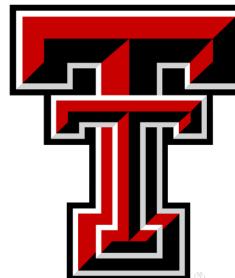


Modeling leaf responses to soil nitrogen availability

Nick Smith (Texas Tech University;
nick.smith@ttu.edu)

Evan Perkowski, Lizz Waring, Christy Goodale, Dave Frey, Qing Zhu, Bill Riley, Trevor Keenan



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

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

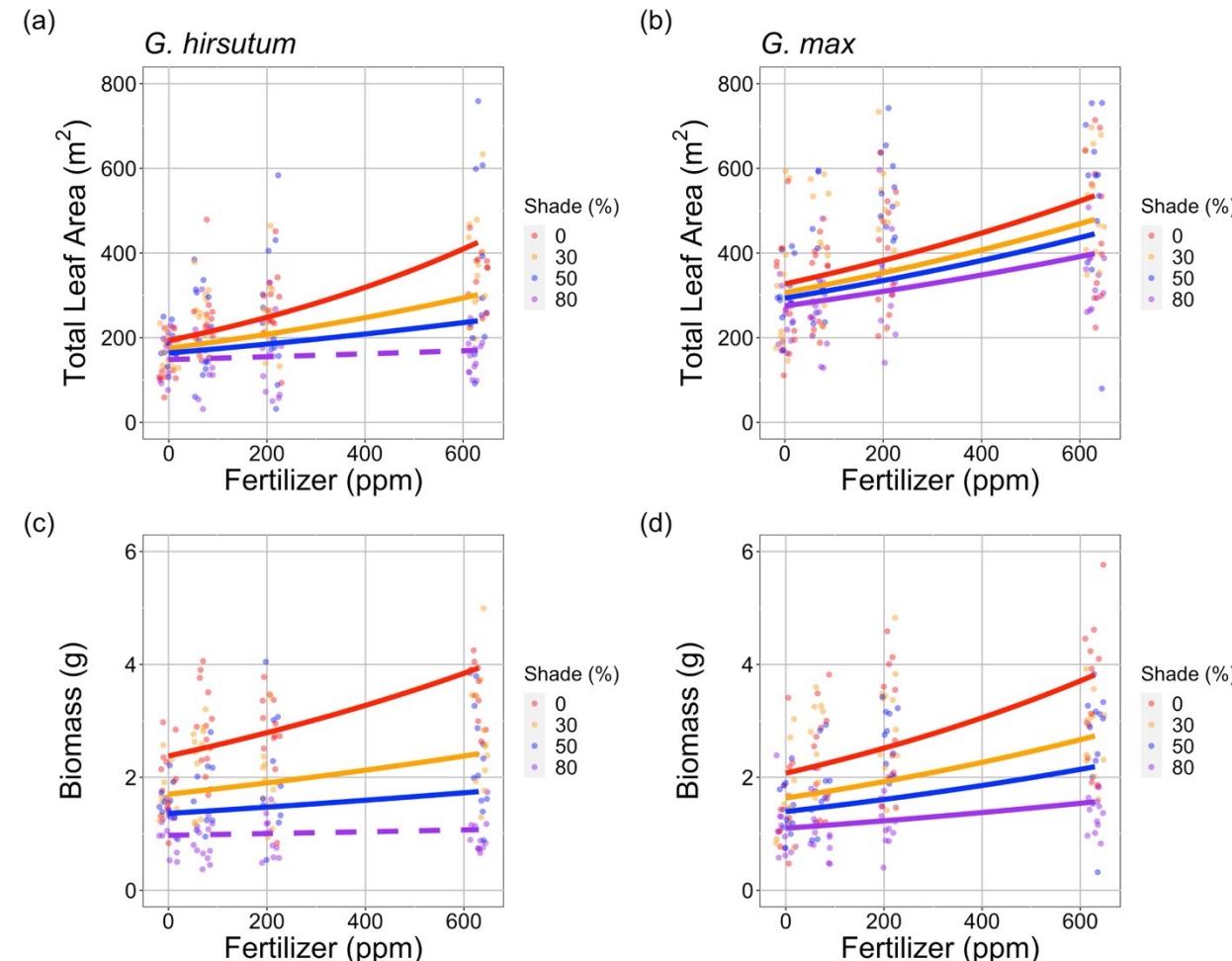
What should models be able to reproduce?

- Increased growth with increased soil N? ✓ - ✗
- Decreased C cost to acquire N with increased soil N in whole plants ✓, maybe in leaves ✗
- Increased tissue N with increased soil N ✓ ✎ ✗
- Decreased relative leaf N allocation to photosynthesis with increased soil N ✓ ✎
- Reduced N with elevated temperature and CO₂ ✓

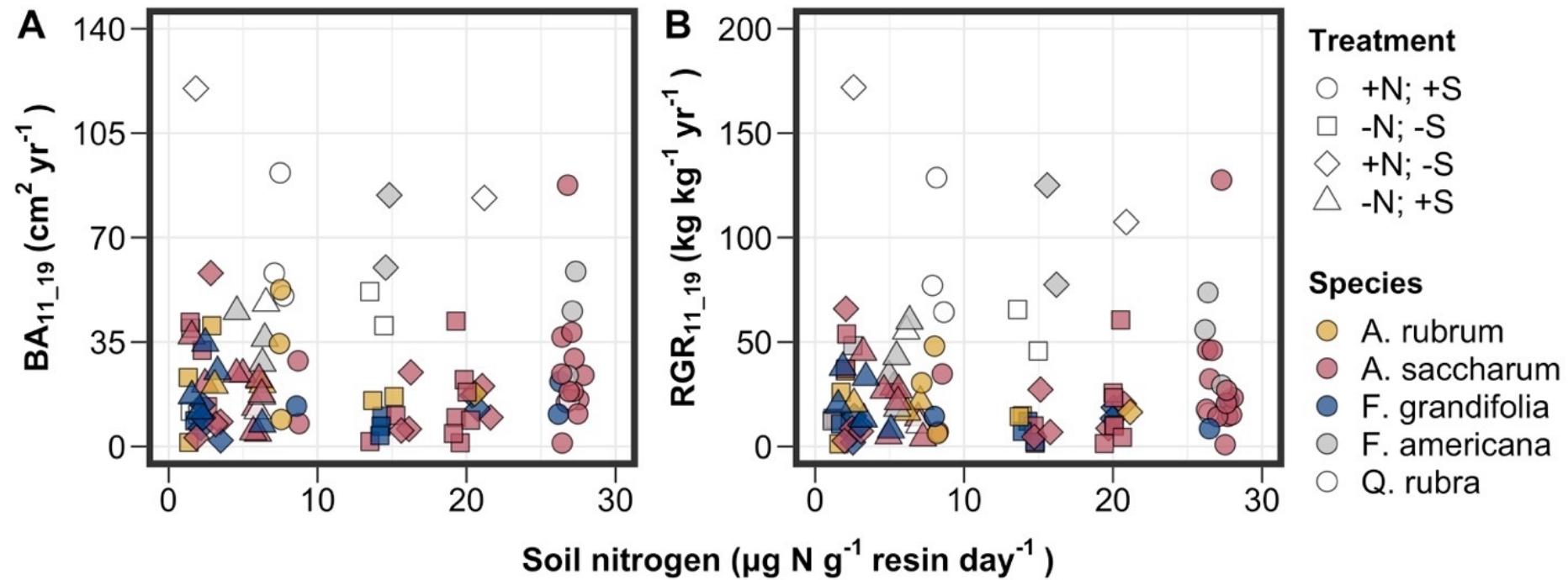
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- Reduced N with elevated temperature and CO₂ ✓

Growth increases with increasing soil N in greenhouse



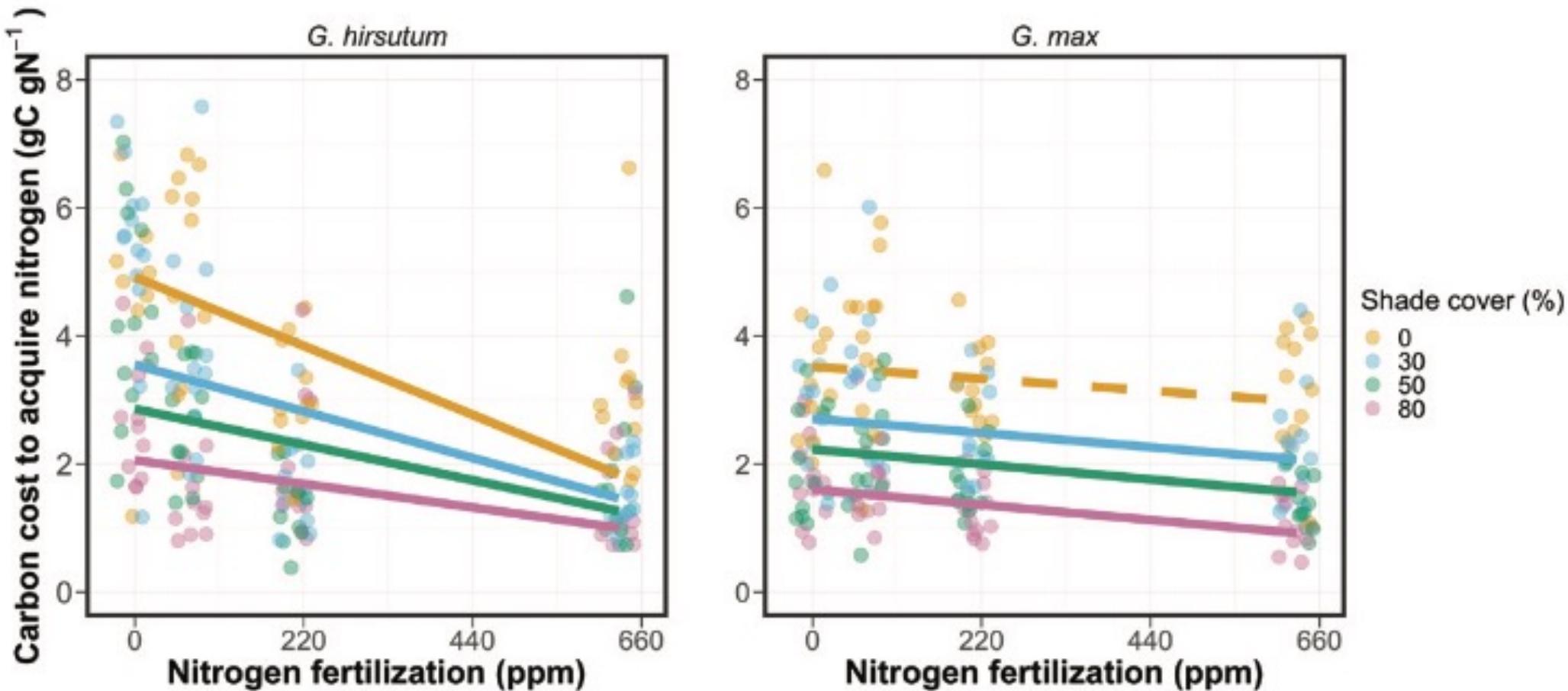
Growth unchanged with increasing soil N in closed canopy forest



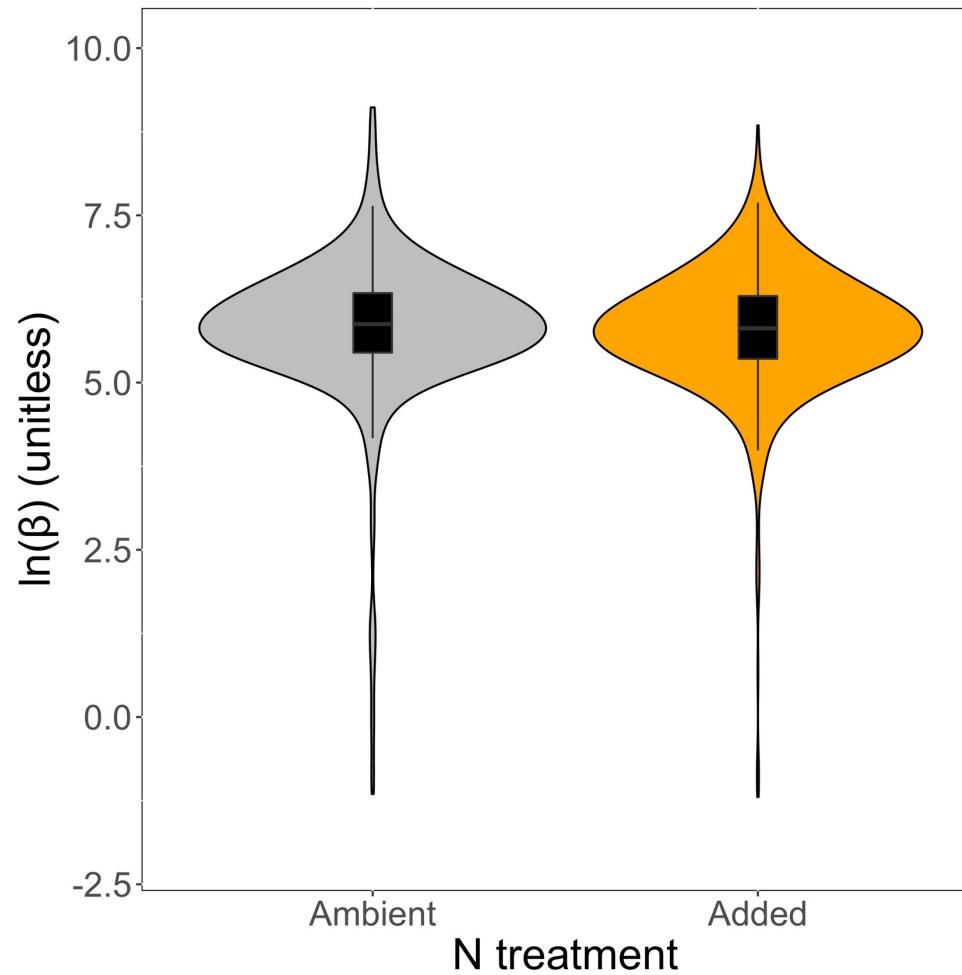
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soil N ✓ ✓
- Reduced N with elevated temperature and CO₂ ✓

C cost to acquire N decreases with increasing soil N



Reduction in relative N acquisition cost with increased N



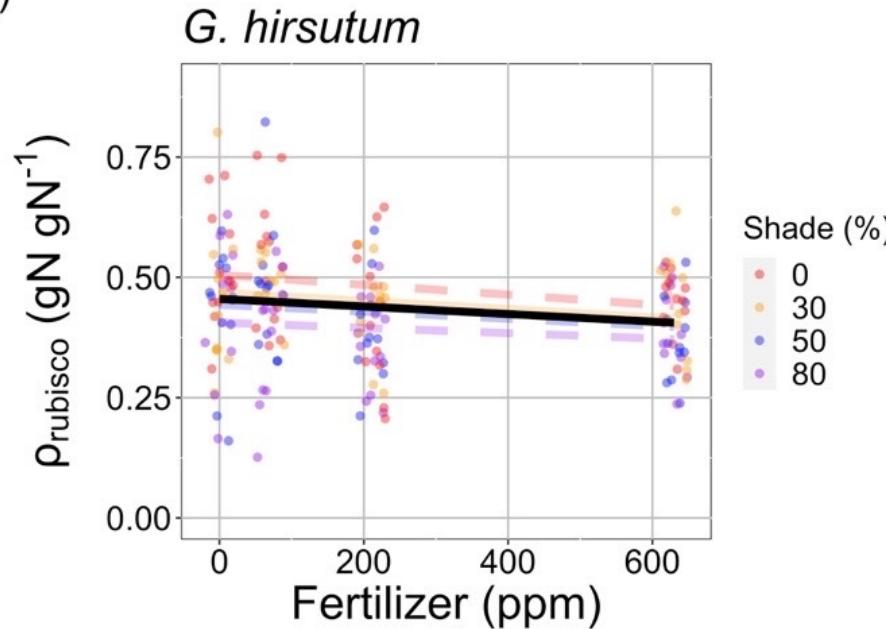
Change is significant,
but slight (-8%)

What should models be able to reproduce?

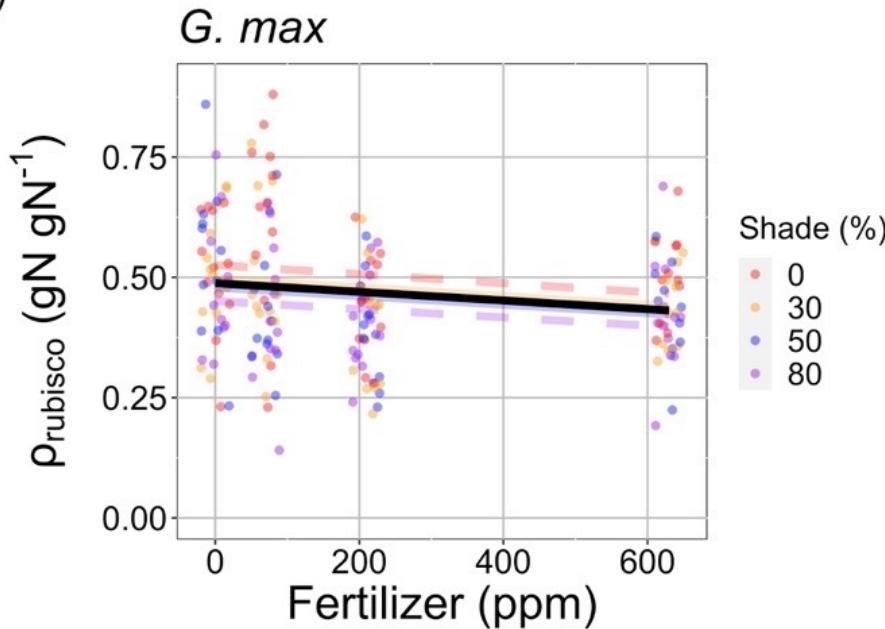
- Increased growth with increased soil N ✓ - ✓
- Decreased C cost to acquire N with increased soil N in whole plants ✓,
maybe in leaves ✓
- Increased tissue N with increased soil N ✓ ✓ ✓
- Decreased relative leaf N allocation to photosynthesis with increased
soil N ✓ ✓
- Reduced N with elevated temperature and CO₂ ✓

Relative leaf N allocation to photosynthesis decreases with increasing soil N

(a)



(b)

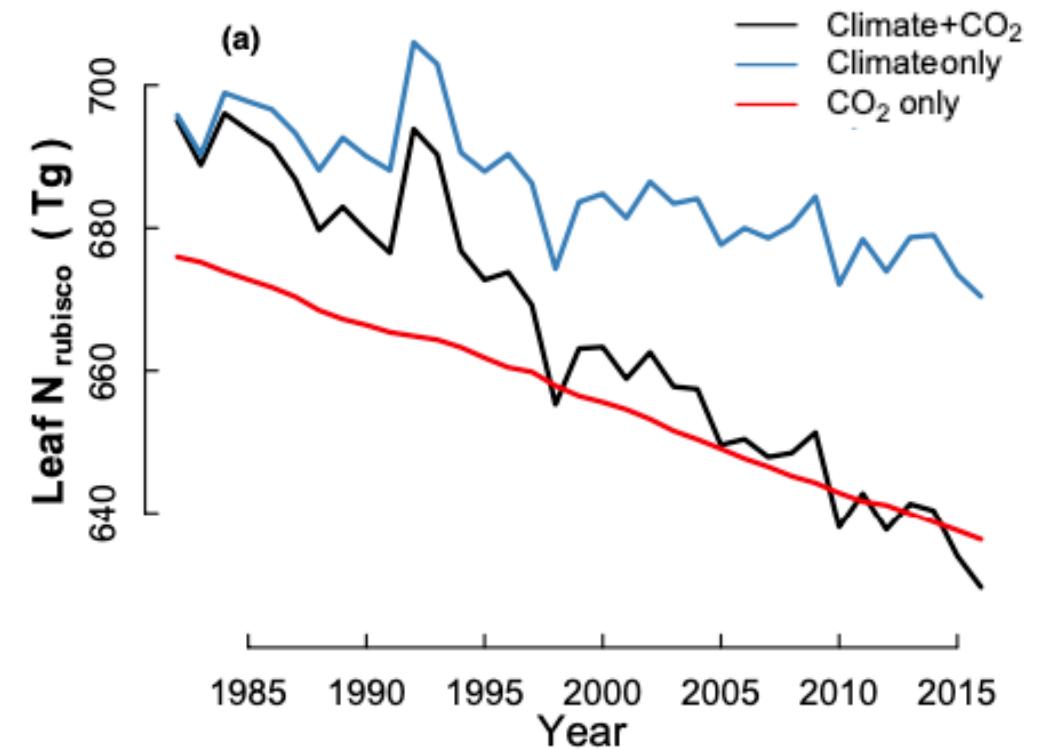
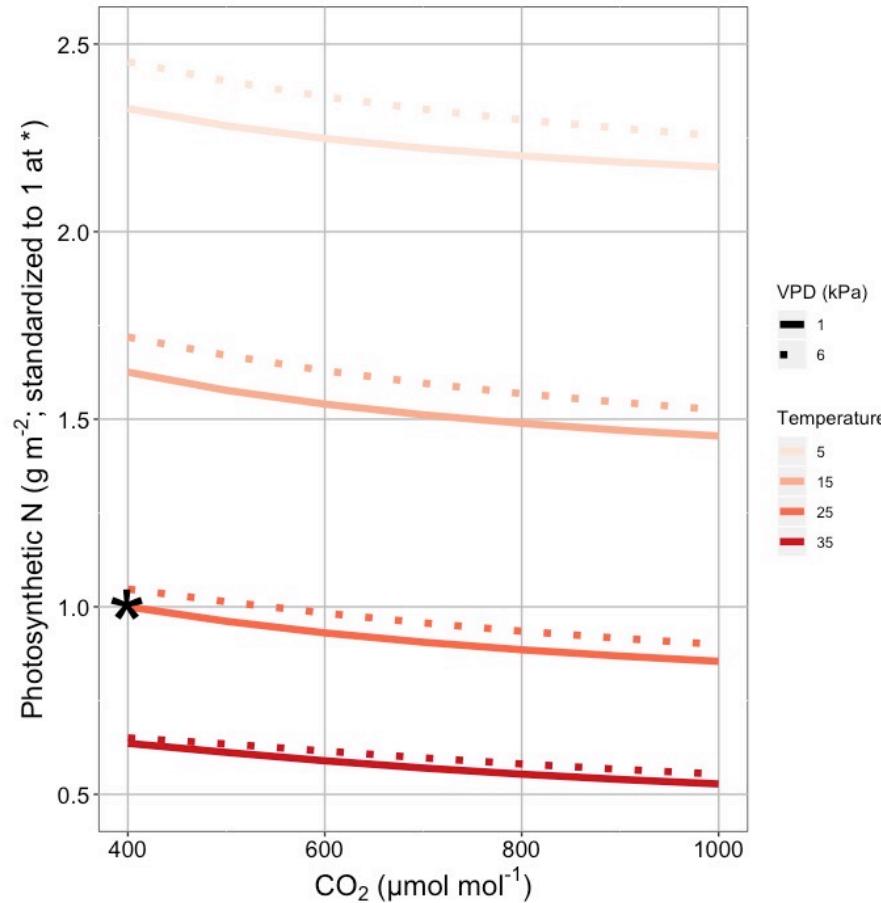


Consistent across all species, treatments, and photosynthetic components (Rubisco, bioenergetics, light harvesting)

What should models be able to reproduce?

- Increased growth with increased soil N ✓ - ✓
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- Increased tissue N with increased soil N ✓ ✓ ✓
- Decreased relative leaf N allocation to photosynthesis with increased soil N ✓ ✓
- Reduced N with elevated temperature and CO₂ ✓

Elevated temperature and CO₂ reduce leaf photosynthetic N



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 ✓ ✓
- Reduced N with elevated temperature and CO₂ ✓

What do models attempt to reproduce?

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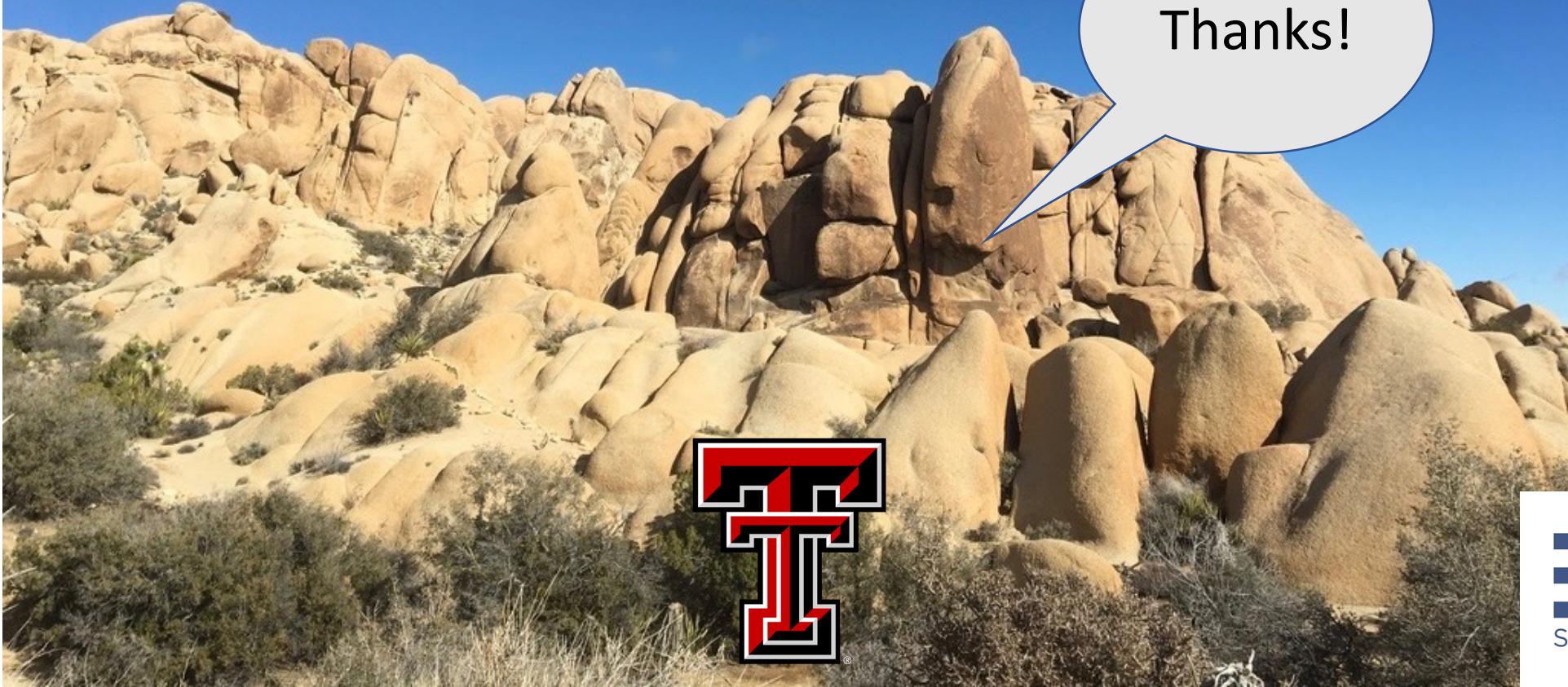
- Increased growth with increased soil N ✓ - ✓
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- Increased tissue N with increased soil N ✓ ✓ ✓
- Decreased relative leaf N allocation to photosynthesis with increased soil N ✓ ✓
- Reduced N with elevated temperature and CO₂ ✓

What can models reproduce reliably from theory?

What can models reproduce reliably from theory?

- 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 ✓ ✓
- Reduced N with elevated temperature and CO₂ ✓

Presentation available at:
www.github.com/SmithEcophysLab/mmee_2022



Soil nitrogen greenhouse
manipulation



Grassland soil nitrogen
manipulations



Temperature and CO₂
manipulations



Forest soil nitrogen
manipulation



Soil nitrogen greenhouse manipulation



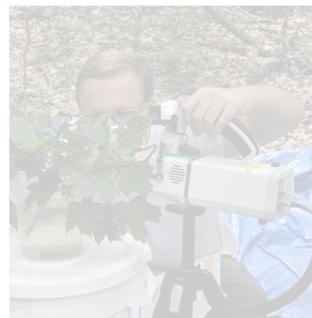
Grassland soil nitrogen manipulations



Temperature and CO₂ manipulations



Forest soil nitrogen manipulation

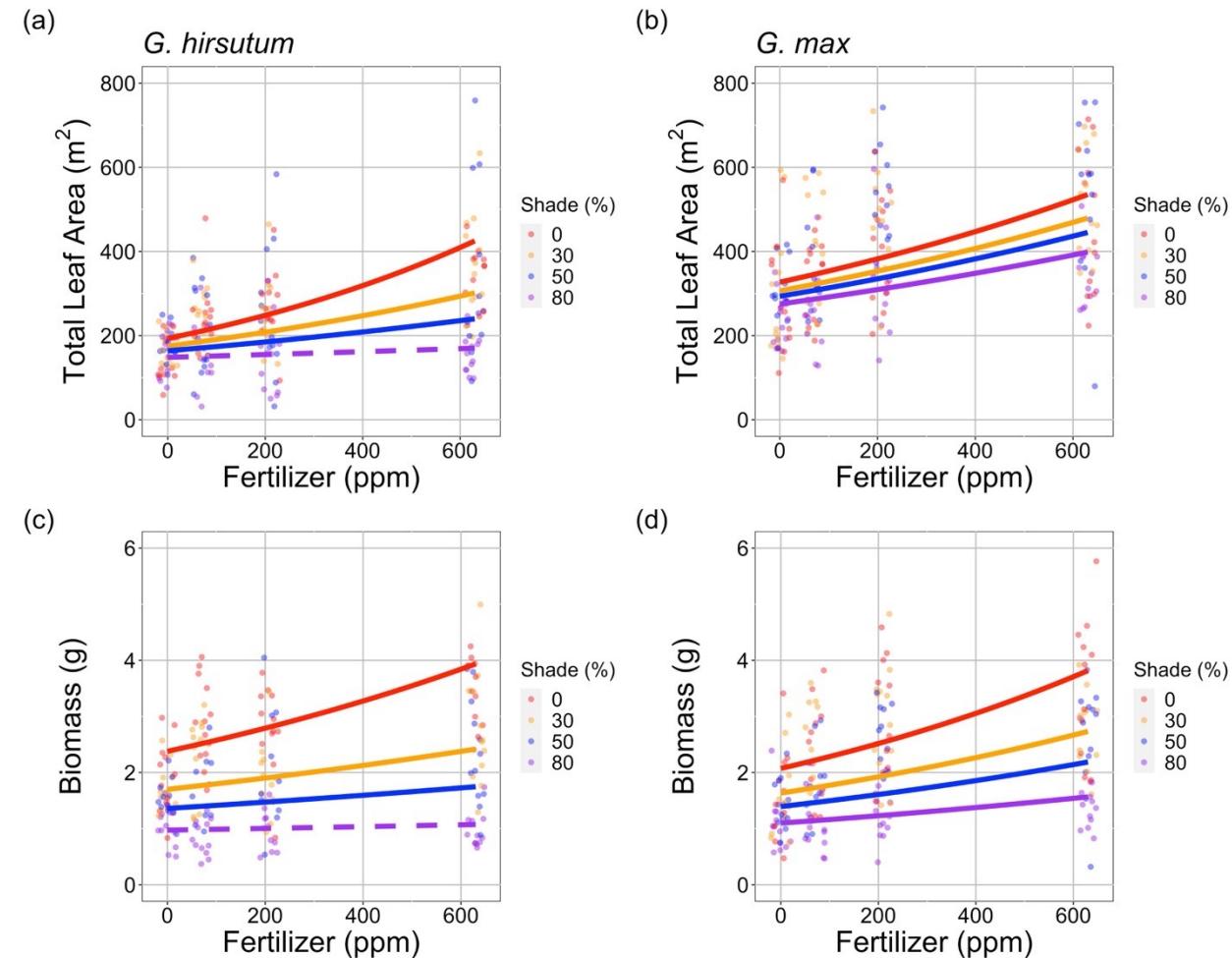


Soil N greenhouse manipulation

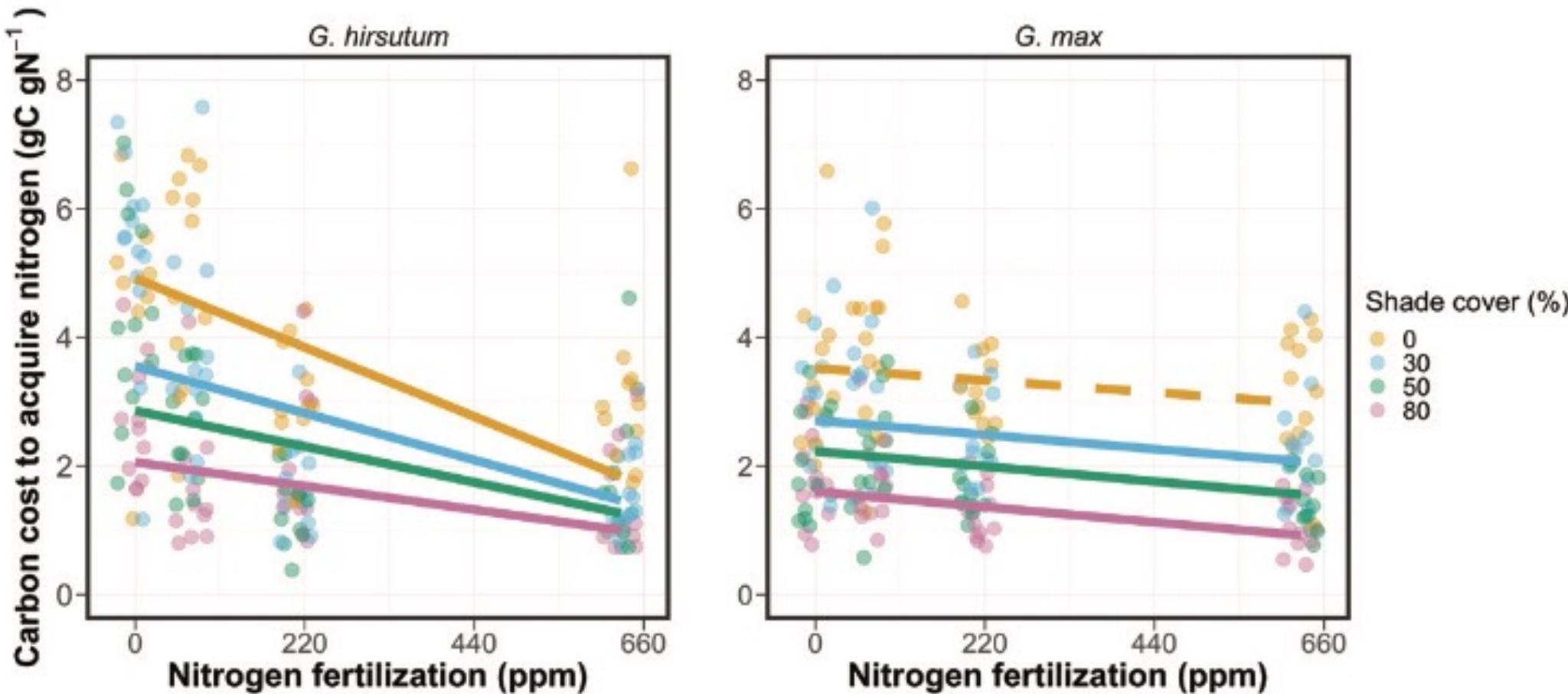
- 4 levels of nitrogen fertilization to low N field soil
 - 0 ppm N – 630 ppm N added twice per week
- 4 levels of light availability
 - Full light ($1662 \mu\text{mol m}^{-2} \text{s}^{-1}$ PAR) to 80% shade
- 2 species
 - Cotton (non-N fixing) and soybean (N fixing)
- Full factorial
- Physiology, allocation,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



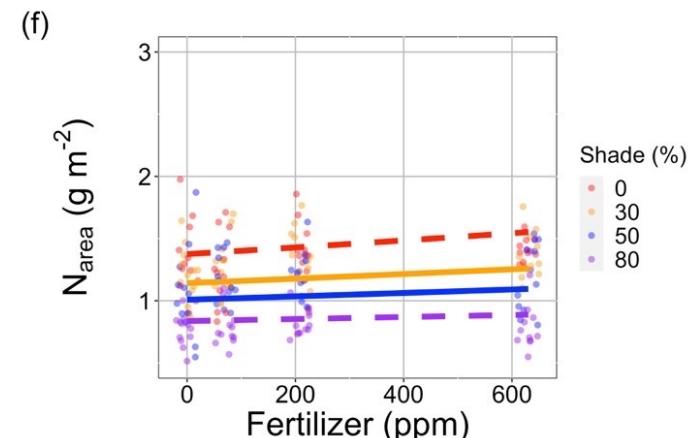
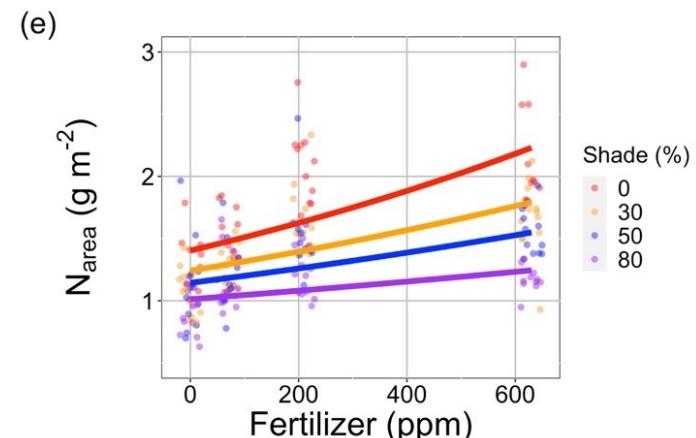
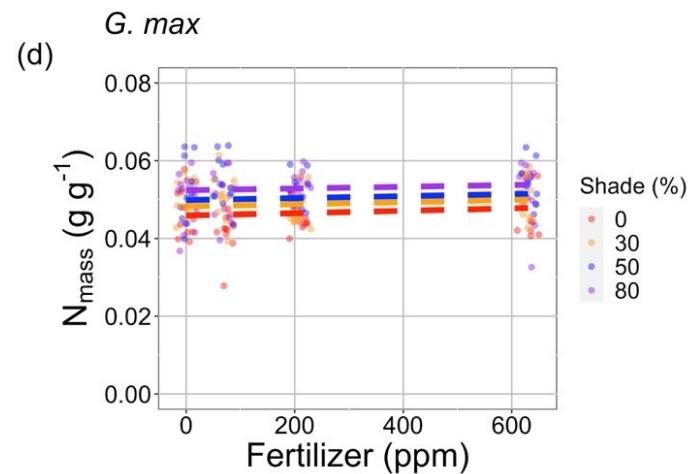
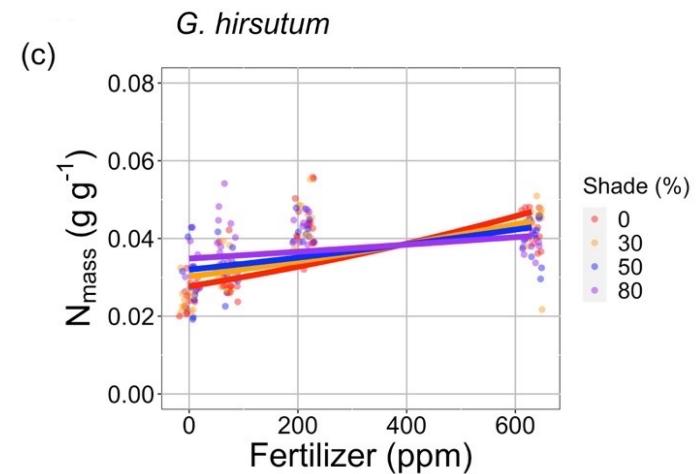
Result: Growth increases with increasing soil N



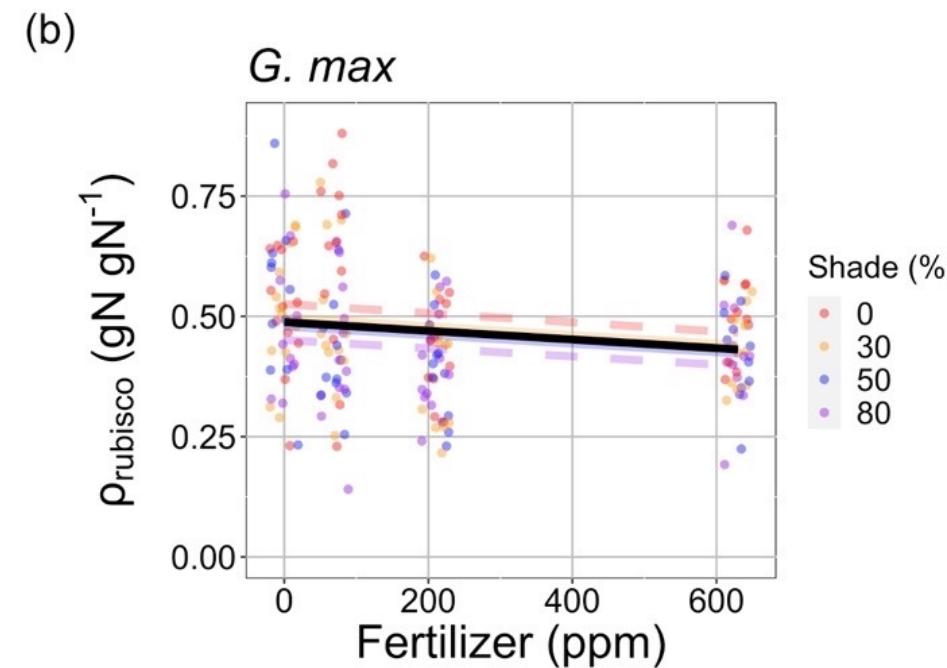
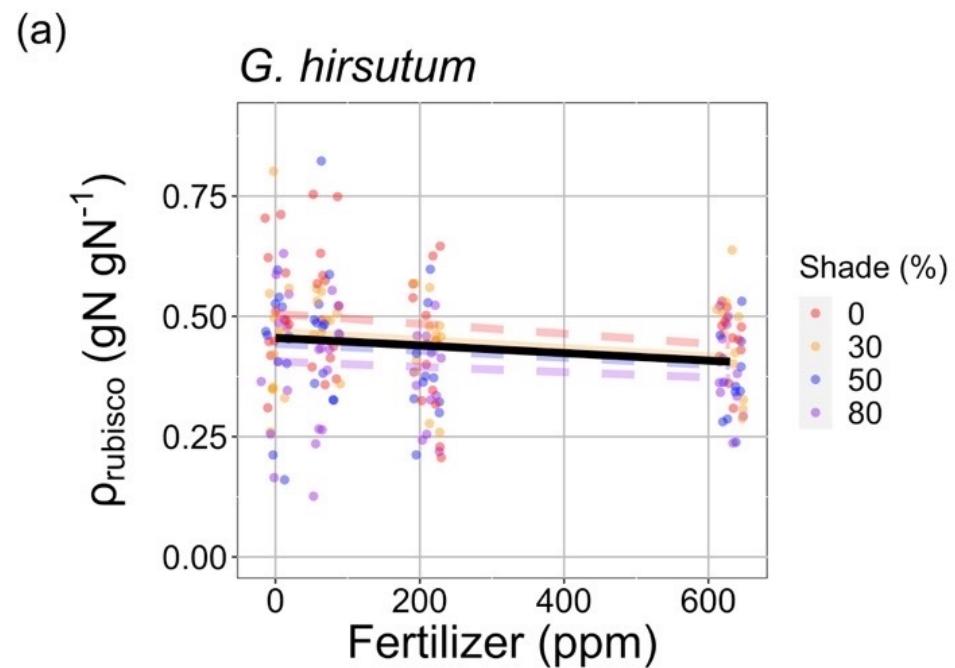
Result: C cost to acquire N decreases with increasing soil N



Result: Tissue N increases with increasing soil N



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



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

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 ✓

Grassland soil nitrogen
manipulations



Soil nitrogen greenhouse
manipulation



Temperature and CO₂
manipulations



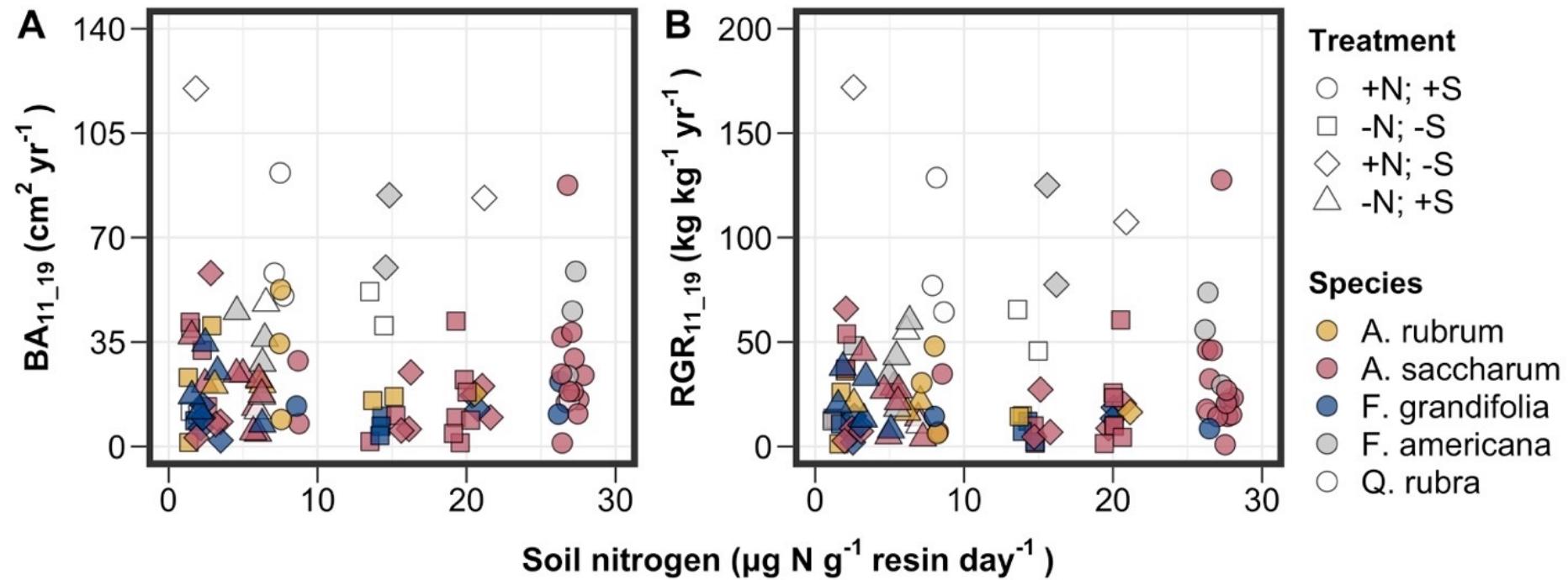
Forest soil nitrogen
manipulation

Forest soil N manipulation

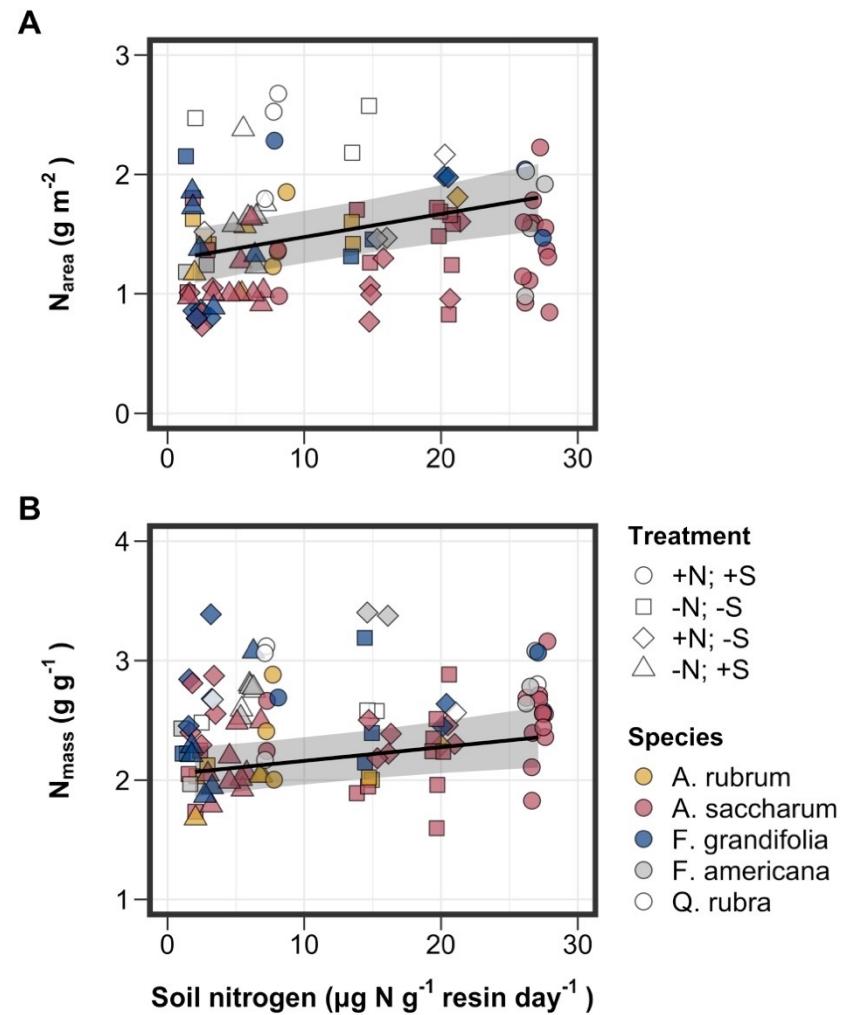
- Closed canopy forest in Ithaca, NY
 - Various deciduous trees
- 2 levels of nitrogen fertilization
 - 0 or 50 kg N $\text{ha}^{-1} \text{ yr}^{-1}$
- 2 levels of sulfur fertilization
 - 0 or 50 kg S $\text{ha}^{-1} \text{ yr}^{-1}$
- Full factorial
- Physiology and growth measured



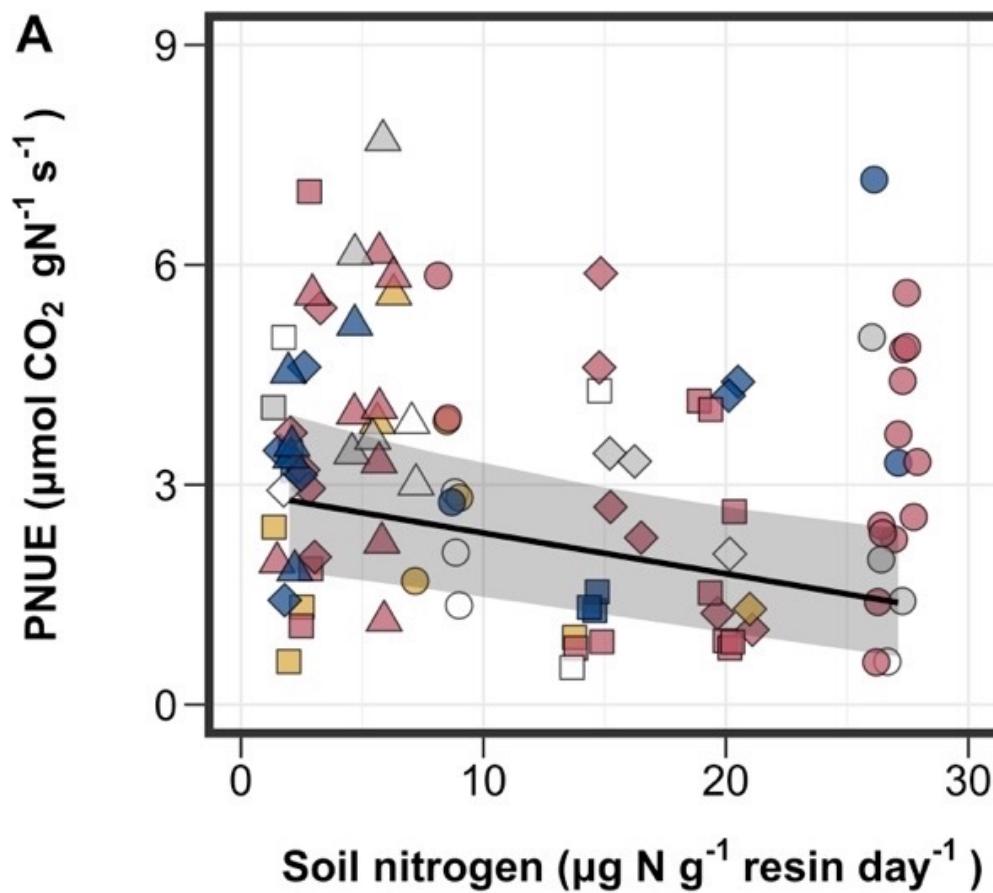
Result: Growth unchanged with increasing soil N



Result: Tissue N increases with increasing soil N



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



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 ✓ ✓

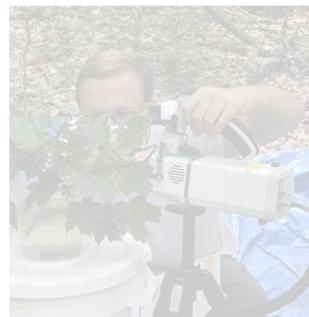
**Grassland soil nitrogen
manipulations**



Soil nitrogen greenhouse
manipulation



Temperature and CO₂
manipulations



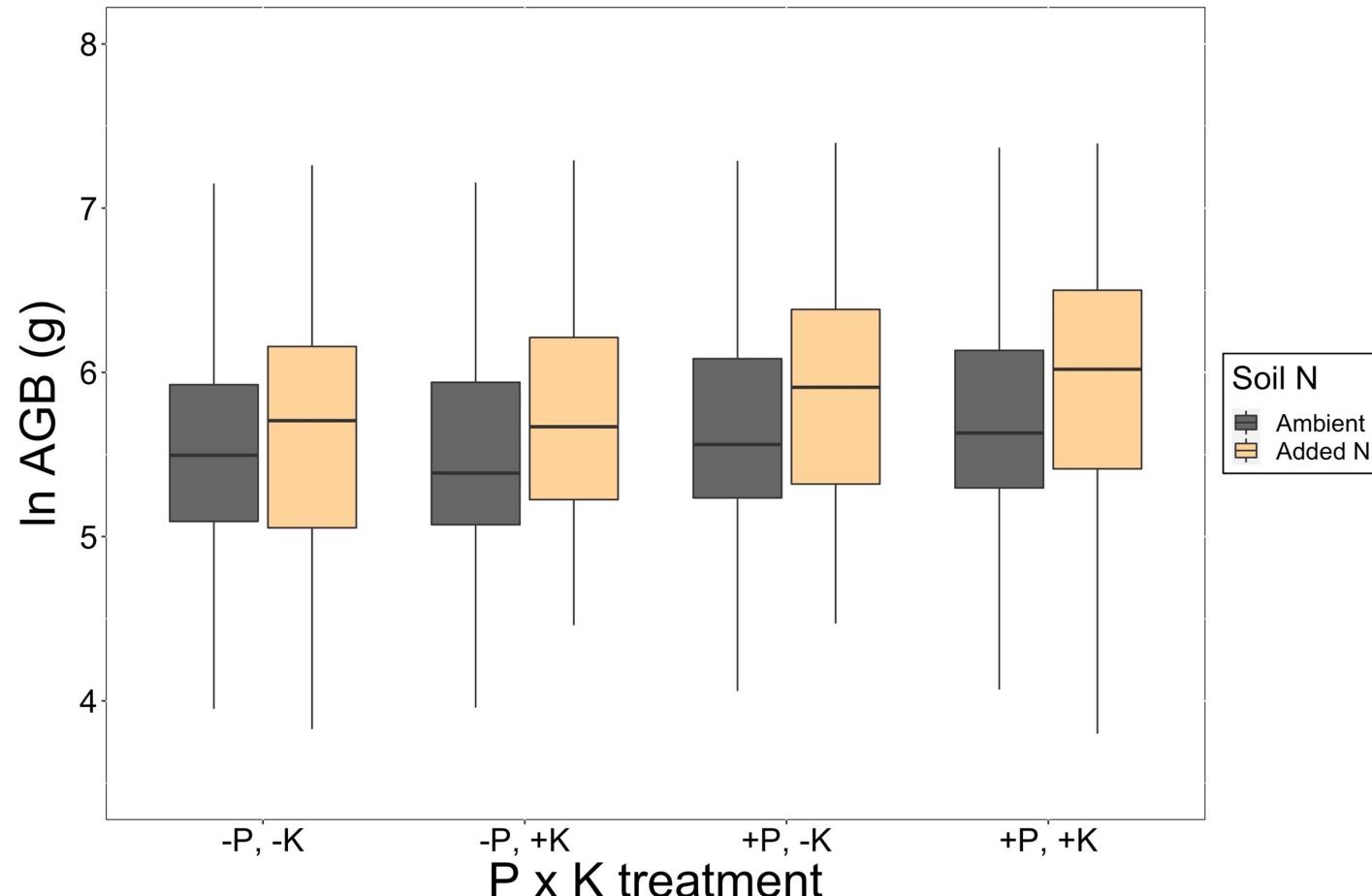
Forest soil nitrogen
manipulation

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 $\delta^{13}\text{C}$
- $\delta^{13}\text{C}$ used to compute ratio of intercellular to extracellular CO_2 and carbon cost ratio of soil resource uptake

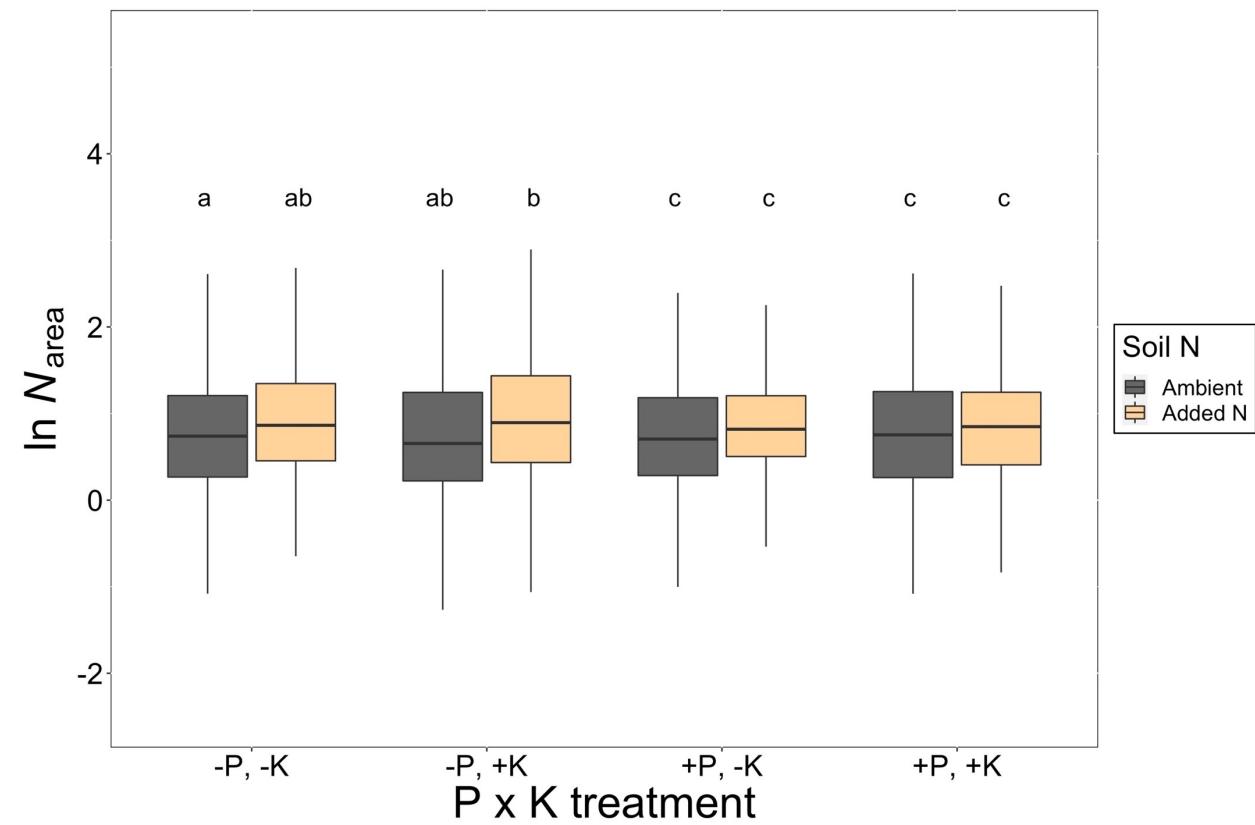
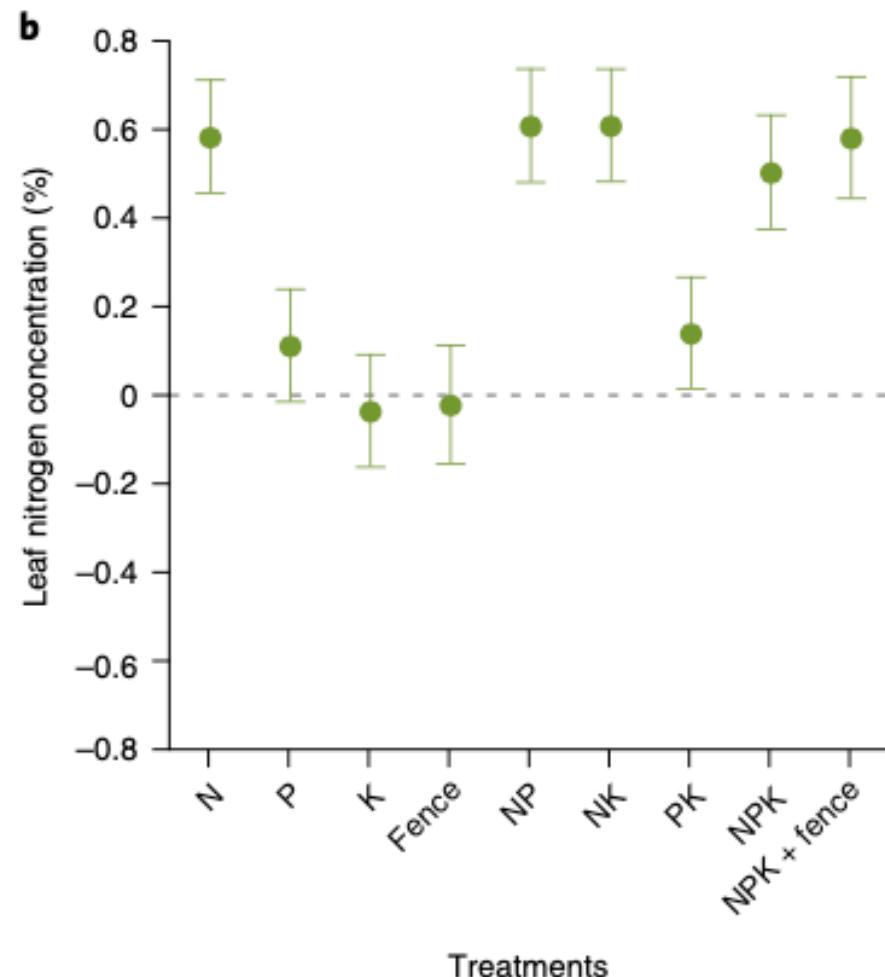


Result: Growth increases with increasing soil N

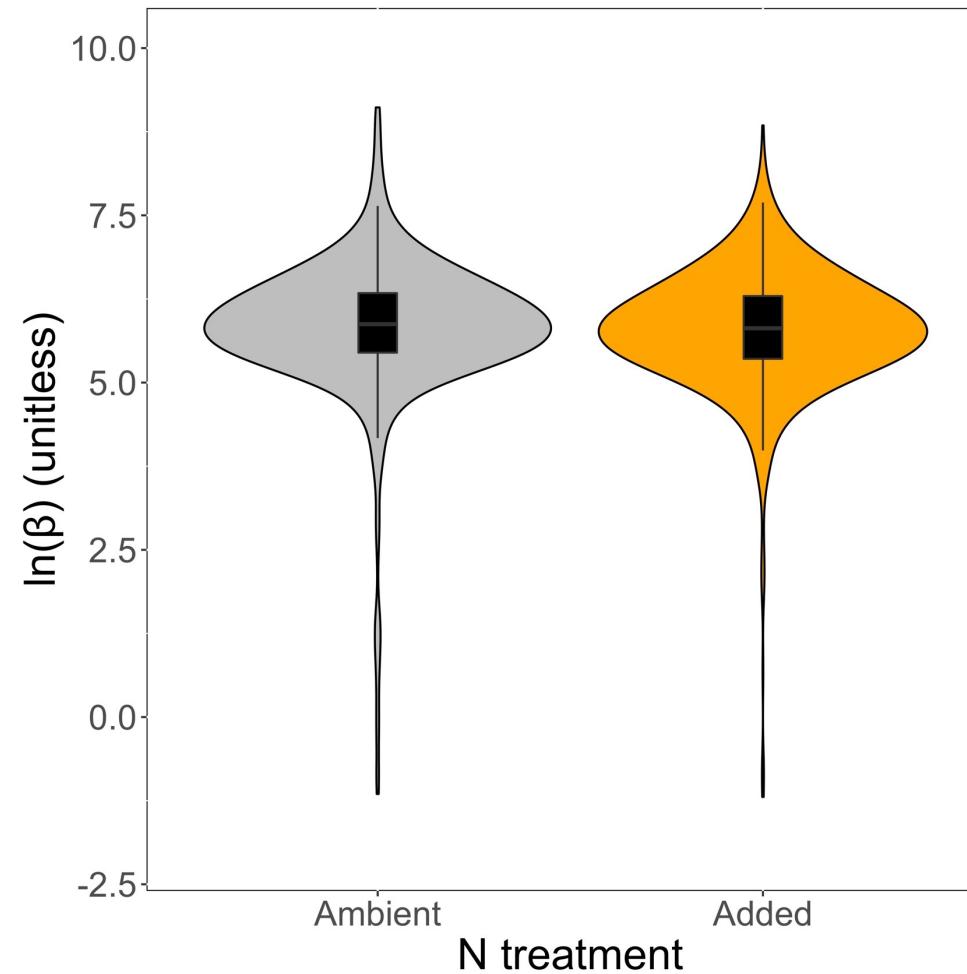


Always increases
regardless of P and K

Result: Tissue N increases with increasing soil N



Result: Reduction in relative N acquisition cost with increased N



Change is significant,
but slight (-8%)

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 ✓ ✓

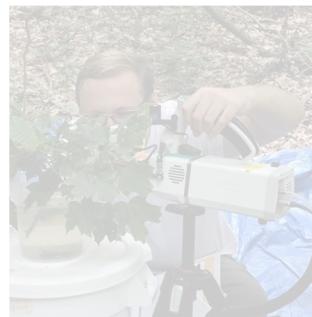
Grassland soil nitrogen
manipulations



Soil nitrogen greenhouse
manipulation



Forest soil nitrogen
manipulation



Temperature and CO₂
manipulations

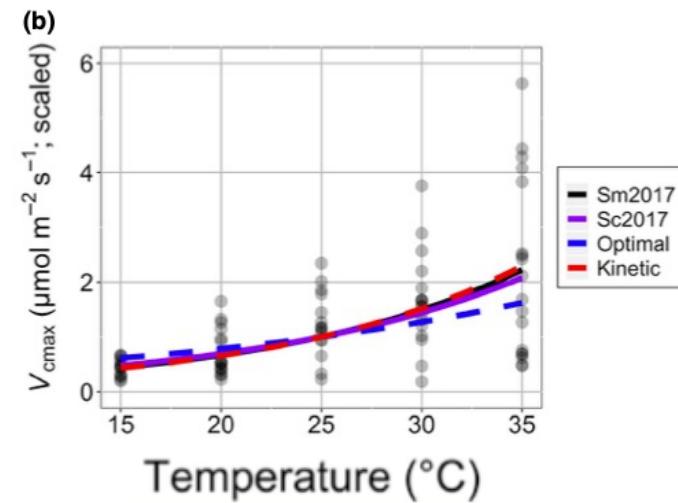
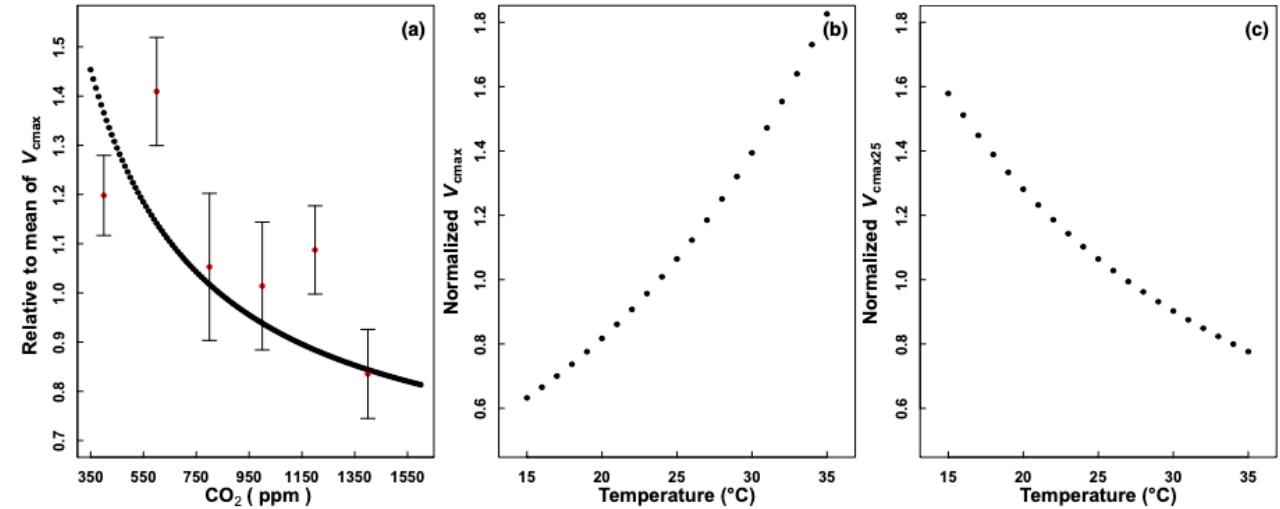
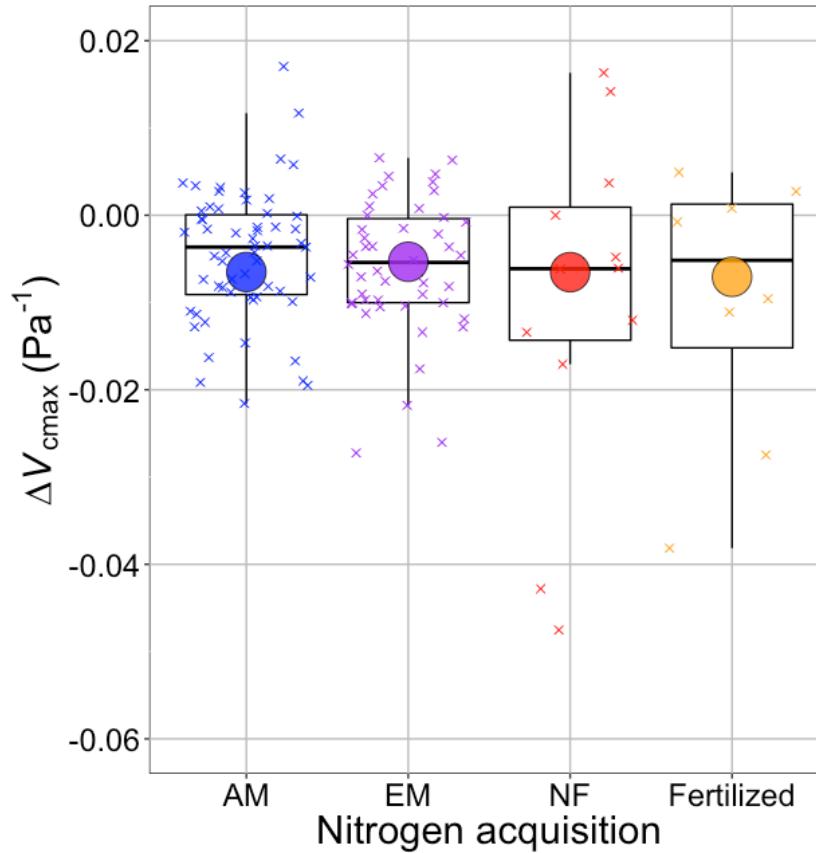


Temperature and CO₂ manipulations

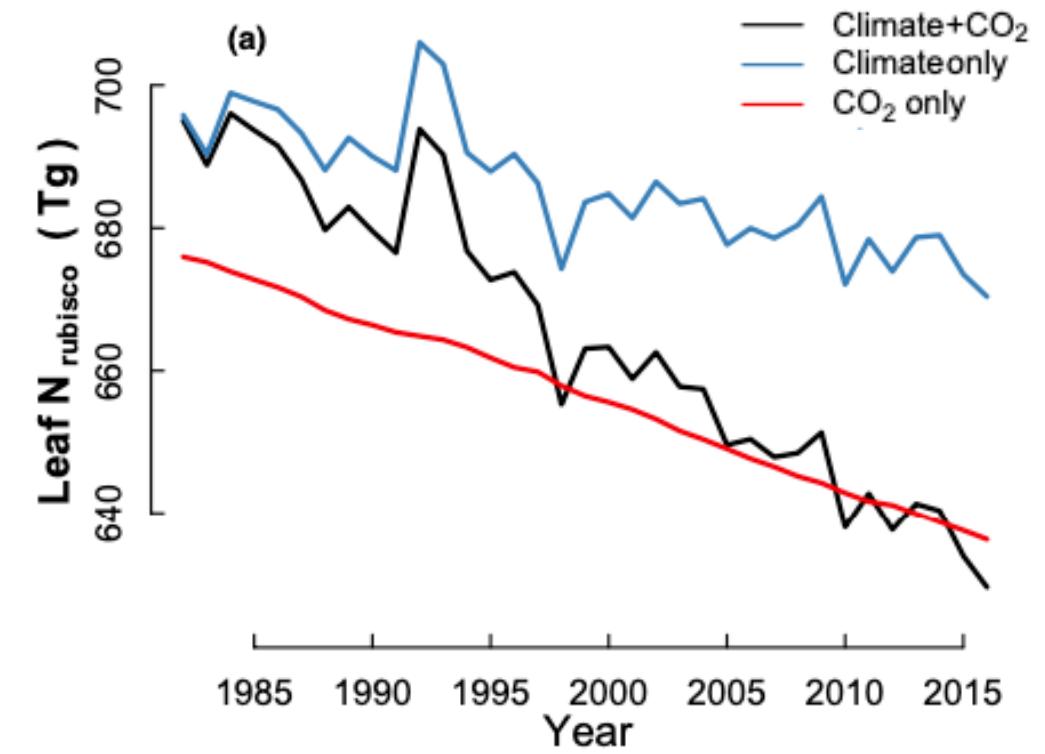
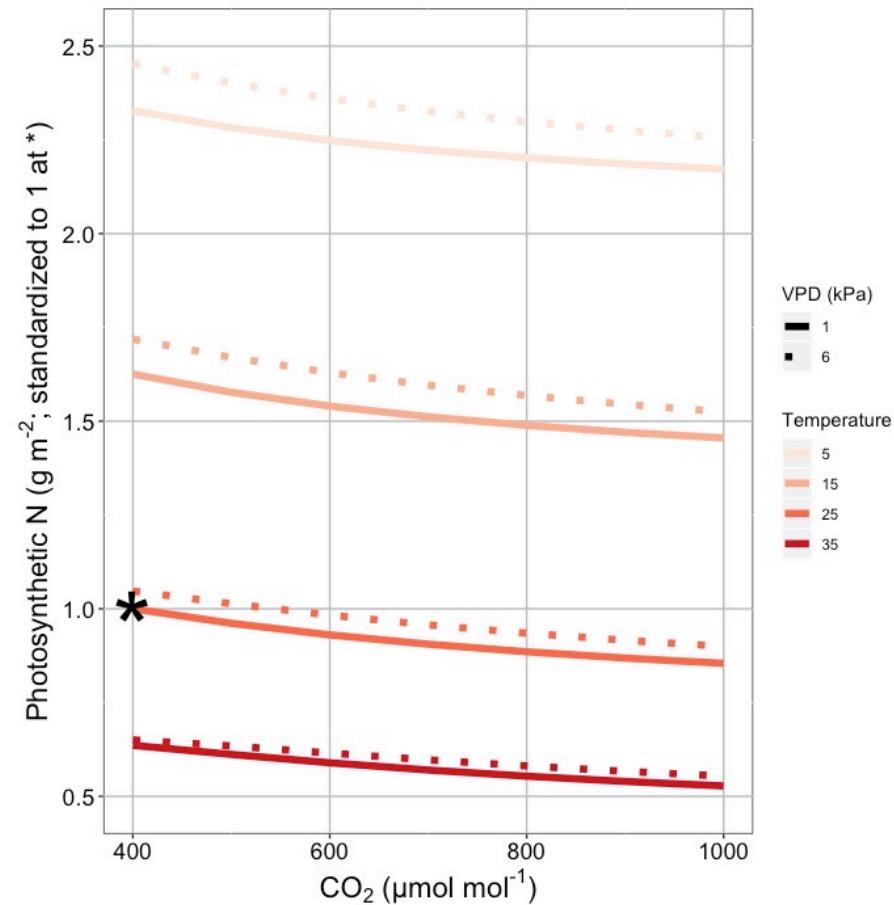
- Model-data testing
 - 2 temperature manipulation experiments
 - 31 elevated CO₂ experiments
- Leaf model simulations
- Canopy model simulations



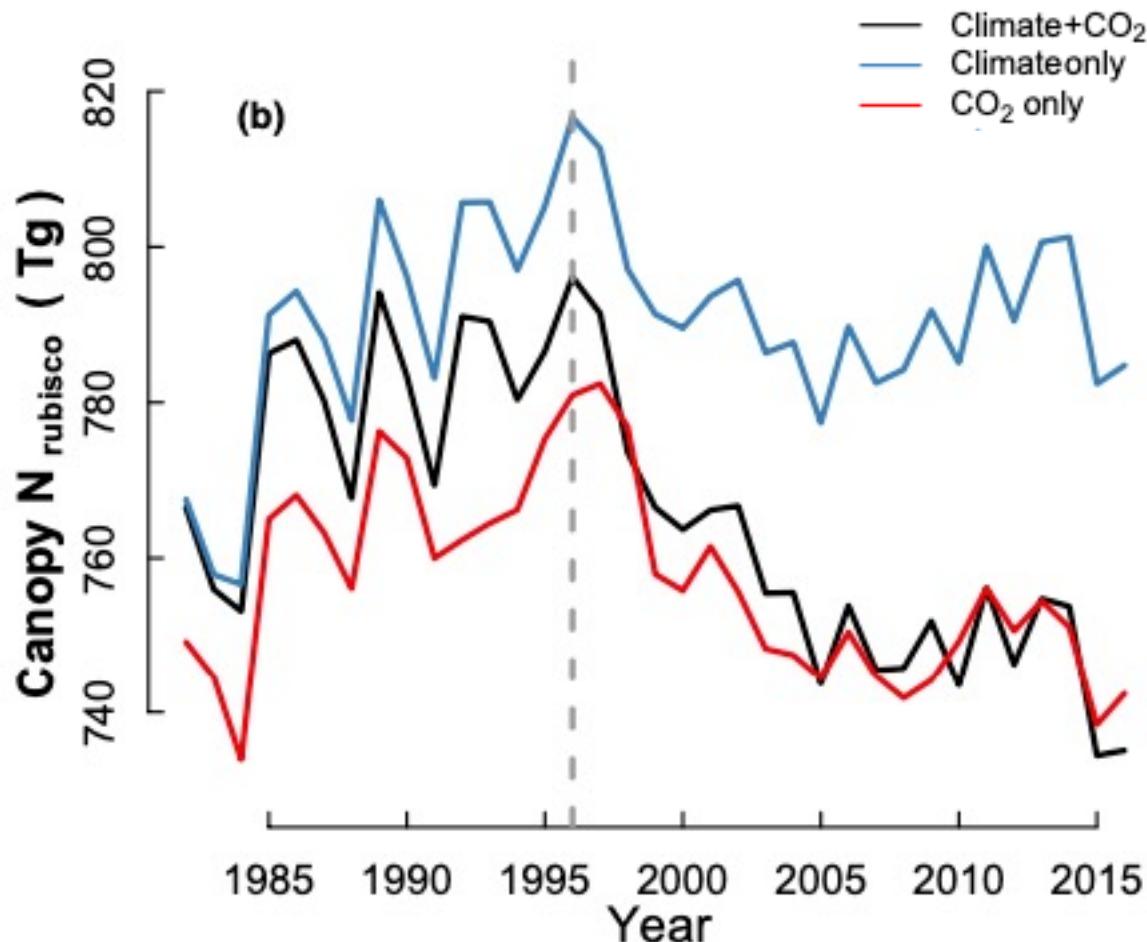
Result: elevated temperature and CO₂ reduce leaf investment in photosynthetic biochemistry



Result: elevated temperature and CO₂ reduce leaf photosynthetic N



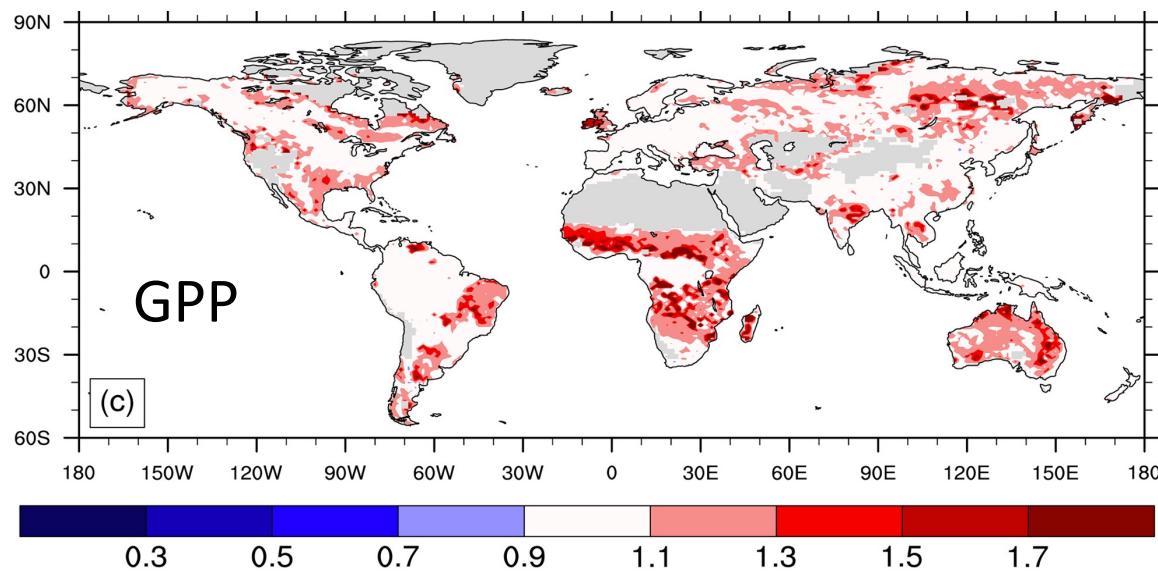
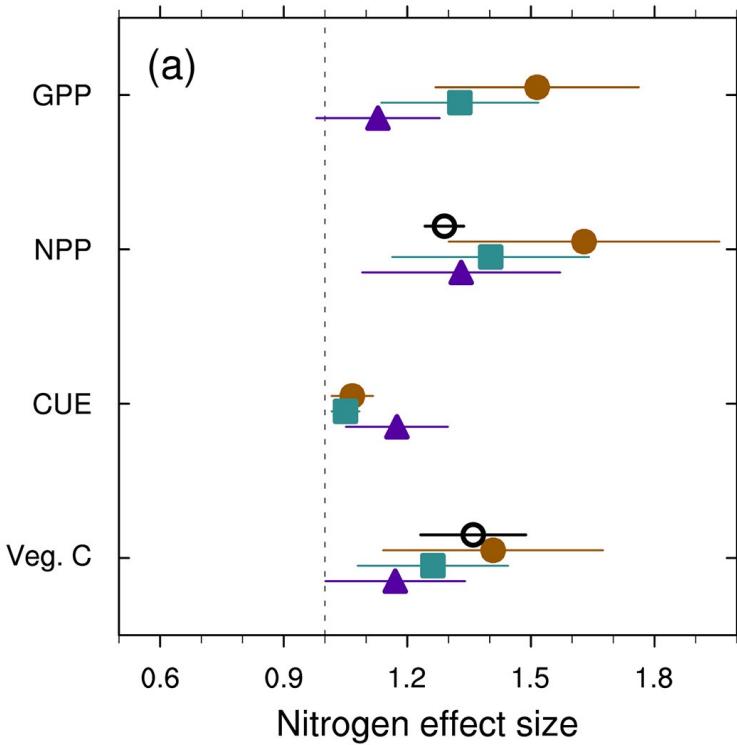
Result: elevated temperature and CO₂ reduce canopy N

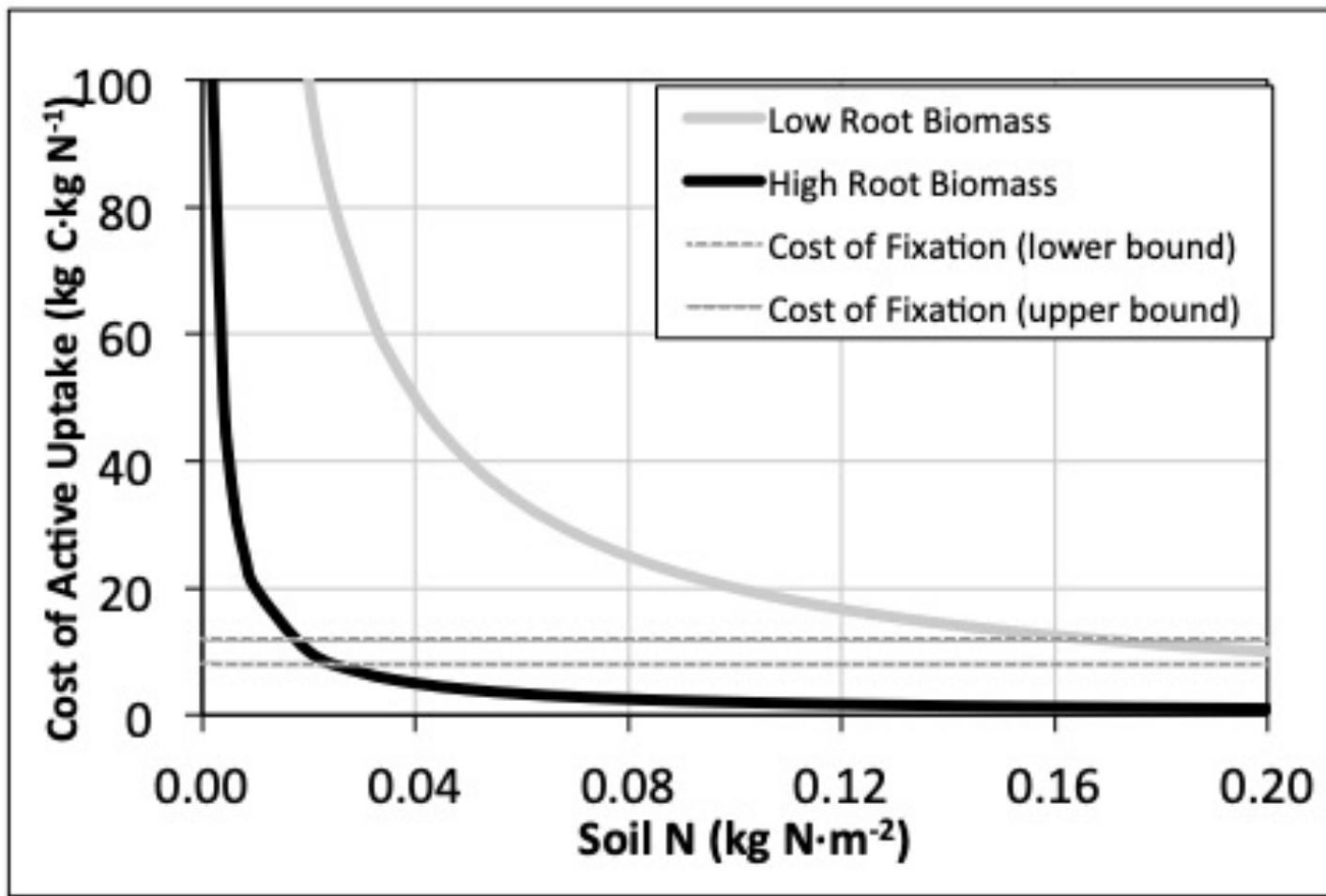


What should models be able to reproduce?

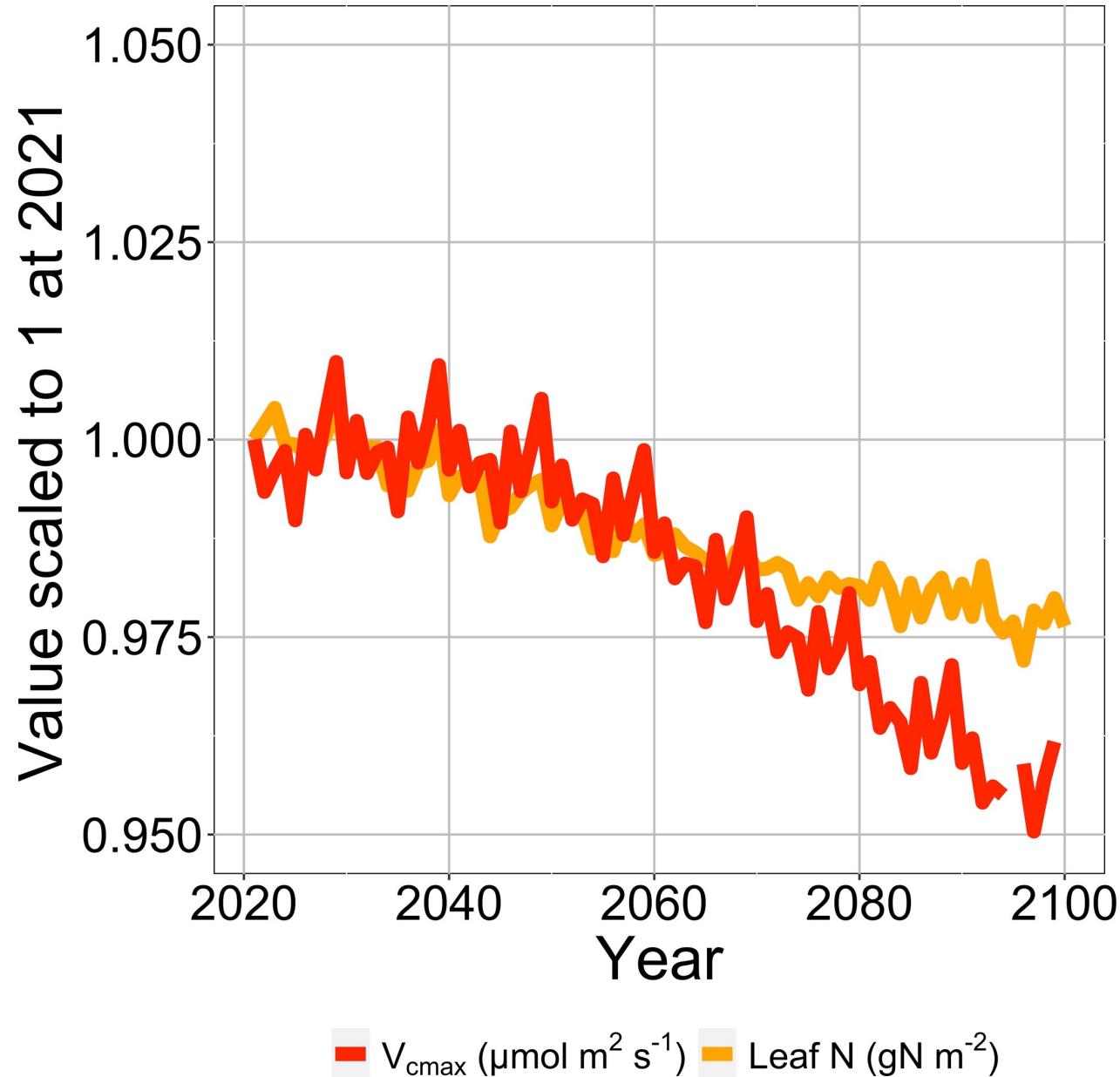
- Increased growth with increased soil N ✓ - ✓
- Decreased C cost to acquire N with increased soil N ✓ ✓
- Increased tissue N with increased soil N ✓ ✓ ✓
- Decreased relative leaf N allocation to photosynthesis with increased soil N ✓ ✓
- Reduced N with elevated temperature and CO₂ ✓

Effect of soil N addition in CLM 5





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



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