Plants aren’t dumb: using optimality theory to answer big questions in plant ecophysiology

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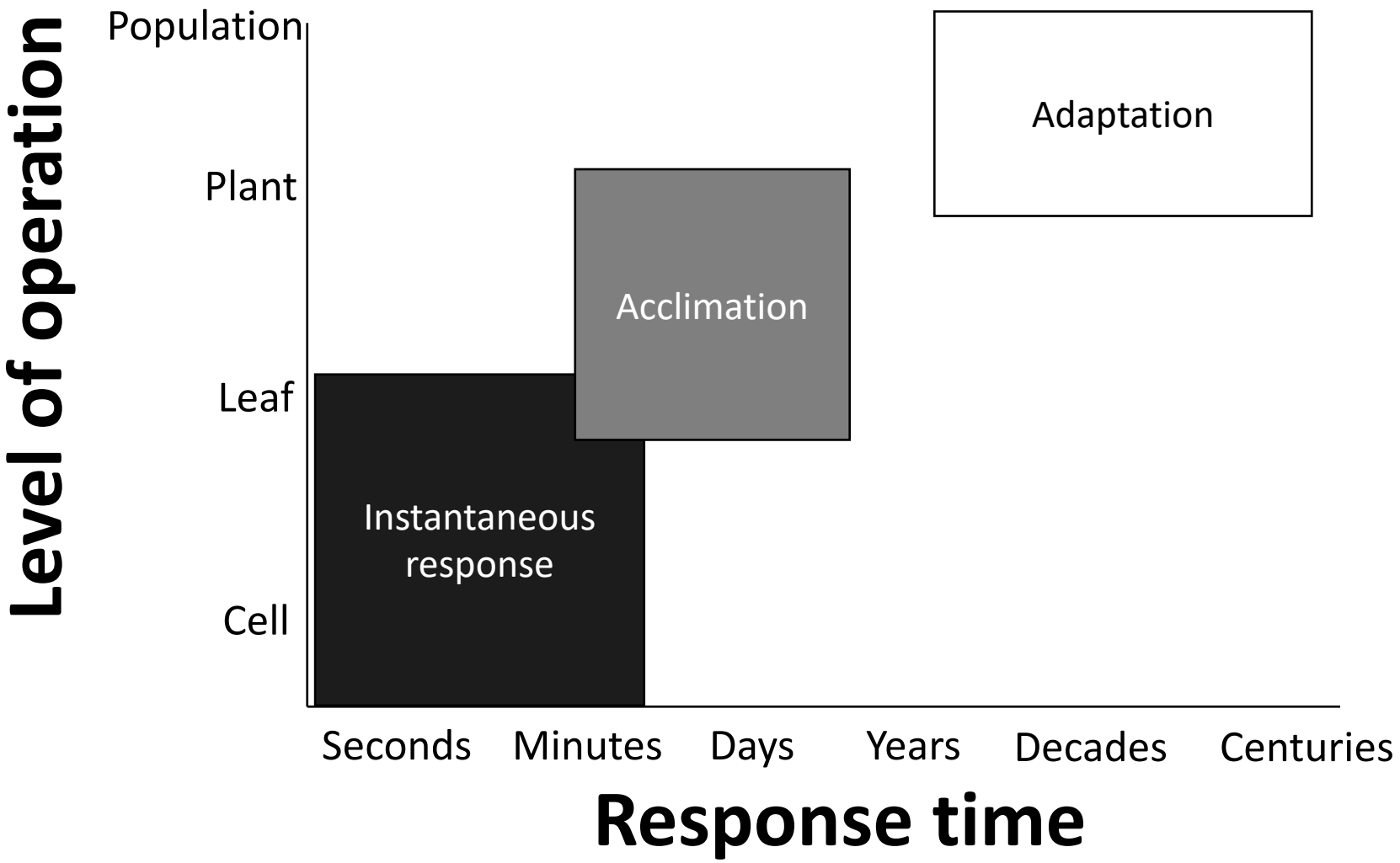
Plants acclimate to environmental conditions



Smith and Dukes (2013)

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Acclimation is ubiquitous and well known…

CO_2: Bazzaz (1990)

Annu. Rev. Ecol. Syst. 1990. 21:167–96

THE RESPONSE OF NATURAL ECOSYSTEMS TO THE RISING GLOBAL CO_2 LEVELS

F. A. Bazzaz

Light: Boardman (1977)

Ann. Rev. Plant Physiol. 1977. 28:355–77

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

PHOTOSYNTHETIC RESPONSE AND ADAPTATION TO TEMPERATURE IN HIGHER PLANTS

Joseph Berry and Olle Björkman[1]

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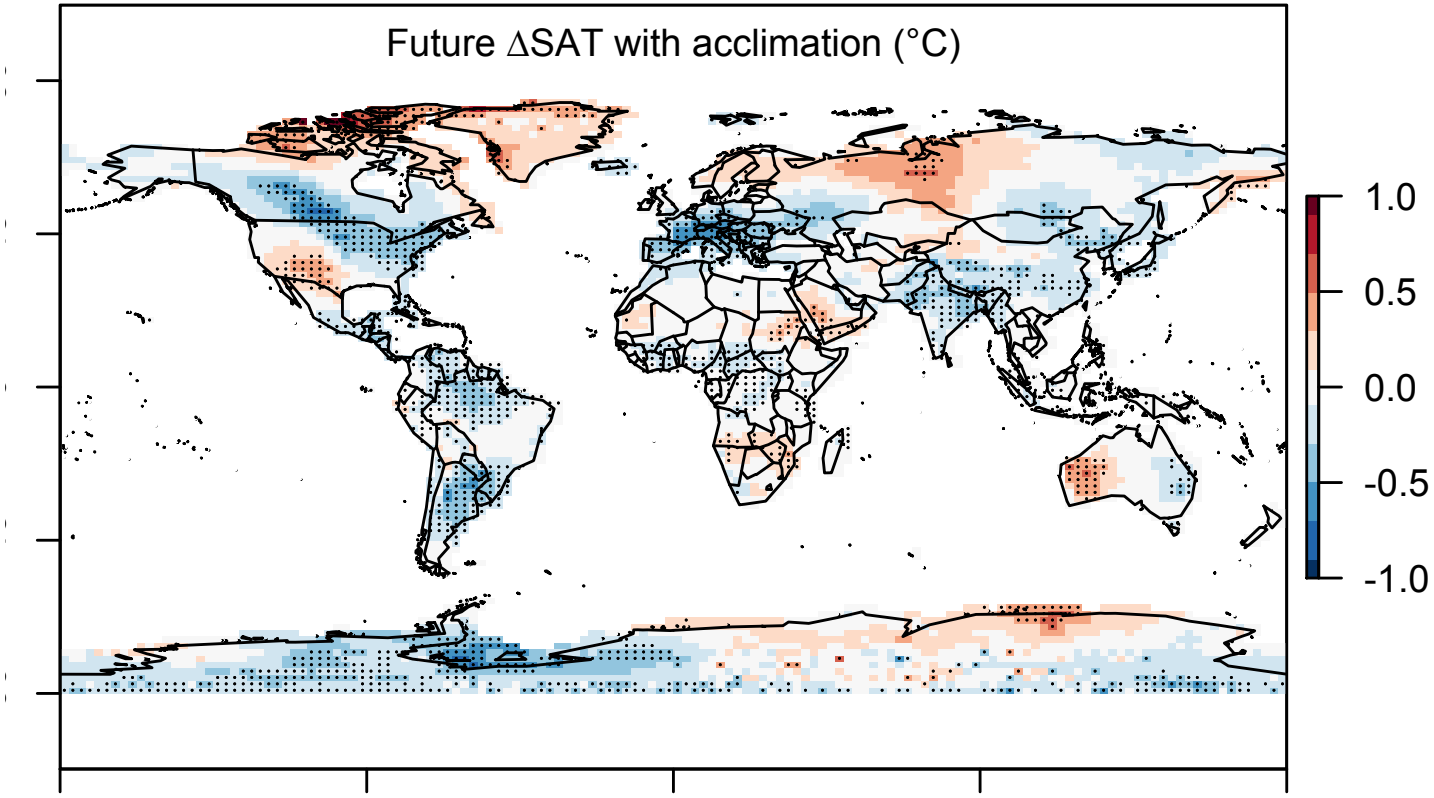
…and can impact carbon cycling and climate…

Acclimation alters future temperature by >1°C



Smith et al. (2017) *JAMES*

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…but the mechanisms underlying photosynthetic acclimation are not well known

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Solution: A testable, theoretical model!

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Least cost theory

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

Wright et al. (2003) *American Naturalist*

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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*

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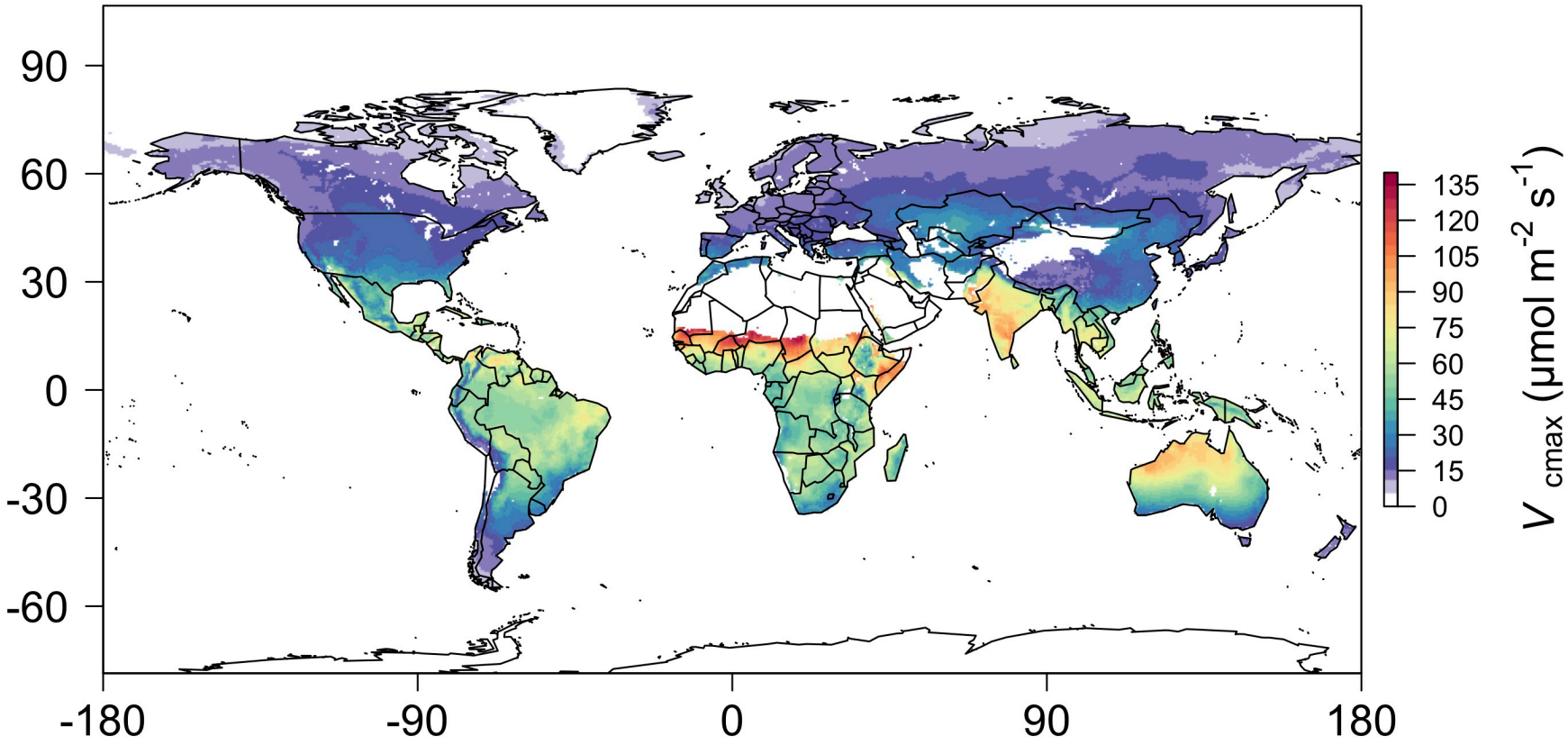
We can predict optimal traits in different environments



Smith et al. (2019) *Ecology Letters*

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

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Let’s tackle some big questions in plant ecophysiology!

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Question 1: Is photosynthesis optimized to the environment?

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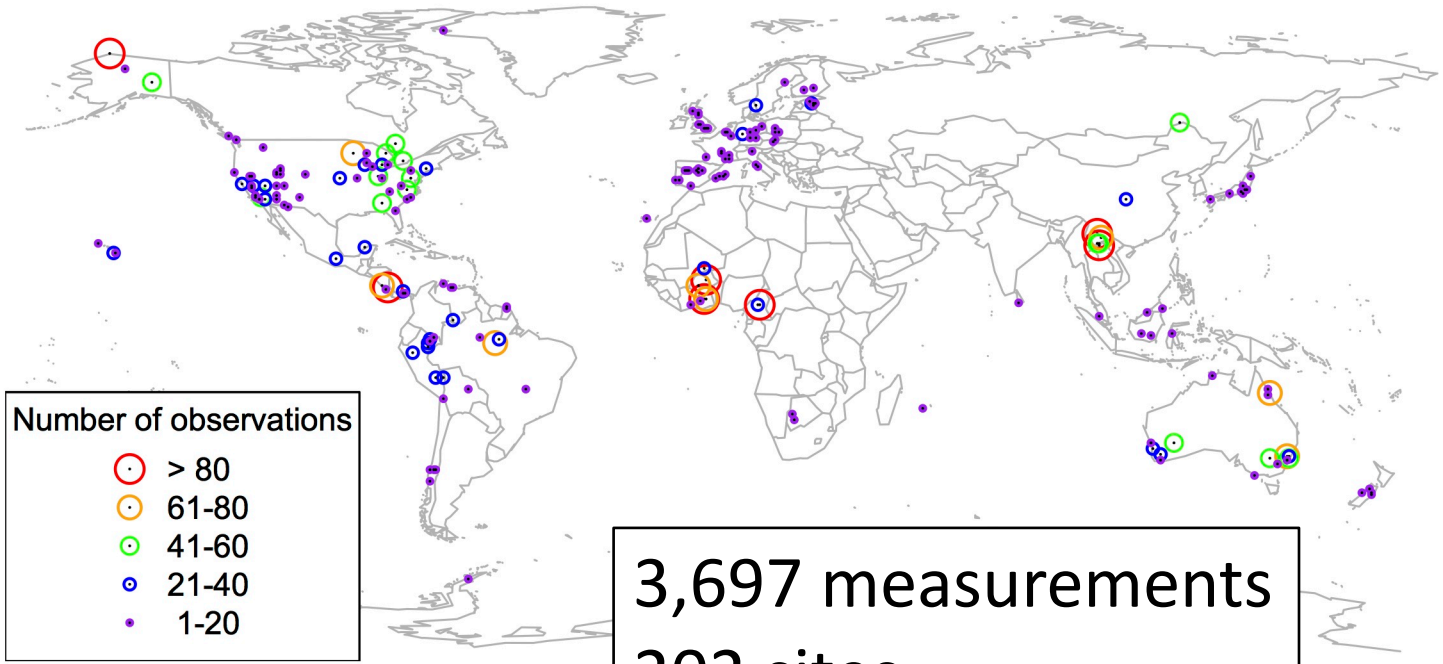
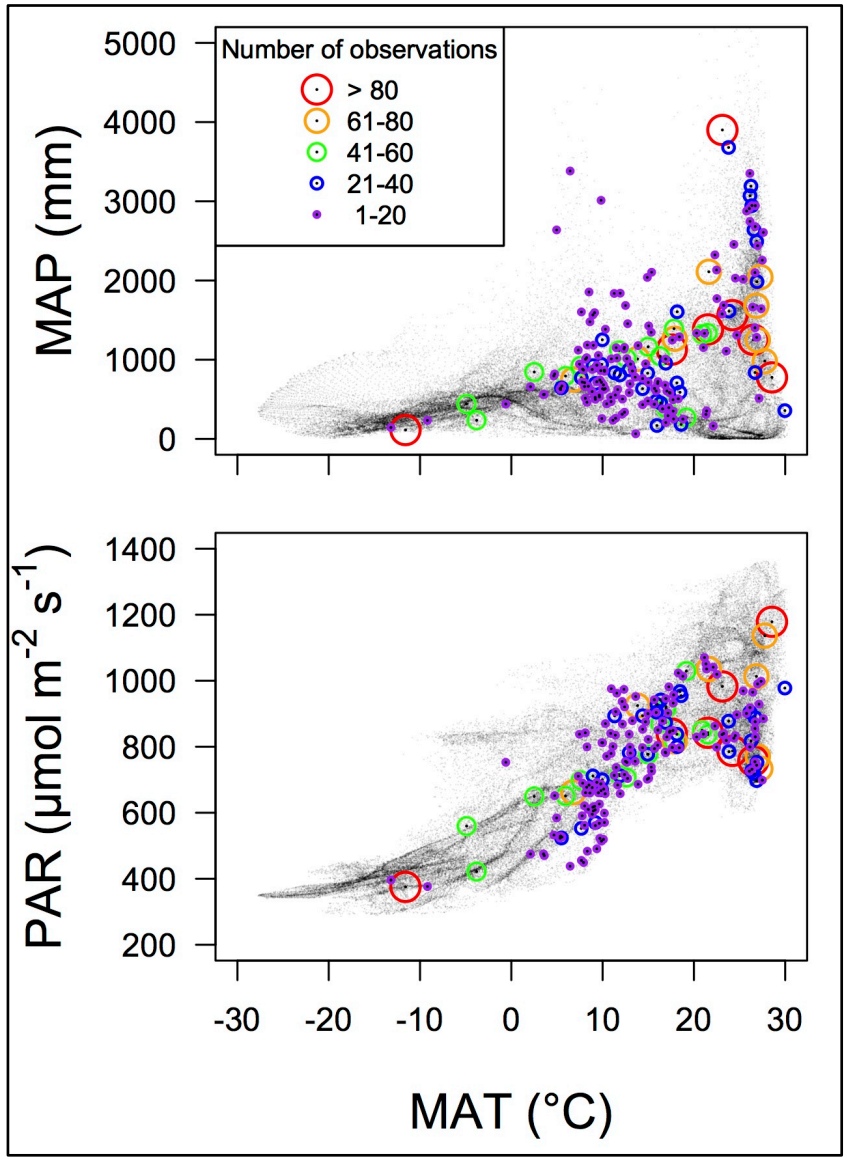
Global V_{cmax} dataset



3,697 measurements
202 sites
> 600 genera



Smith et al. (2019) *Ecology Letters*

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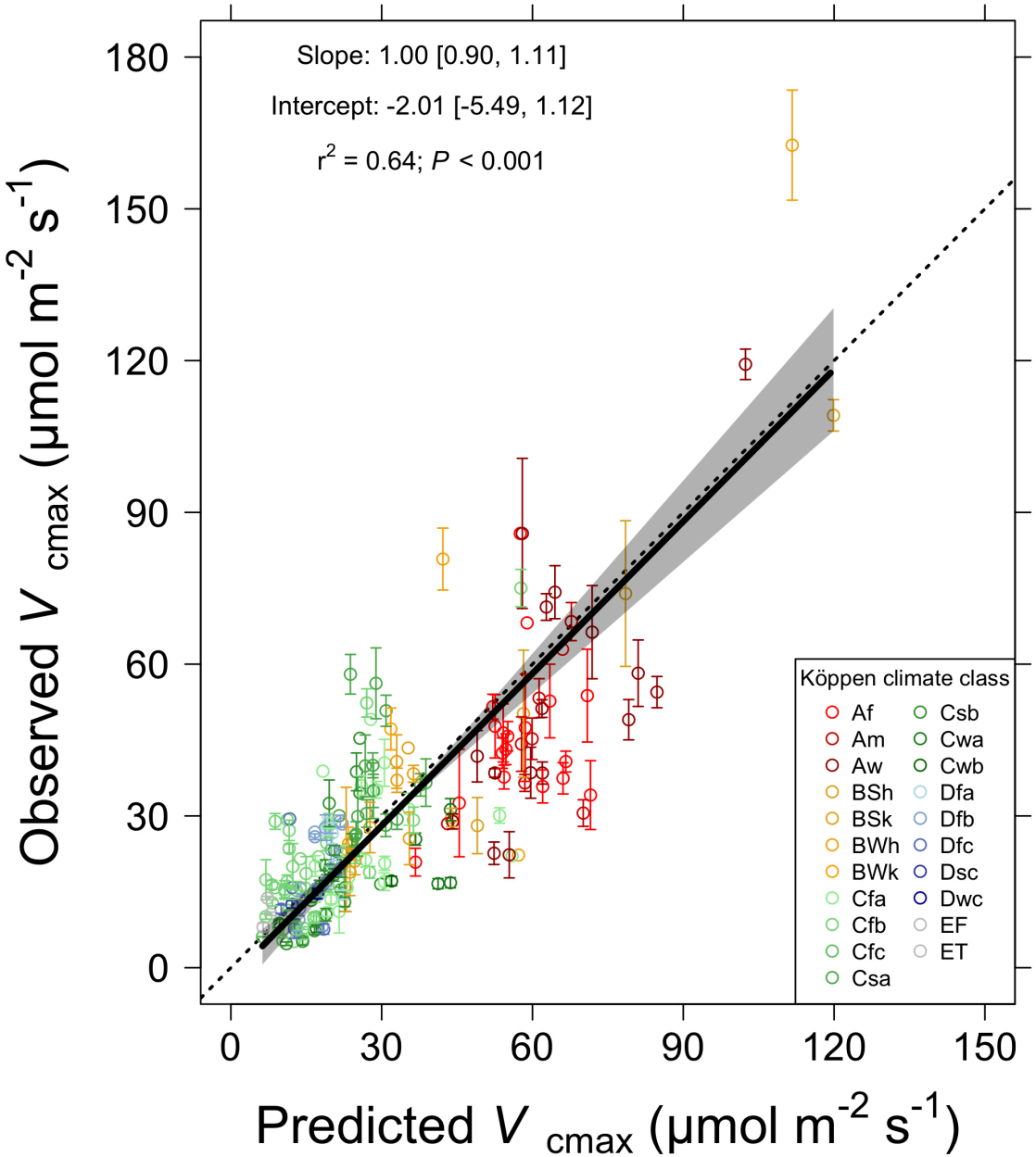

Smith et al. (2019) *Ecology Letters*

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Question 1: Is photosynthesis optimized to the environment?

YES! Photosynthesis acclimates spatially as expected from optimization

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Question 2: Does photosynthesis respond to soil nutrients?

Lizz Waring
TTU

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From the least cost hypothesis…

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

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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

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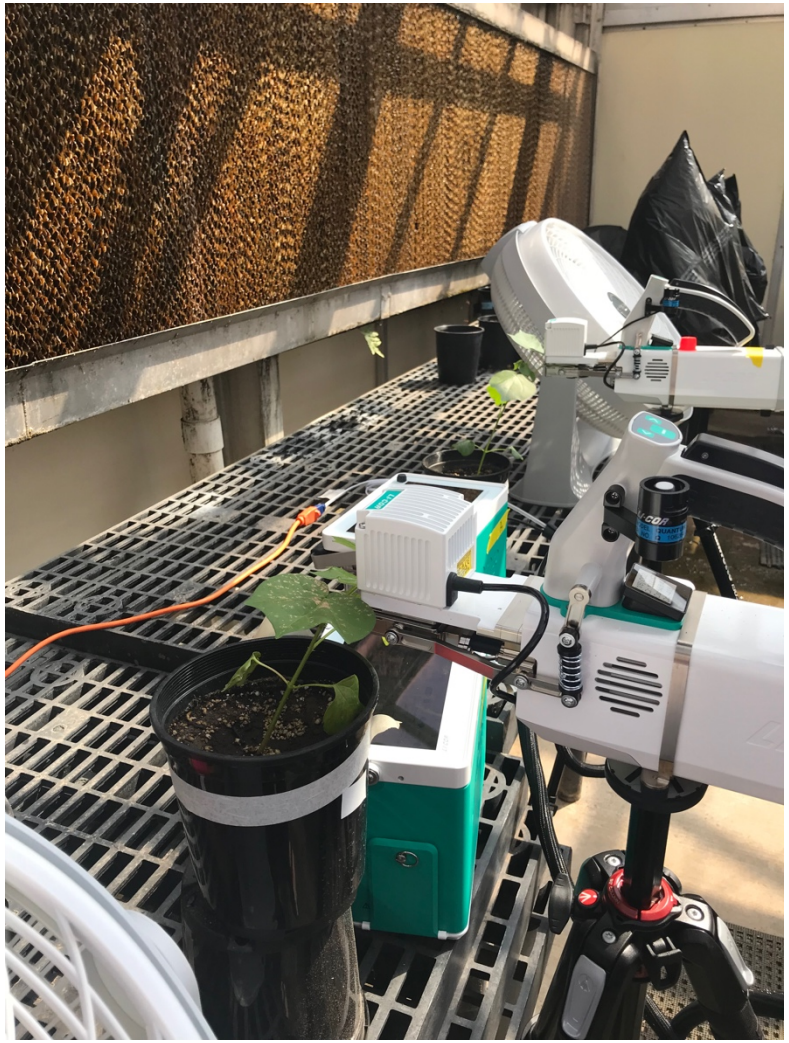
But let's test it experimentally



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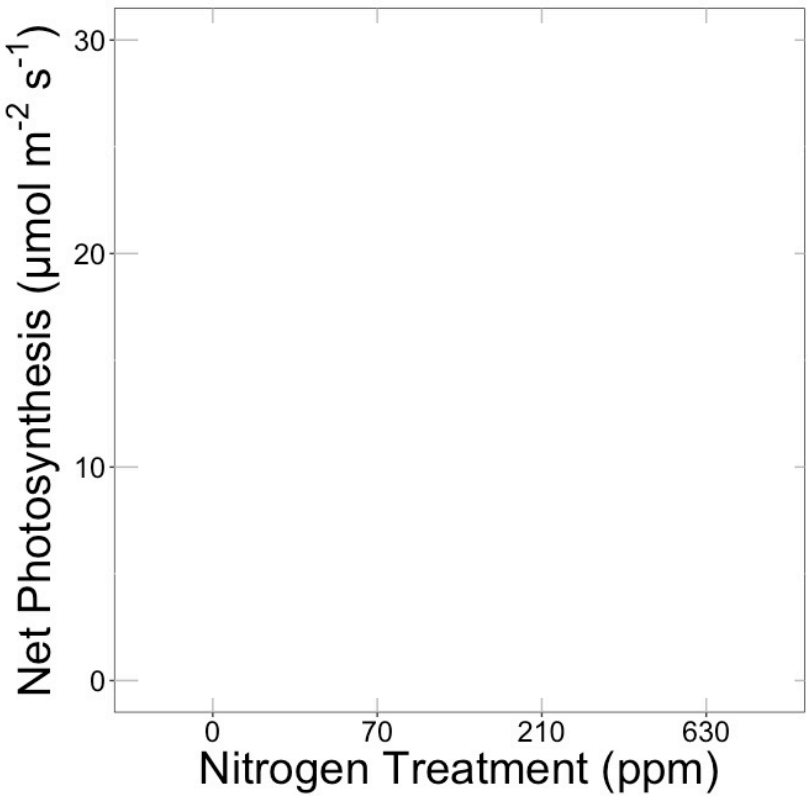

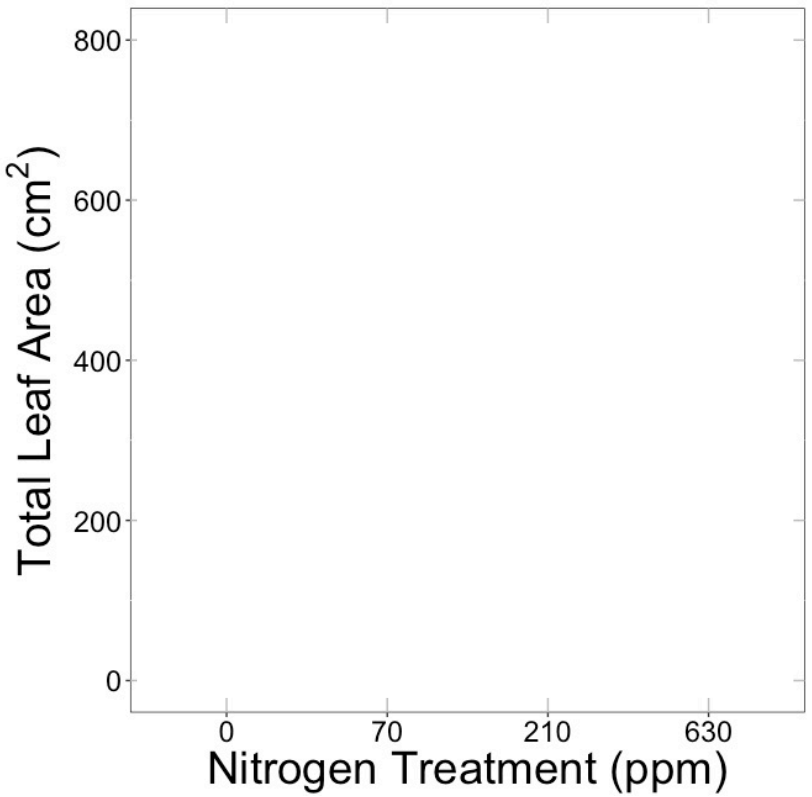

Waring and Smith (in prep)

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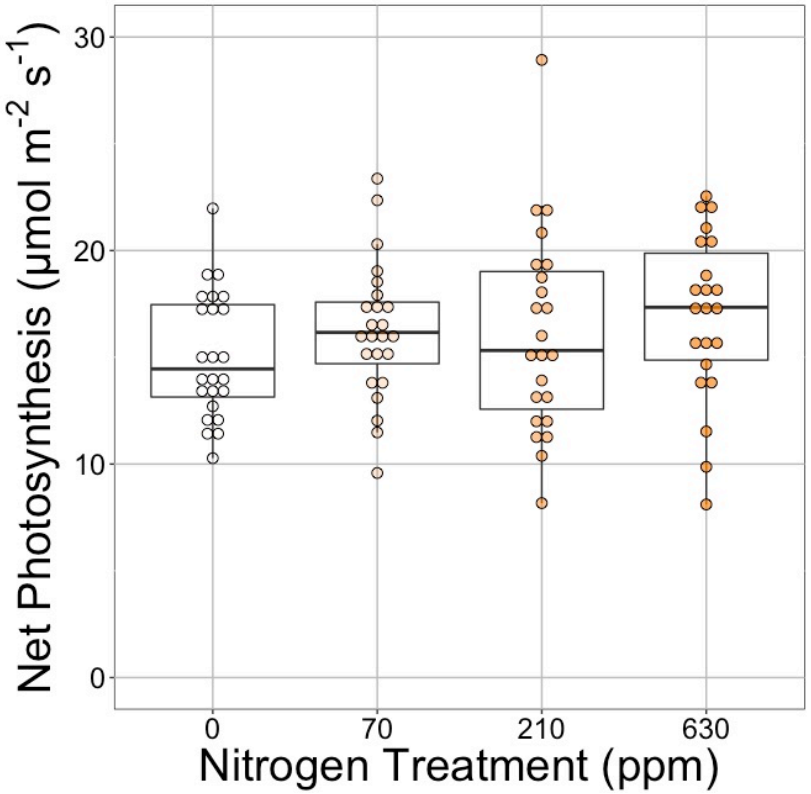
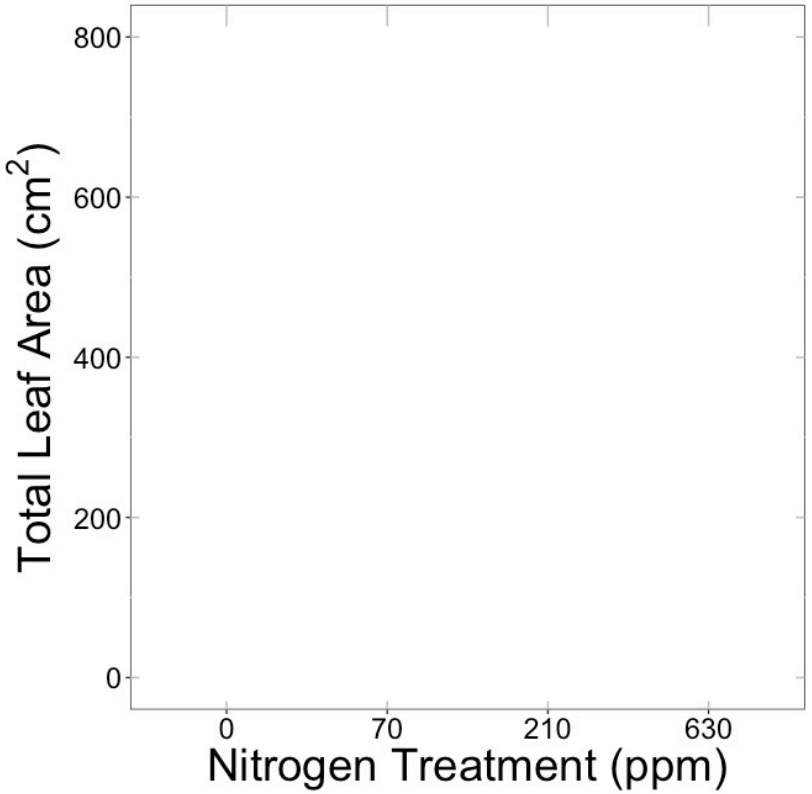
No change (P = 0.42)





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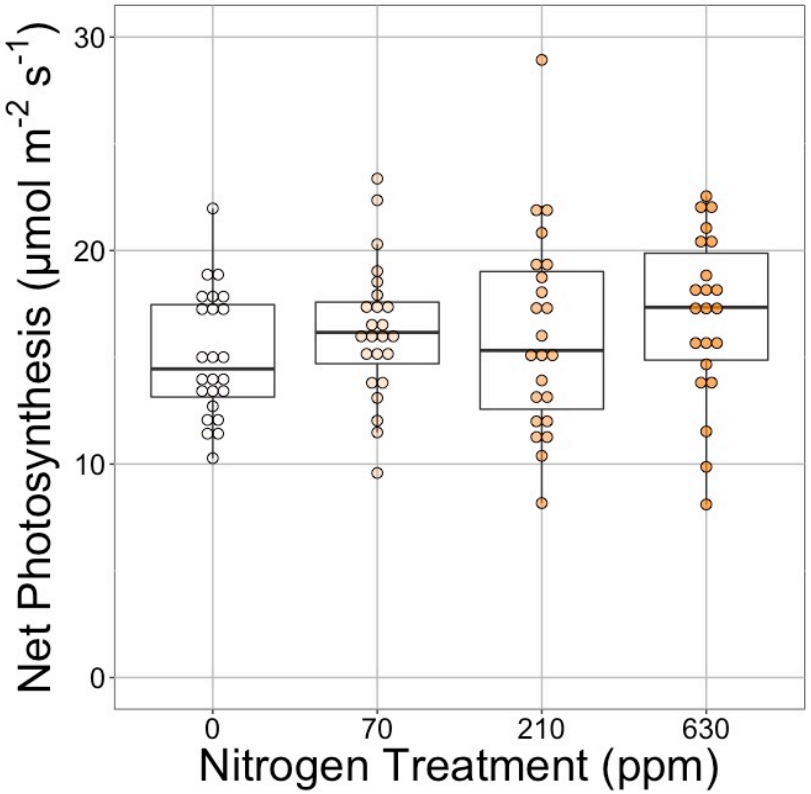
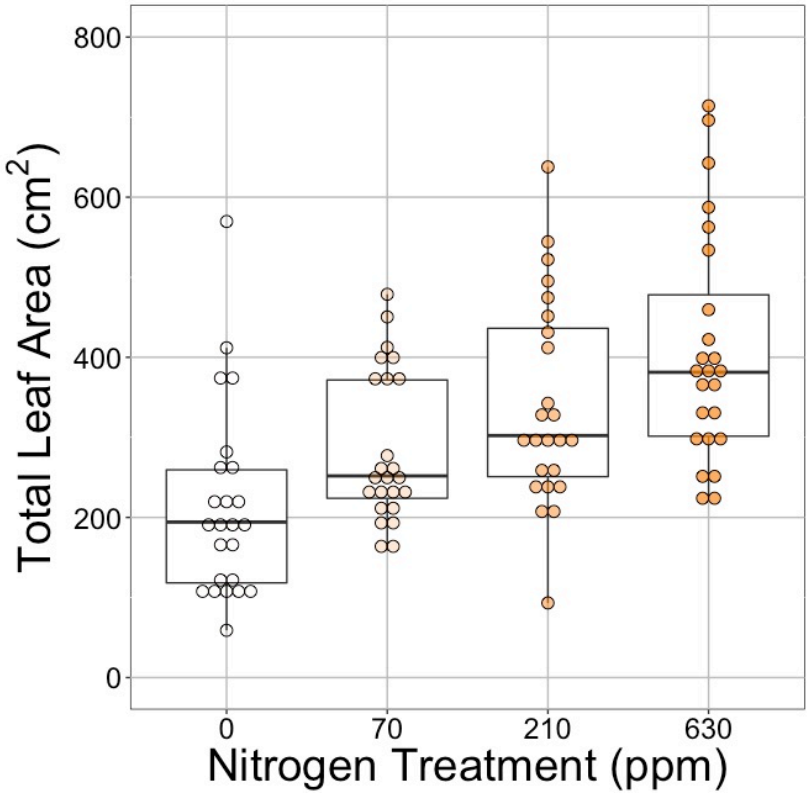
Leaf area, but not photosynthesis increases with N addition

No change (P = 0.42)



91% increase (P < 0.05)



Waring and Smith (in prep)

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But do greenhouse experiments translate to the field?

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Grassland soil nutrient addition network:

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

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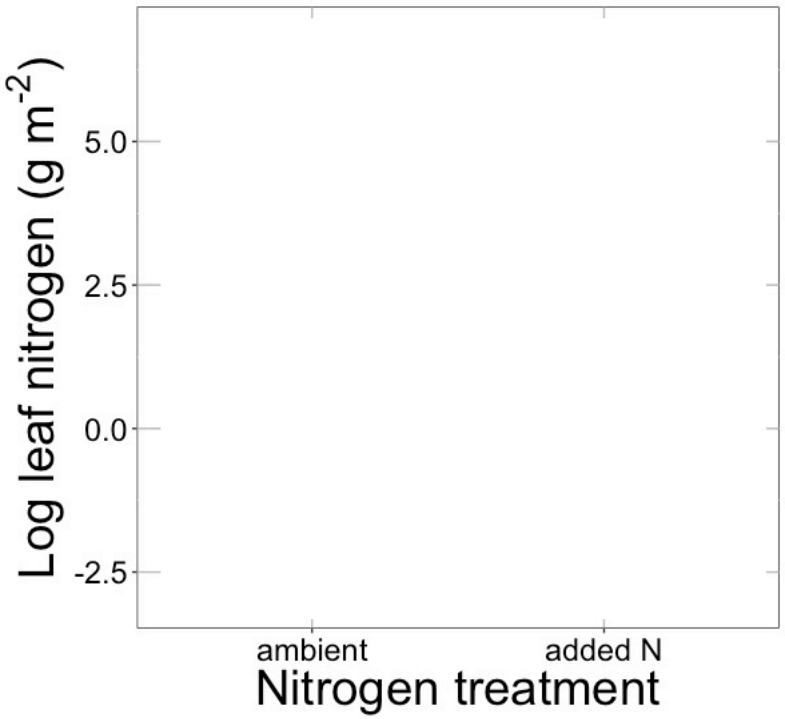

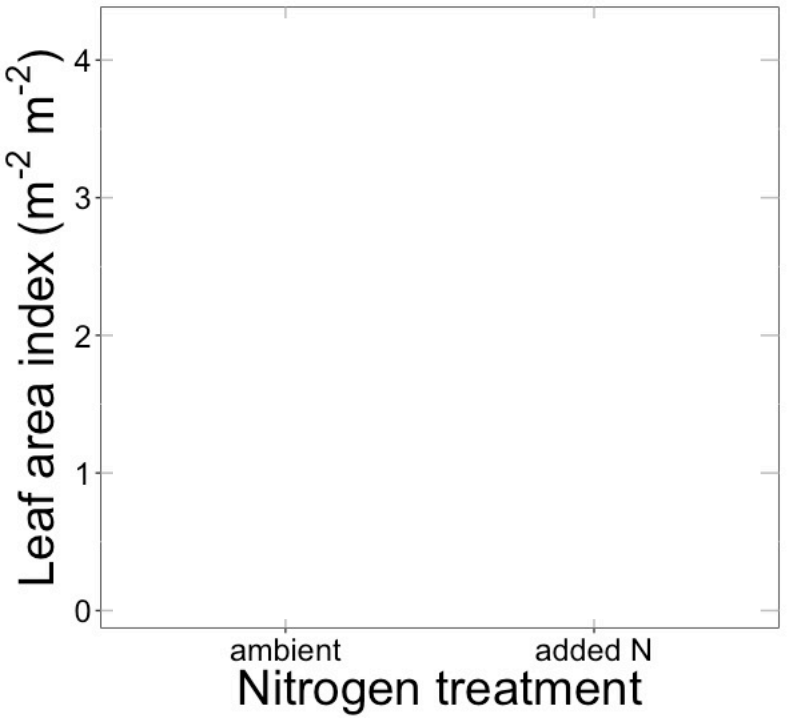

nutrient network

Waring et al. (in prep)

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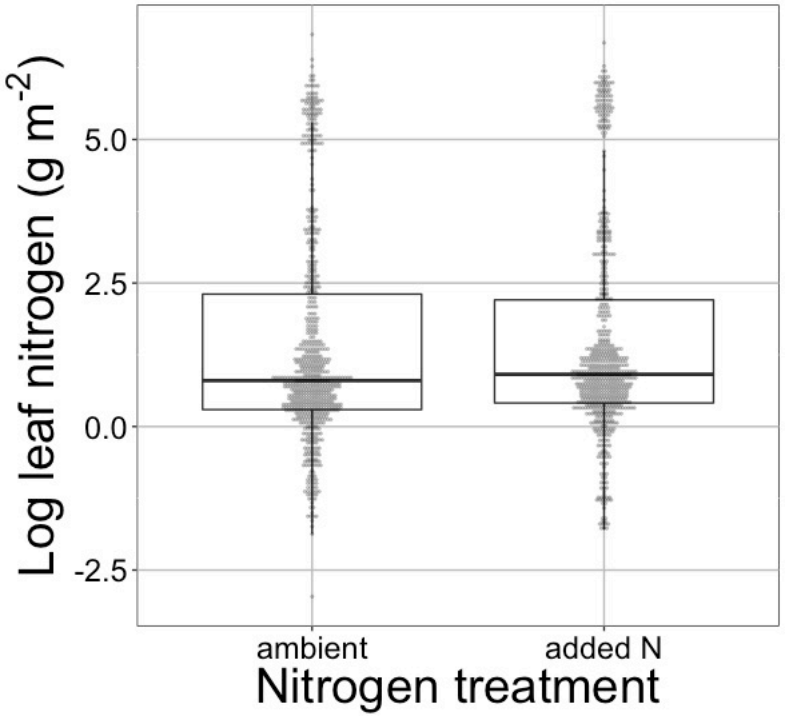
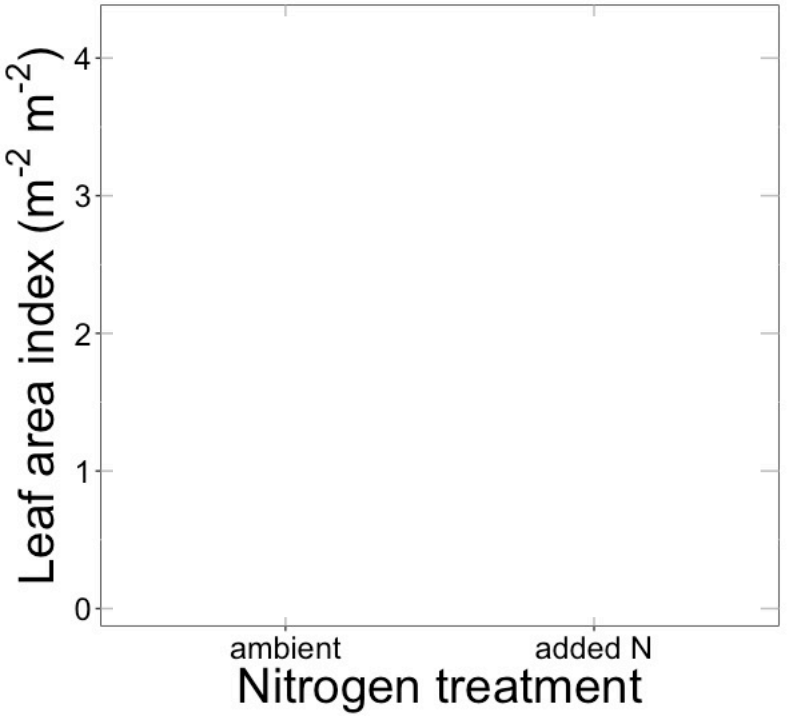
No change (P > 0.05)





nutrient network

Waring et al. (in prep)

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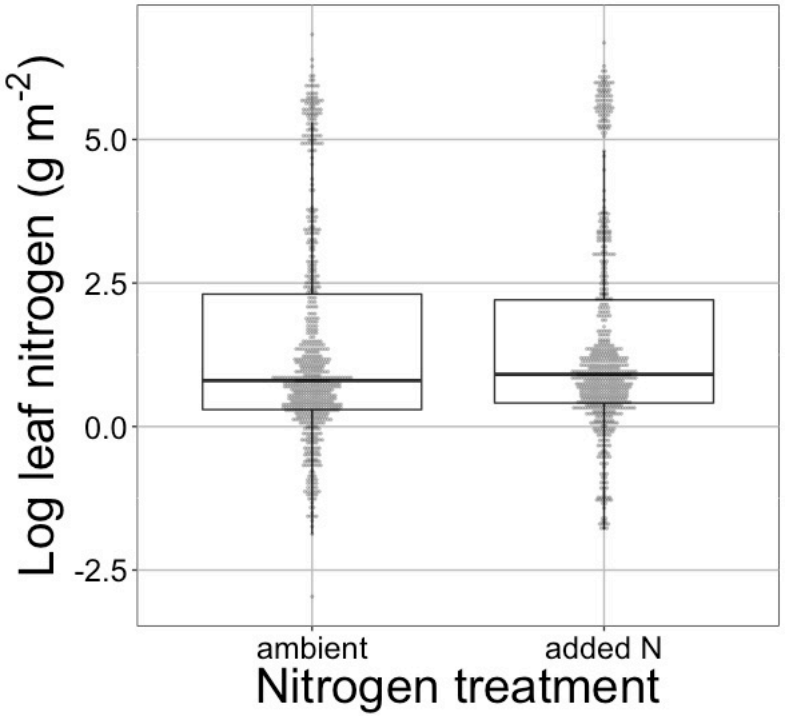
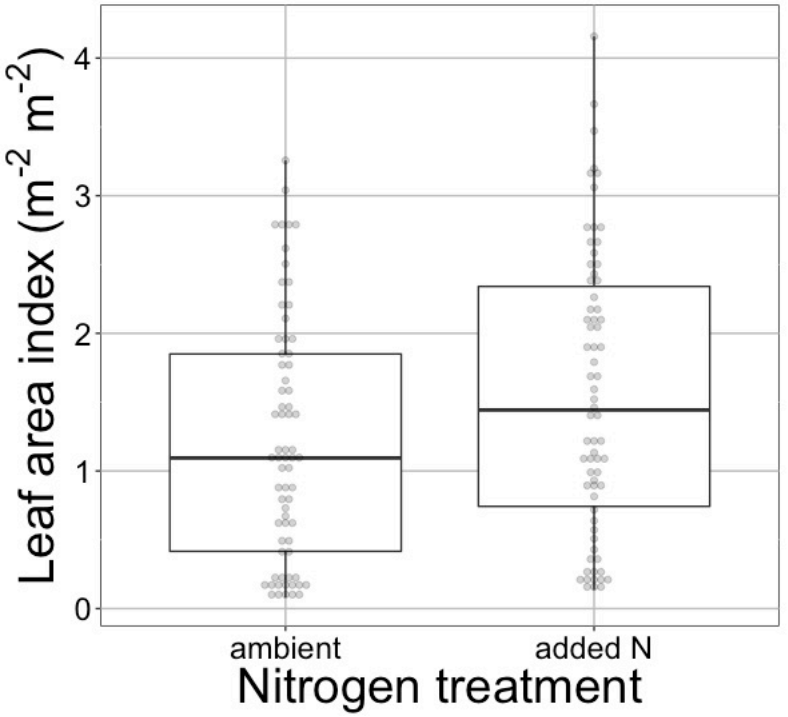
Globally, N addition increases leaf area, not leaf N

No change (P > 0.05)



41% increase (P < 0.05)



nutrient network

Waring et al. (in prep)

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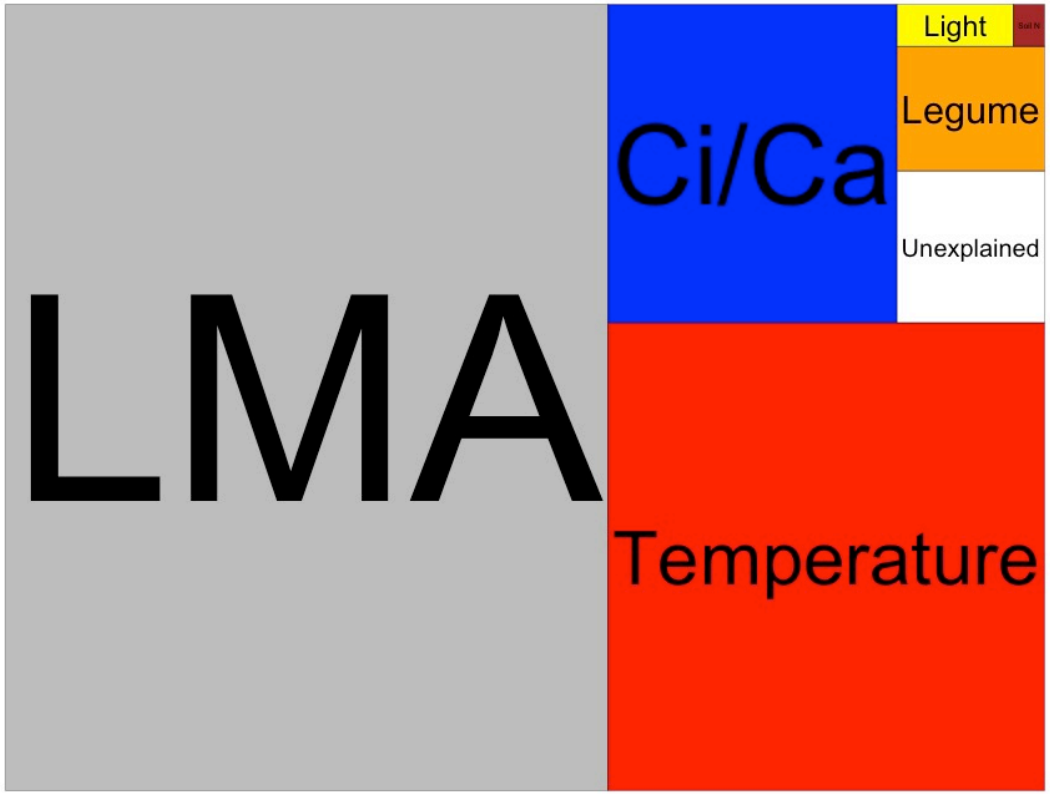
Globally, N addition has no impact on leaf N



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

nutrient network

Waring and Smith (in prep)

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Question 2: Does photosynthesis respond to soil nutrients?

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

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Question 3: What does acclimation mean for future conditions?

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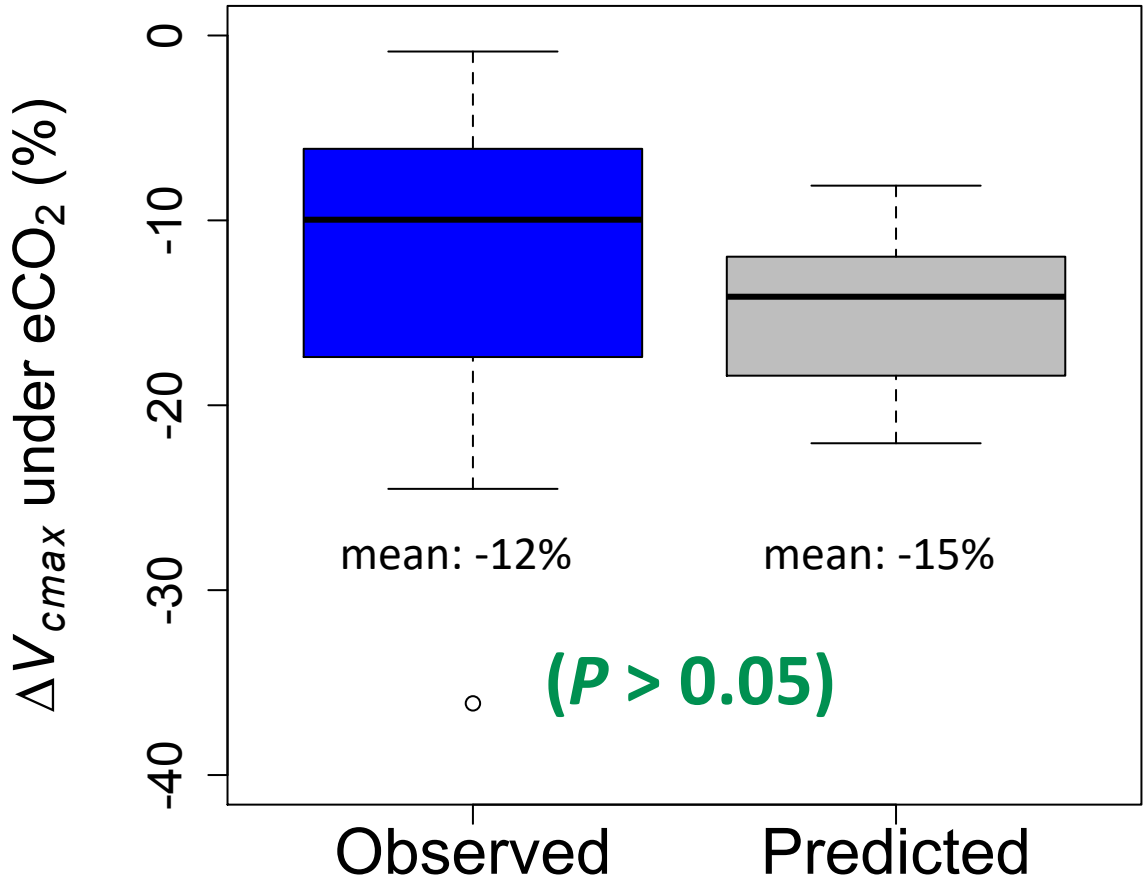
Photosynthetic traits change with future conditions in ways expected from optimization



Smith and Keenan (in prep)

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Let’s run a model out into the future!

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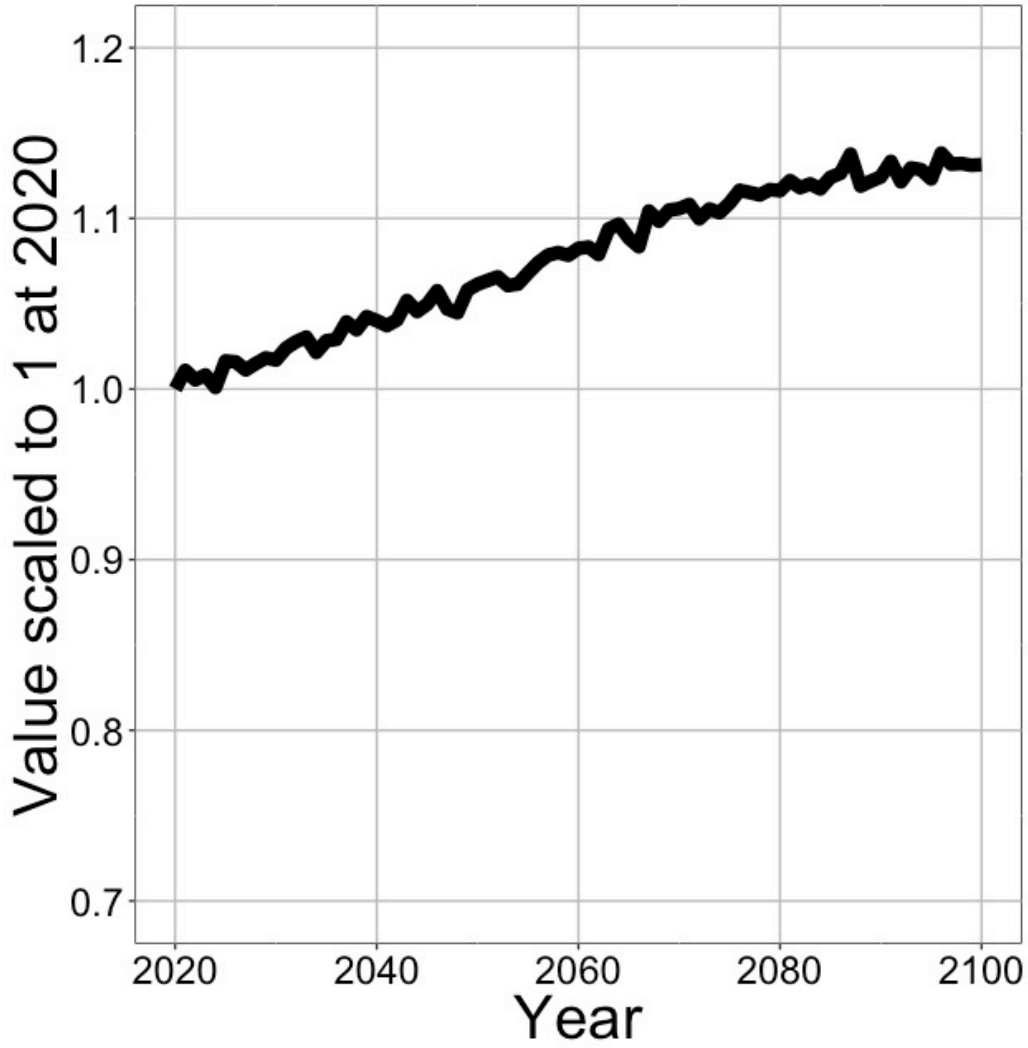
Photosynthesis increases in future



Net Photosynthesis

Smith et al. (in prep)

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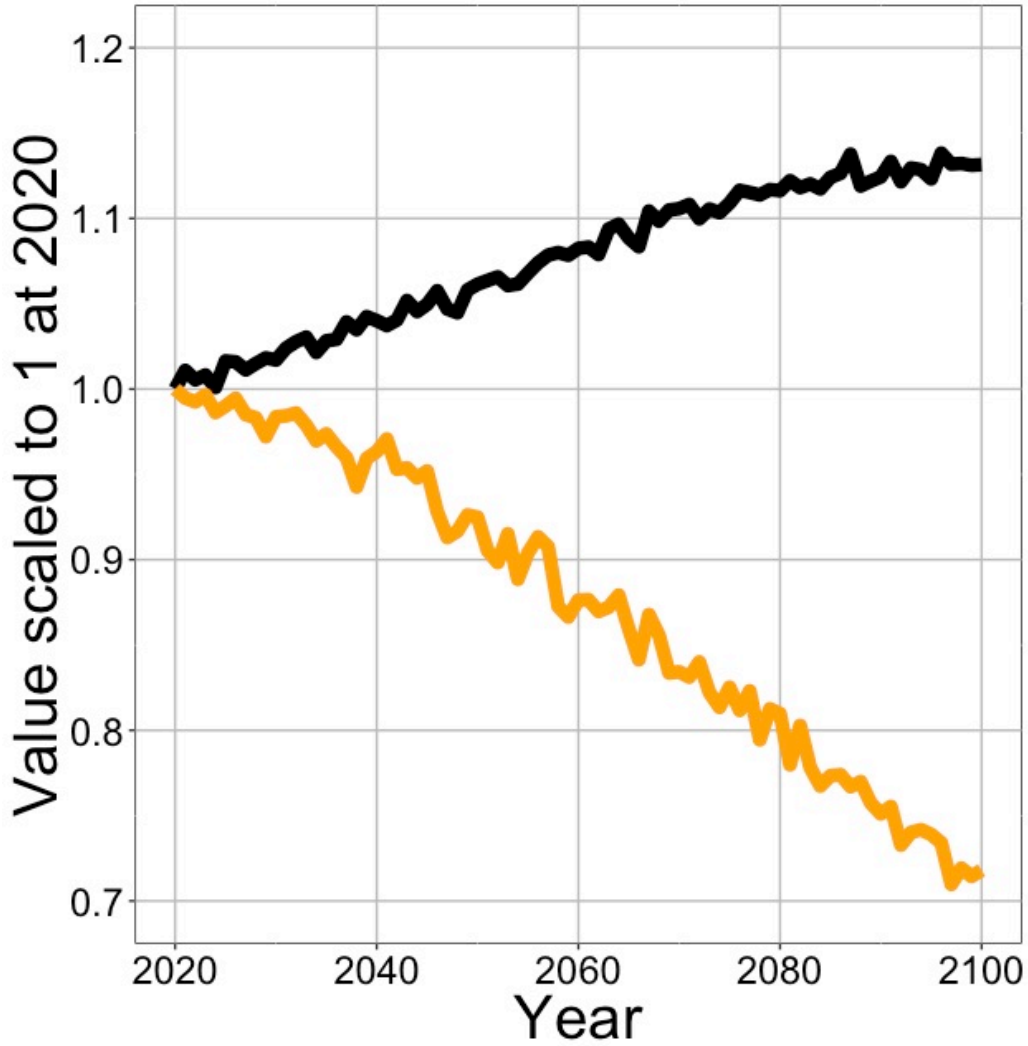
Photosynthesis increases in future (at lower nutrient use)

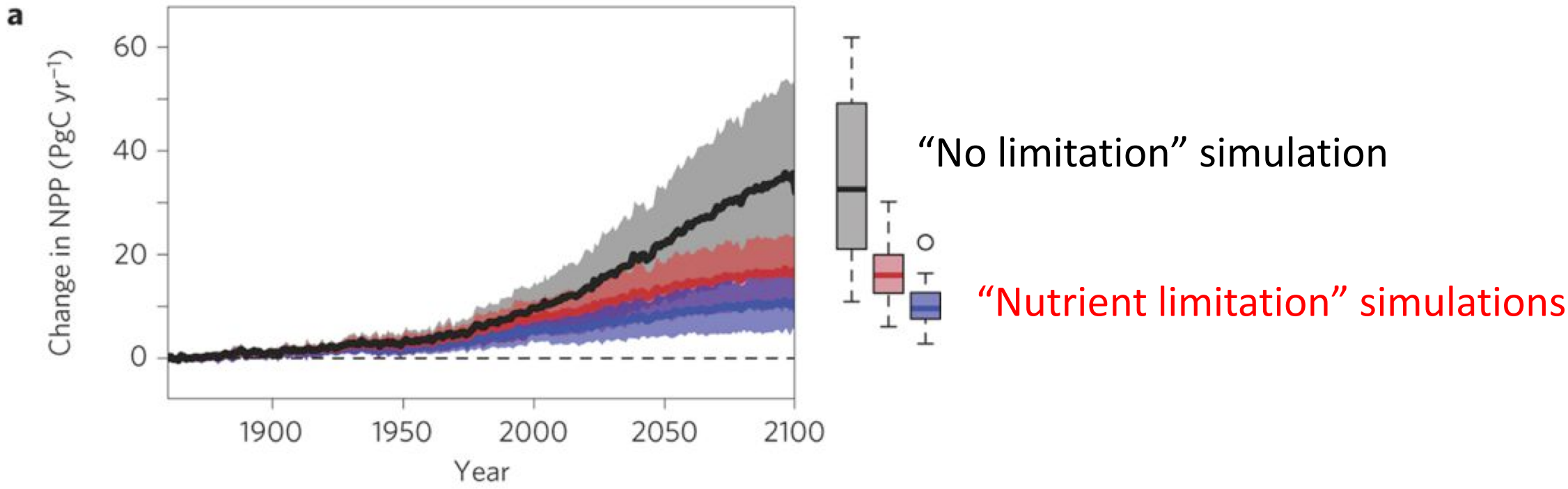


Net Photosynthesis

Leaf Nitrogen

Smith et al. (in prep)

Need to rethink nutrient limitation in models



Weider et al. (2015)

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Question 3: What does acclimation mean for future conditions?

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

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Question 4: When is C_4 photosynthesis an advantage over C_3 photosynthesis?

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C_3 versus C_4 optimization

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C_4 versus C_3 optimization

C_4 photosynthesis has…

- No photorespiration
- An additional limitation (PEP carboxylation)

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C_4 versus C_3 optimization

C_4 photosynthesis has…

- **No photorespiration**
- An additional limitation (PEP carboxylation)

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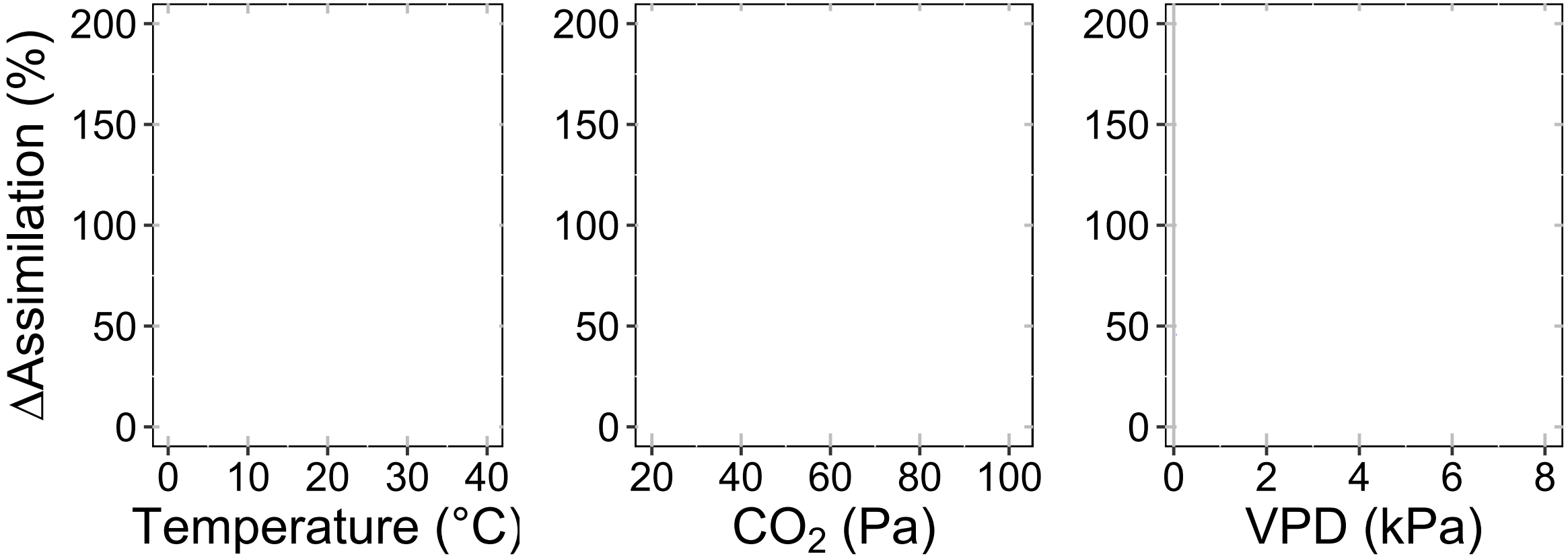
Relative advantage of C_4 physiology



Scott and Smith (in prep)

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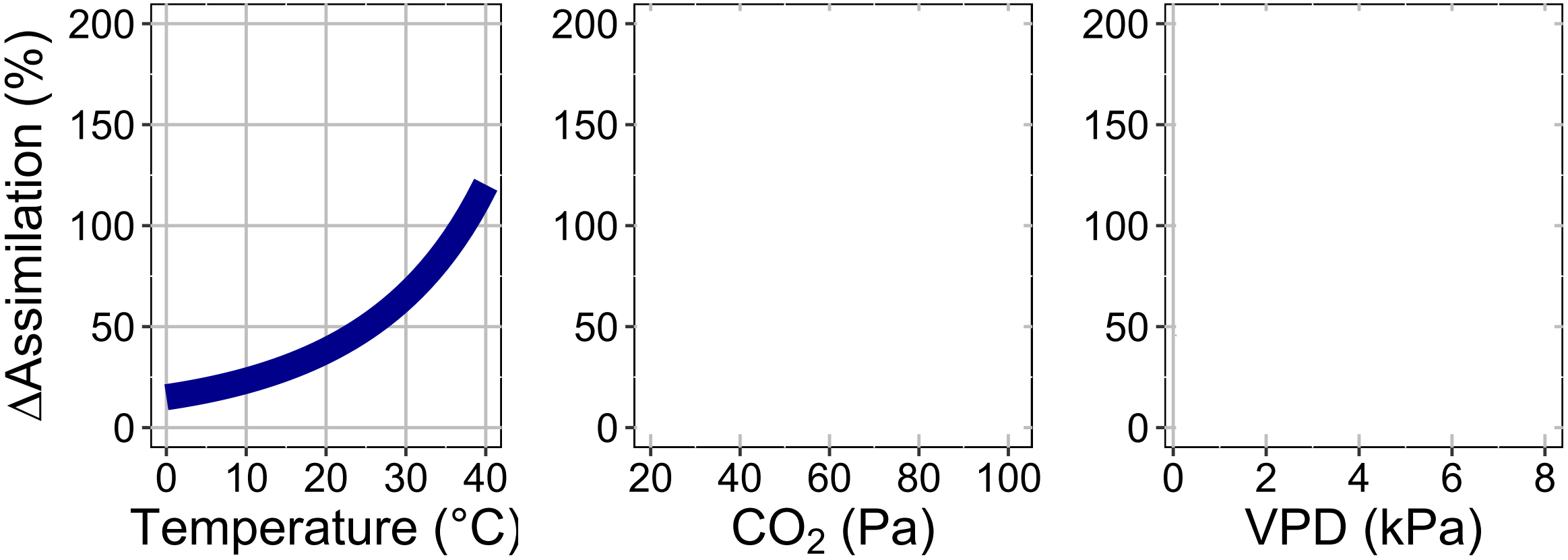
Relative advantage of C_4 physiology



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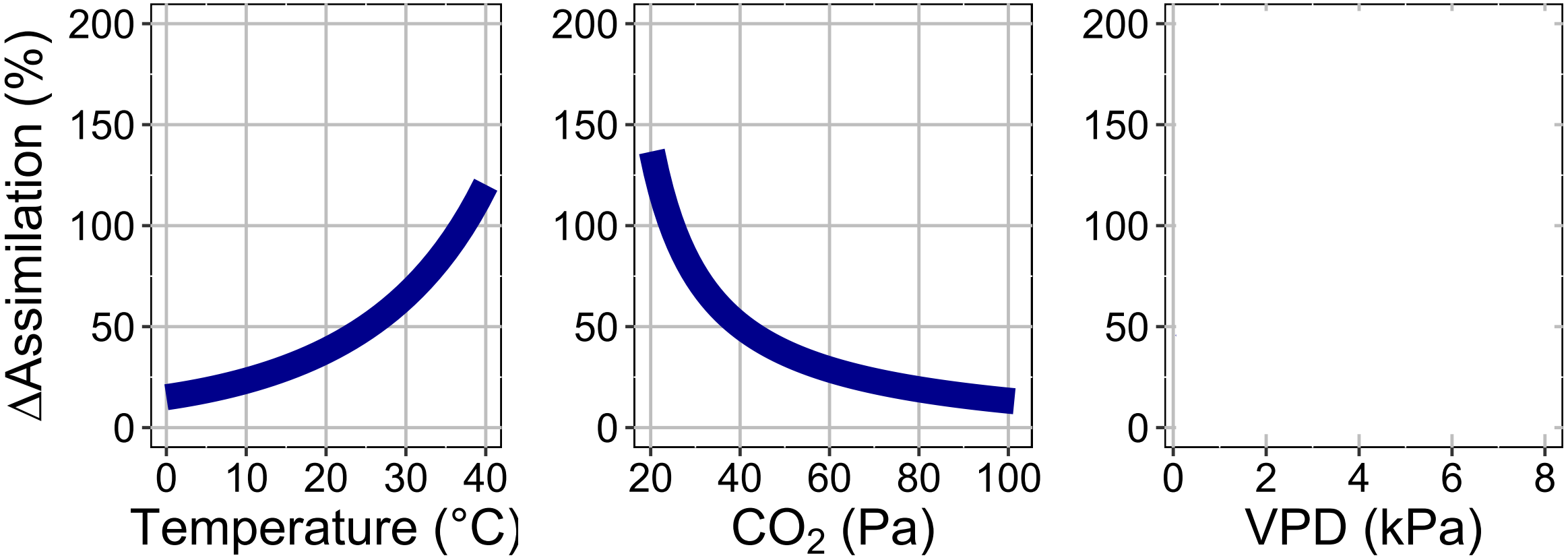
Relative advantage of C_4 physiology



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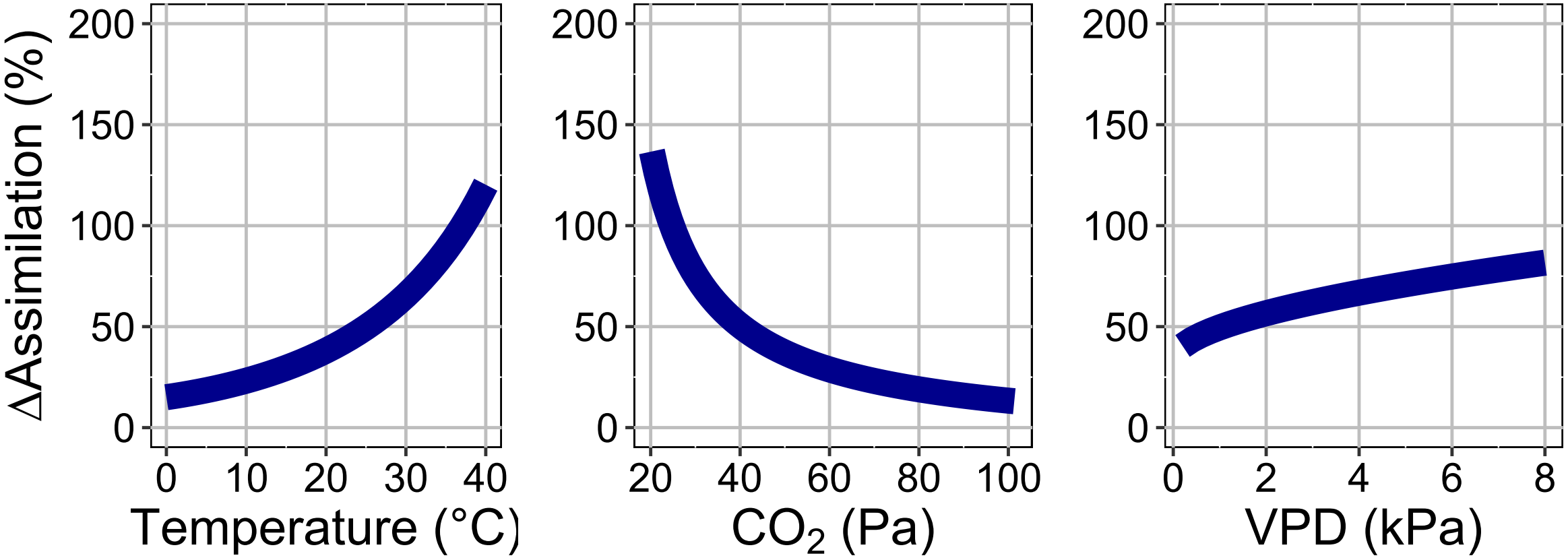
Relative advantage of C_4 physiology



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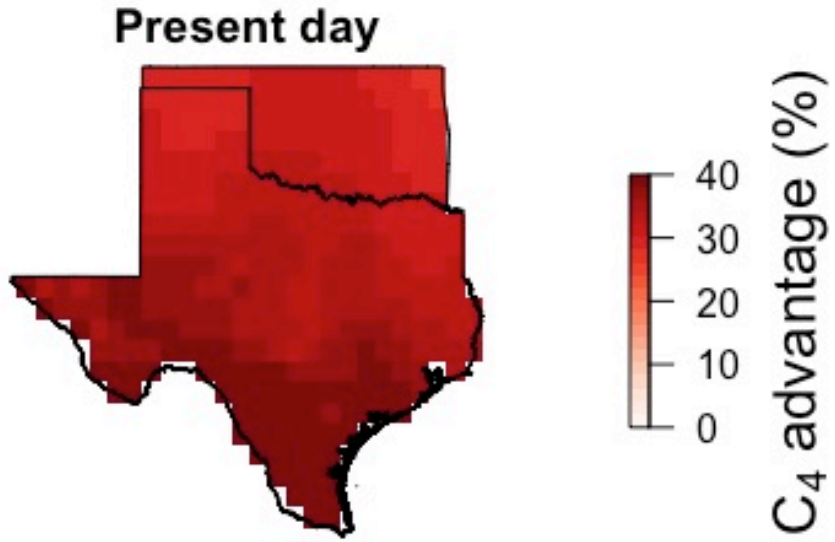

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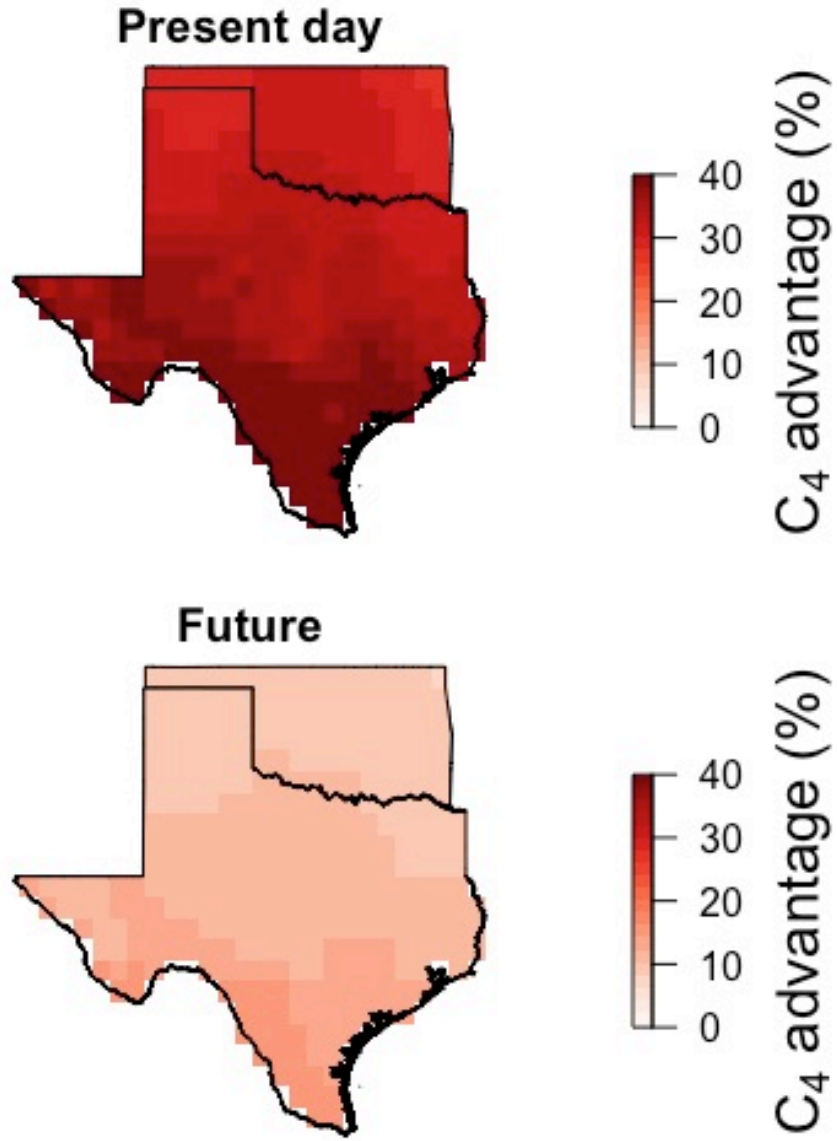

Scott and Smith (in prep)

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Question 4: When is C_4 photosynthesis an advantage over C_3 photosynthesis?

C_4 is better in hot, dry, low CO_2 environments

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Question 4: When is C_4 photosynthesis an advantage over C_3 photosynthesis?

C_4 is better in hot, dry, low CO_2 environments

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Conclusions

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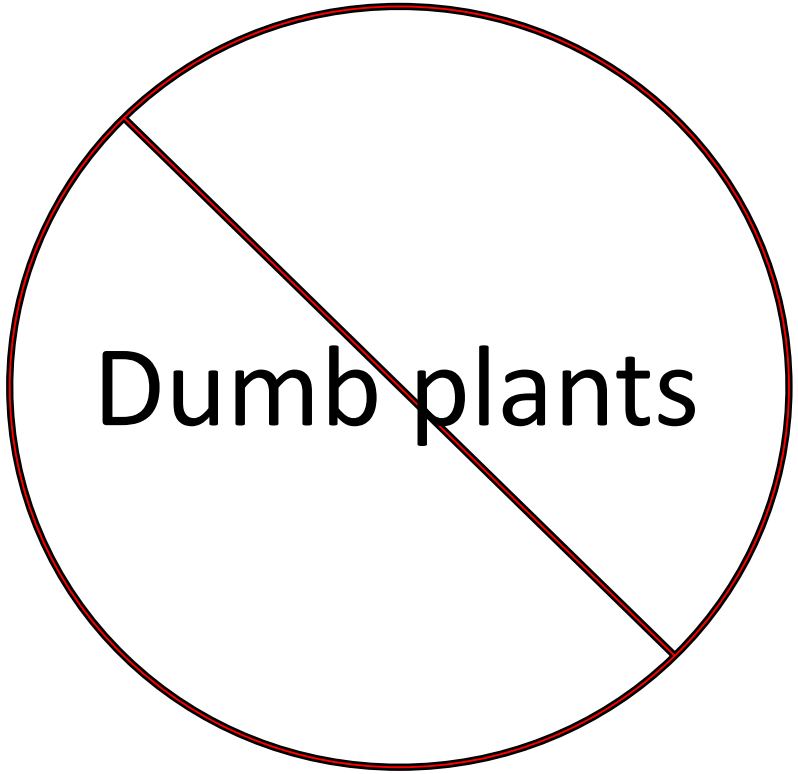
Conclusions

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



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Conclusions

- Theory yields mechanistic insight about acclimation and associated feedbacks

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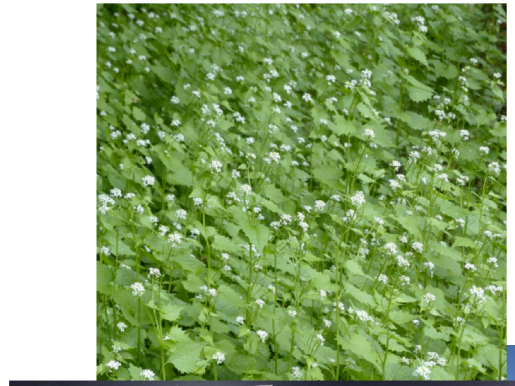
Conclusions

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



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