Modeling leaf responses to soil nitrogen availability

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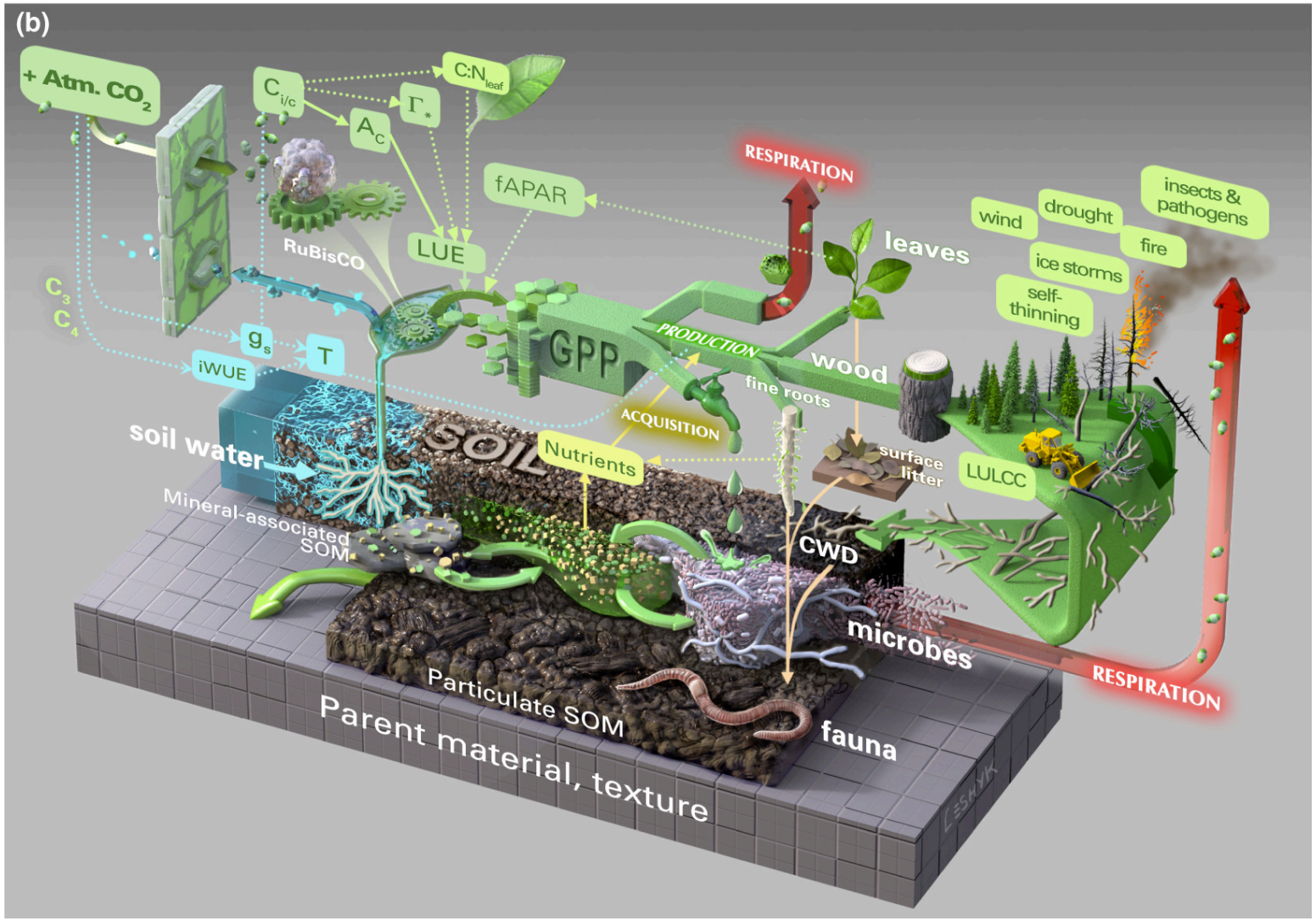
Terrestrial Carbon and Nitrogen cycles are tightly coupled



Walker et al. (2020)

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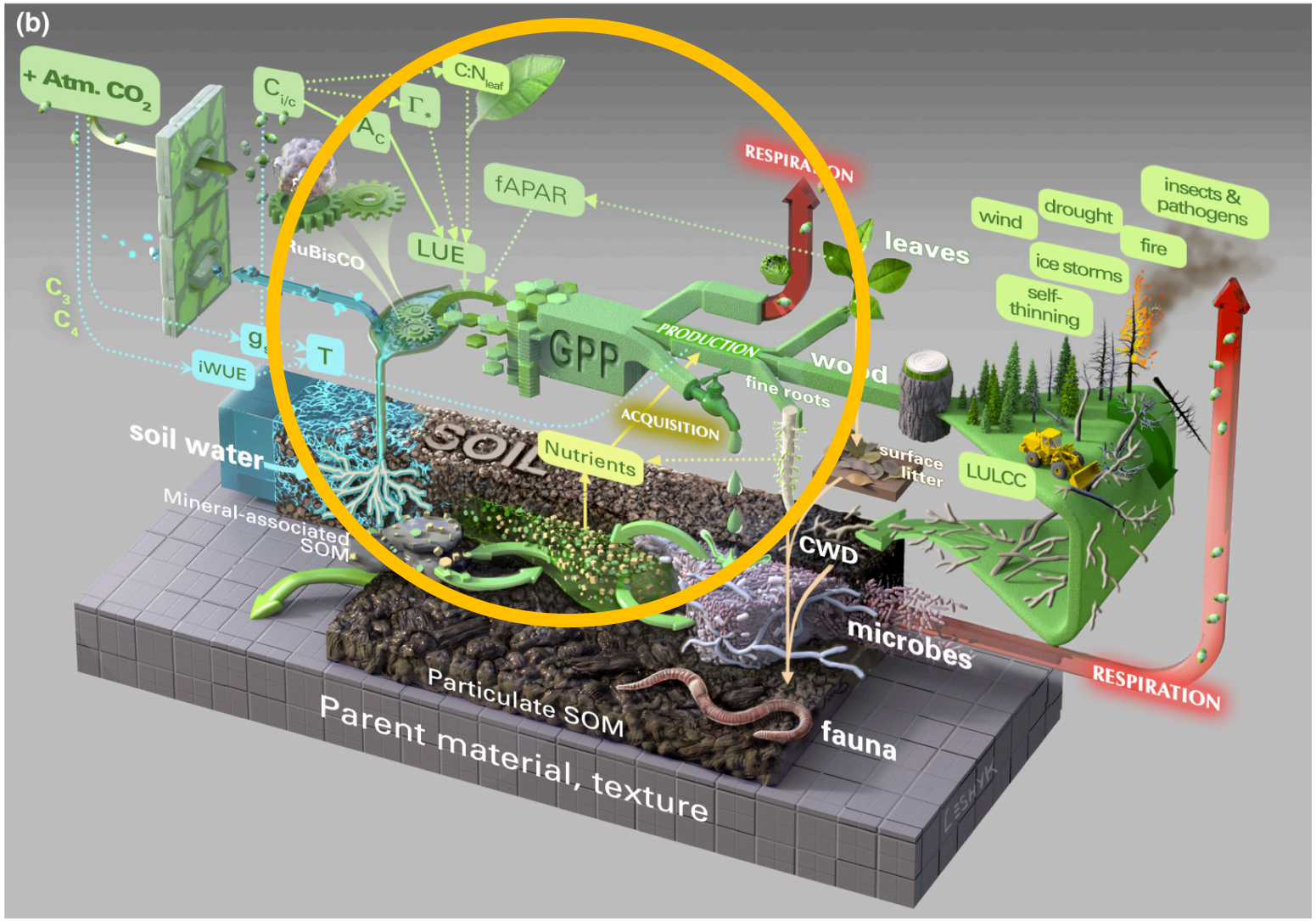
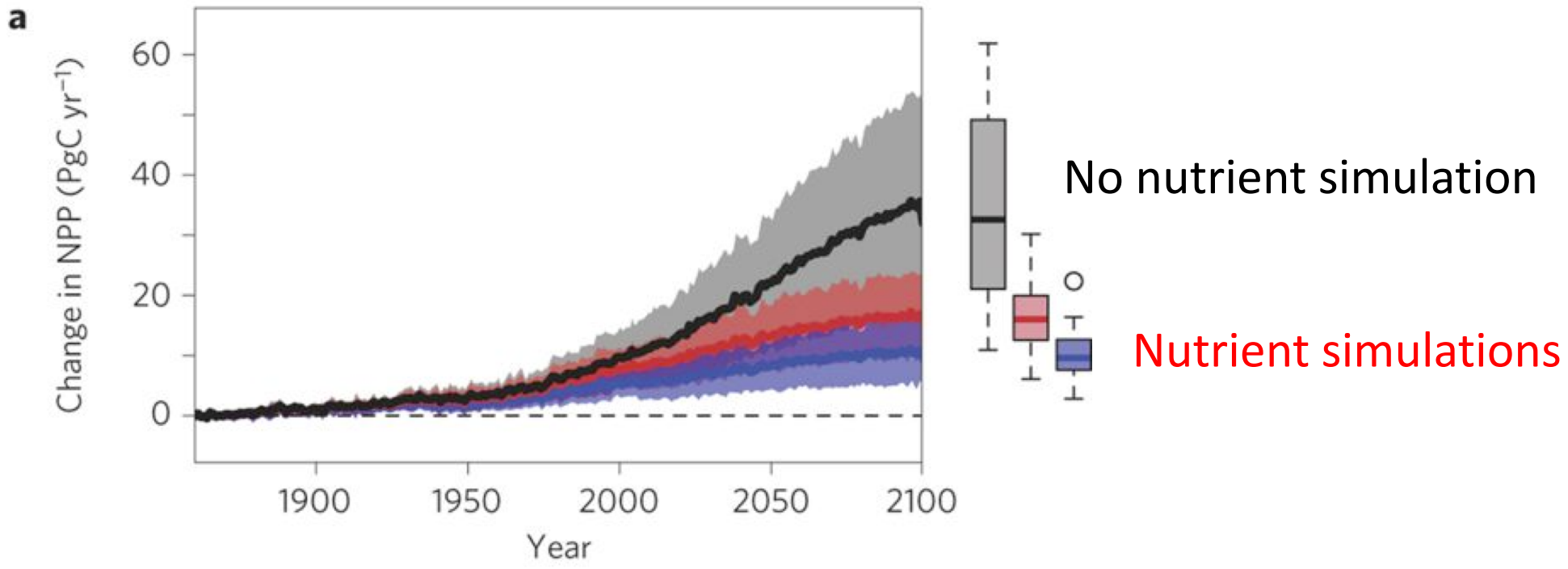


Walker et al. (2020)

This coupling can alter ESM predictions



Weider et al. (2015)

What aspects of this coupling should we be predicting with our models?

1. Evidence from experiments
2. Where we stand with models

Soil nitrogen greenhouse manipulation

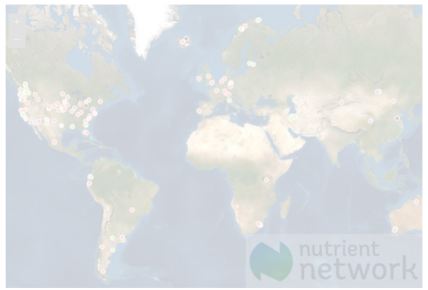
Grassland soil nitrogen manipulations

Forest soil nitrogen manipulation

Temperature and CO_2 manipulations

Soil nitrogen greenhouse manipulation

Grassland soil nitrogen manipulations

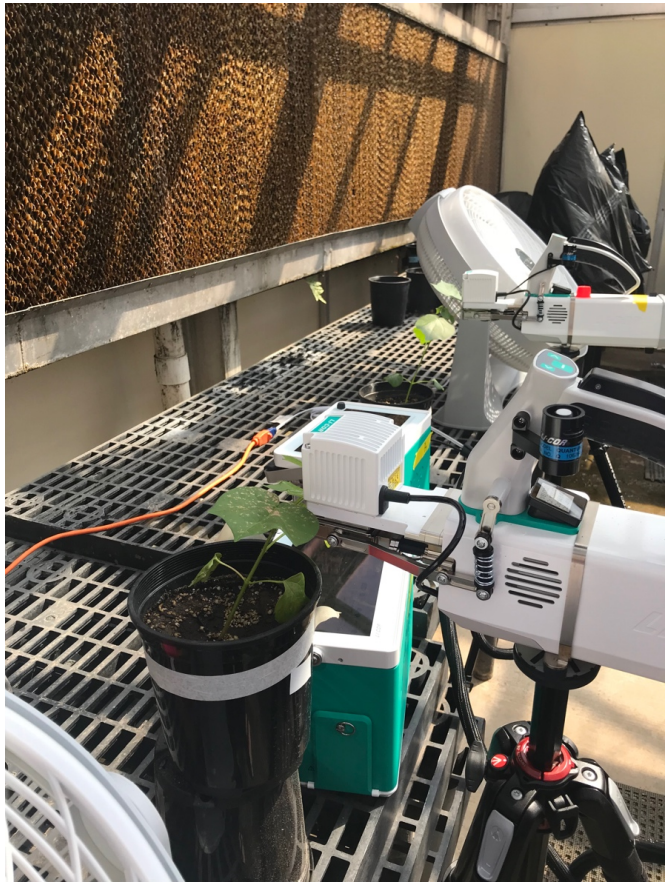


Forest soil nitrogen manipulation

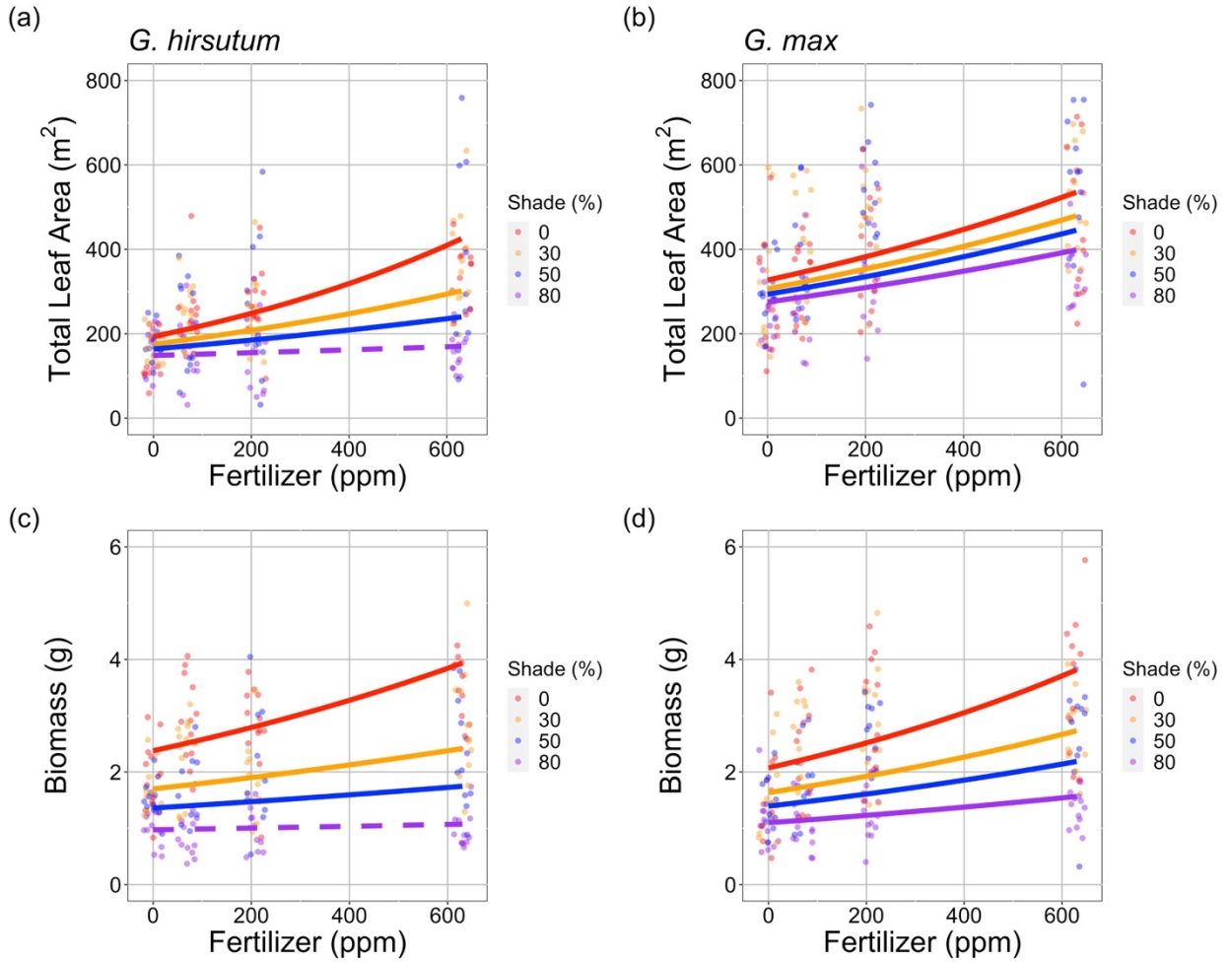
Temperature and CO_2 manipulations

Soil N greenhouse manipulation

- 4 levels of nitrogen fertilization to low N field soil
  - 0 ppm N – 630 ppm N added twice per week
- 4 levels of light availability
  - Full light (1662 µmol m^{-2} s^{-1} PAR) to 80% shade
- 2 species
  - Cotton (non-N fixing) and soybean (N fixing)
- Full factorial
- Physiology, allocation, and growth measured

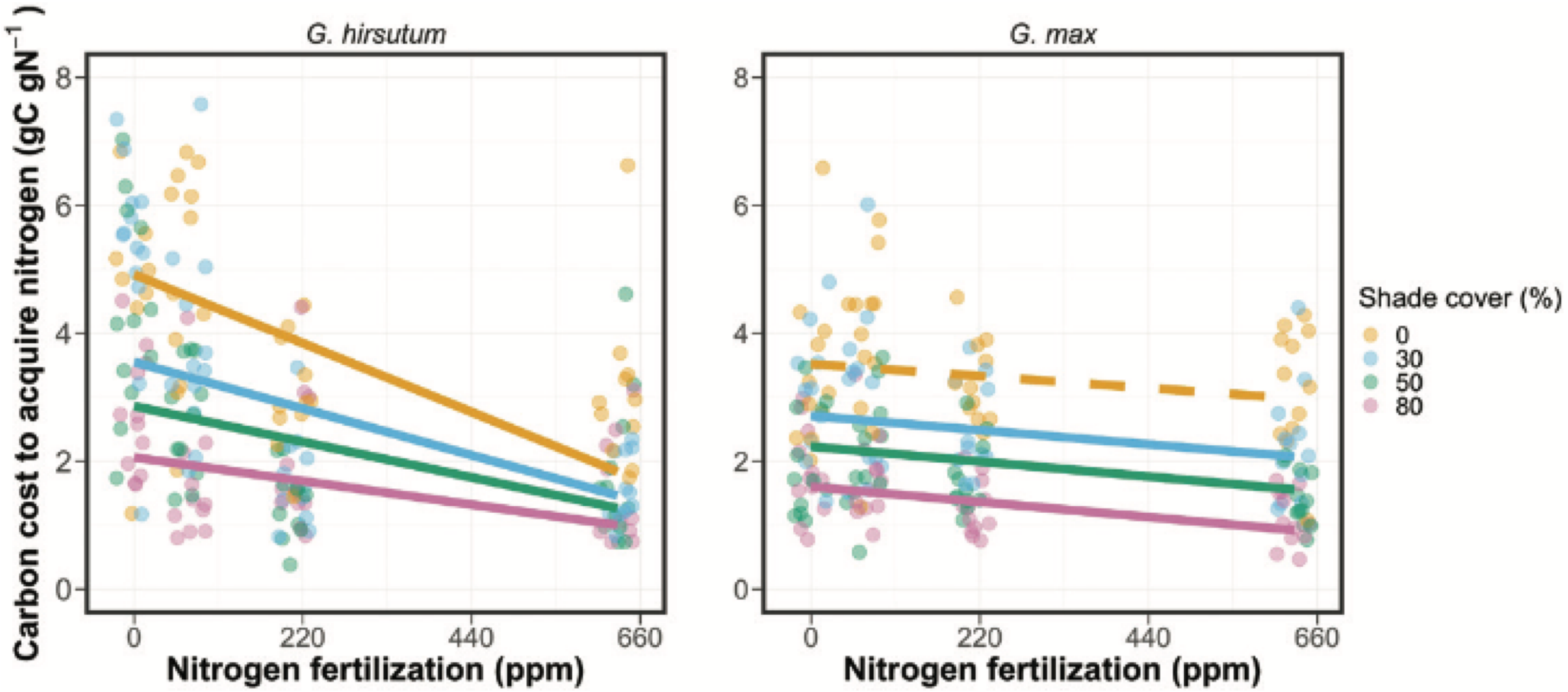


Result: Growth increases with increasing soil N



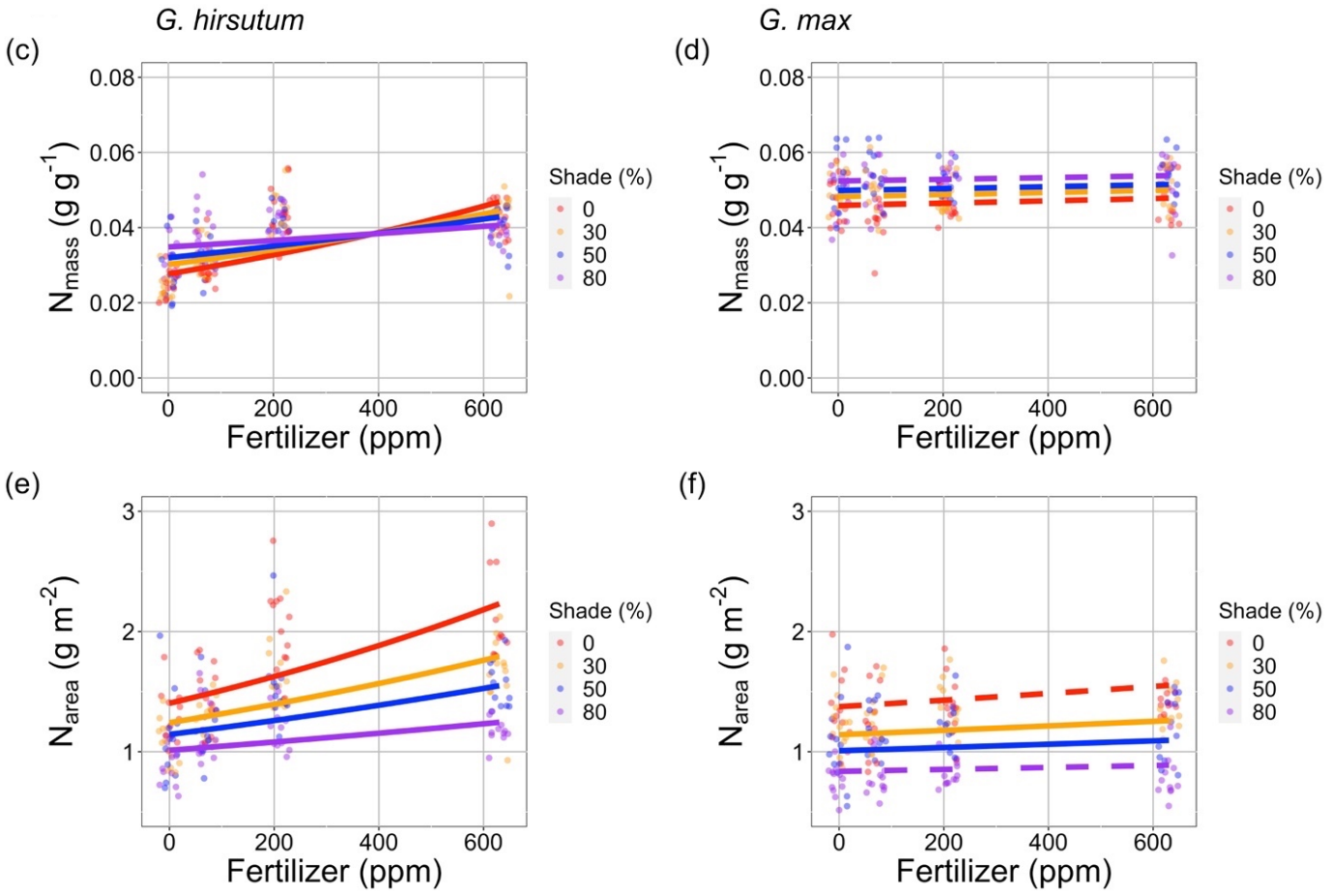
Waring et al. (in prep)

Result: C cost to acquire N decreases with increasing soil N



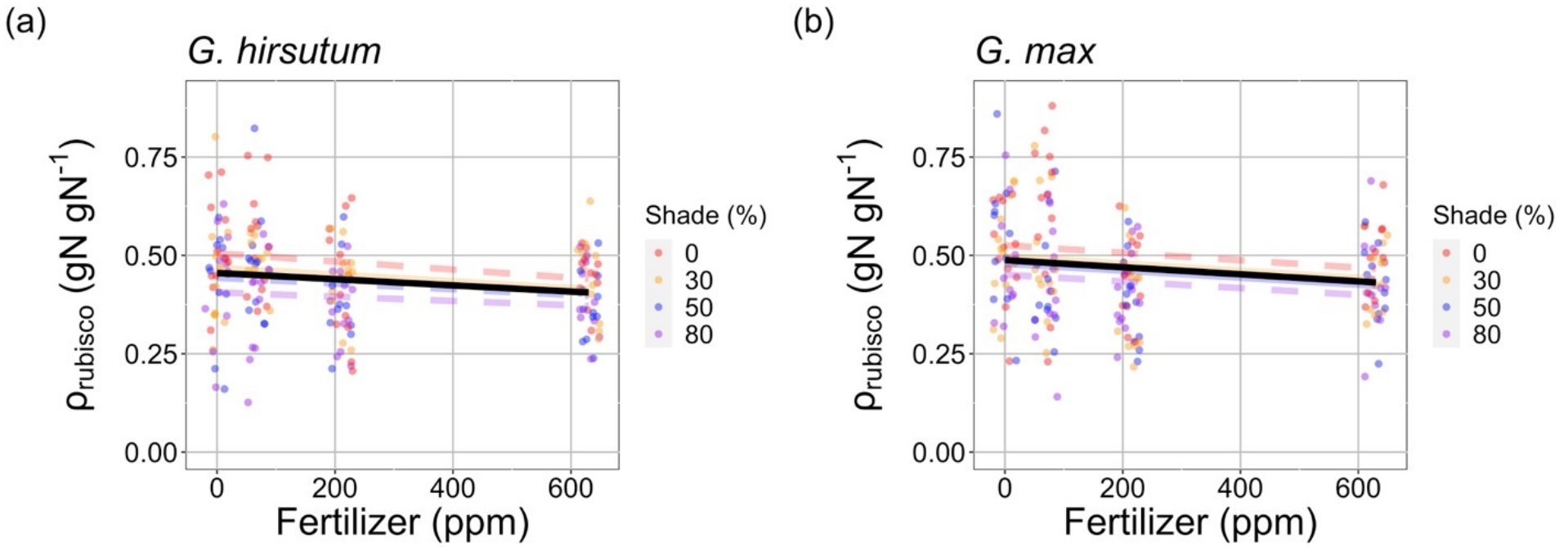
Perkowski et al. (2021)

Result: Tissue N increases with increasing soil N



Waring et al. (in prep)

Result: Relative leaf N allocation to photosynthesis decreases with increasing soil N



Consistent across all species, treatments, and photosynthetic components (Rubisco, bioenergetics, light harvesting)

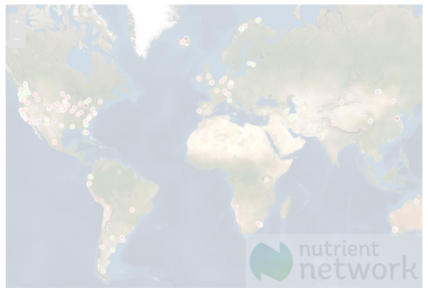
Waring et al. (in prep)

What should models be able to reproduce?

- Increased growth with increased soil N √
- Decreased C cost to acquire N with increased soil N √
- Increased tissue N with increased soil N √
- Decreased relative leaf N allocation to photosynthesis with increased soil N √

Soil nitrogen greenhouse manipulation

Grassland soil nitrogen manipulations



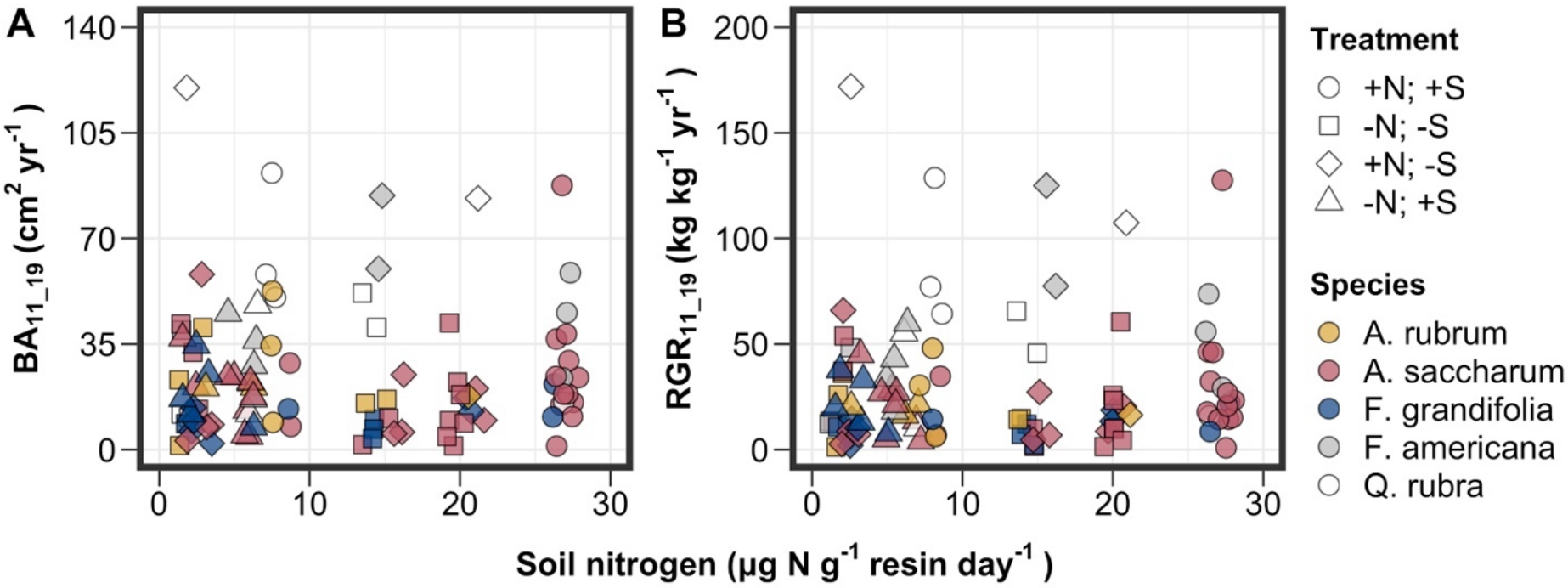
Forest soil nitrogen manipulation

Temperature and CO_2 manipulations

Forest soil N manipulation

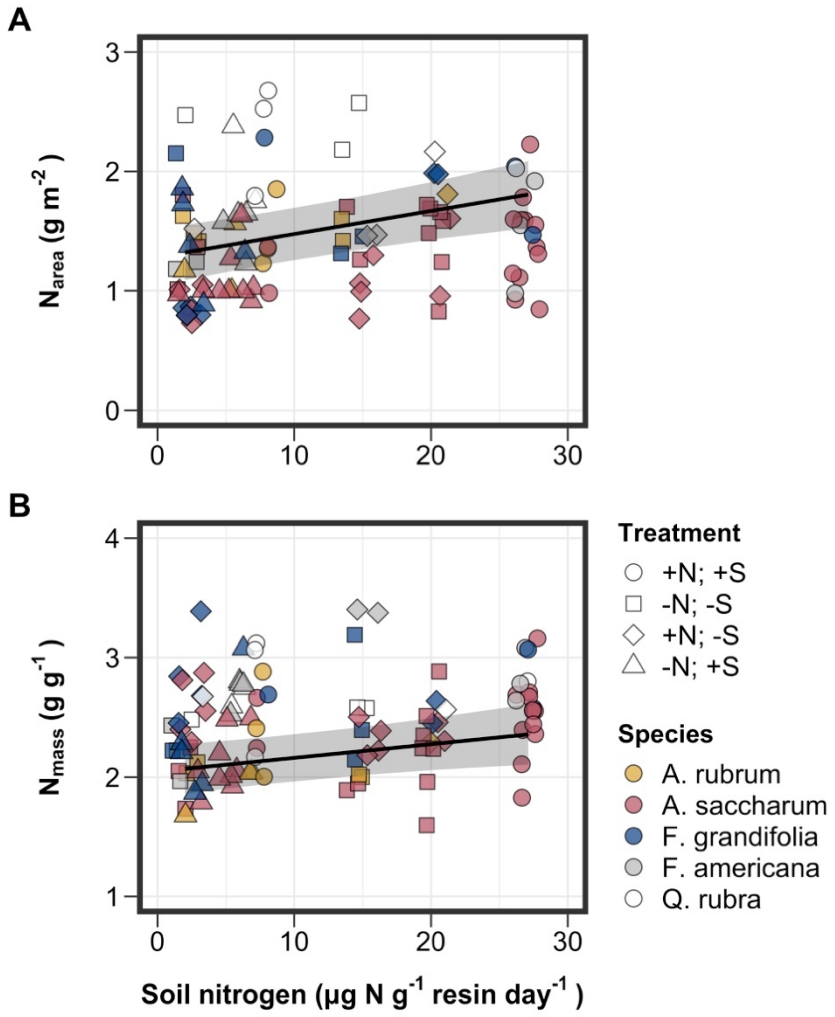
- Closed canopy forest in Ithaca, NY
  - Various deciduous trees
- 2 levels of nitrogen fertilization
  - 0 or 50 kg N ha^{-1} yr^{-1}
- 2 levels of sulfur fertilization
  - 0 or 50 kg S ha^{-1} yr^{-1}
- Full factorial
- Physiology and growth measured

Result: Growth unchanged with increasing soil N



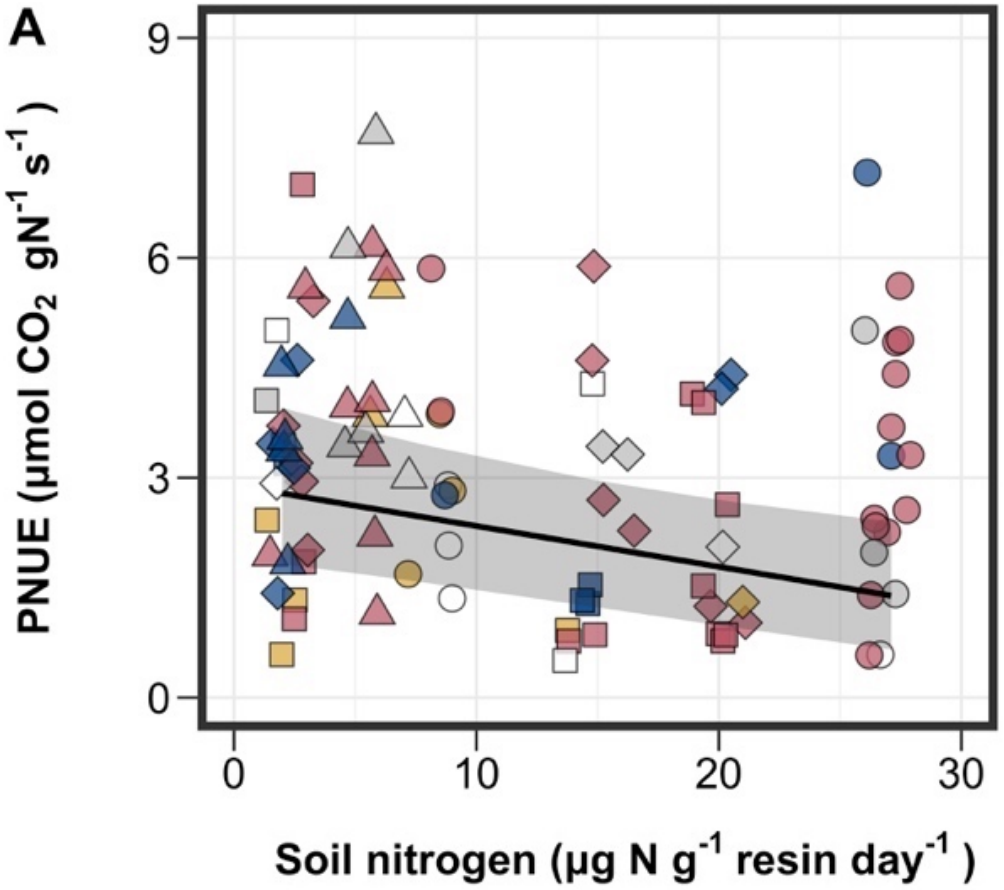
Perkowski et al. (in prep)

Result: Tissue N increases with increasing soil N



Perkowski et al. (in prep)

Result: Relative leaf N allocation to photosynthesis decreases with increasing soil N



Waring et al. (in prep)

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- Decreased C cost to acquire N with increased soil N √
- Increased tissue N with increased soil N √ √
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Soil nitrogen greenhouse manipulation

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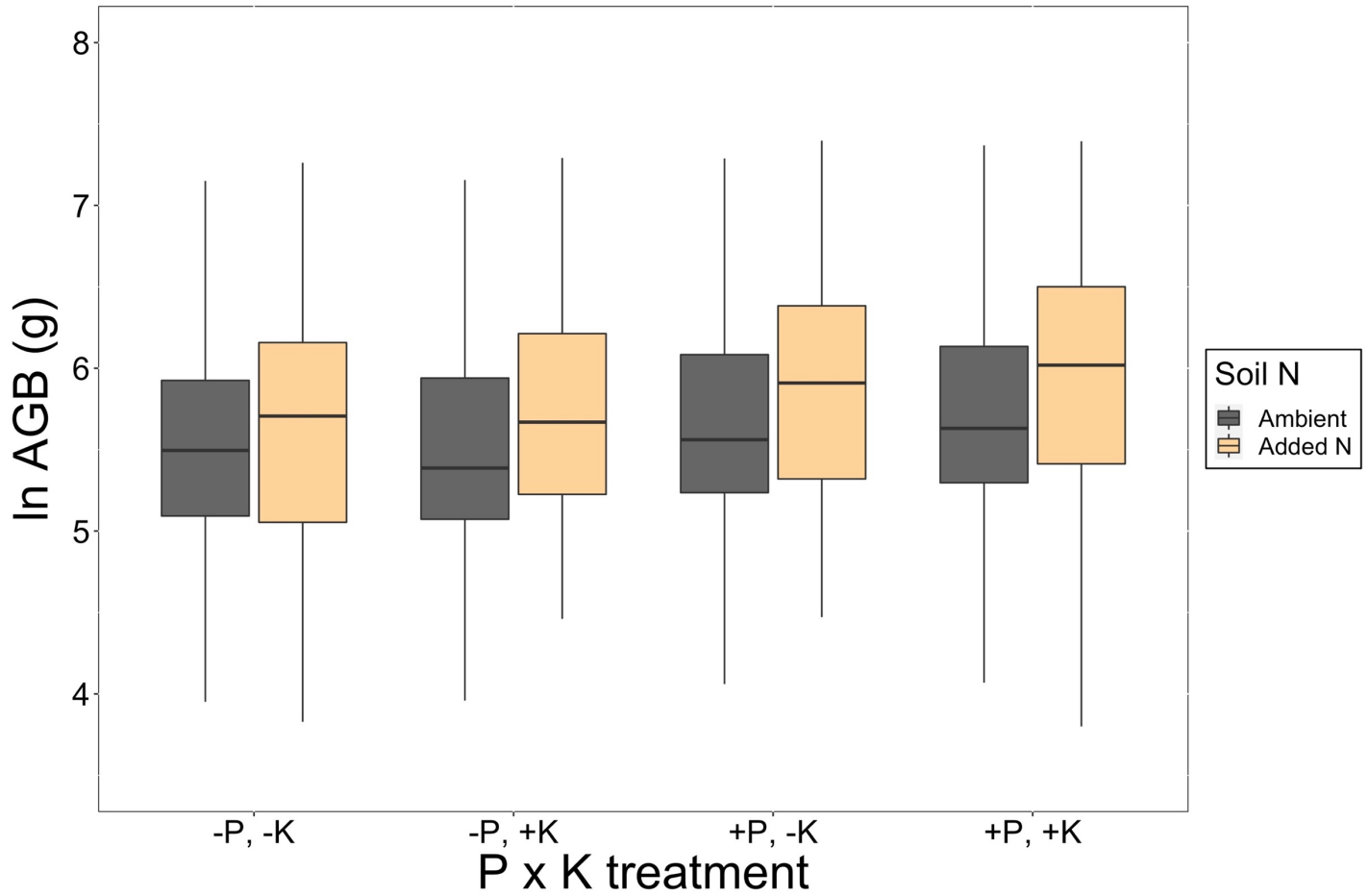
Temperature and CO_2 manipulations

Global grassland soil N manipulations

- Nutrient Network
  - Global grassland factorial N+P+K addition
- Leaf trait dataset
  - 19 sites
  - 2129 individuals
  - 208 species
- Leaf N and $\delta^{13}C$
- $\delta^{13}C$ used to compute ratio of intercellular to extracellular CO_2 and carbon cost ratio of soil resource uptake

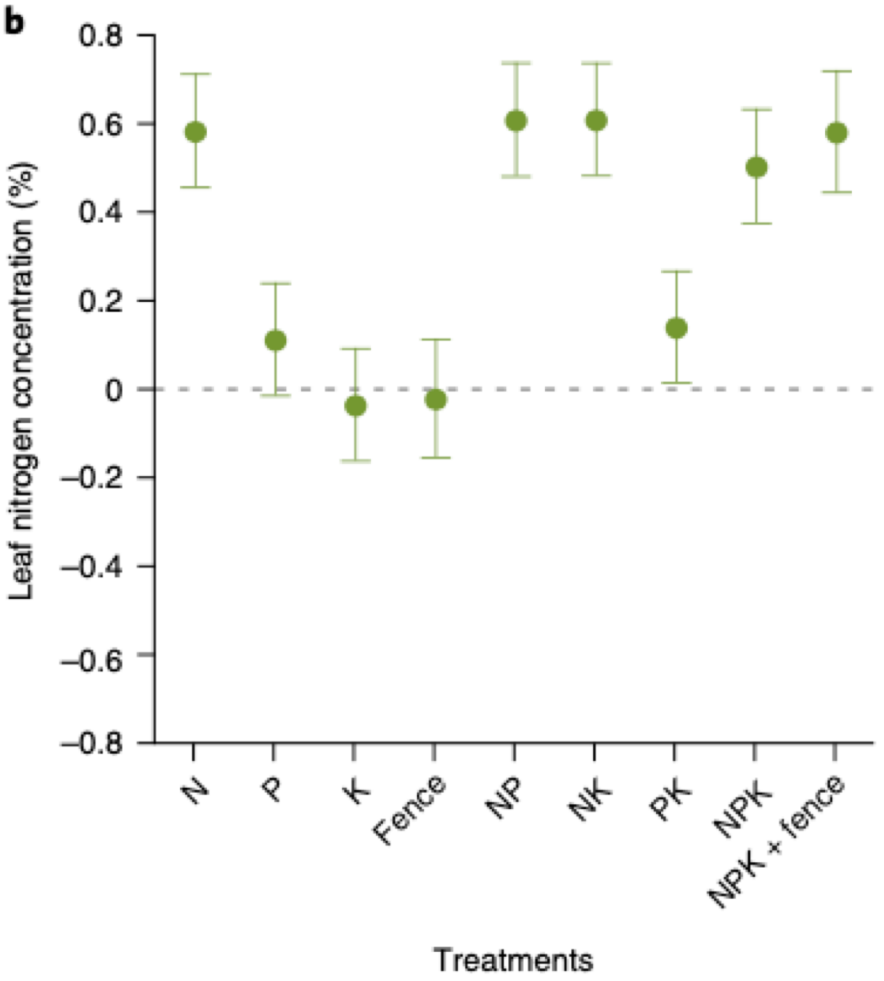
Result: Growth increases with increasing soil N

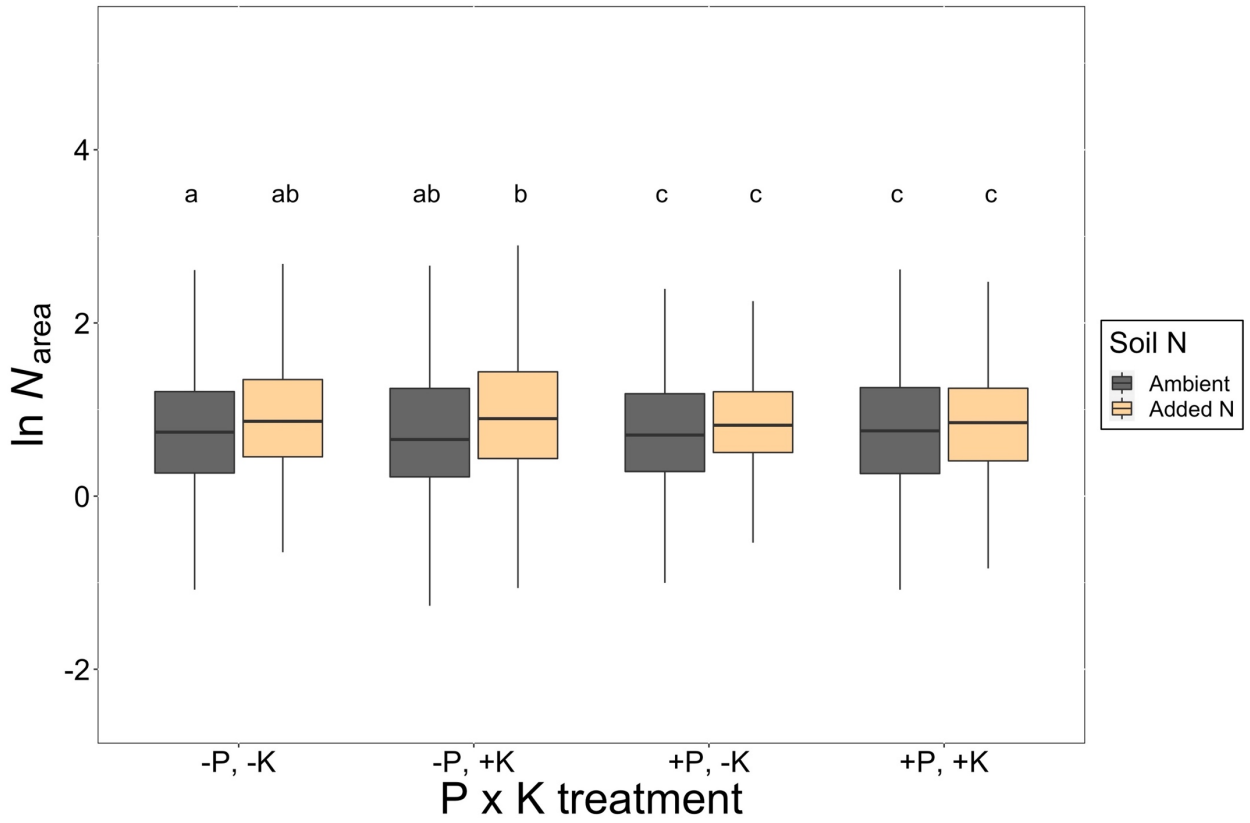


Always increases regardless of P and K

Smith et al. (in prep)

Result: Tissue N increases with increasing soil N

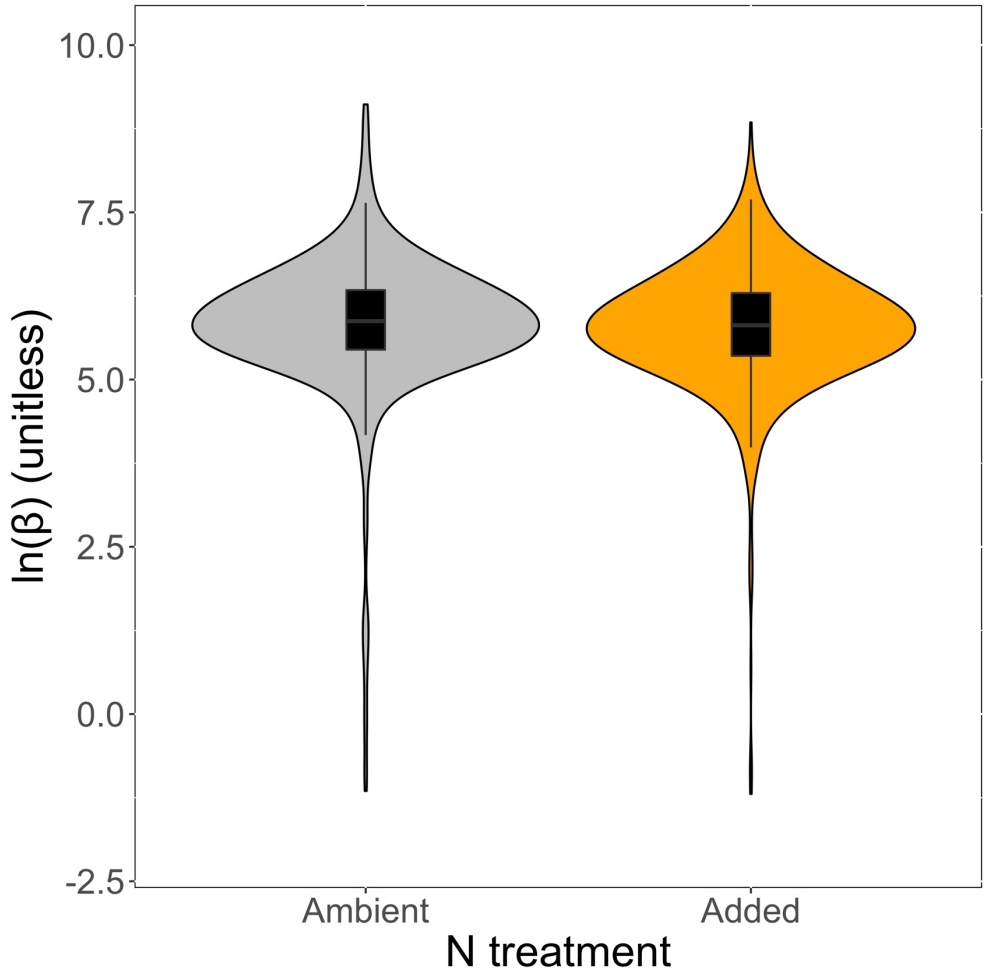




Firn et al. (2019)

Smith et al. (in prep)

Result: Reduction in relative N acquisition cost with increased N



Change is significant, but slight (-8%)

Smith et al. (in prep)

What should models be able to reproduce?

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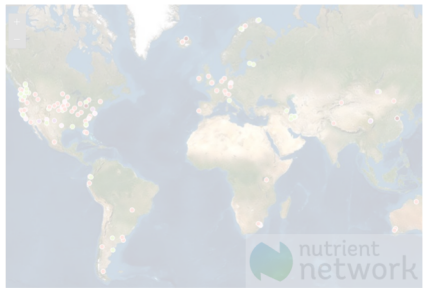
Soil nitrogen greenhouse manipulation

Grassland soil nitrogen manipulations



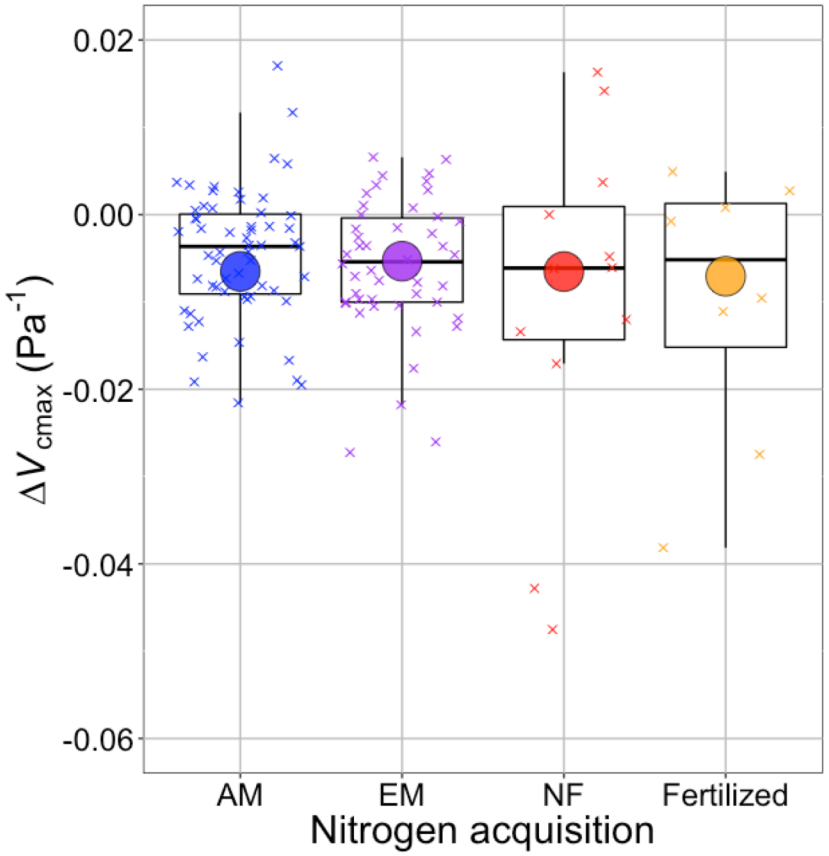
Forest soil nitrogen manipulation

Temperature and CO_2 manipulations

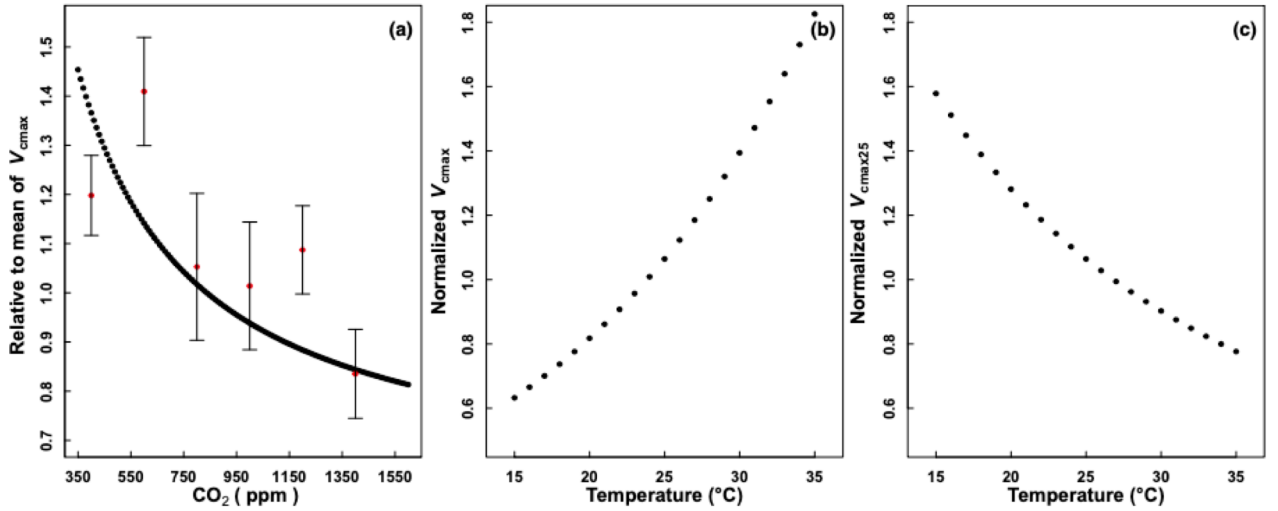
Temperature and CO_2 manipulations

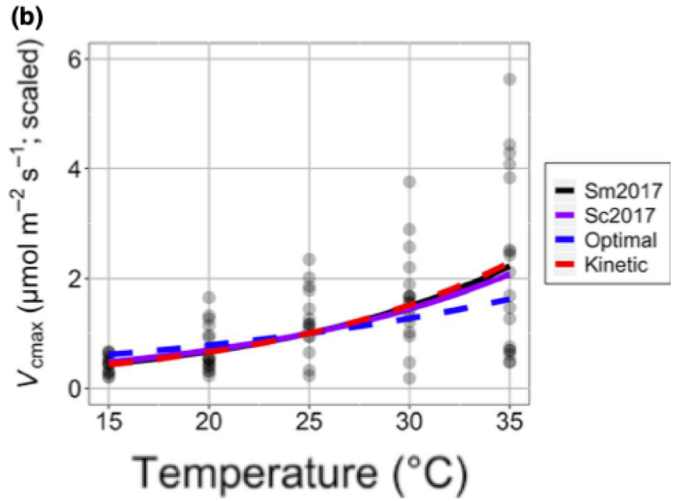
- Model-data testing
  - 2 temperature manipulation experiments
  - 31 elevated CO_2 experiments
- Leaf model simulations
- Canopy model simulations

Result: elevated temperature and CO_2 reduce leaf investment in photosynthetic biochemistry



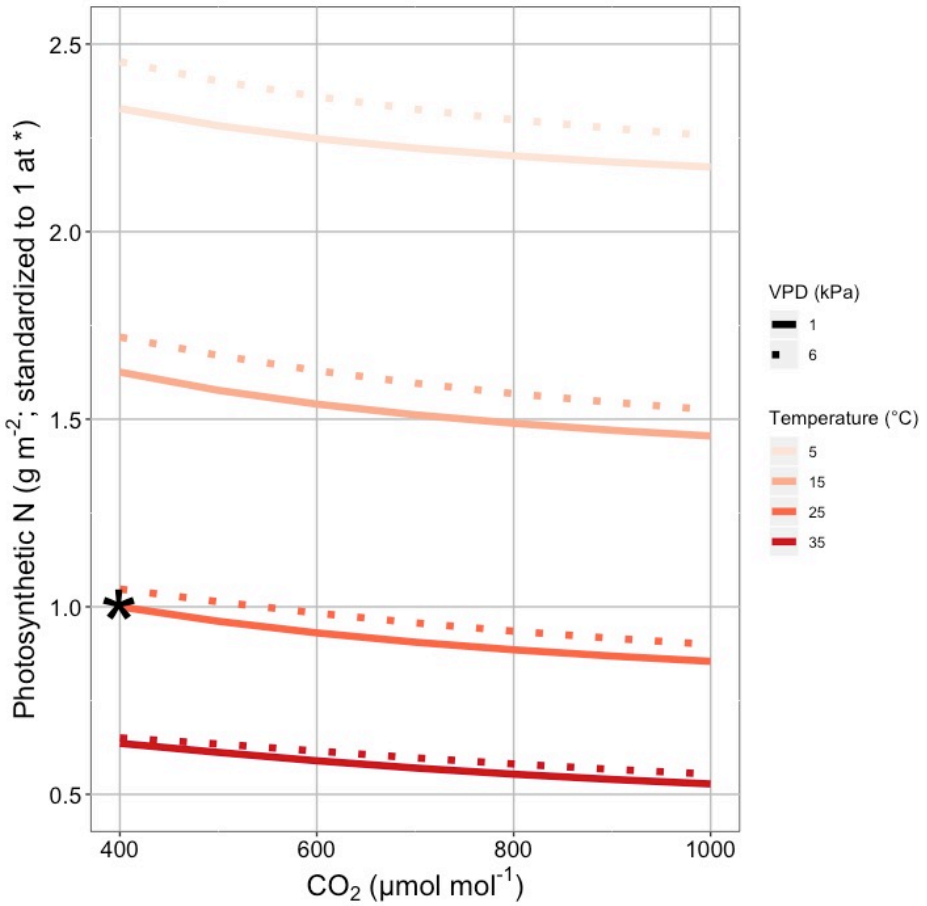
Smith and Keenan (2020)

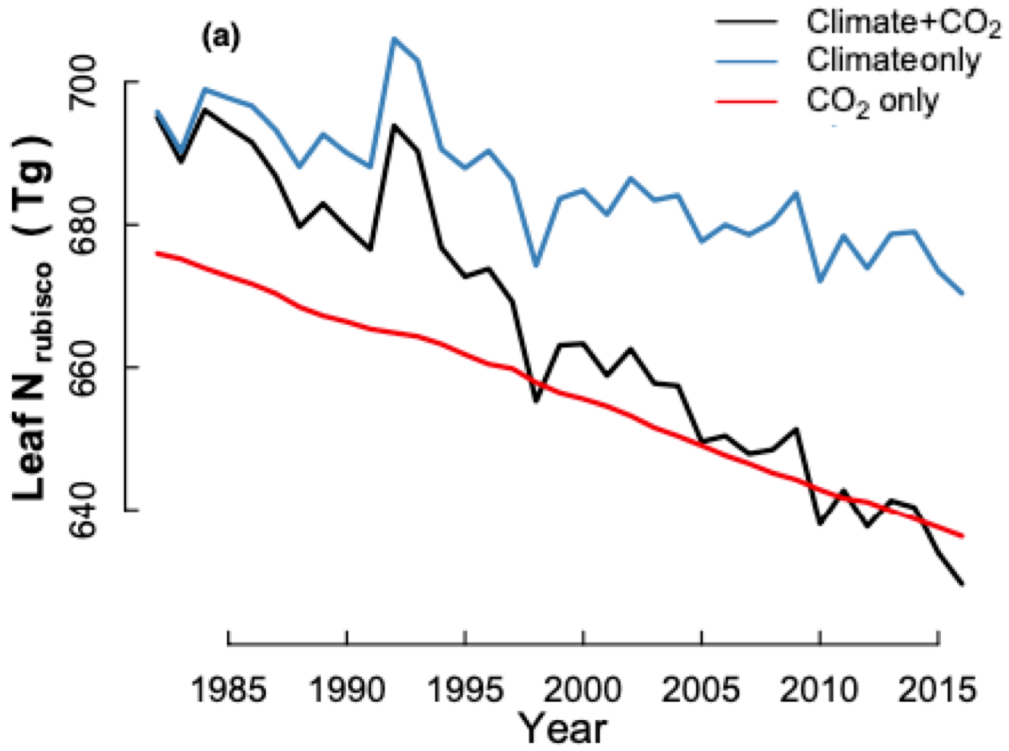




Dong et al. (2022)

Result: elevated temperature and CO_2 reduce leaf photosynthetic N

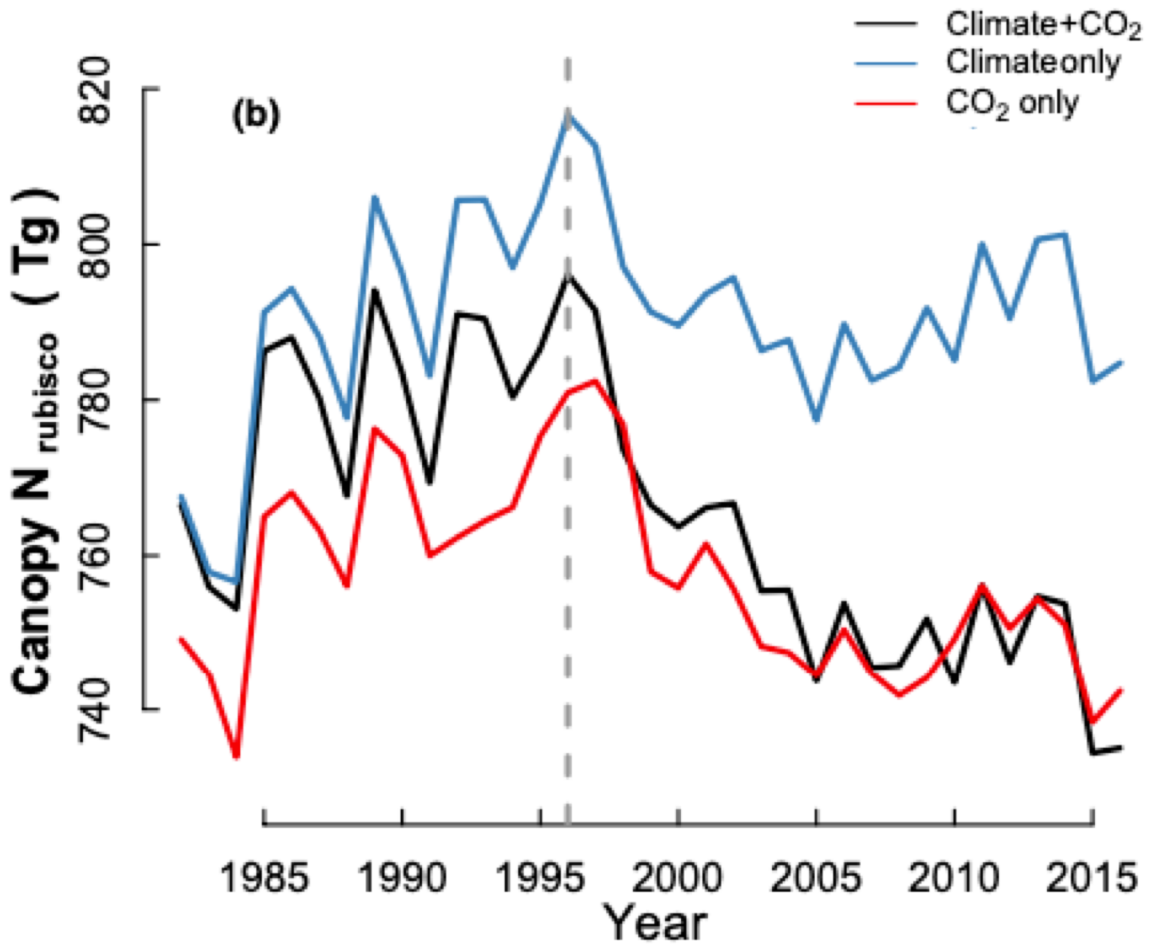




Smith and Keenan (2020)

Dong et al. (2022)

Result: elevated temperature and CO_2 reduce canopy N



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- Reduced N with elevated temperature and CO_2 √

What do models attempt to reproduce?

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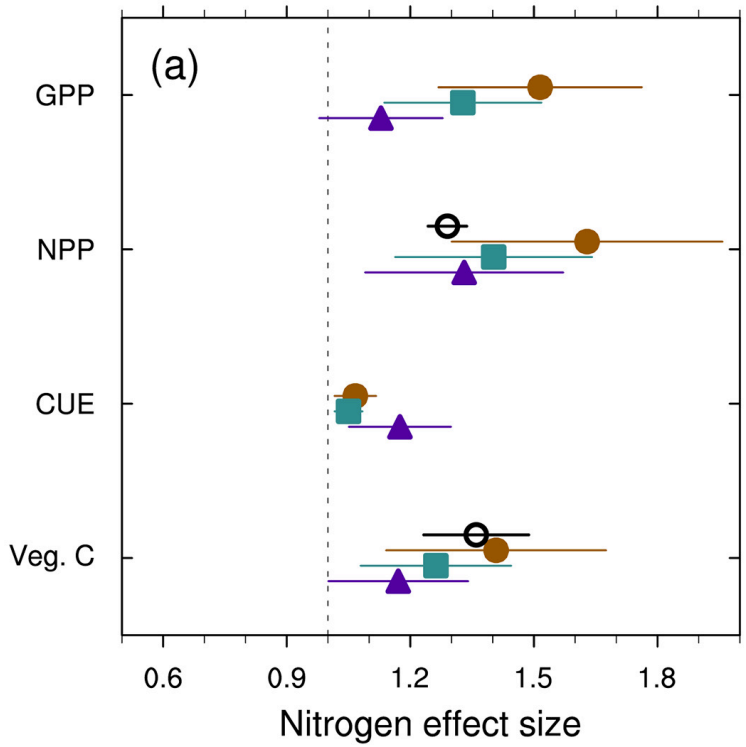
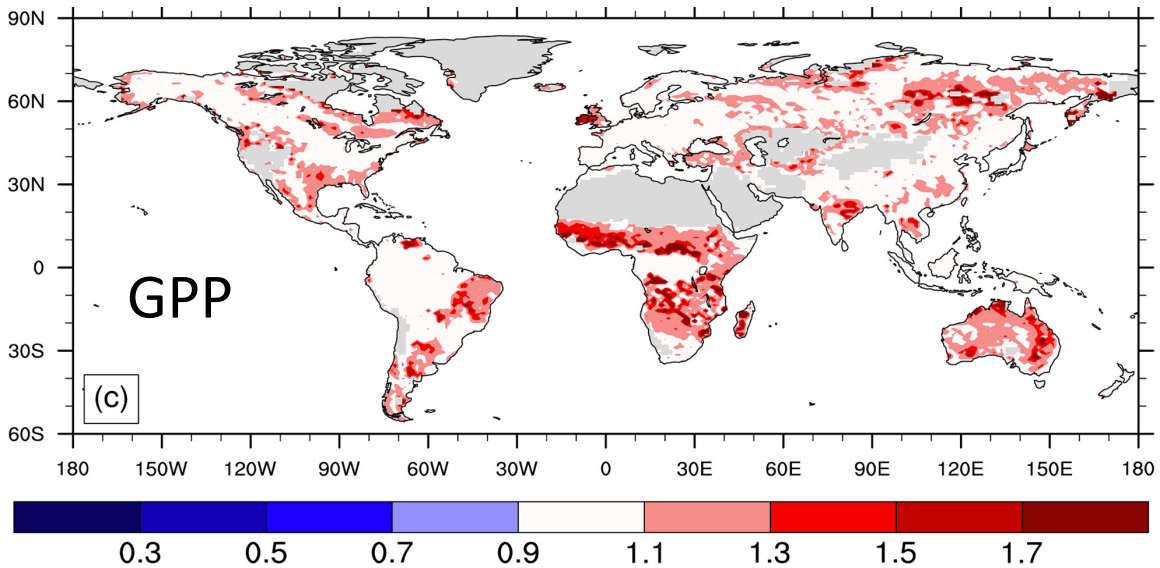
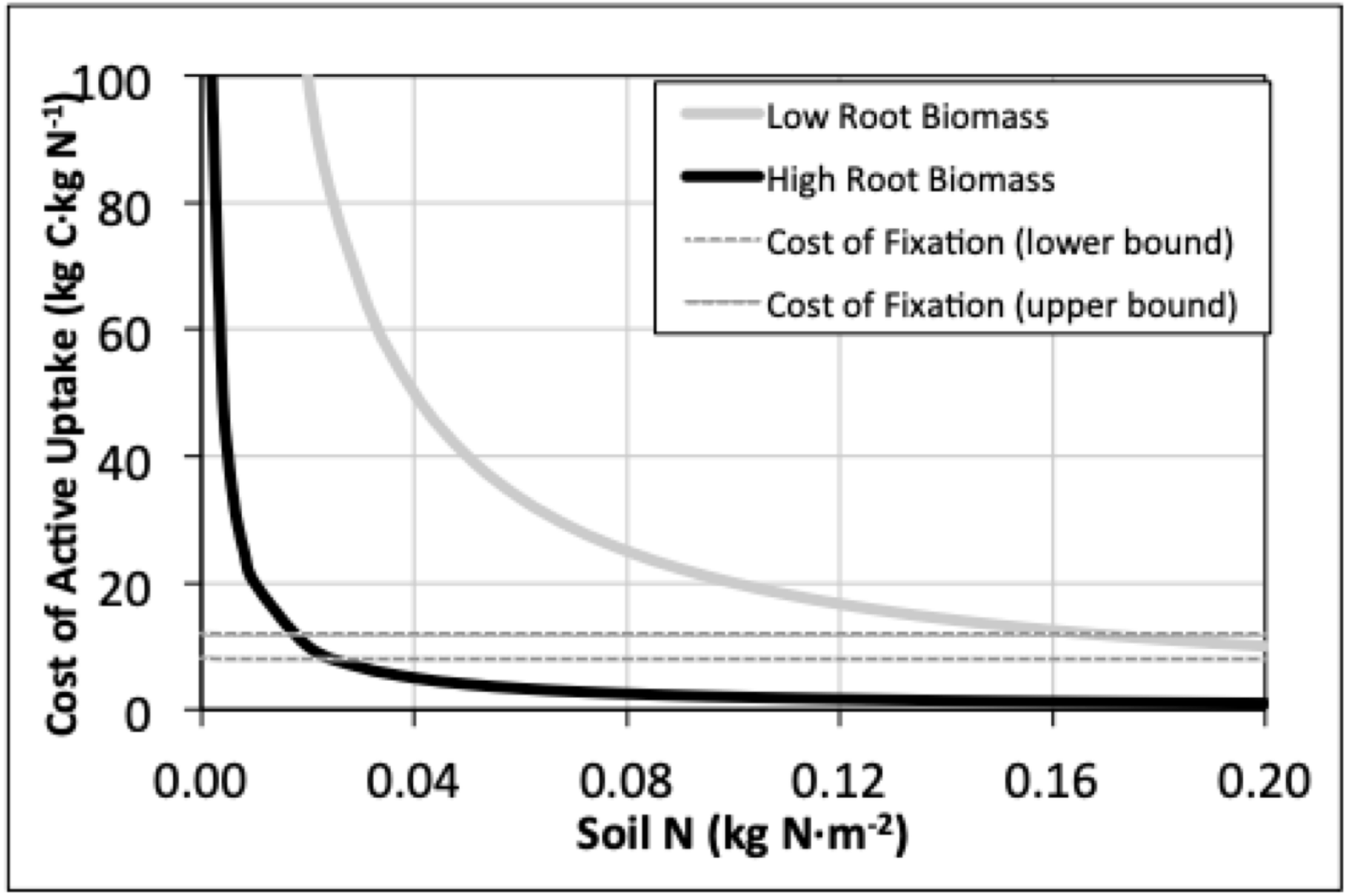




Effect of soil N addition in CLM 5

Wieder et al. (2019)



Effect of soil N on C cost of N uptake in FUN model

Fisher et al. (2010)

What can models reproduce reliably from theory?

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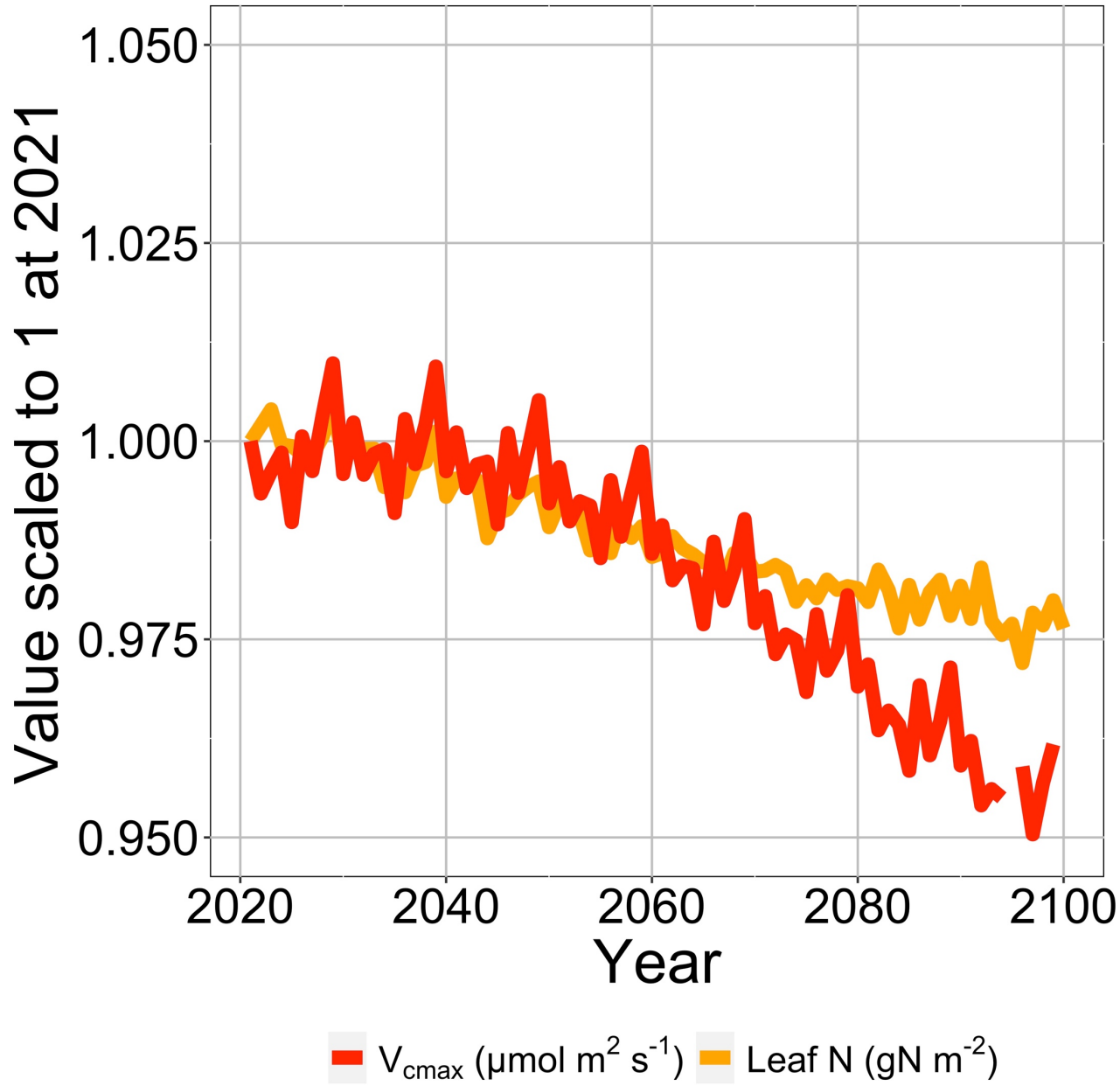
- Reduced N with elevated temperature and CO_2 √



Reduced future allocation to photosynthesis and leaf N in an ELM simulation modified with EEO photosynthesis

Smith et al. (in prep)

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