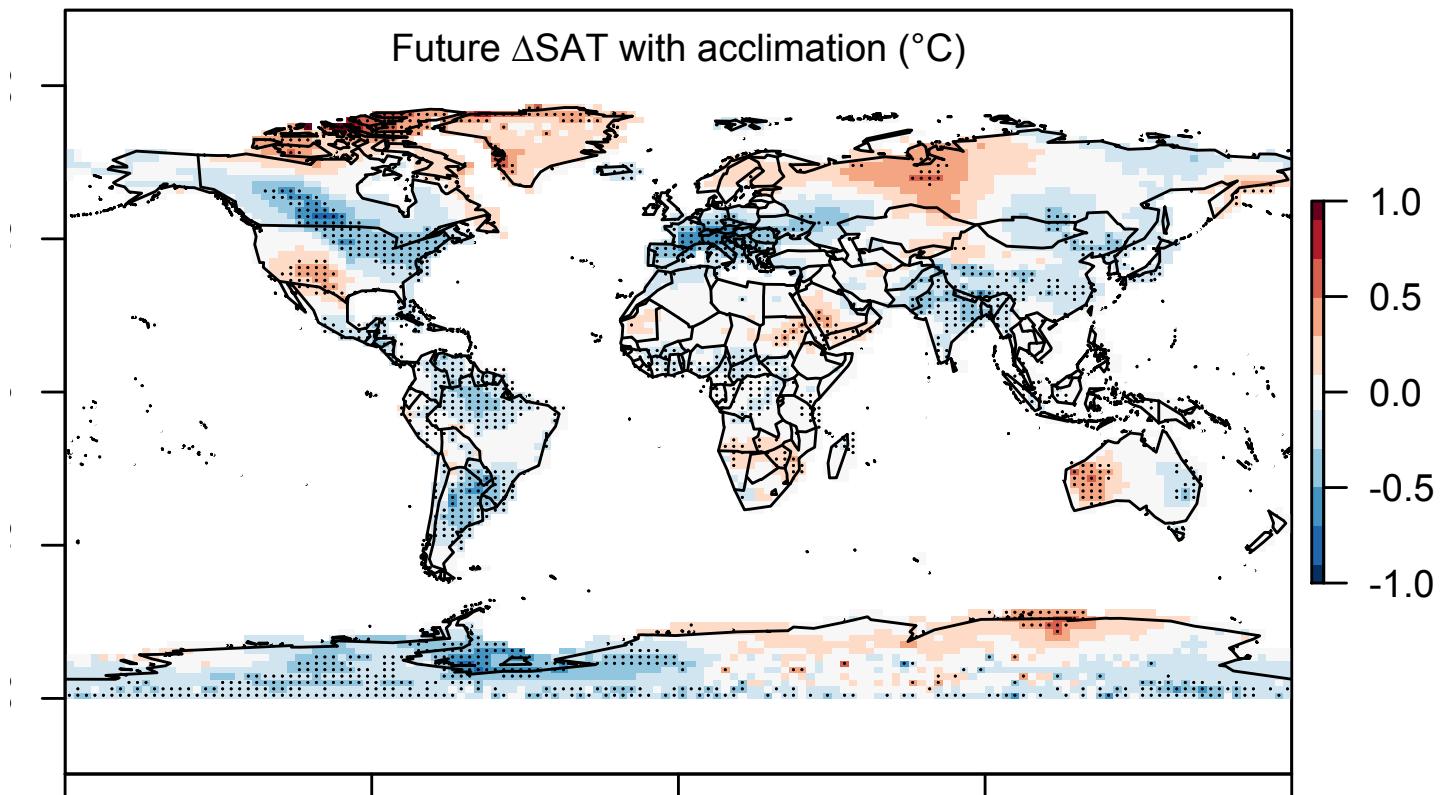
Ann. Rev. Plant Physiol. 1980, 31:491–543
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PHOTOSYNTHETIC RESPONSE AND ADAPTATION TO TEMPERATURE IN HIGHER PLANTS

Joseph Berry and Olle Björkman¹

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

Acclimation alters future temperature by $>1^{\circ}\text{C}$



...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)

Least cost theory

[TALK TO ME LATER ABOUT THE MATHS]

Wright et al. (2003). *American Naturalist*

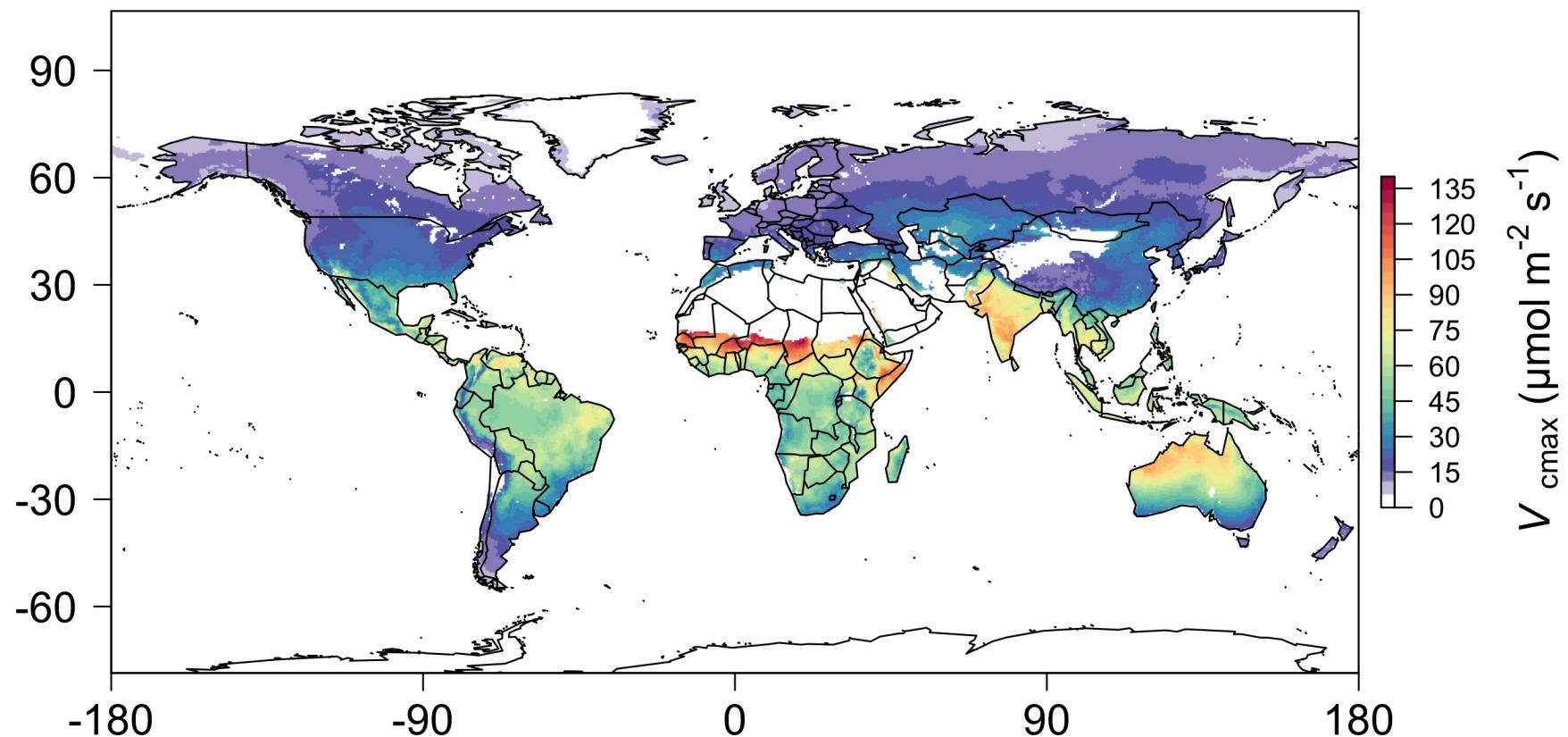
Prentice et al. (2014). *Ecology Letters*

Wang et al. (2017). *Nature Plants*

Smith et al. (2019). *Ecology Letters*

Stocker et al. (2019). *Geoscientific Model Development Discussion*

We can predict optimal traits in different environments

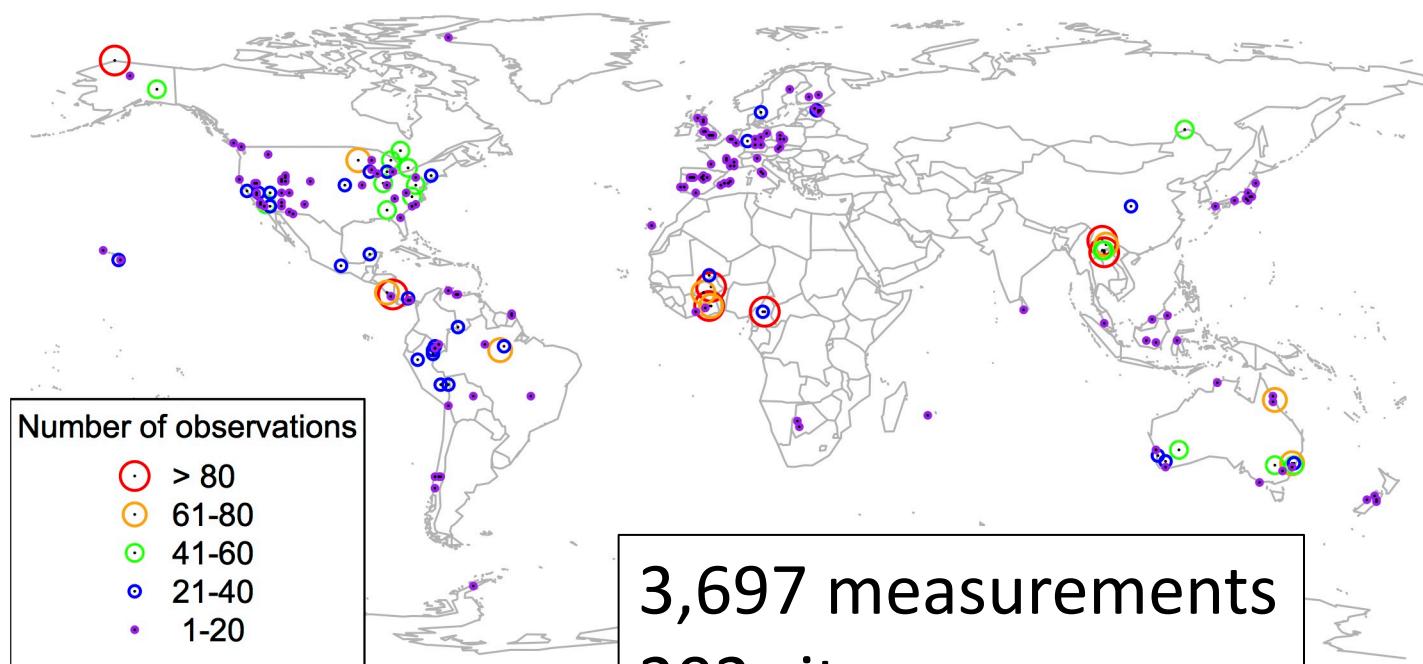


We can use the theory as a null model to explore acclimation mechanisms

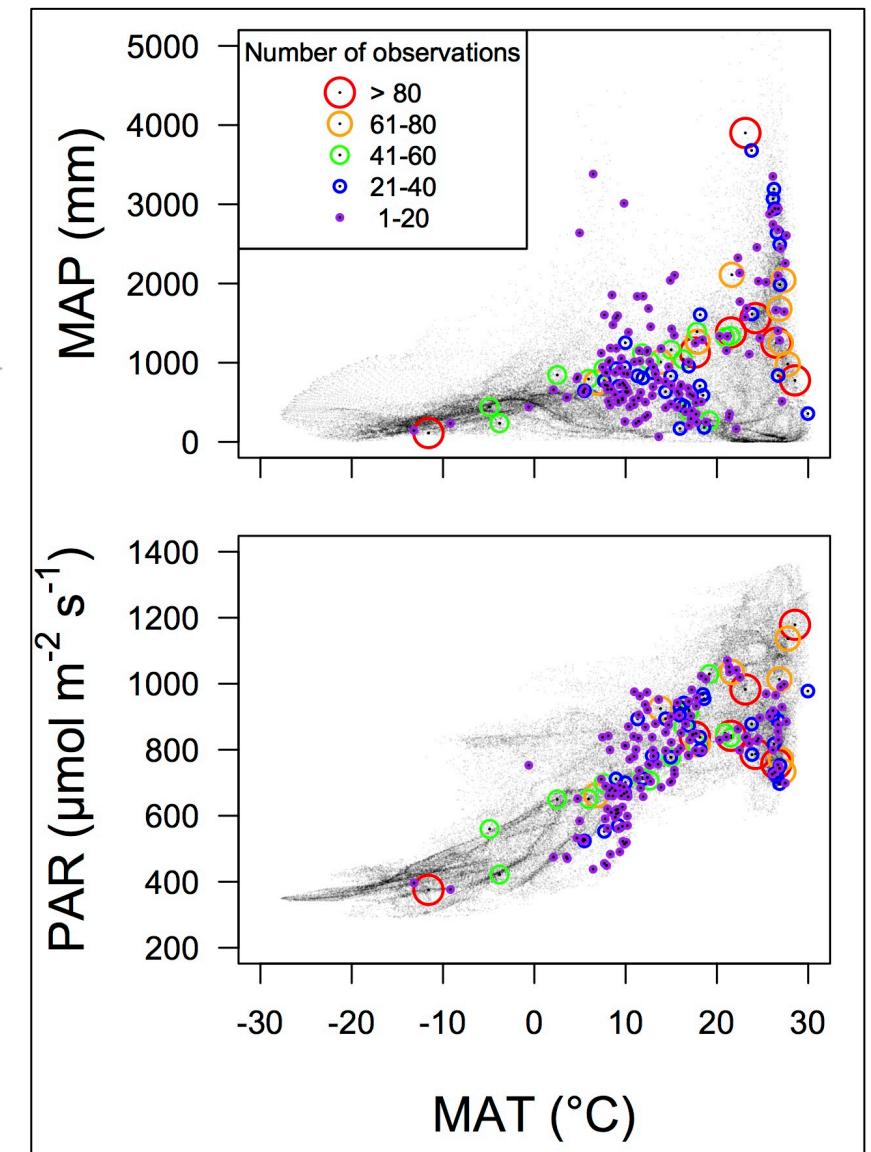
Let's tackle some big questions in
plant ecophysiology!

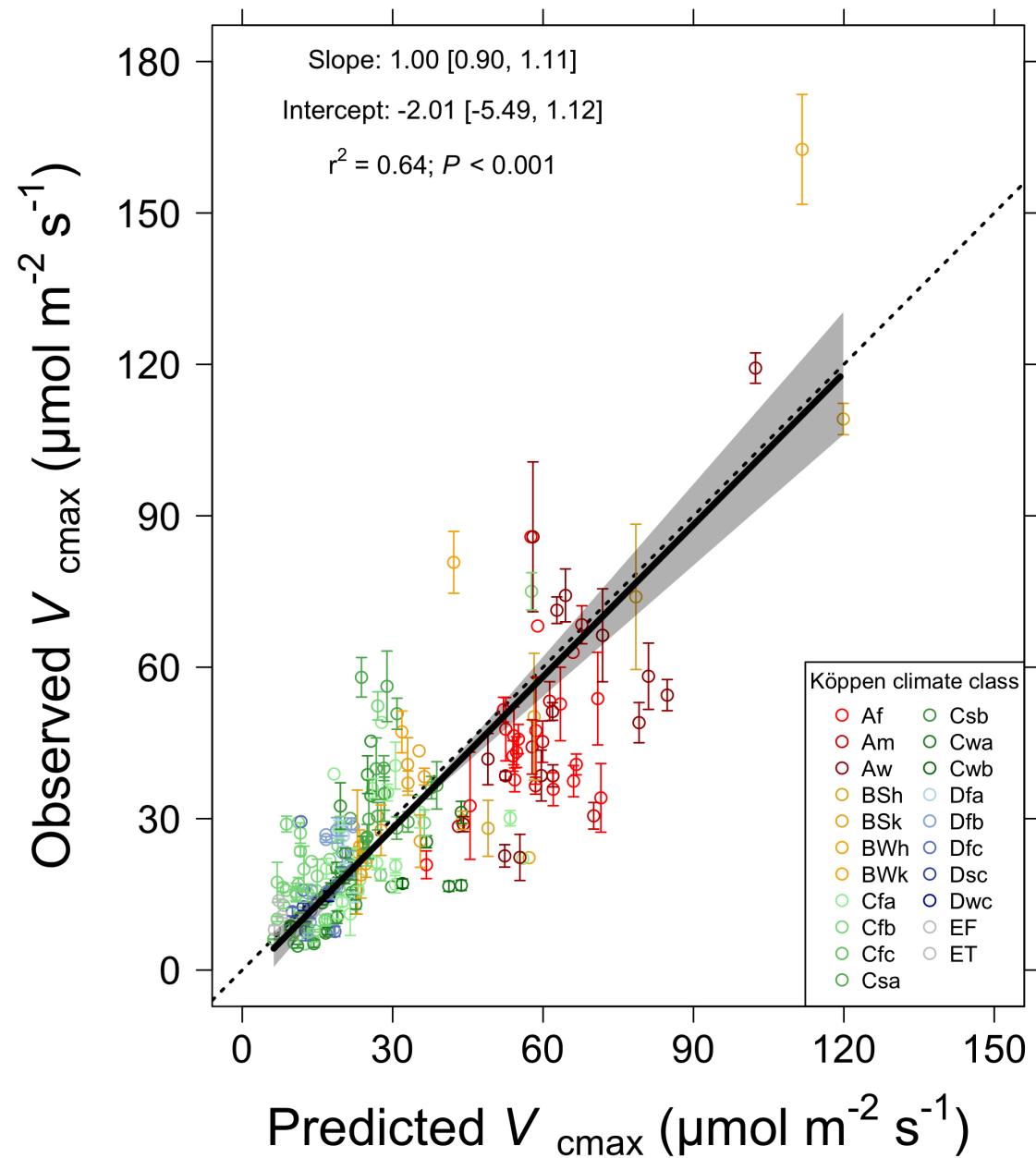
Question 1: Is photosynthesis
optimized to the environment?

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: Does photosynthesis respond to soil nutrients?

Lizz Waring
TTU



From the least cost hypothesis...

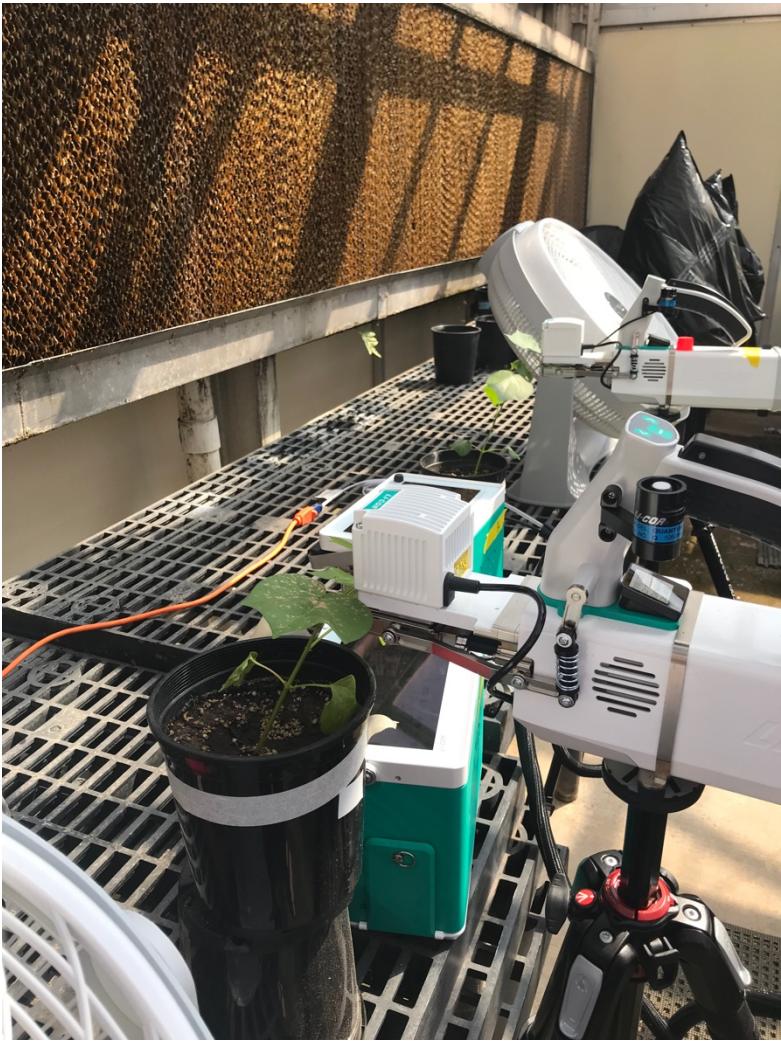
Added nutrients will not increase photosynthesis
because light limitation will kick in

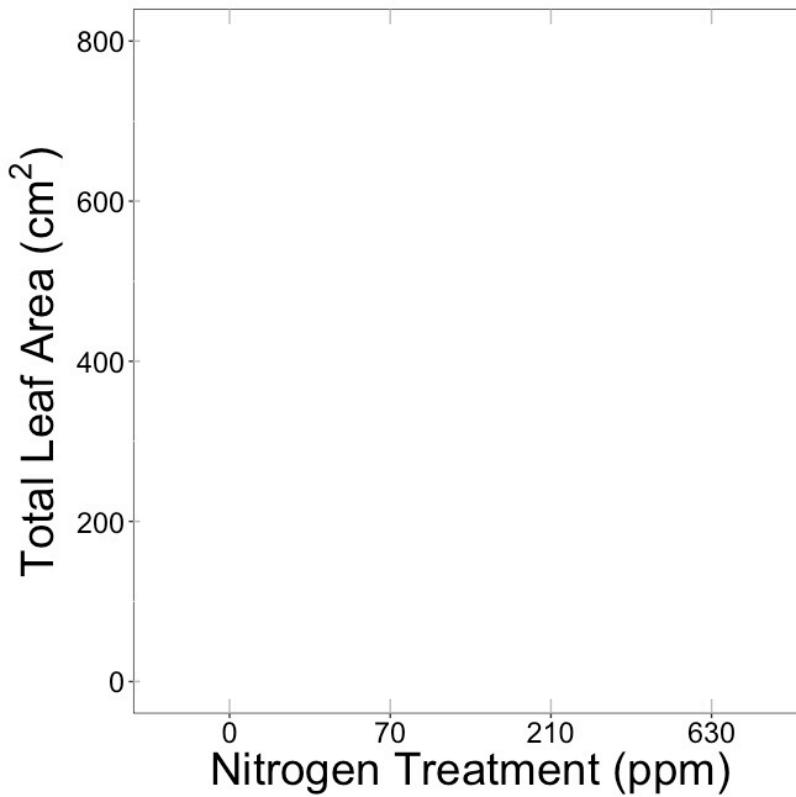
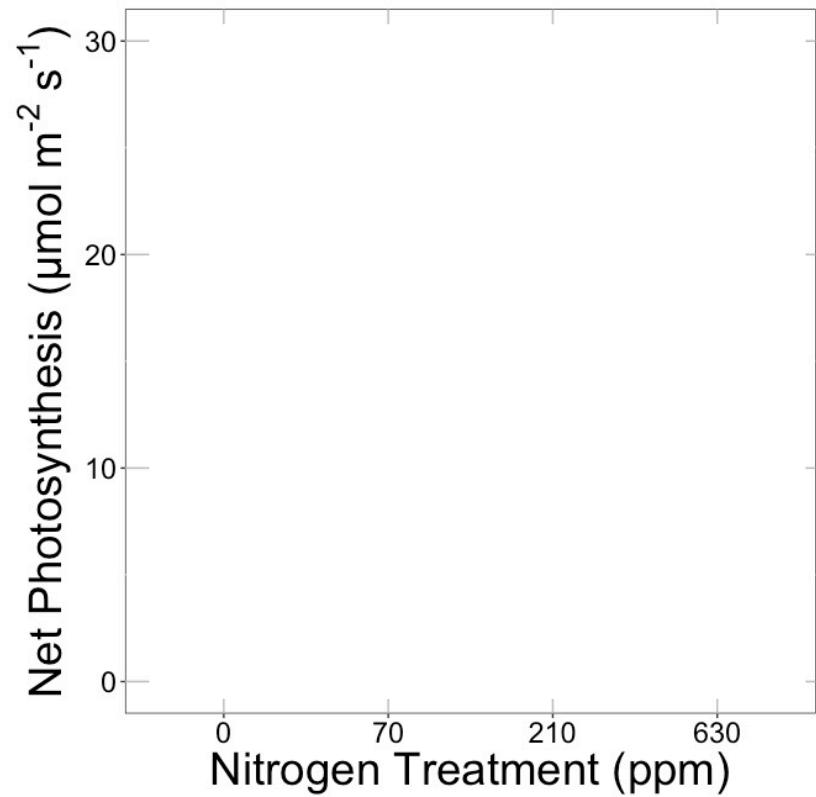
From the least cost hypothesis...

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

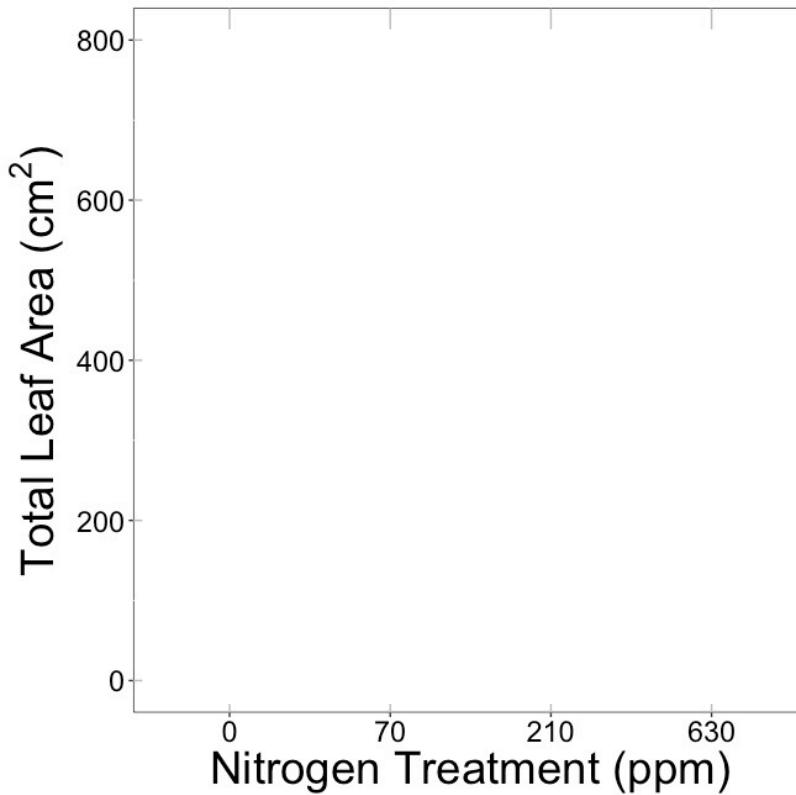
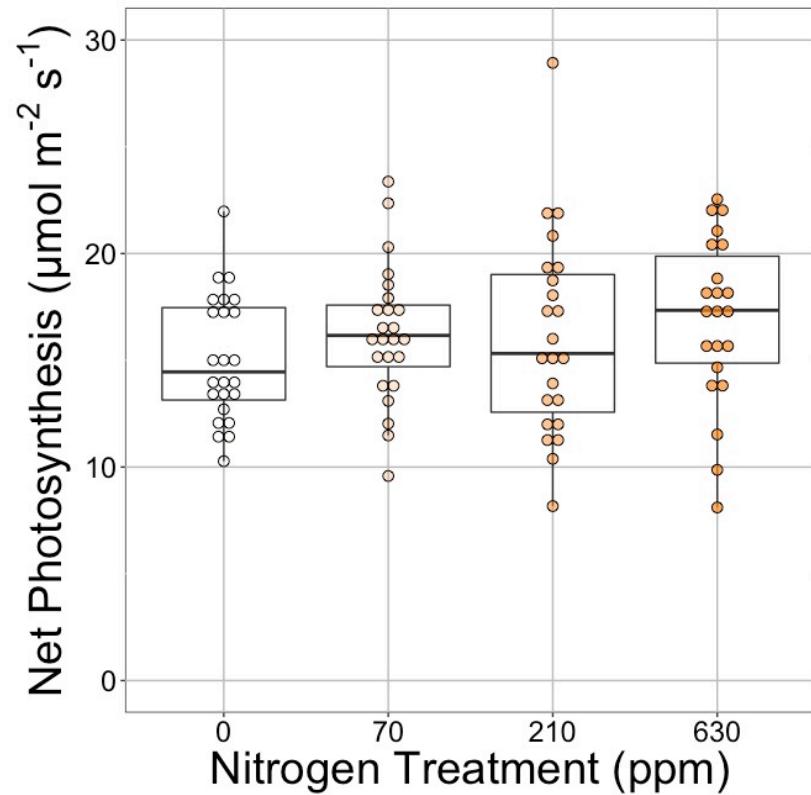
**Optimal response might be to
increase leaf area to access more
light**

But let's test it experimentally



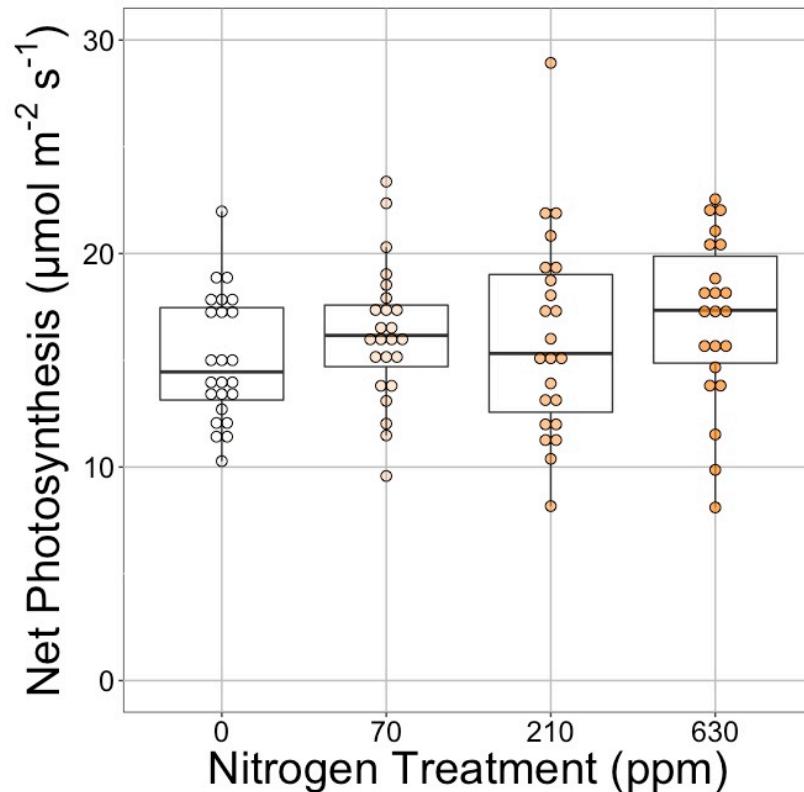


No change ($P = 0.42$)

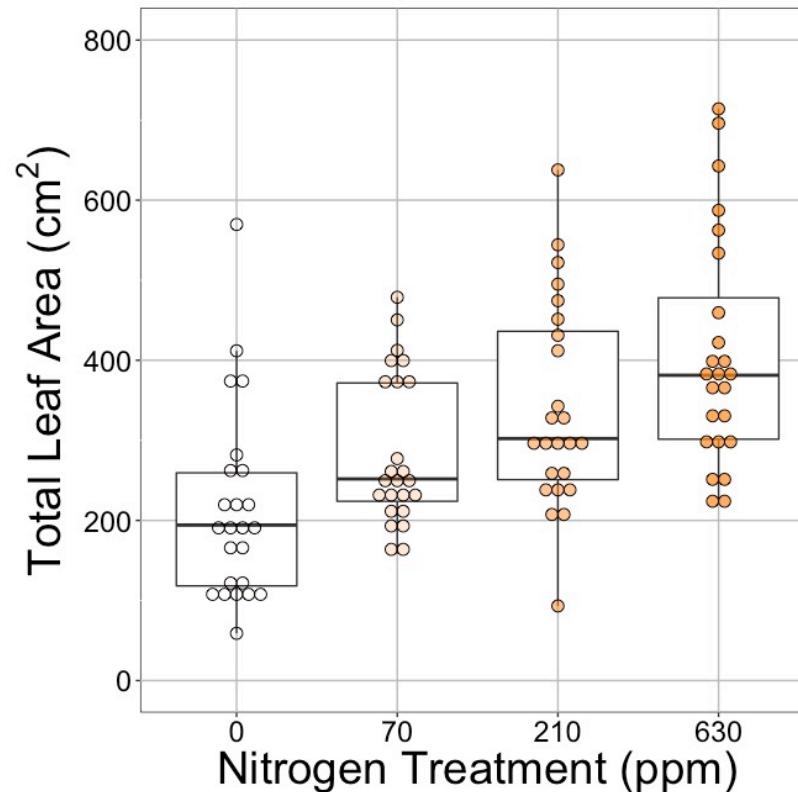


Leaf area, but not photosynthesis increases with N addition

No change ($P = 0.42$)



91% increase ($P < 0.05$)



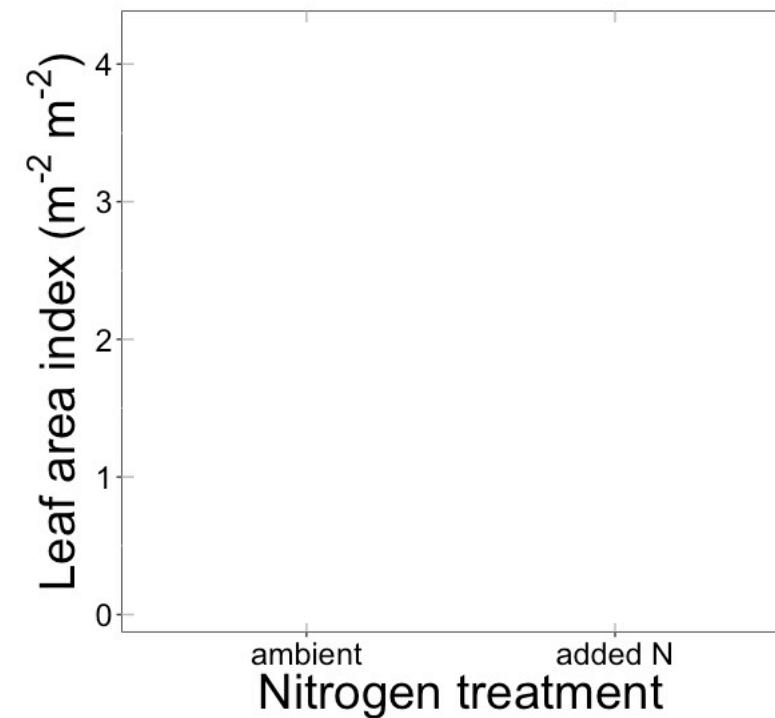
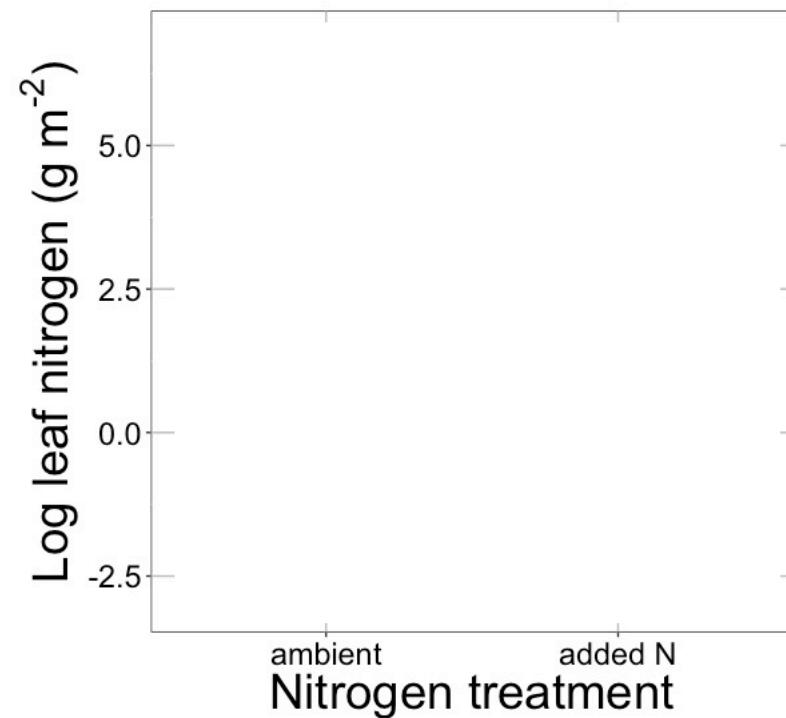
But do greenhouse experiments
translate to the field?



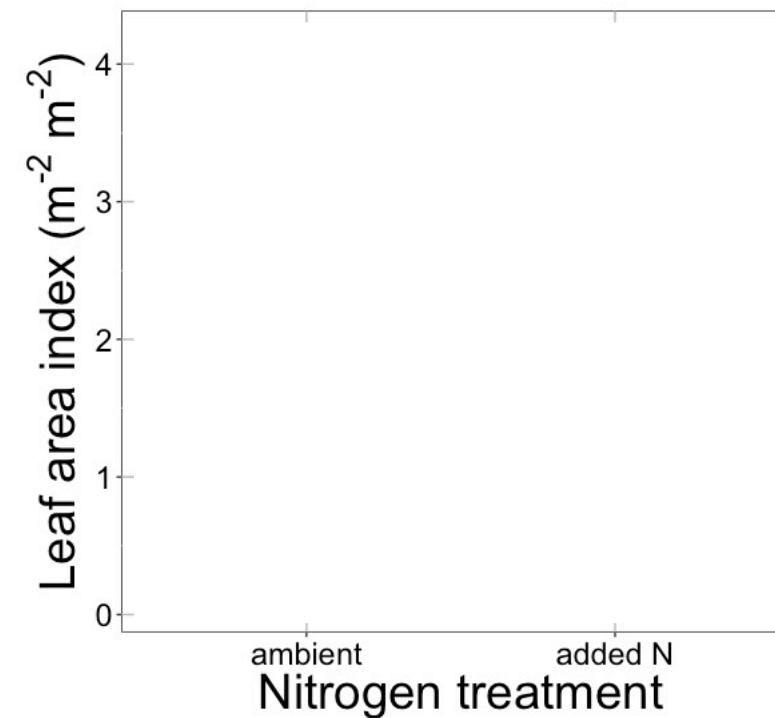
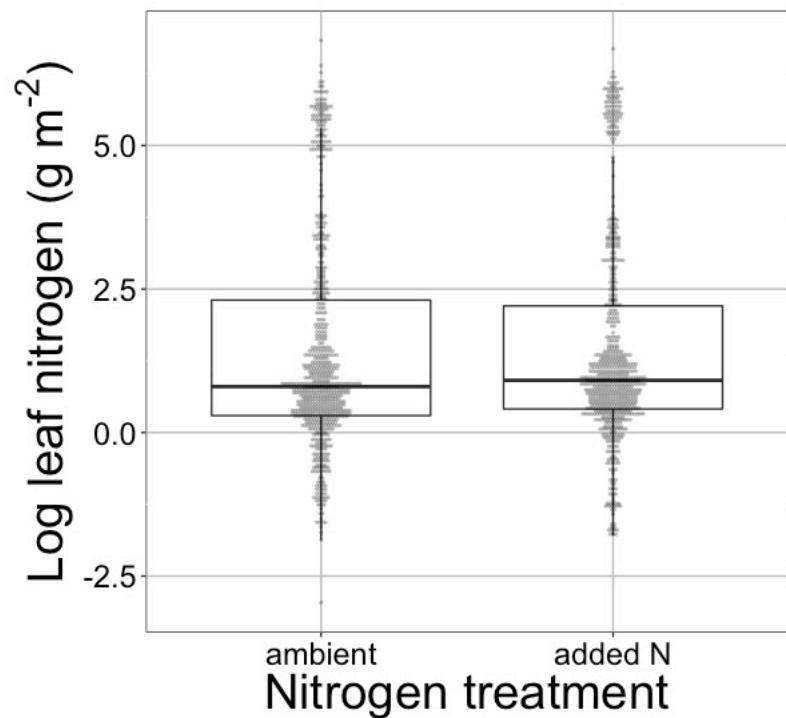
nutrient
network

Grassland soil nutrient addition network:

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

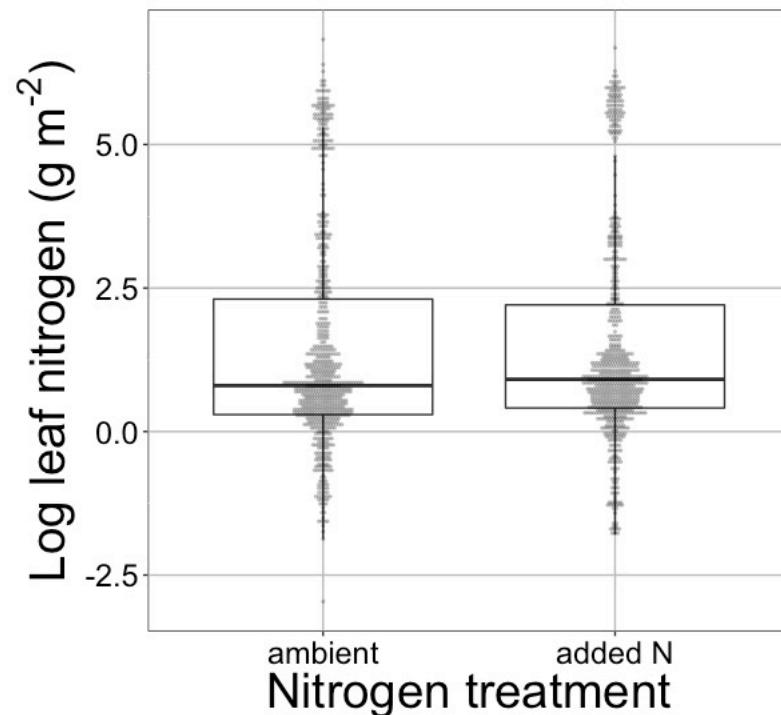


No change ($P > 0.05$)

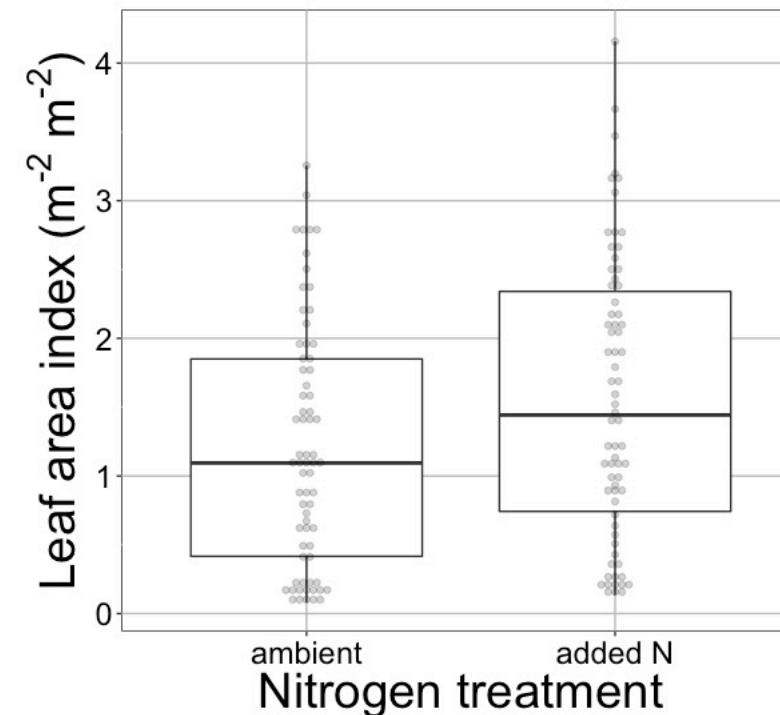


Globally, N addition increases leaf area, not leaf N

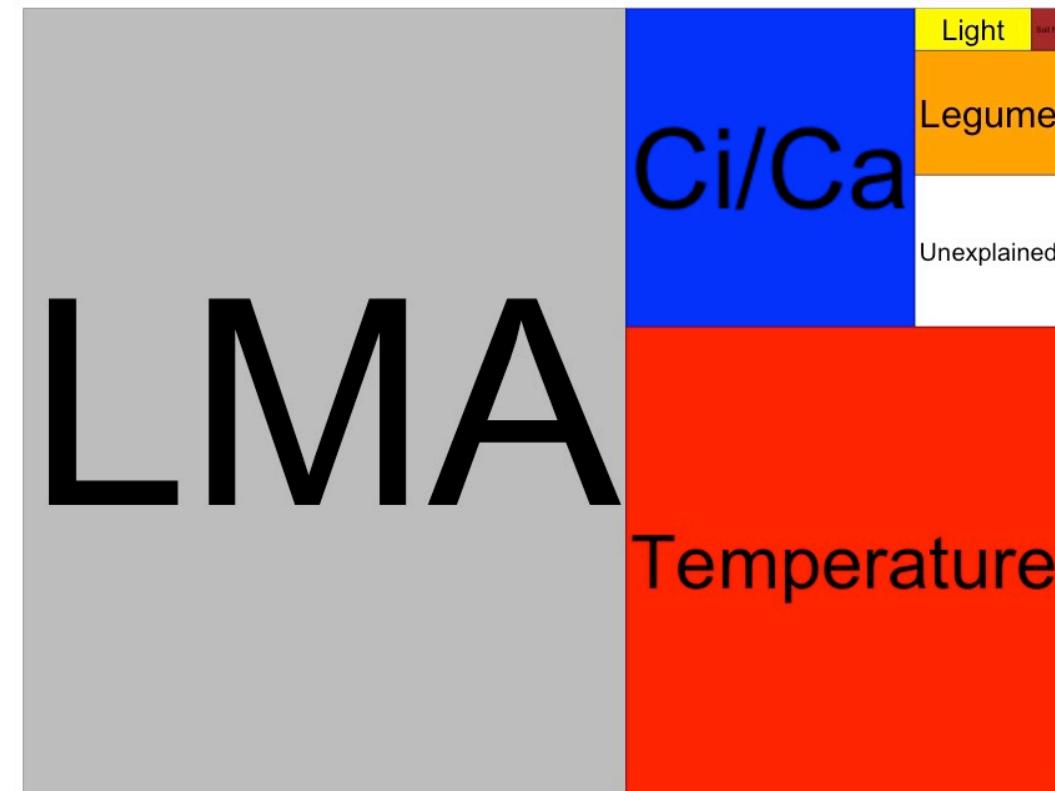
No change ($P > 0.05$)



41% increase ($P < 0.05$)



Globally, N addition has no impact on leaf N



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

Question 2: Does photosynthesis respond to soil nutrients?

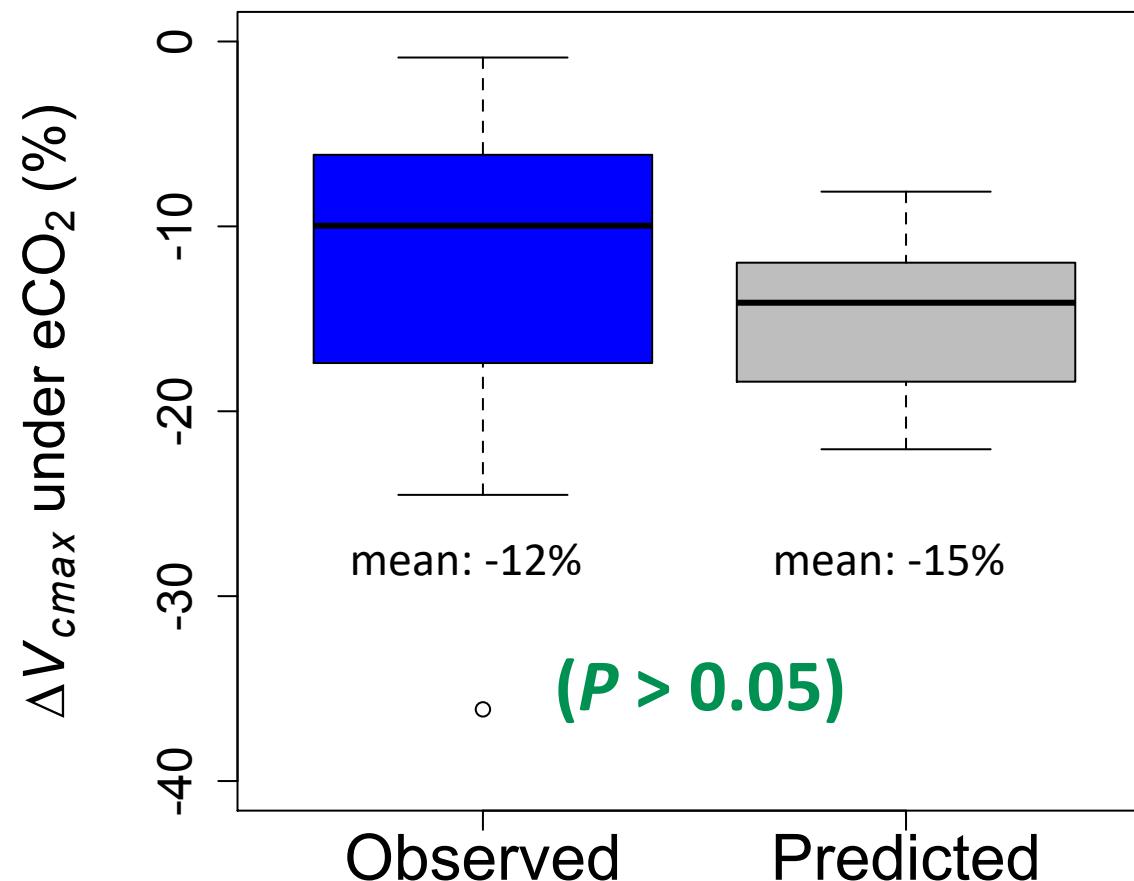
No, plants respond to added nutrients by increasing leaf area, not photosynthesis

Question 3: What does acclimation mean for future conditions?



Energy Exascale
Earth System Model

Photosynthetic traits change with future conditions in ways expected from optimization

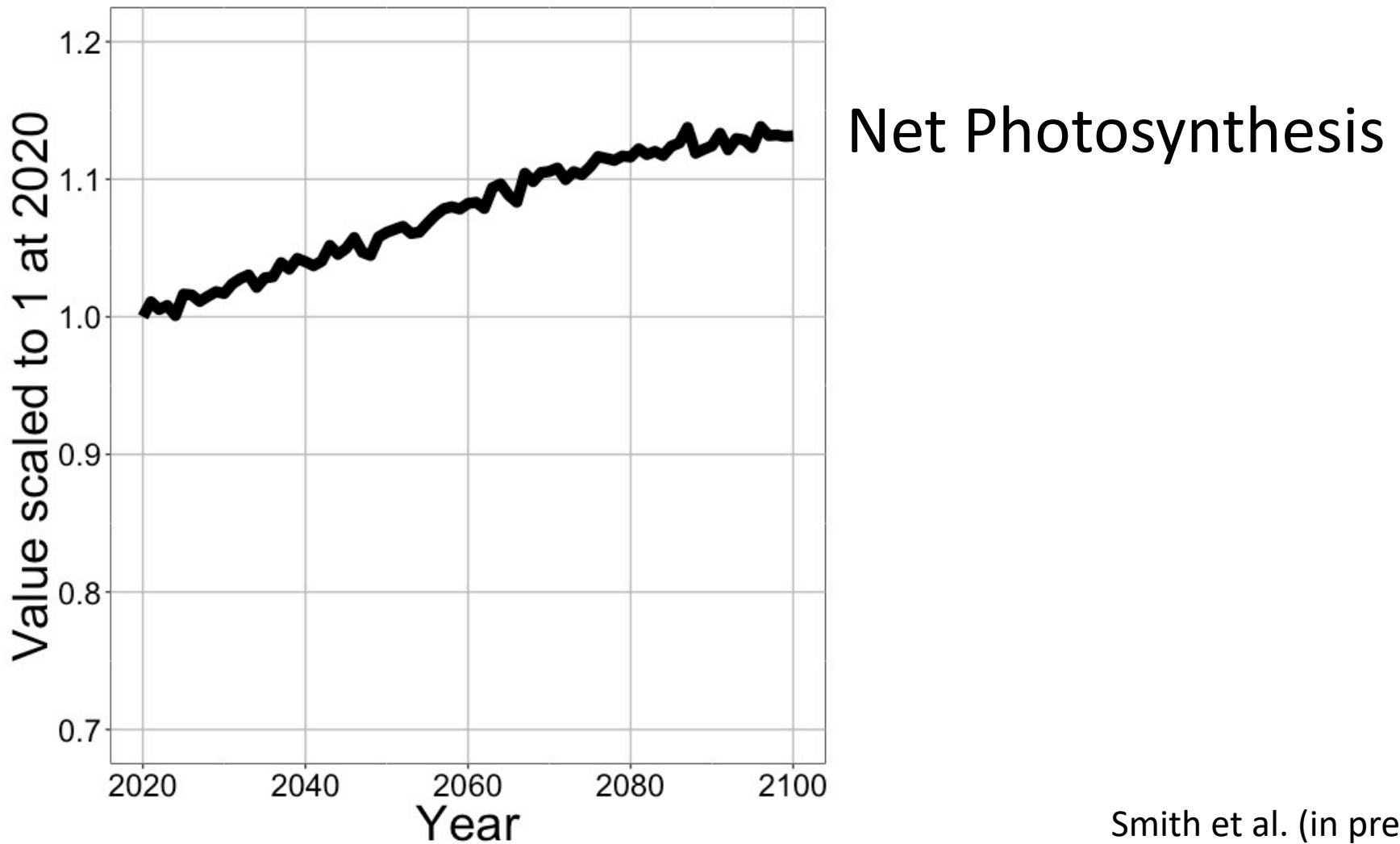


Let's run a model out into the future!

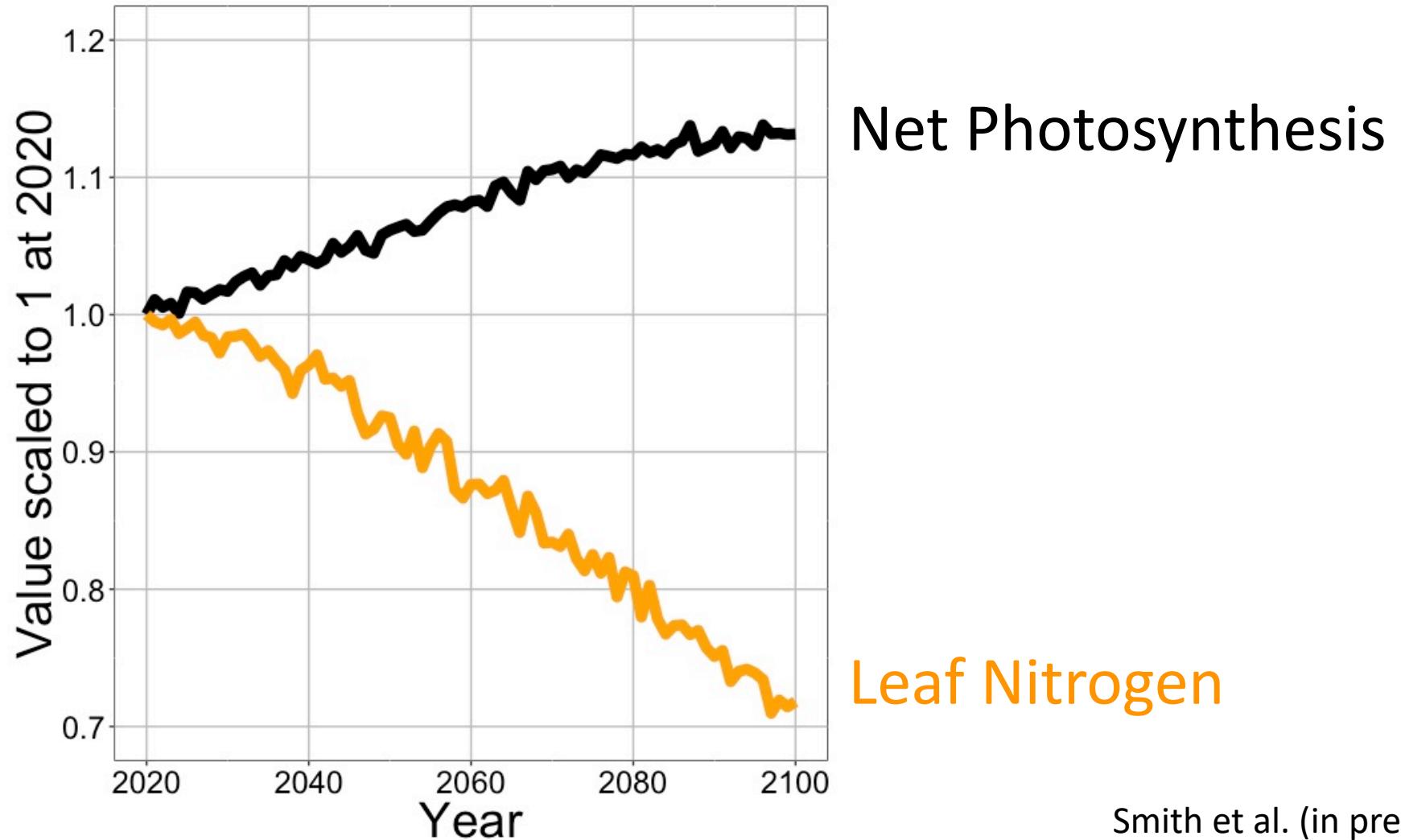


Energy Exascale
Earth System Model

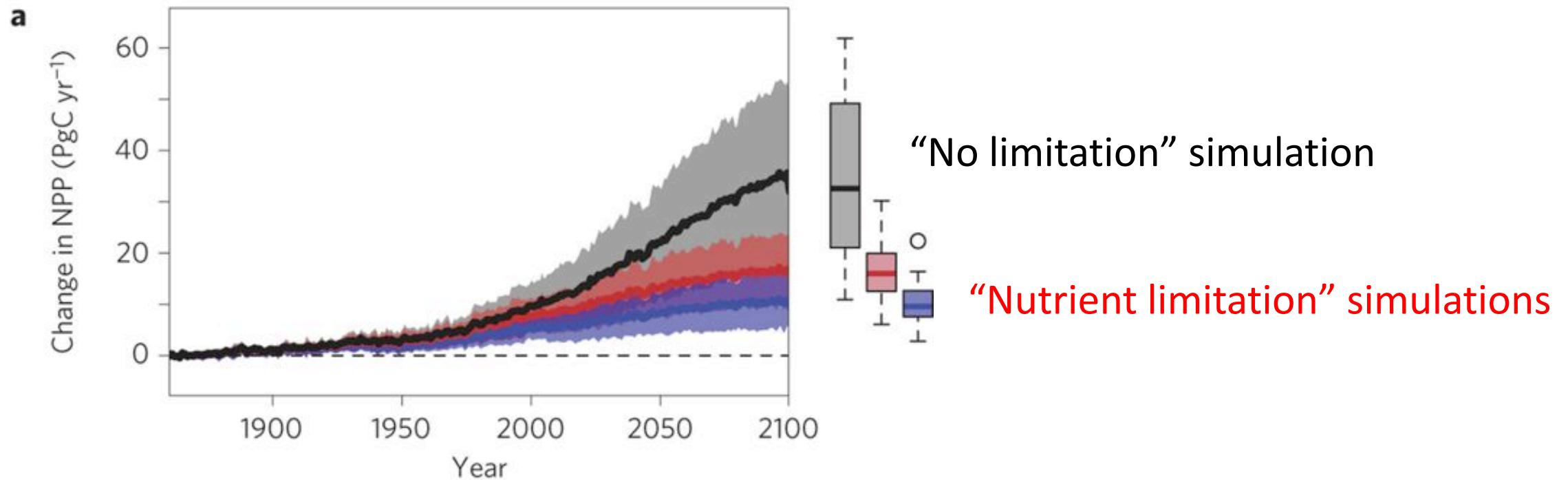
Photosynthesis increases in future



Photosynthesis increases in future (at lower nutrient use)



Need to rethink nutrient limitation in models



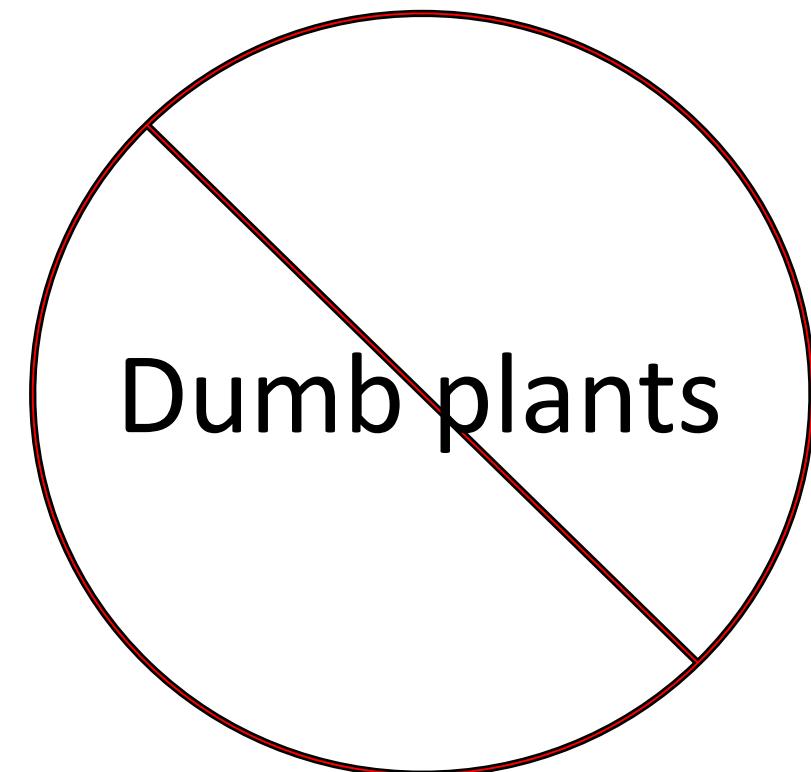
Question 3: What does acclimation mean for future conditions?

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

Conclusions

Conclusions

- Plants aren't dumb!
 - Need to make sure our models allow for acclimation responses



Conclusions

- Theory yields mechanistic insight about acclimation and associated feedbacks

Conclusions

- Theory yields mechanistic insight about acclimation and associated feedbacks
- We're using it to study
 - C3/C4 competition
 - Plant invasion
 - Mycorrhizal symbioses
 - Agriculture
 - Herbarium specimens



Presentation available at:

www.github.com/SmithEcophysLab/agu_2019



Thanks!