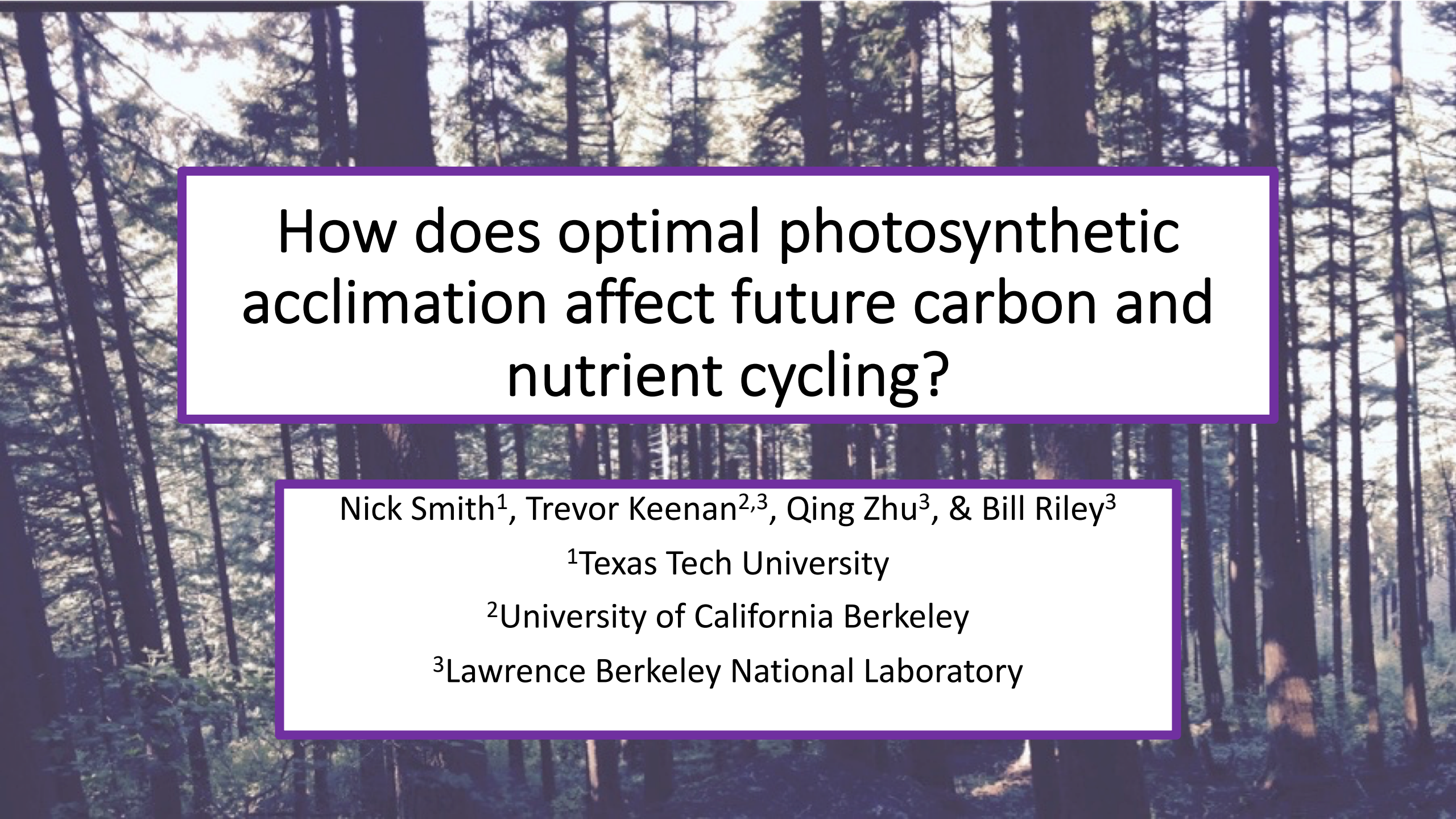

How does optimal photosynthetic acclimation affect future carbon and nutrient cycling?

Nick Smith[1], Trevor Keenan[2,3], Qing Zhu[3], & Bill Riley[3]

[1]Texas Tech University

[2]University of California Berkeley

[3]Lawrence Berkeley National Laboratory

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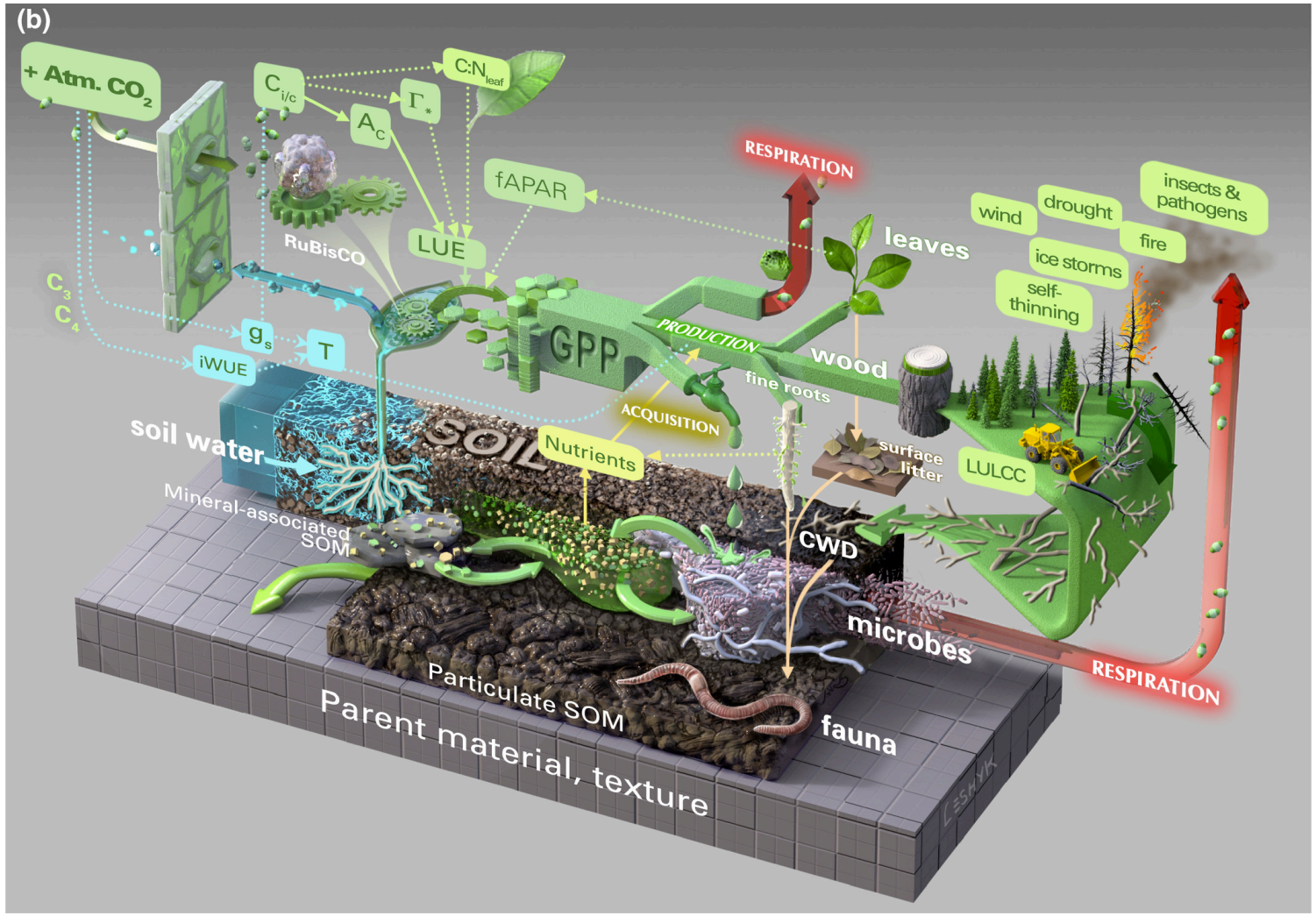
Photosynthesis connects C and N cycles



Walker et al. (2020)

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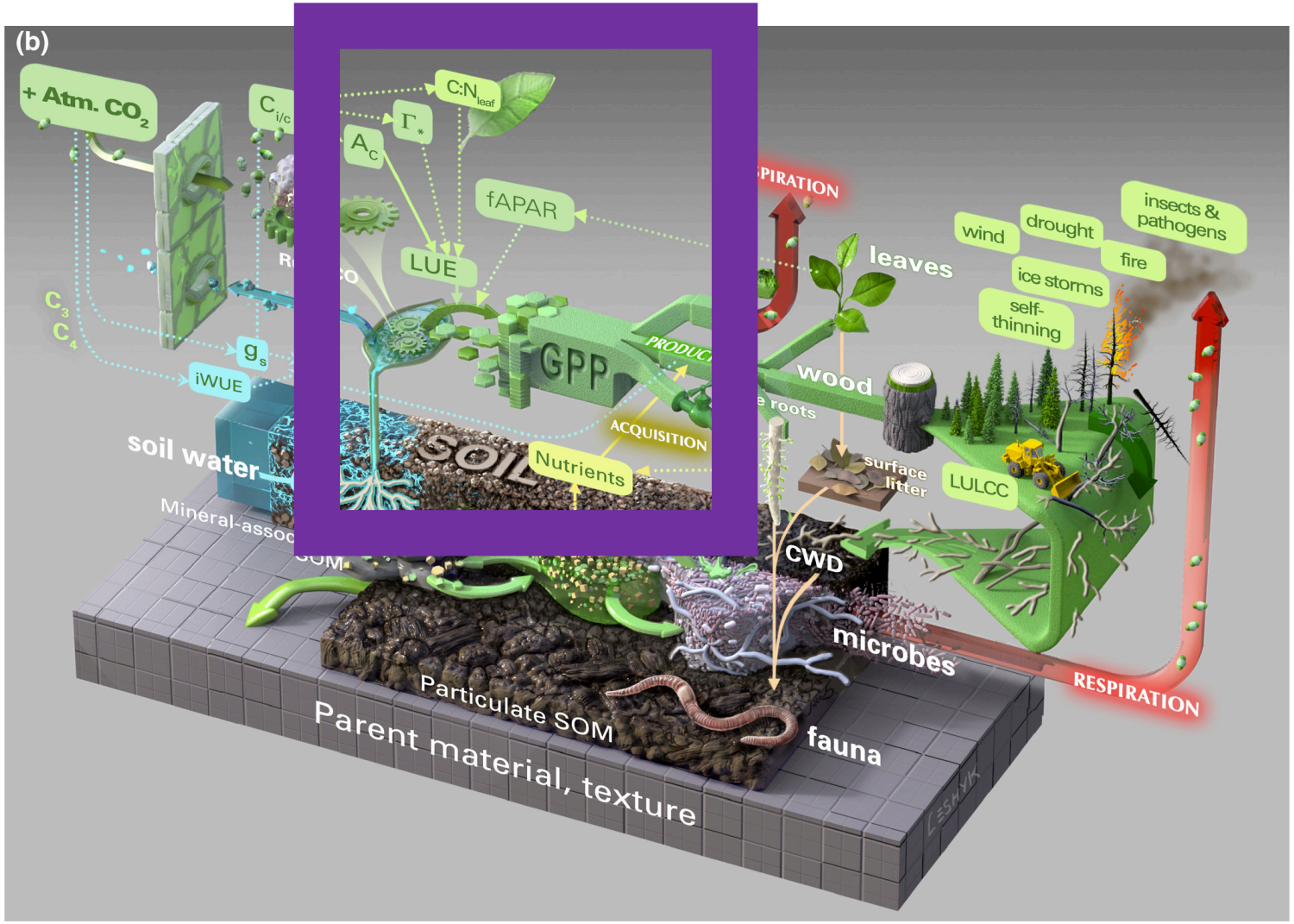
Photosynthesis connects C and N cycles



Walker et al. (2020)

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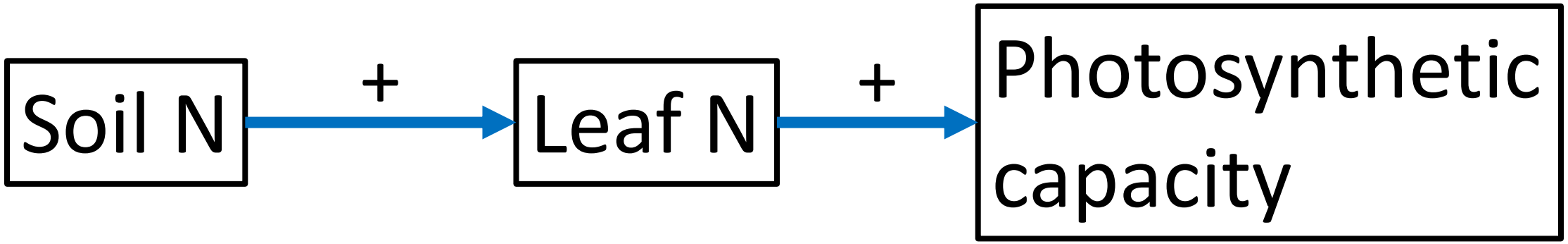
Models simulate photosynthetic capacity from soil N



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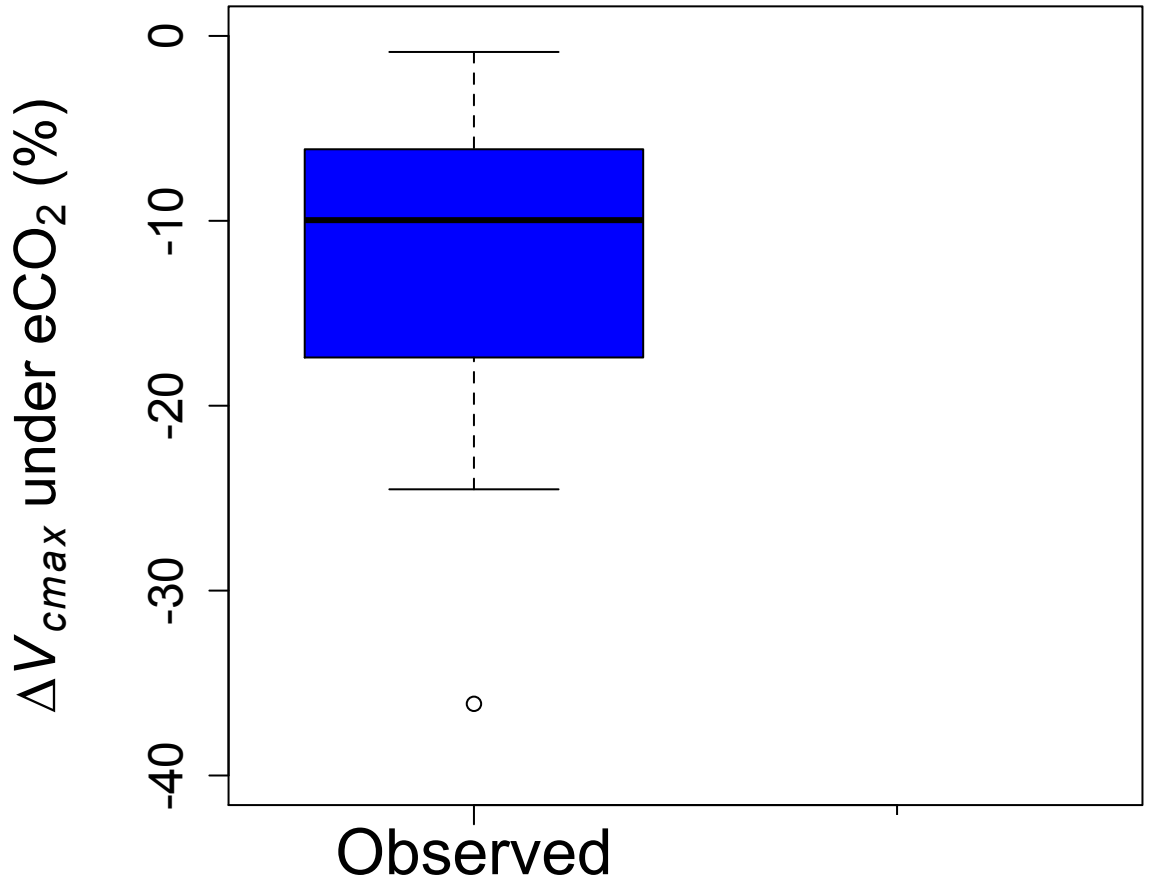
Elevated CO_2 reduces photosynthetic capacity



Smith and Keenan (2020)

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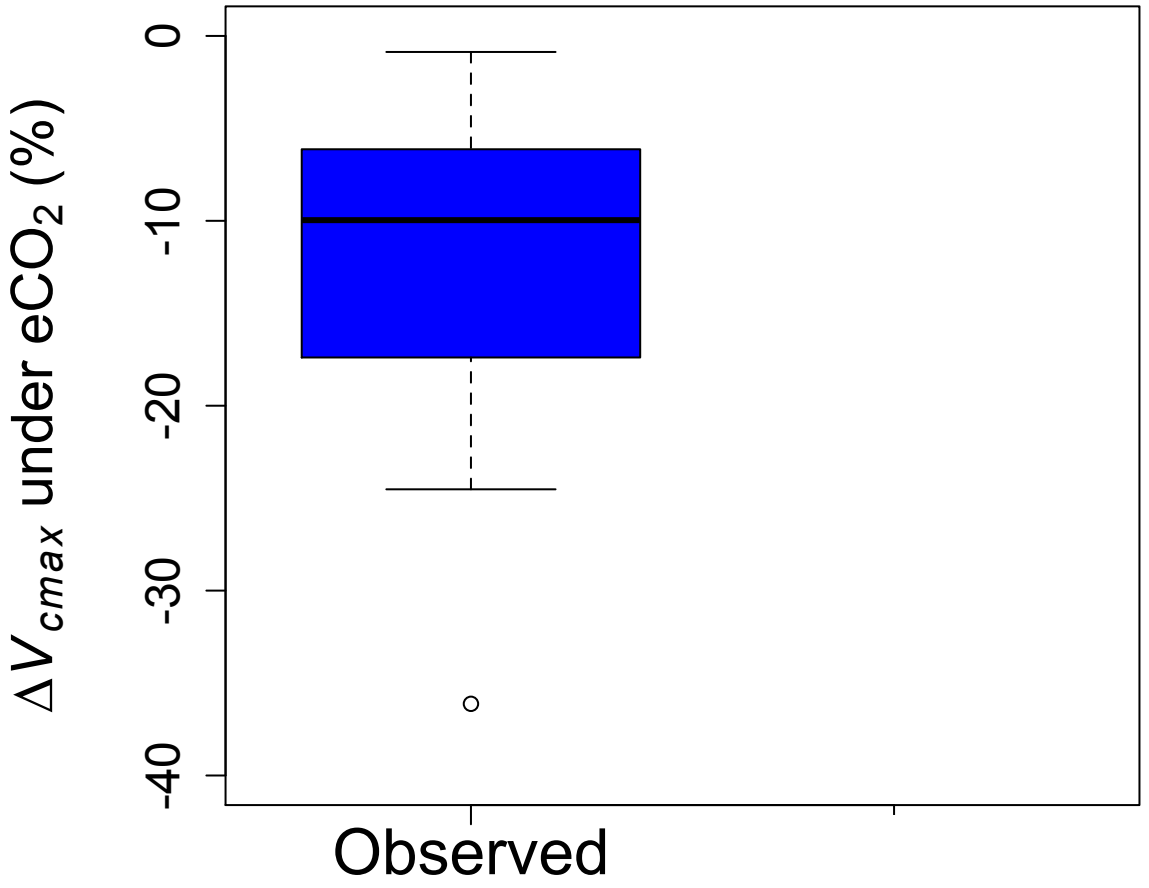
This may be due to N limitation



Smith and Keenan (2020)

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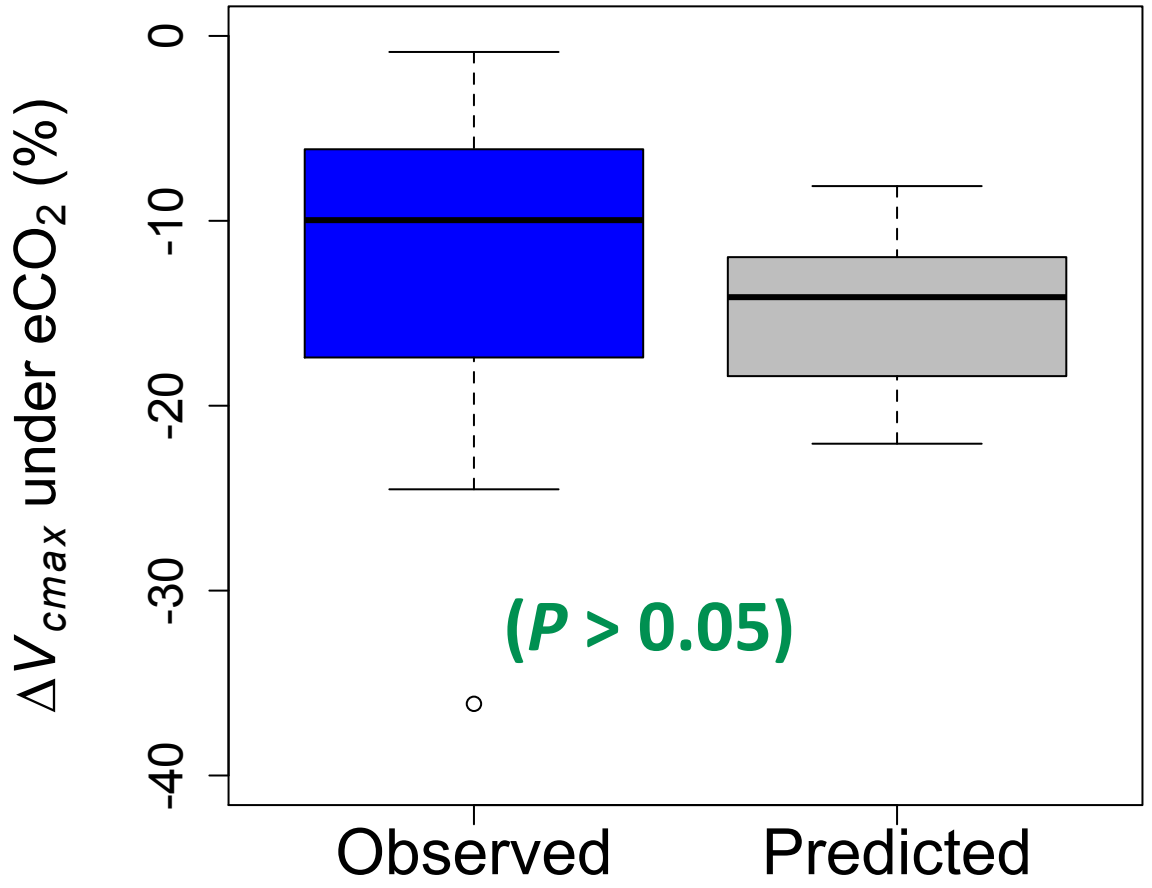
There is another explanation for this effect: photosynthetic least cost theory



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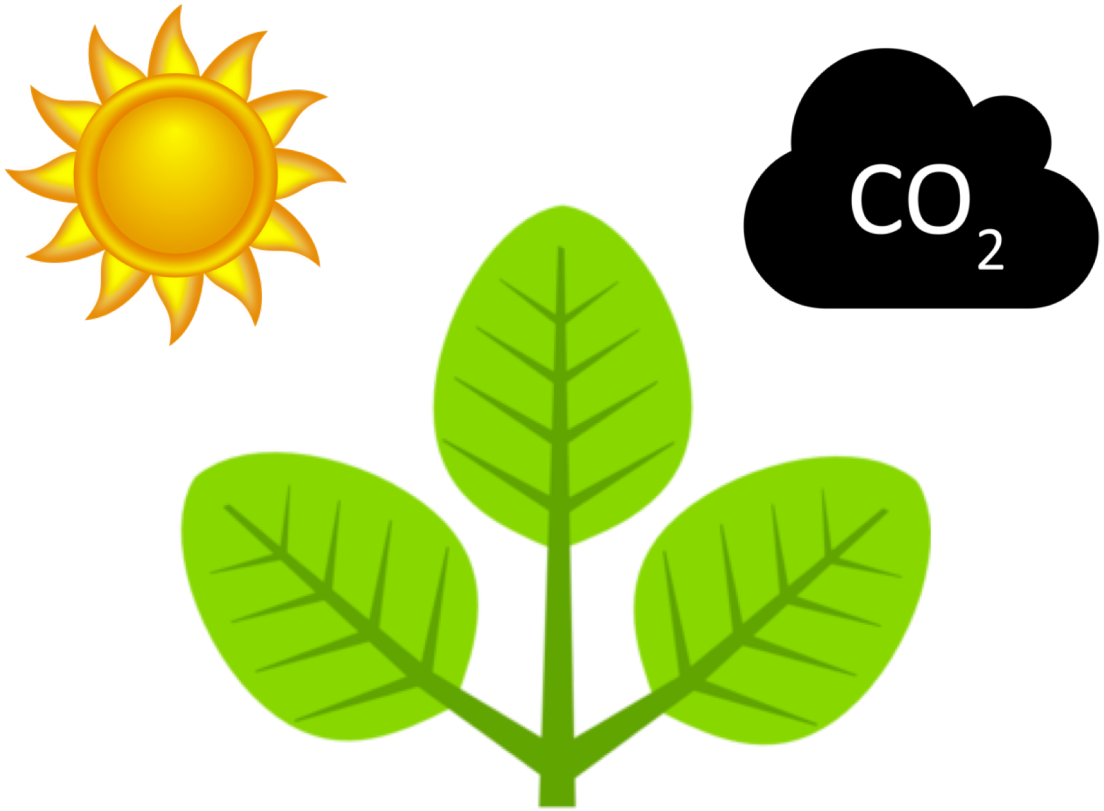
Least cost theory



Optimal setup = equal limitation by all factors

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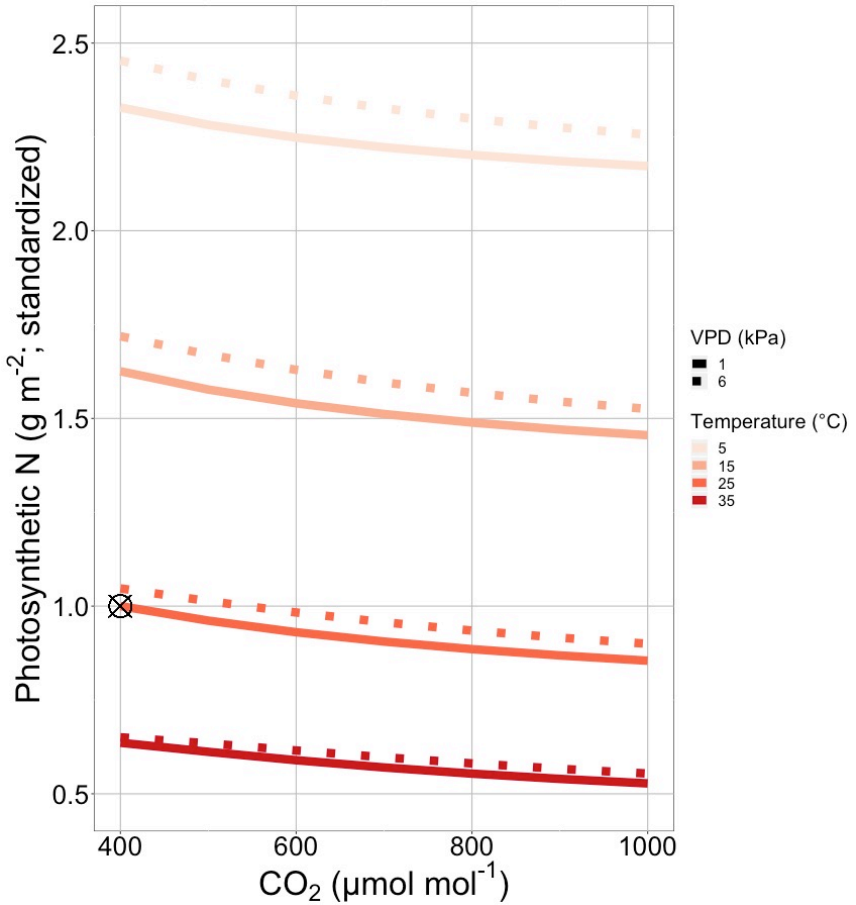
Optimally, demand for photosynthetic proteins will decrease with elevated CO_2 and warming



Reason 1: more CO_2 = less need for enzymes to maximize light use

Reason 2: warming increases enzymatic rate = less enzymes needed

Smith and Keenan (2020)

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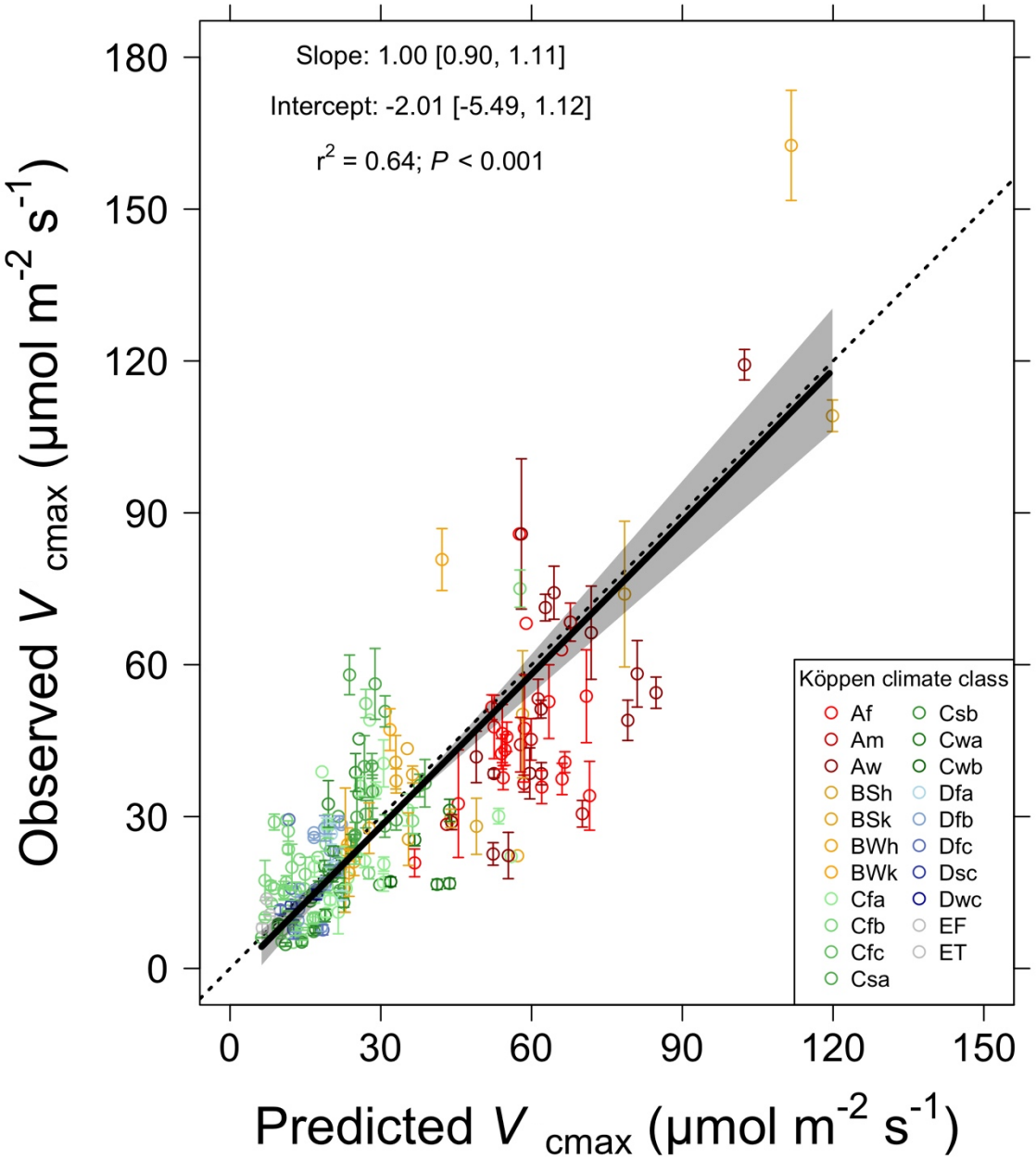

Optimal V_{cmax} is similar to observed values

Smith et al. (2019)

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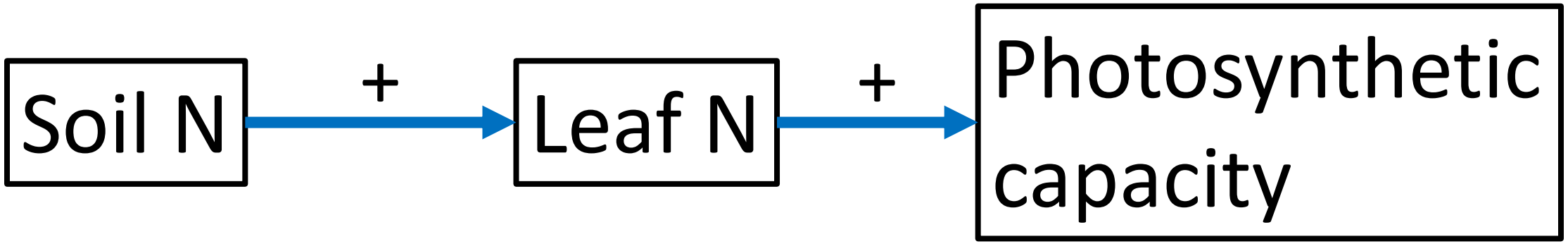
Current photosynthesis scheme



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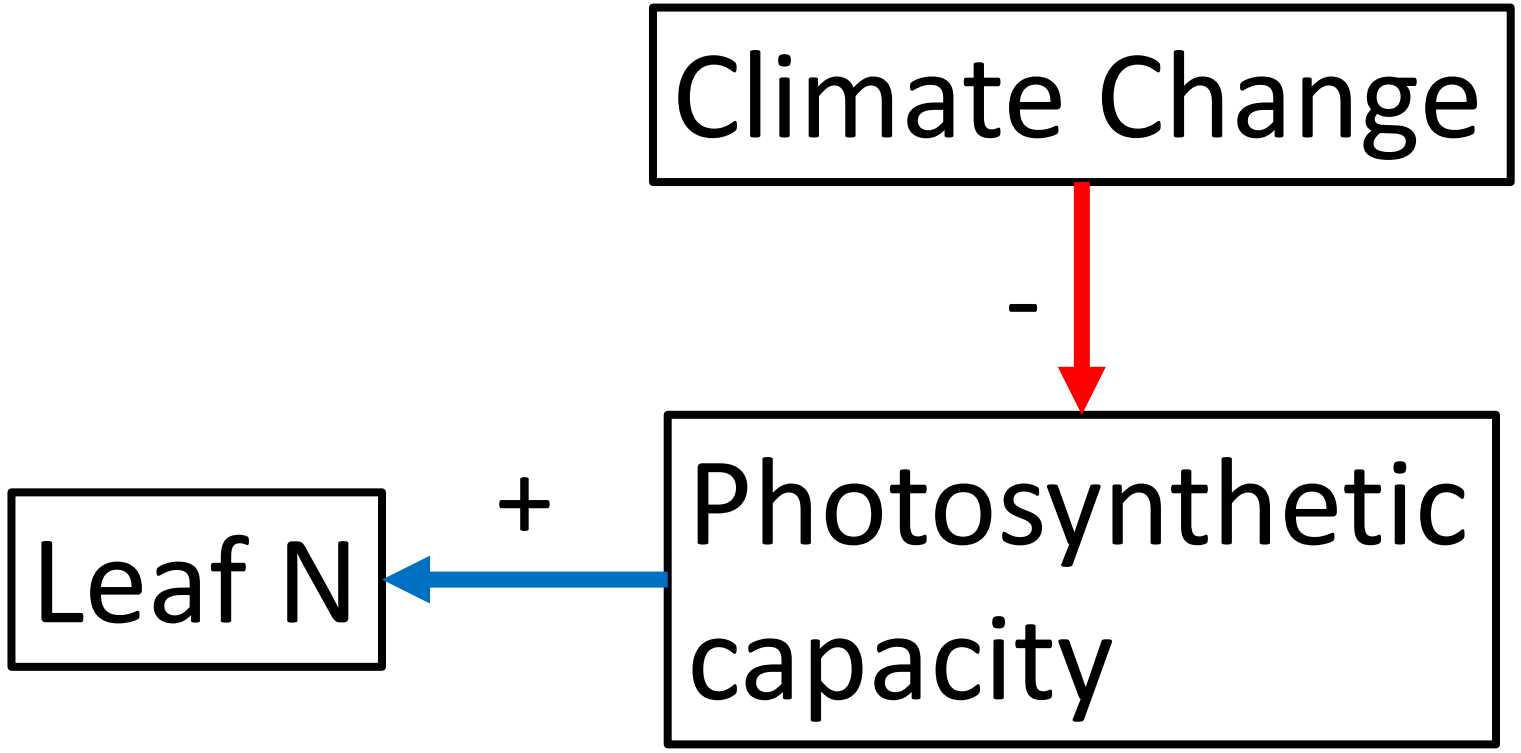
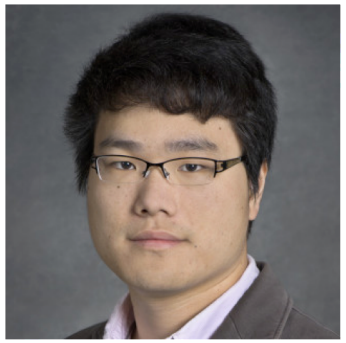
New photosynthesis scheme



nick.smith@ttu.edu; @nick_greg_smith

Let’s run a model!



Qing Zhu (LBNL)

E3SM Energy Exascale Earth System Model

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ELM fixed phenology runs

- Two canopy model with fixed LAI
- No nitrogen model
- Least cost theory determines leaf nutrient demand
- Leaf nitrogen back calculated from photosynthesis
- Simulations to 2100 (RCP 8.5)

E3SM Energy Exascale Earth System Model

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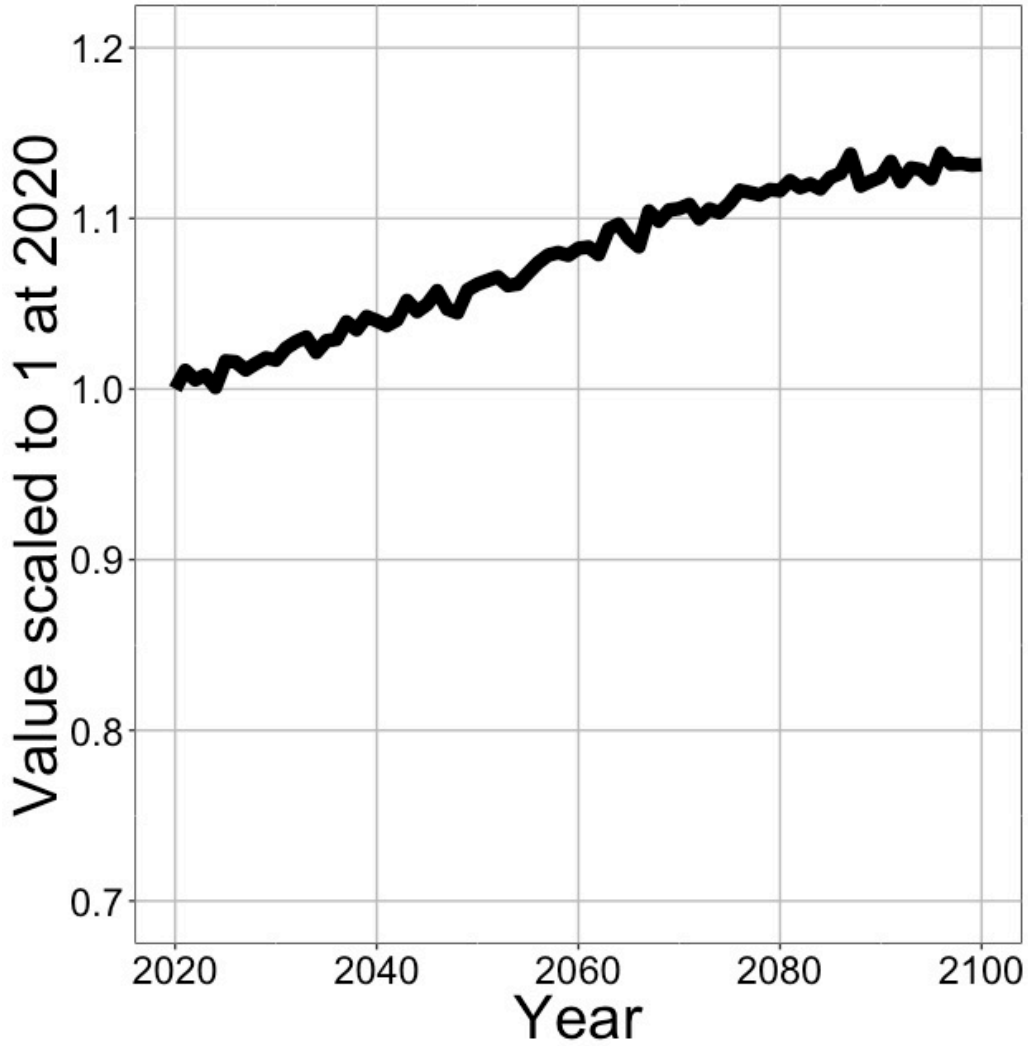
Optimal photosynthesis increases in future



Net Photosynthesis

Smith et al. (in prep)

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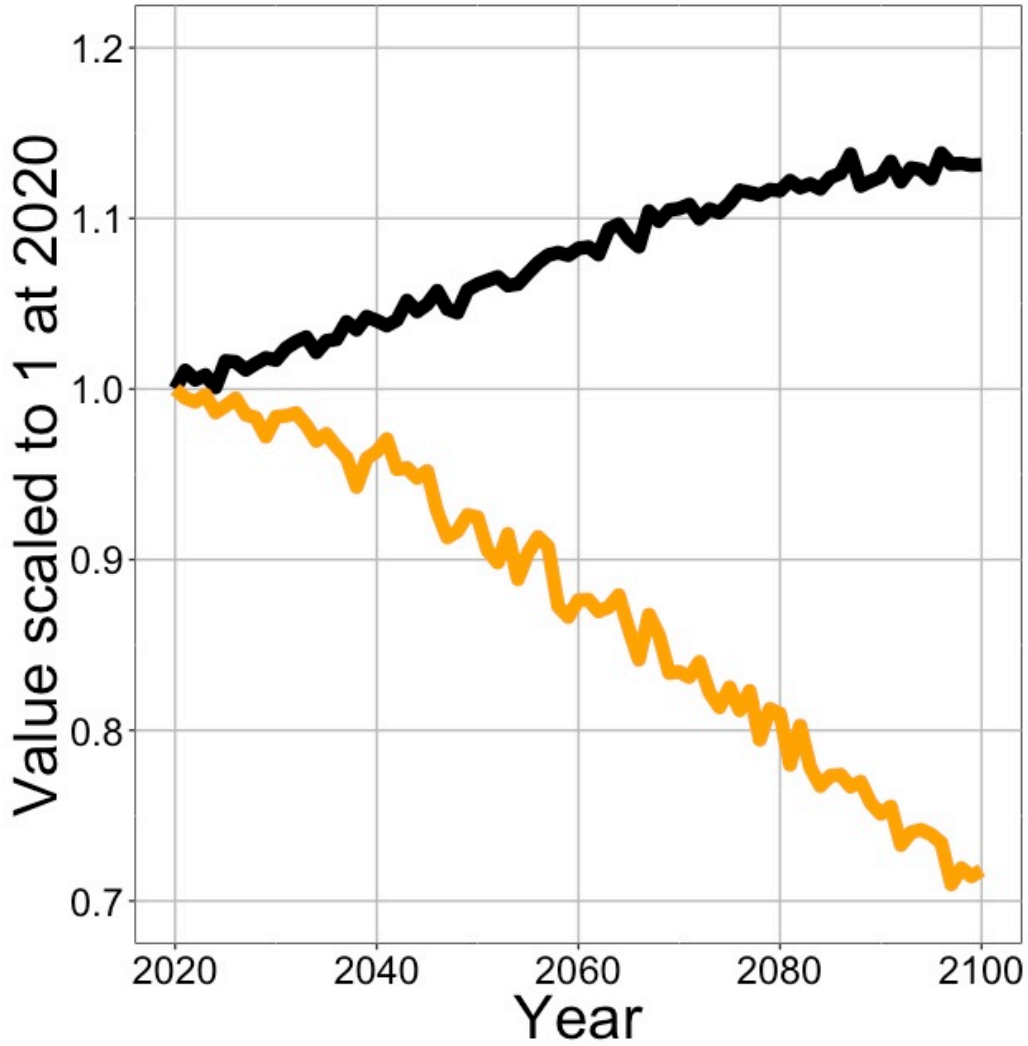
Optimal photosynthesis increases in future (at lower nitrogen use)



Net Photosynthesis

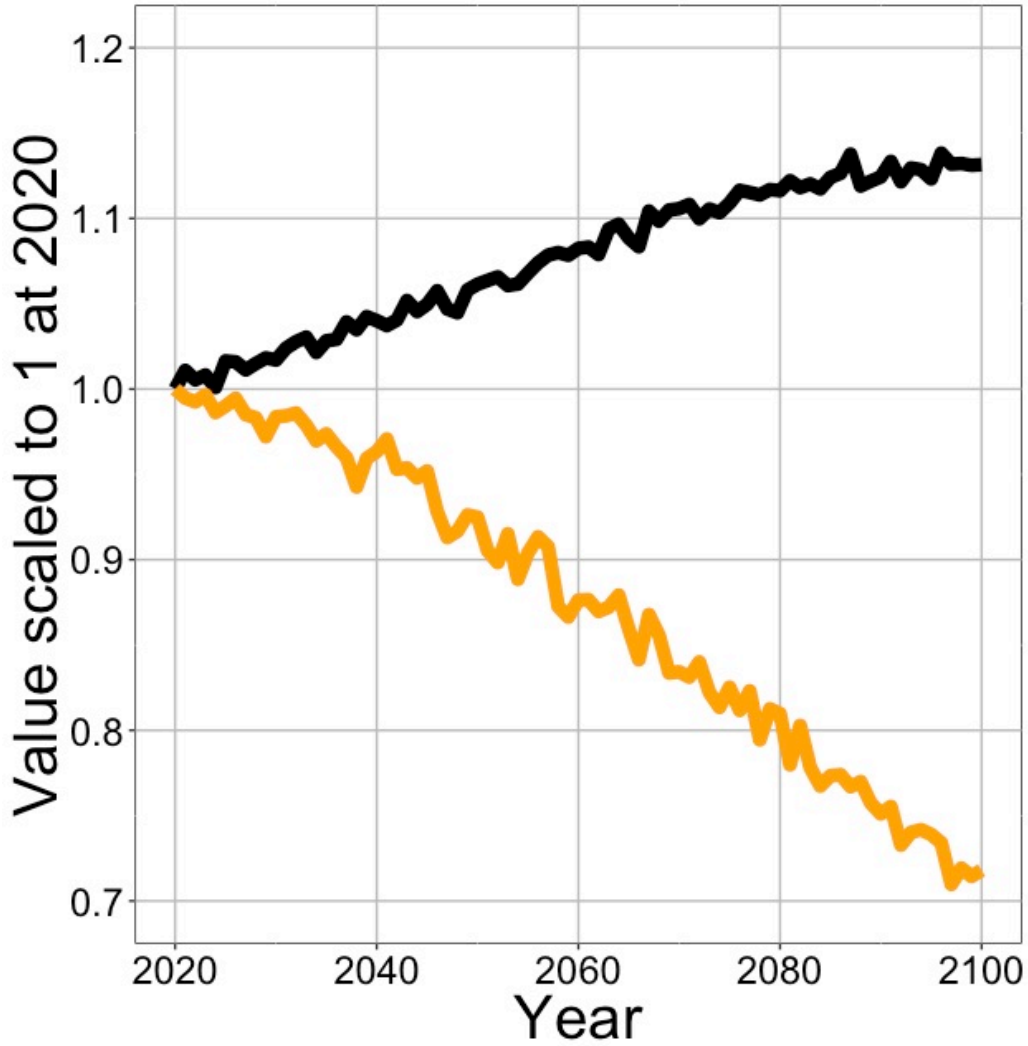
Leaf Nitrogen

Smith et al. (in prep)

nick.smith@ttu.edu; @nick_greg_smith

Optimal photosynthesis increases in future (at lower nitrogen use)

Base ELM shows <5% change in leaf N



Net Photosynthesis

Leaf Nitrogen

Smith et al. (in prep)

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What does this mean for the ecosystem?

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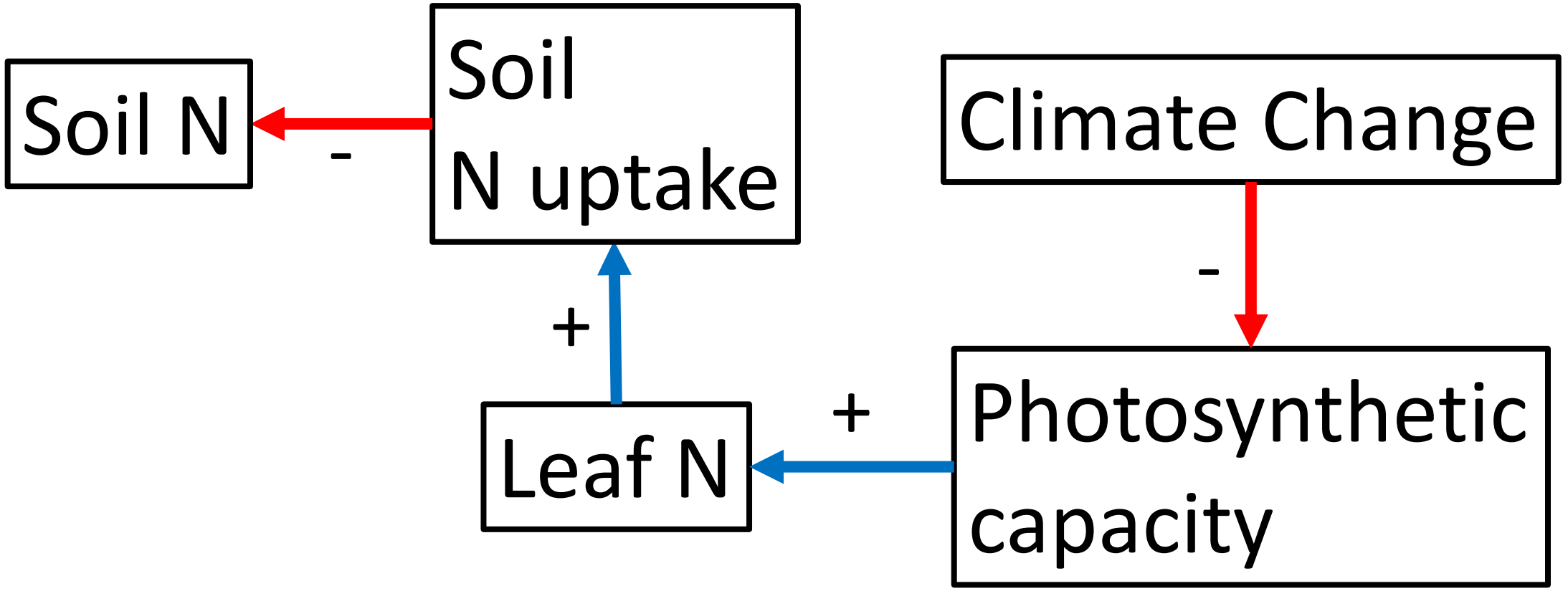
New scheme might increase soil N



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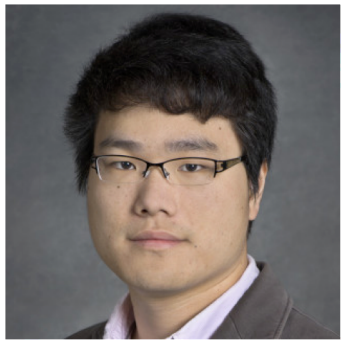
Let’s run a model!



Qing Zhu (LBNL)

E3SM Energy Exascale Earth System Model

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ELM biogeochemistry runs

- Least cost theory determines leaf nutrient demand
- Using available nutrients, plants try to meet this demand
  - If demand cannot be met, leaves are purged
  - If demand is met, any excess nutrients are used to build new tissue using ELM's dynamic allocation scheme
- Allocation, but not photosynthetic nutrient demand, varies by PFT
- Simulations done with and without calculated nutrient savings
- Simulations to 2100 (RCP 8.5)

E3SM Energy Exascale Earth System Model

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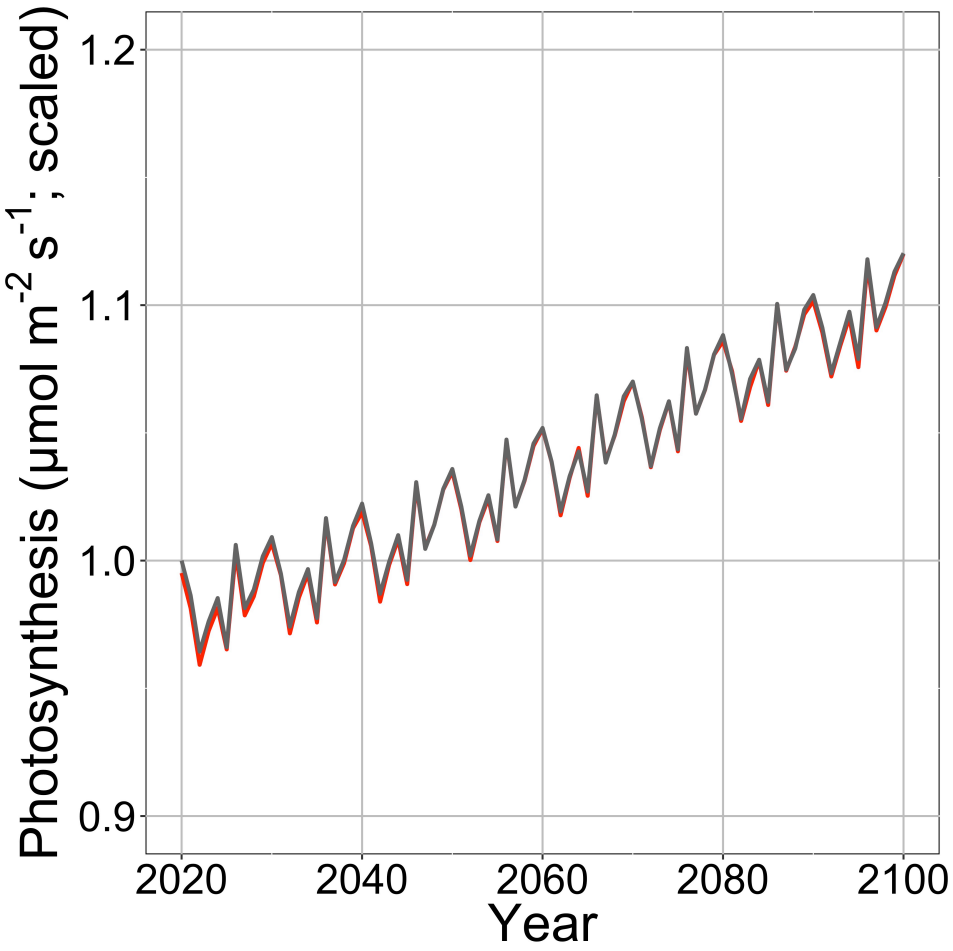
Nutrient savings does not impact leaf photosynthesis



Optimal photosynthesis with N savings

Optimal photosynthesis without N savings

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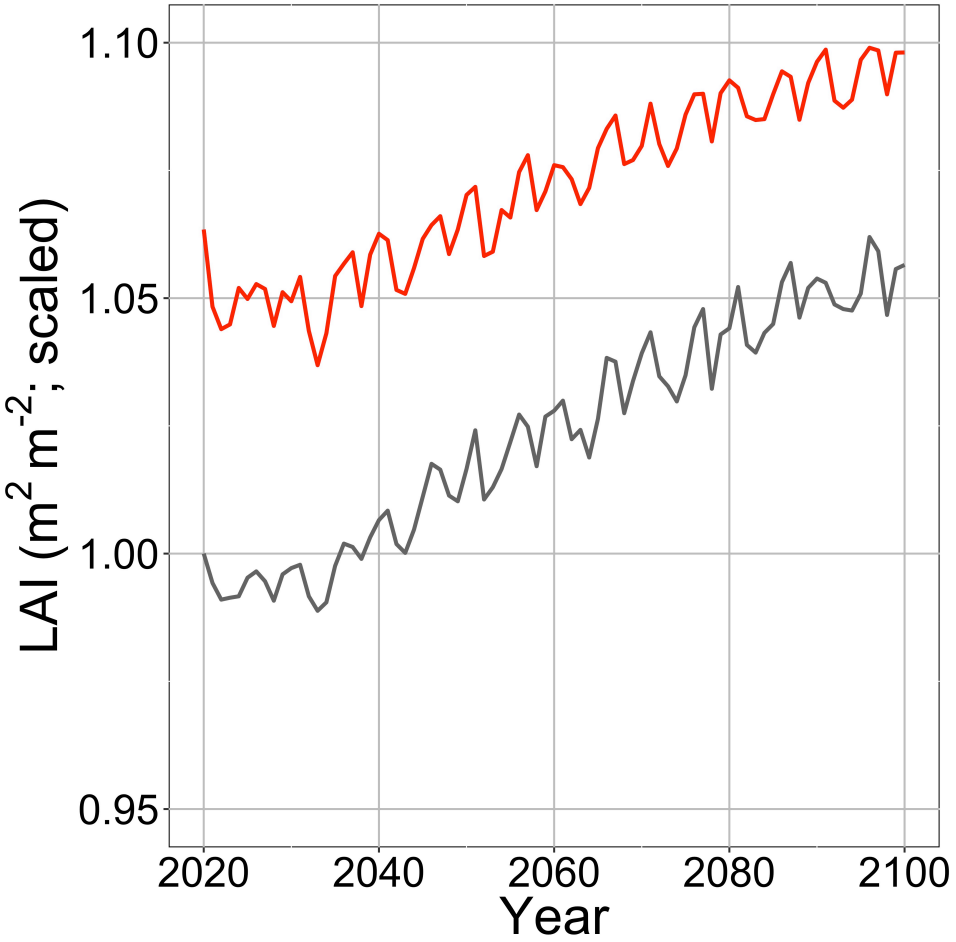
Nutrient savings is used to build new tissues



Optimal photosynthesis with N savings

Optimal photosynthesis without N savings

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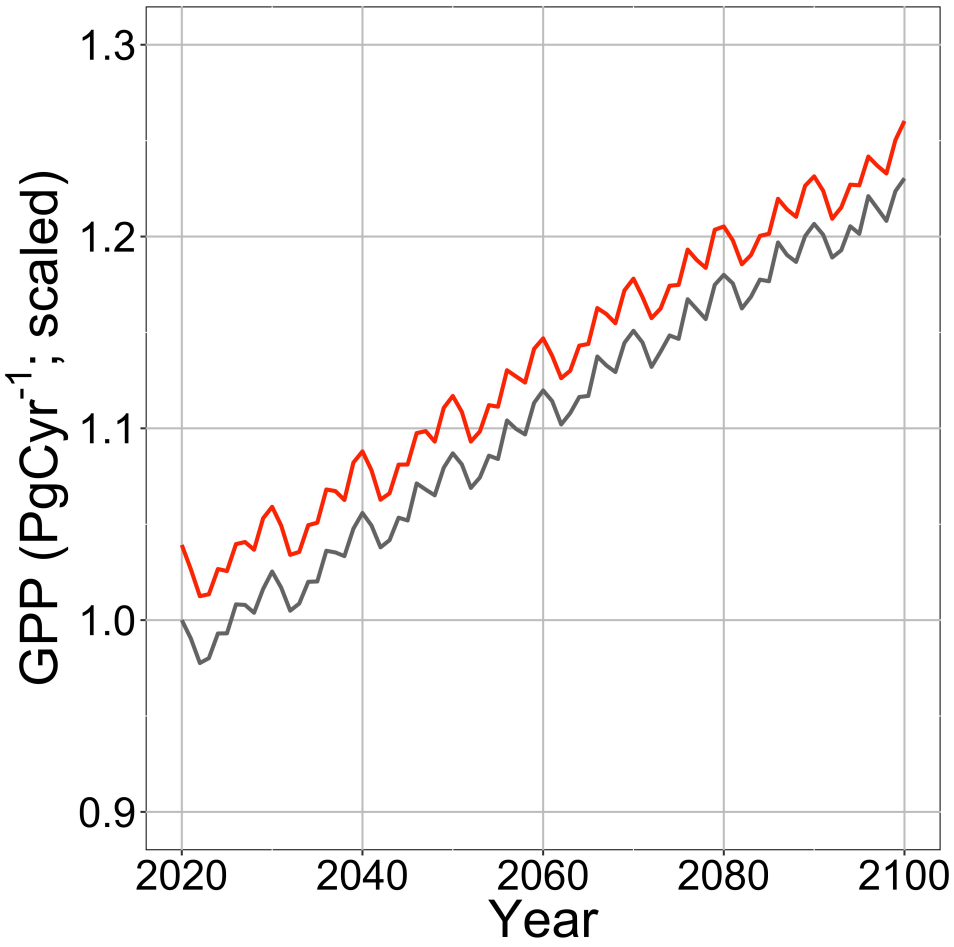
N savings increases 2100 GPP by 2.5%



Optimal photosynthesis with N savings

Optimal photosynthesis without N savings

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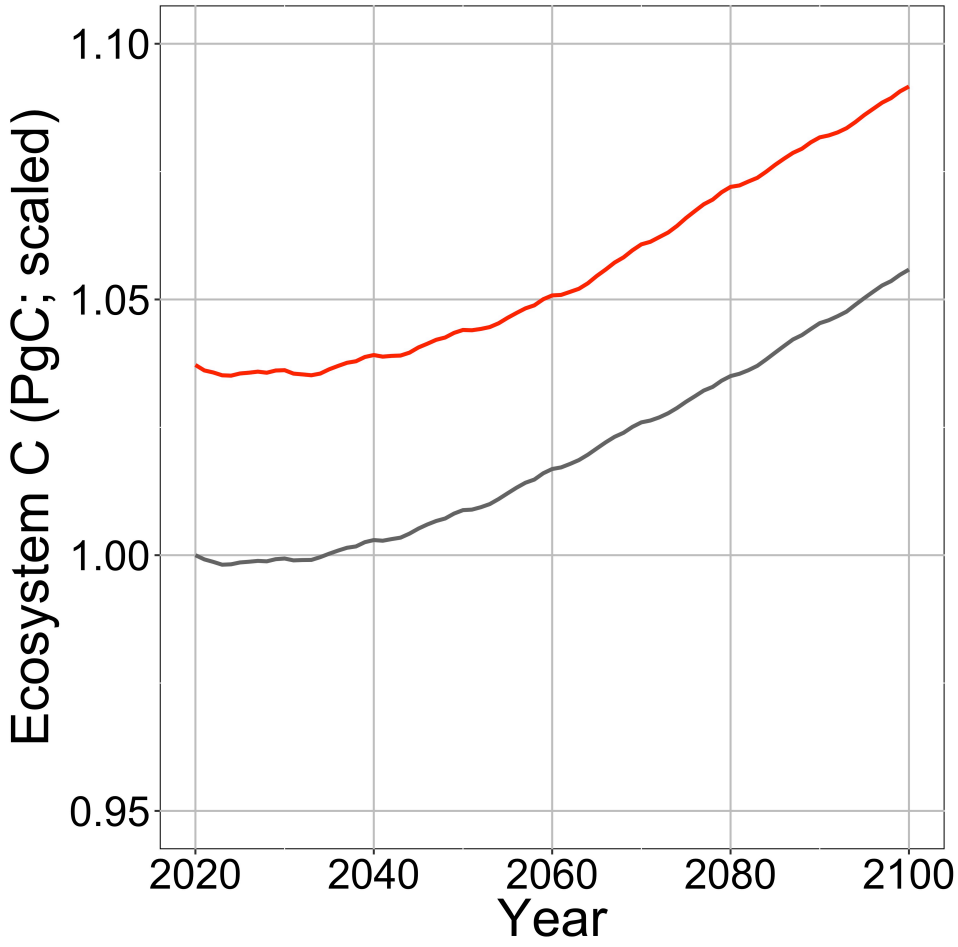
N savings increases 2100 ecosystem C by 3.4%



Optimal photosynthesis with N savings

Optimal photosynthesis without N savings

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What does this all mean?

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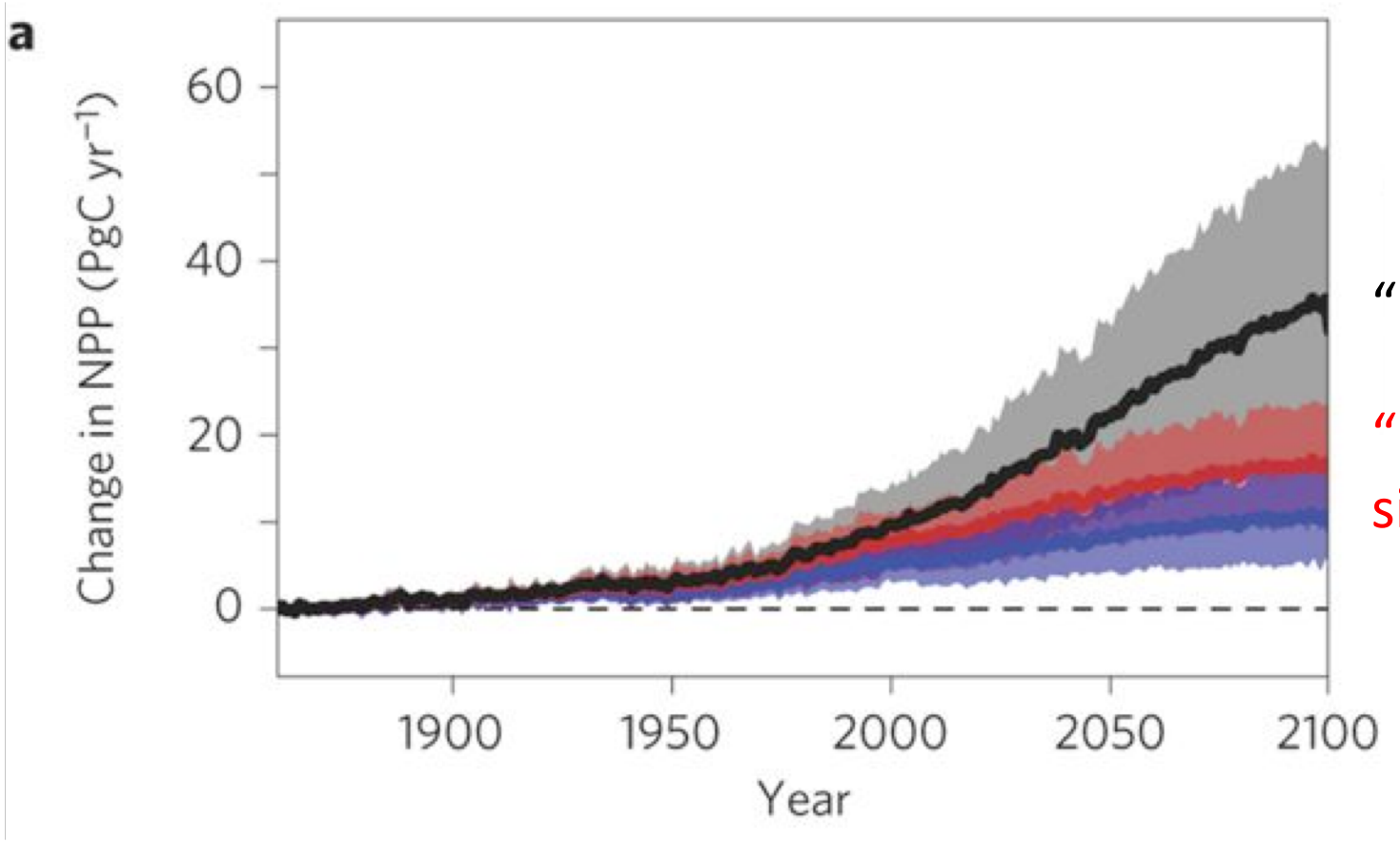
Future progressive nutrient limitation may be overestimated



"No limitation" simulation

"Nutrient limitation" simulations

Weider et al. (2015)

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Conclusions

- Photosynthetic N demand is reduced under future elevated CO_2 and temperature
  - Least cost optimality theory can predict this
- The theory can (and should) be incorporated into ESMs
  - No added parameters
- Progressive nitrogen limitation will not be as strong as current models predict

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