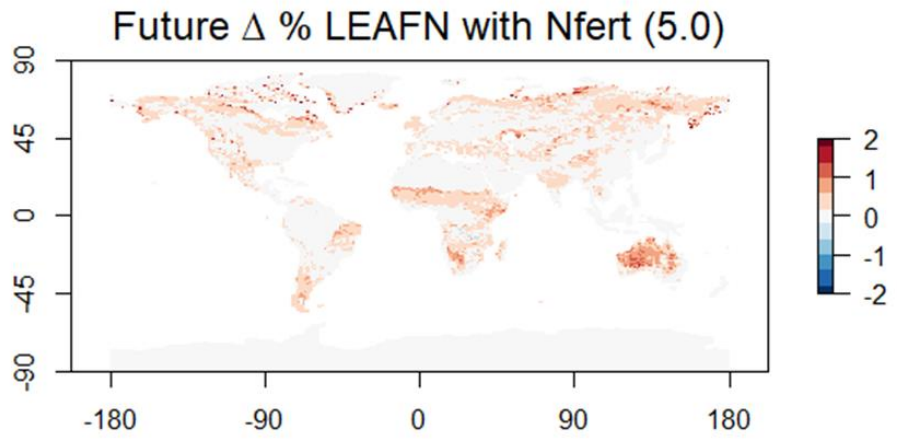
Nitrogen fertilization and carbon assimilation across scales: leaf level to global change

Dr. Lizz Waring

Texas Tech University

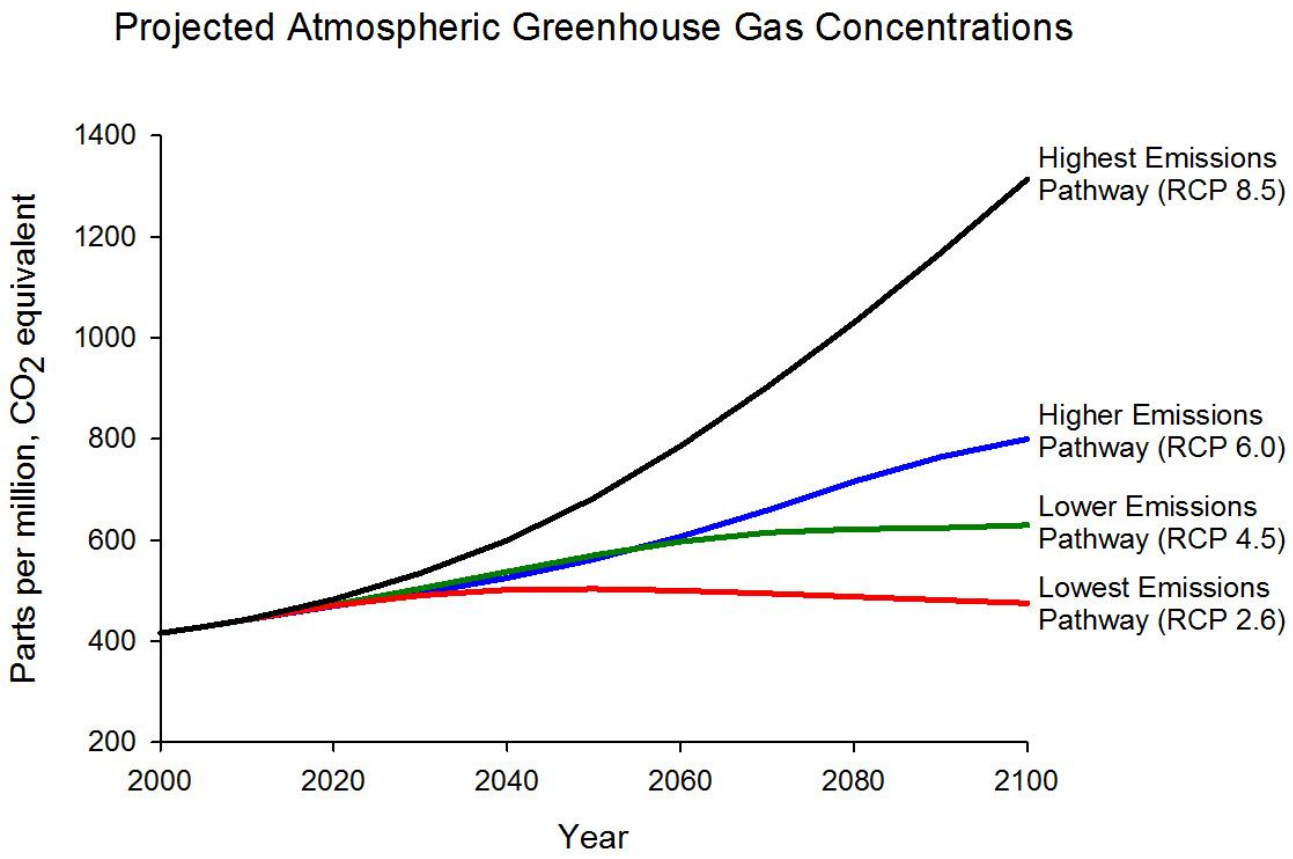
@LizzWaring



The distance past (2010)

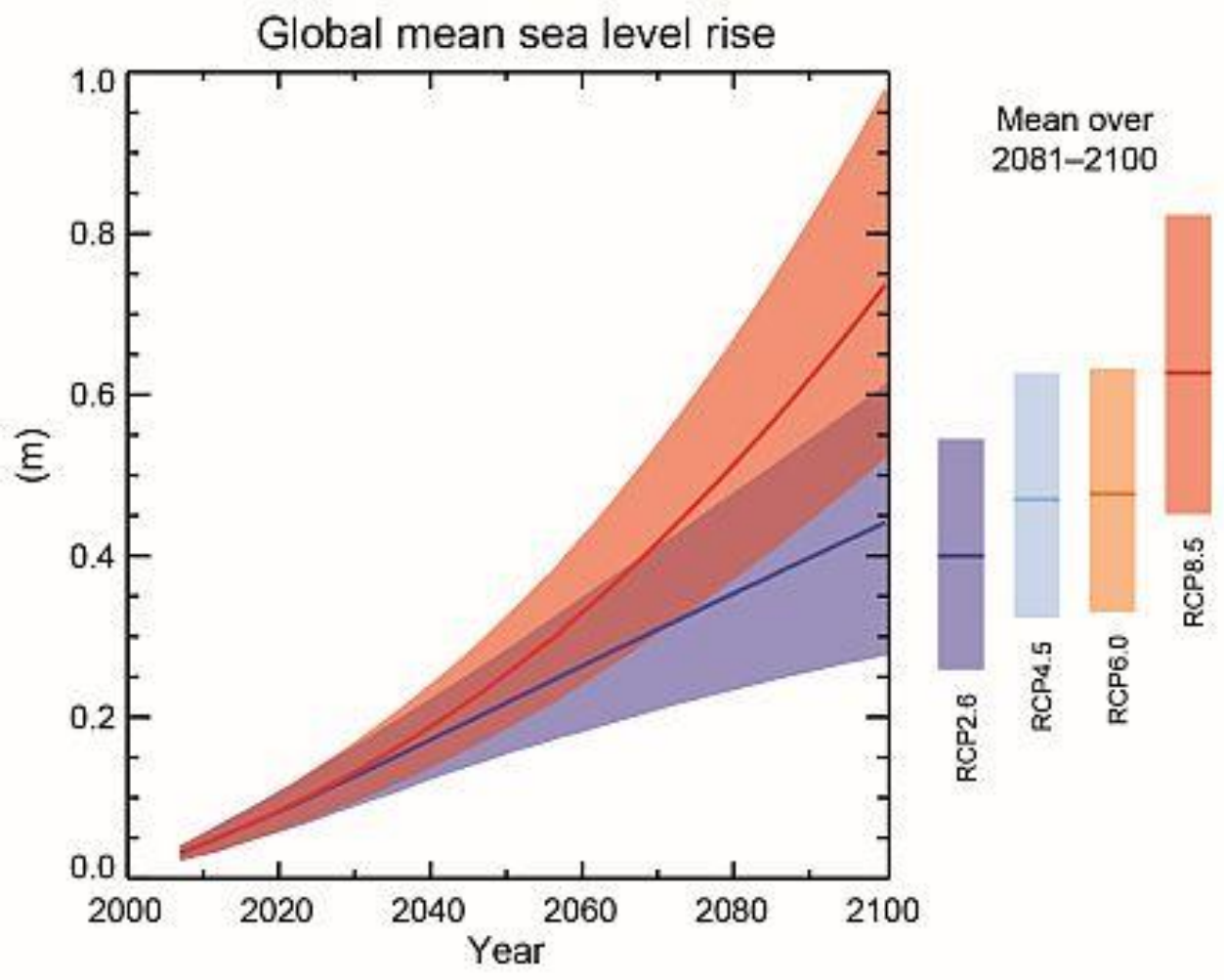
Global Change

- Increased CO_2



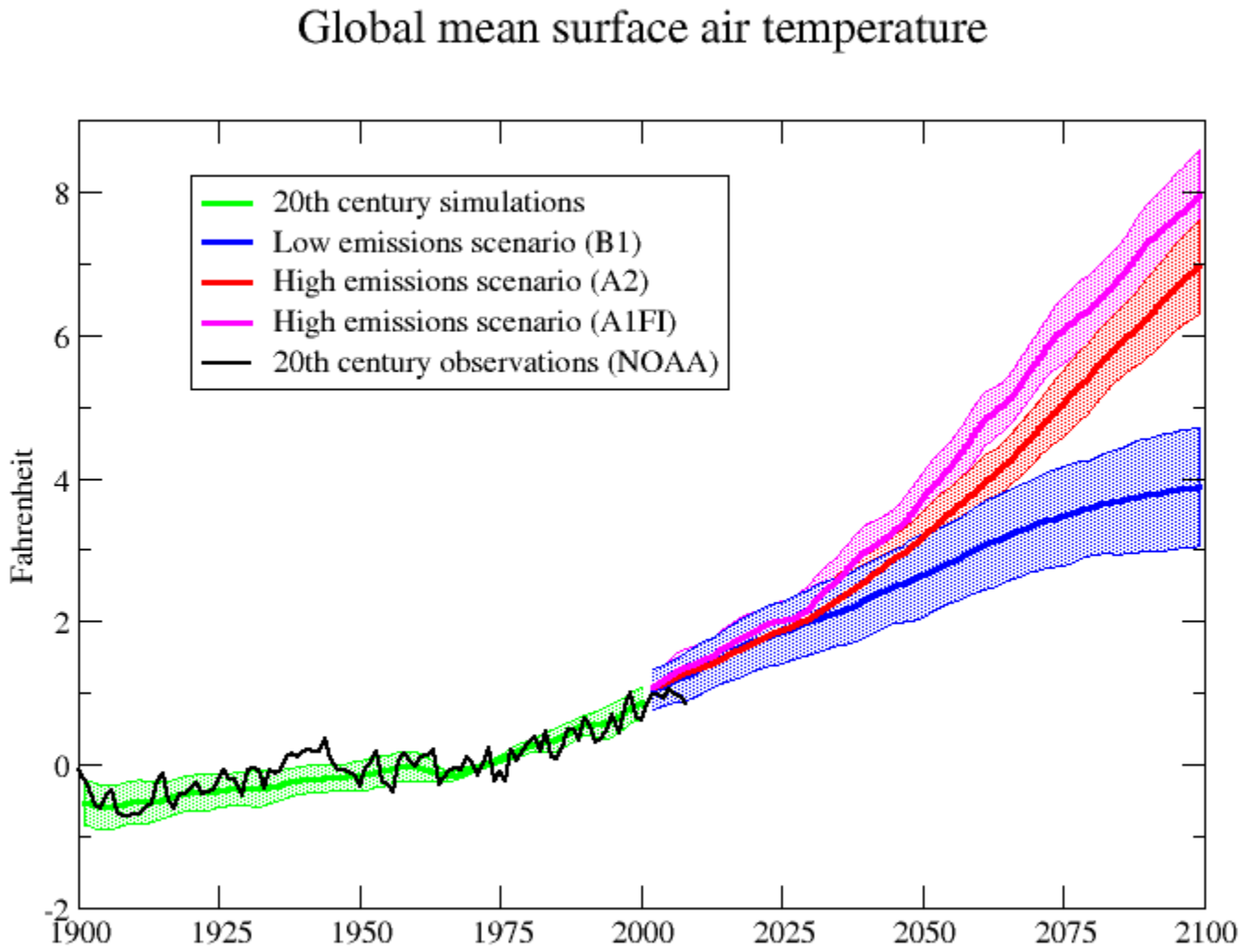
Global Change

- Increased CO_2
- Sea Level Rise



Global Change

- Increased CO_2
- Sea Level Rise
- Increased Temperatures

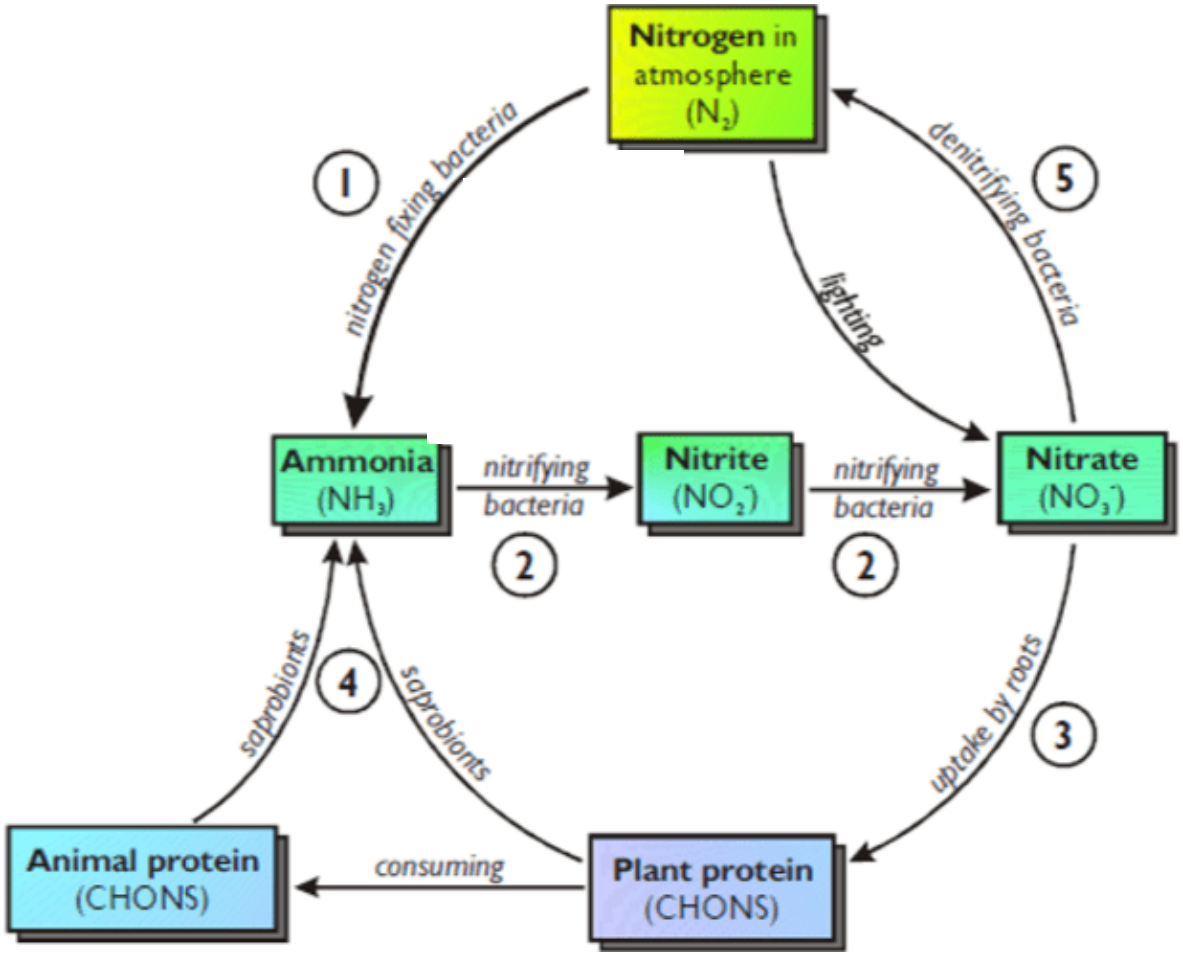


Ecosystem services

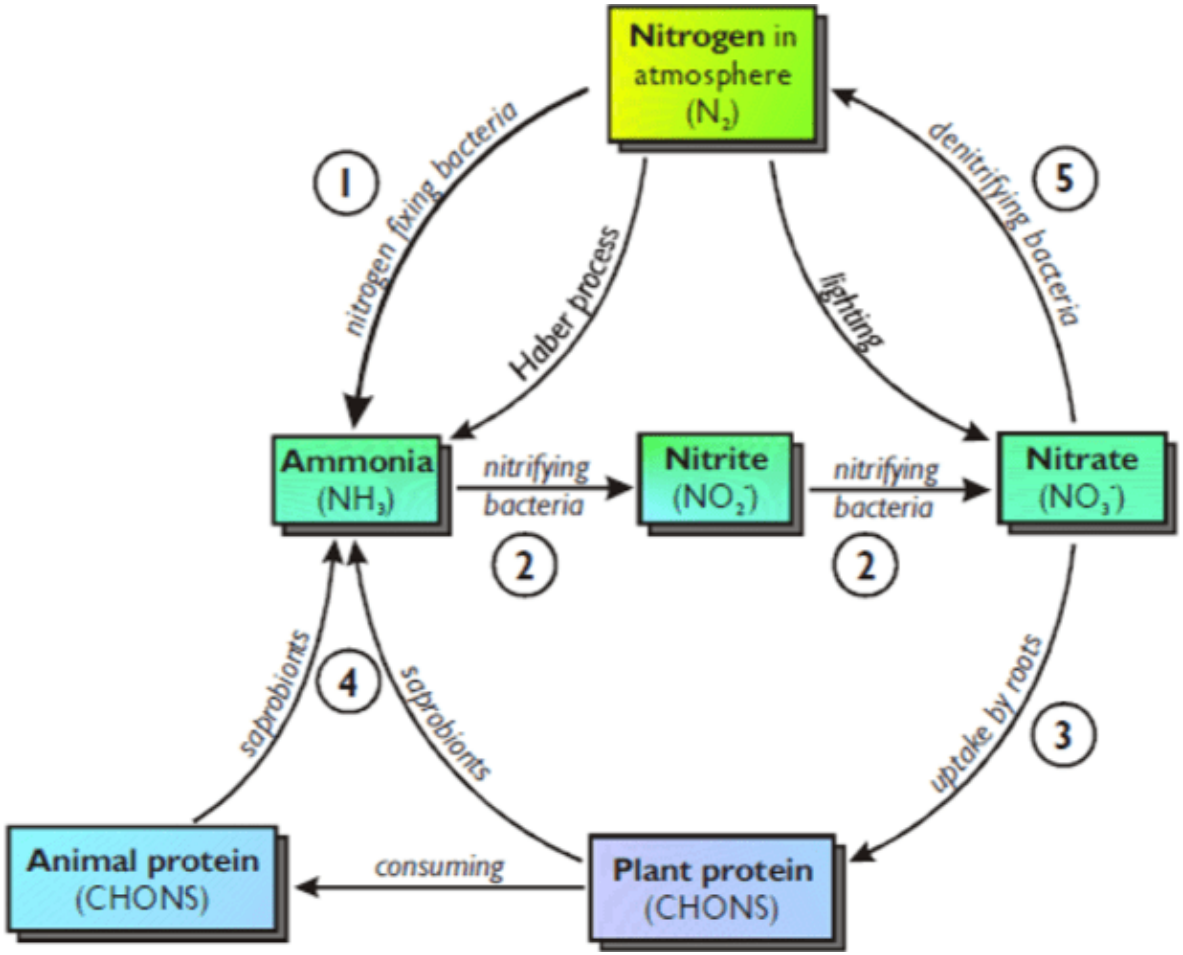
- The aspects of ecosystems used to produce human wellbeing (Fisher et al, 2008 Ecol Apps.)

- N fertilizer as a global change driver by impacting ecosystem services

Terrestrial N inputs increasing

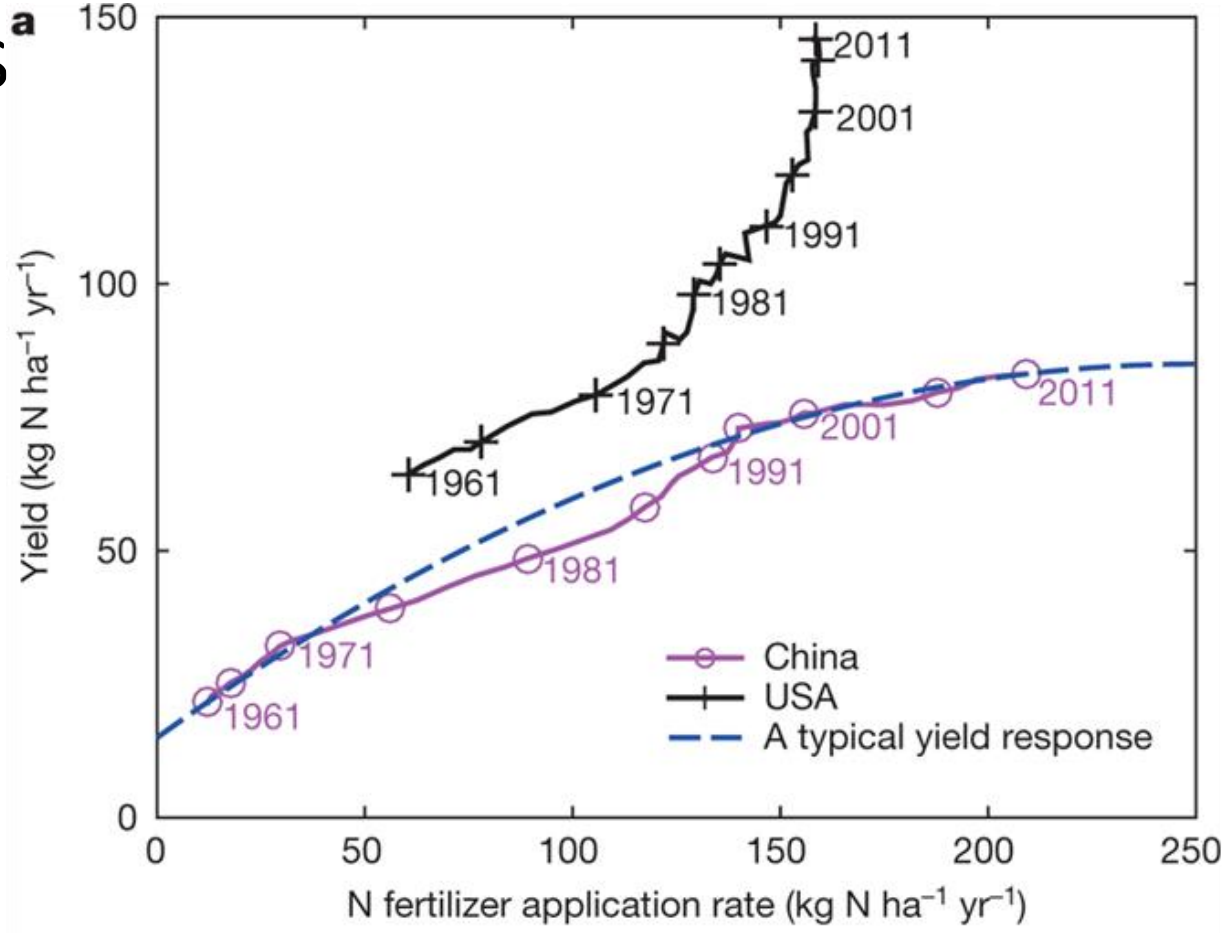


Terrestrial N inputs increasing



Terrestrial N inputs increasing

- Example: China and US

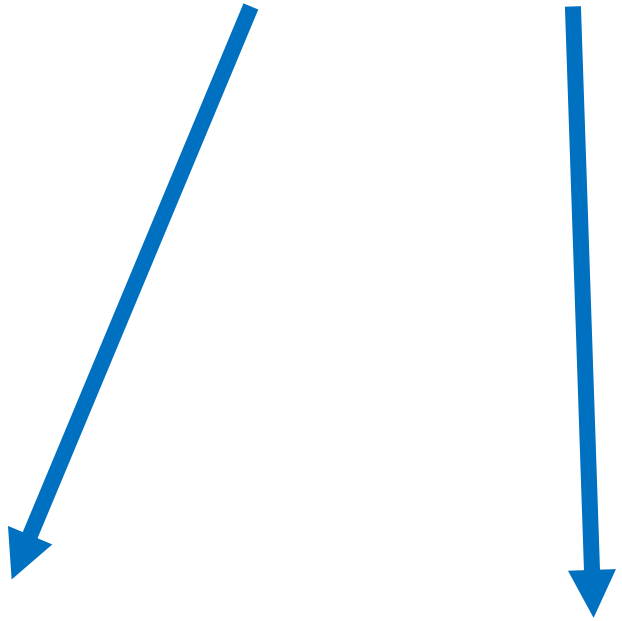


X Zhang *et al. Nature* 1-9 (2015) doi:10.1038/nature15743

Increased Nitrogen

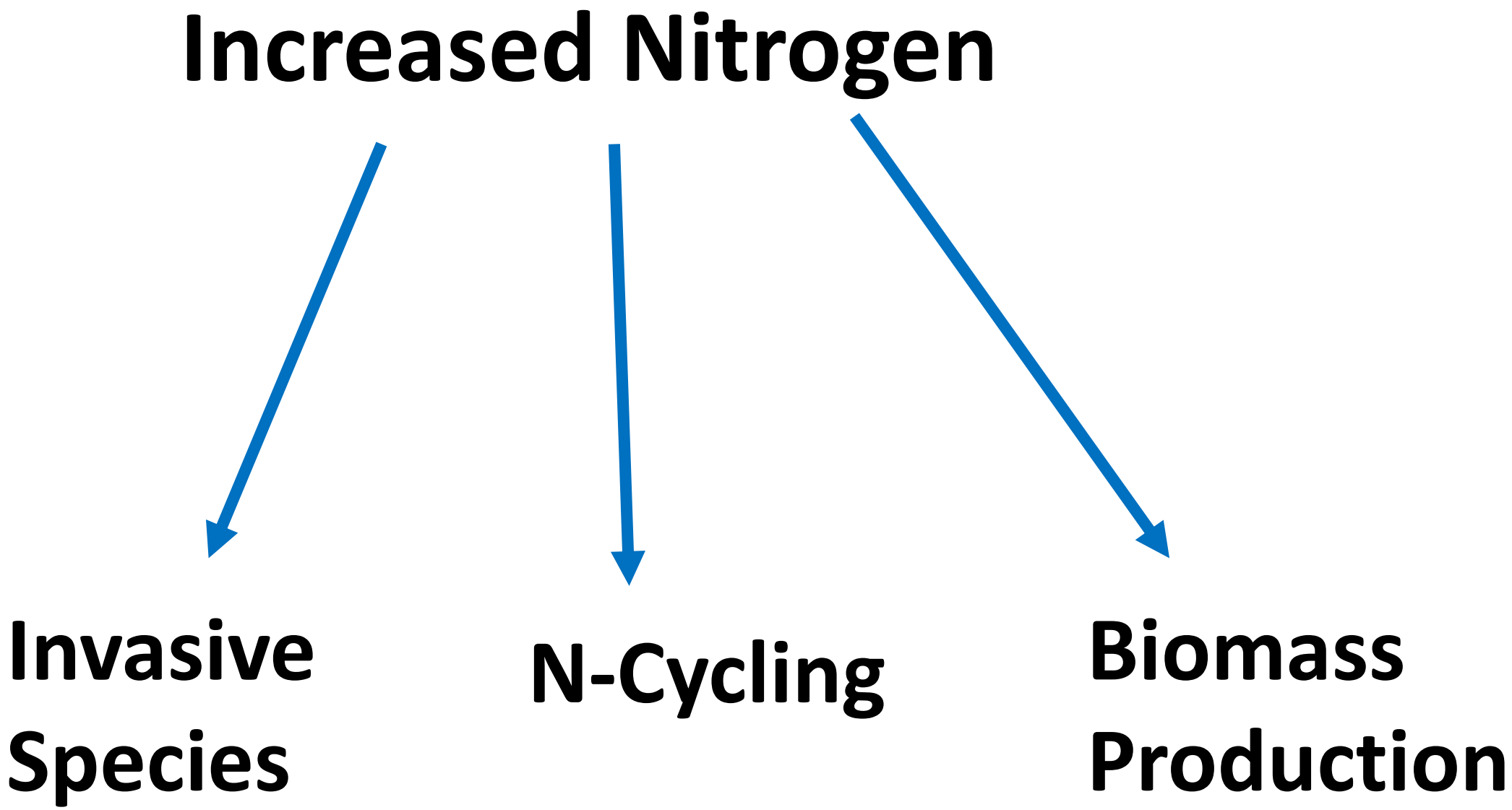
N-Cycling

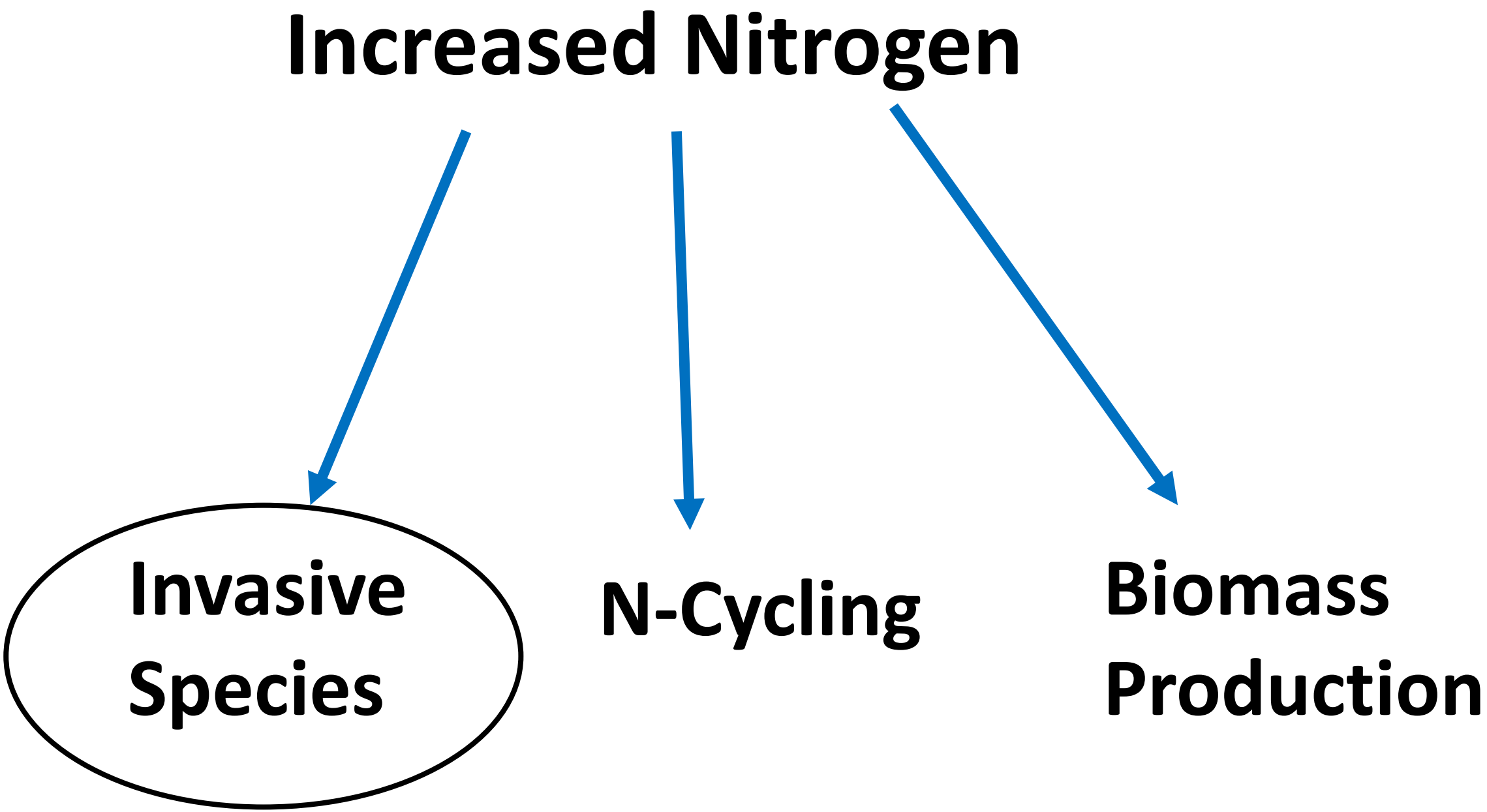
Increased Nitrogen



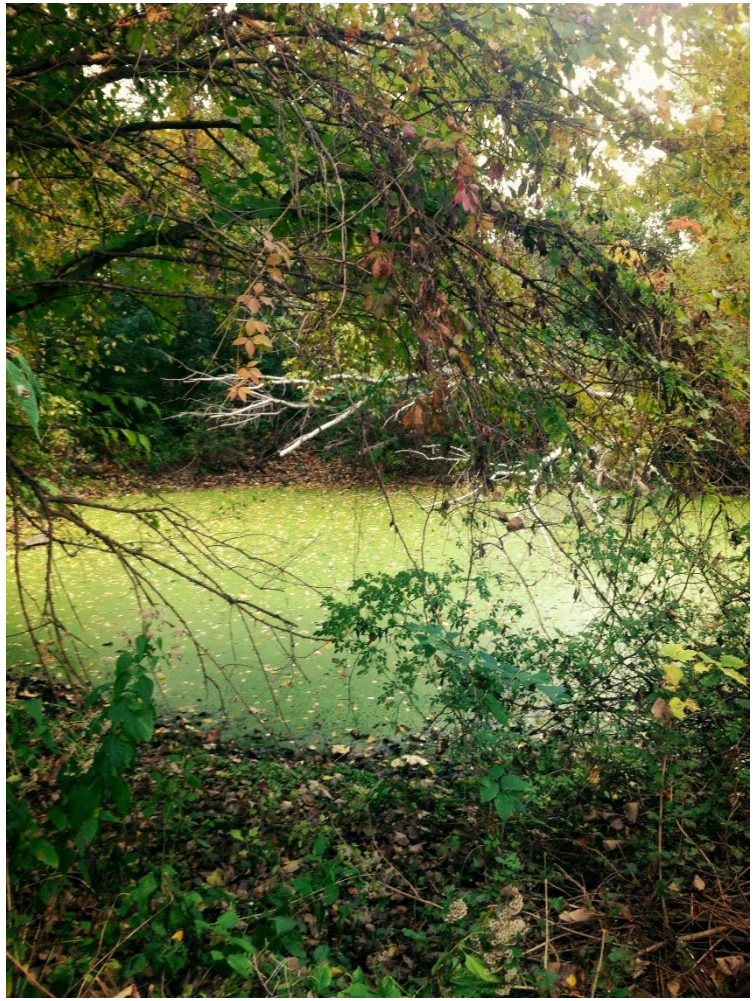
Invasive Species

N-Cycling


Increased Nitrogen
Invasive Species
N-Cycling
Biomass Production


Increased Nitrogen
Invasive Species
N-Cycling
Biomass Production

What is a wetland?



Wetland Services

- Ecosystem Services
  - High biodiversity
  - Flood prevention
  - Nutrient cycling
    - Nitrogen

What is an invasive species?

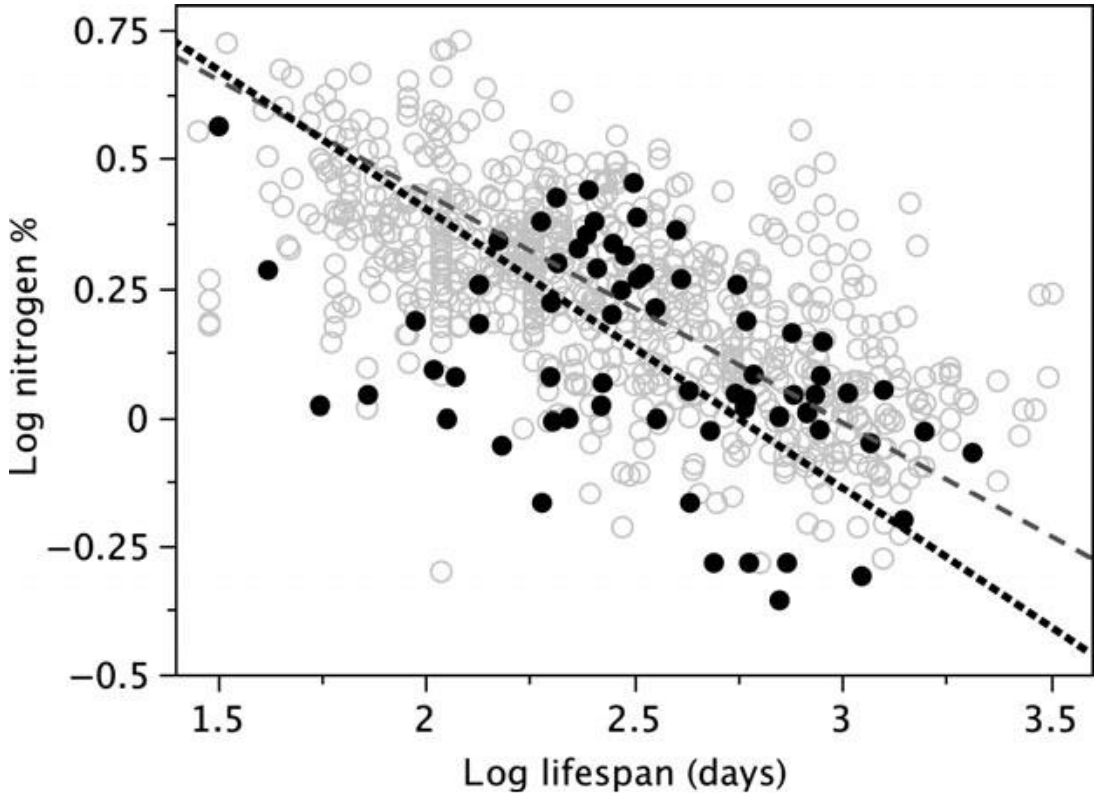
Wetlands and Invasion

- Most likely to be invaded
  - Water flow
  - Nitrogen sinks

- What will happen with environmental change?

Aggressive vs Conservative Species

- Leaf Economic Spectrum
- Aggressive species traits
  - Broad leaves
  - High photosynthetic rates
  - Short leaf lifespan
- Conservative species traits
  - Thick leaves
  - Lower leaf N
  - Longer leaf lifespan



From Journal of Ecology, Reich 2014

Phalaris arundinacea L. - Aggressive Species

- “Reed Canarygrass”
- Few native populations in North America
- Mostly hybrid of native European and Asian populations

Carex stricta Lam- Conservative Species

- “Tussock Sedge”
- Native east of Great Plains
- Biodiversity

Question

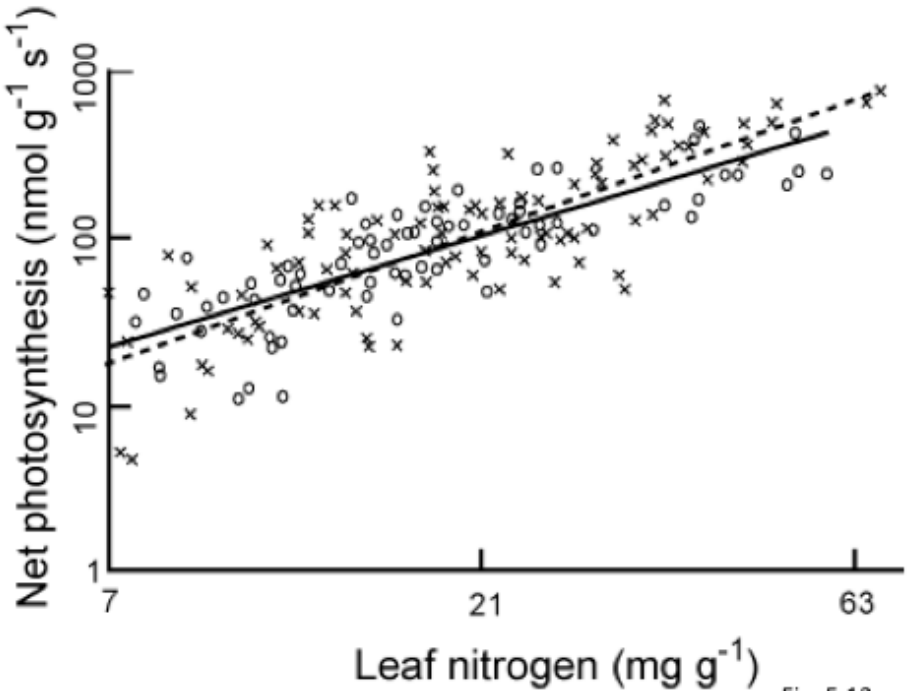
- Do any seasonal changes in leaf traits relate to changes in the availability of soil N?
- Hypothesis: *Phalaris arundinacea* has more plastic leaf trait responses to soil N than are *Carex* species.

Field Methods 2013

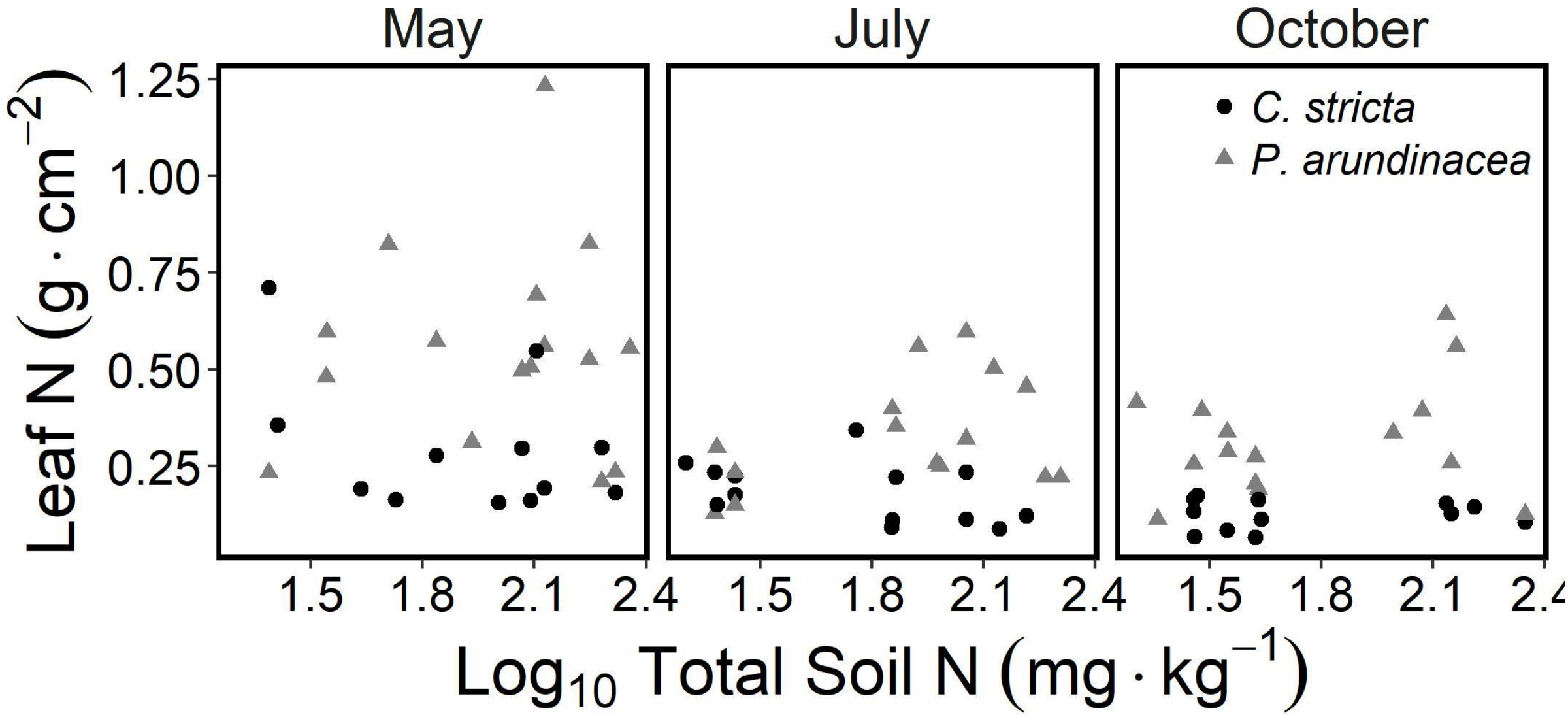
- 20 total sites
  - 10 with both spp, 6 with *Phalaris*, 4 with *Carex*
- Proxies for photosynthetic data
  - Leaf total N
  - SLA (specific leaf area)
  - Also collected soil for quantify soil N

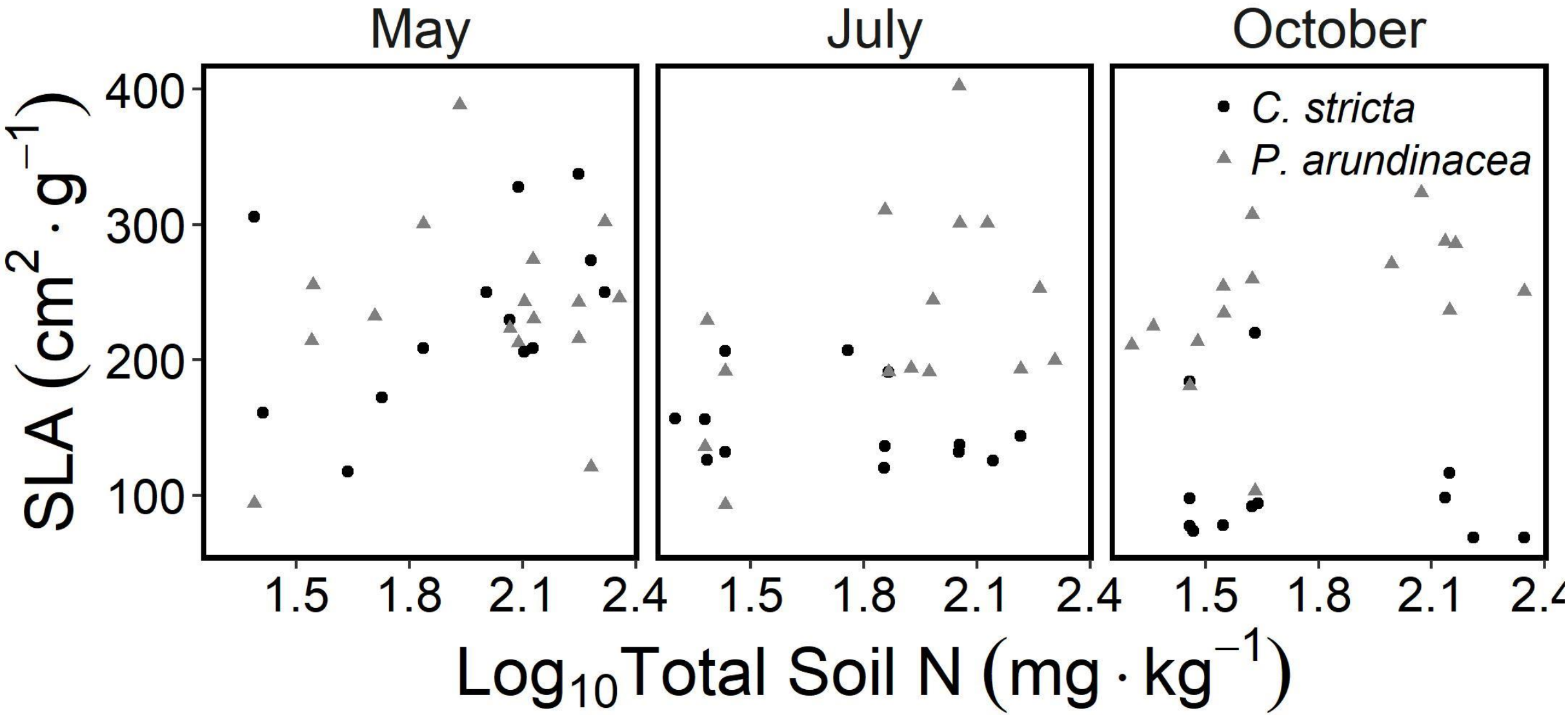
Leaf Nitrogen and Photosynthesis

- First step of Calvin-Benson Cycle catalyzed by Rubisco
- Strong relationship
- Link carbon and nitrogen metabolism
- In terms of *Phalaris arundinacea* invasions :
  - Literature credits much of *Phalaris* invasive success to excess nitrate



Redrawn from Reich et al. (1997) in Chapin 2011


May
July
October
C. stricta
P. arundinacea
Leaf N (g · cm⁻²)
1.25
1.00
0.75
0.50
0.25
1.5
1.8
2.1
2.4
Log10 Total Soil N (mg · kg⁻¹)


May
July
October
C. stricta
P. arundinacea
SLA (cm^2 · g^{-1})
400
300
200
100
1.5
1.8
2.1
2.4
Log$_{10}$Total Soil N (mg · kg^{-1})

Noisy Data, New questions

- Are any seasonal changes in leaf traits affected by the growth of the species together in mixed stands ?
- Does soil N availability affect how the species respond in mixed stands?
- Hypothesis: *Phalaris arundinacea* has more plastic leaf trait responses to soil N than are *Carex* species.

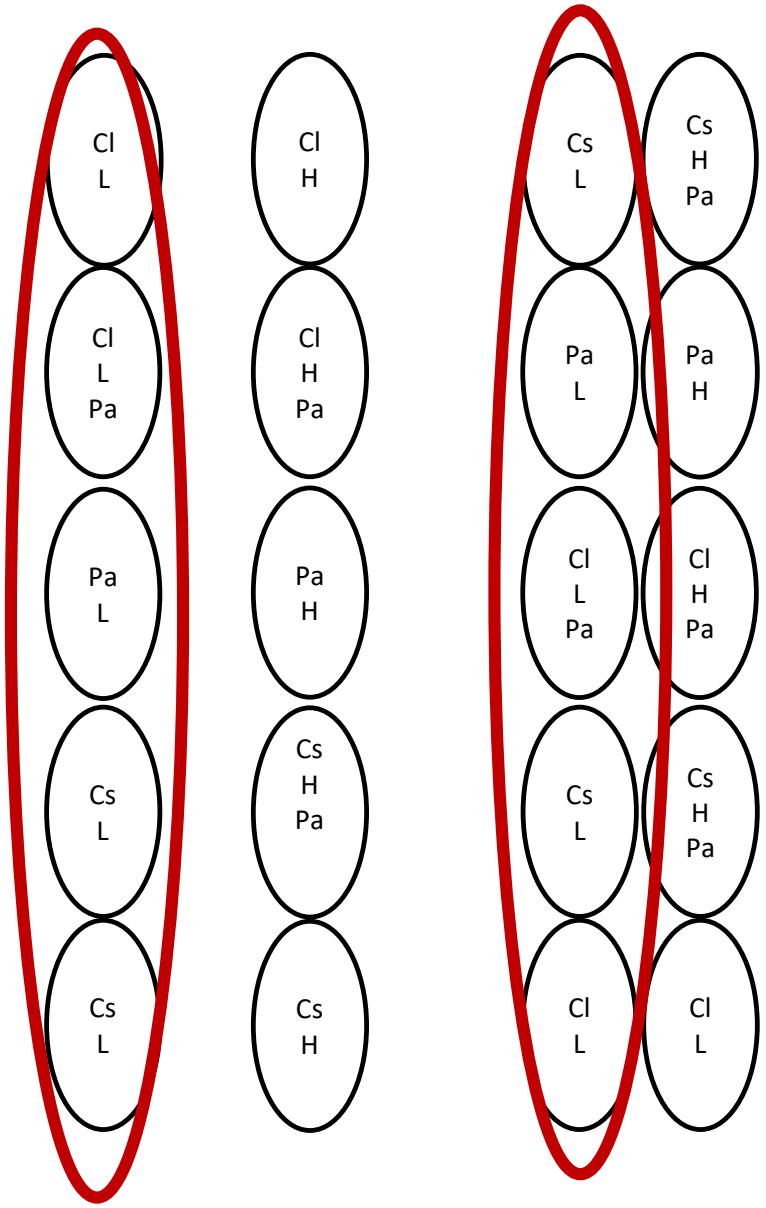
New character in the story

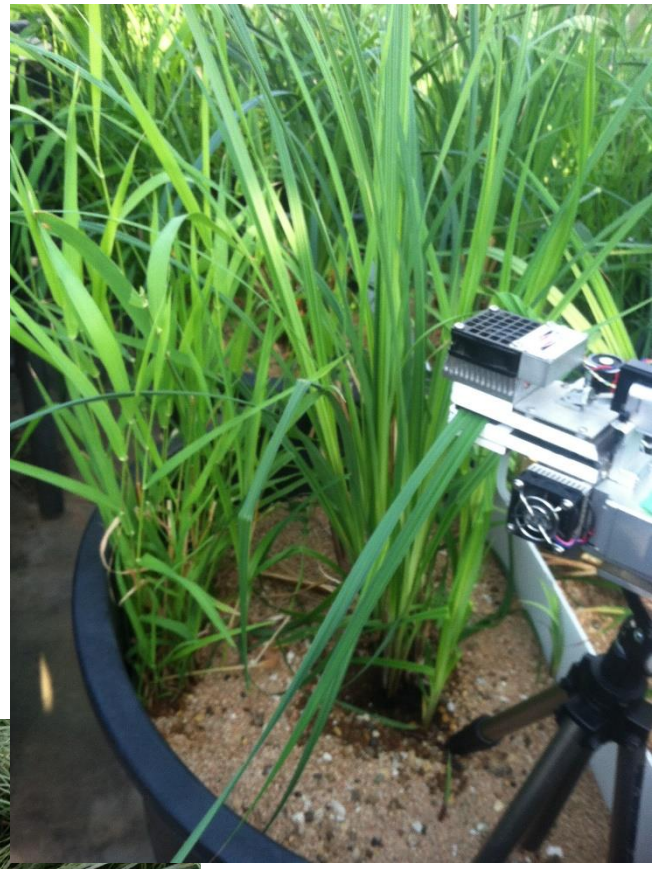
- *Carex lacustris* Wiild.
- Lake Sedge
- Grows to be ~1-1.5 m tall
- Wide, fibrous leaves
- Mostly reproduces with rhizomes
- Native species
- Restoration species

Methods

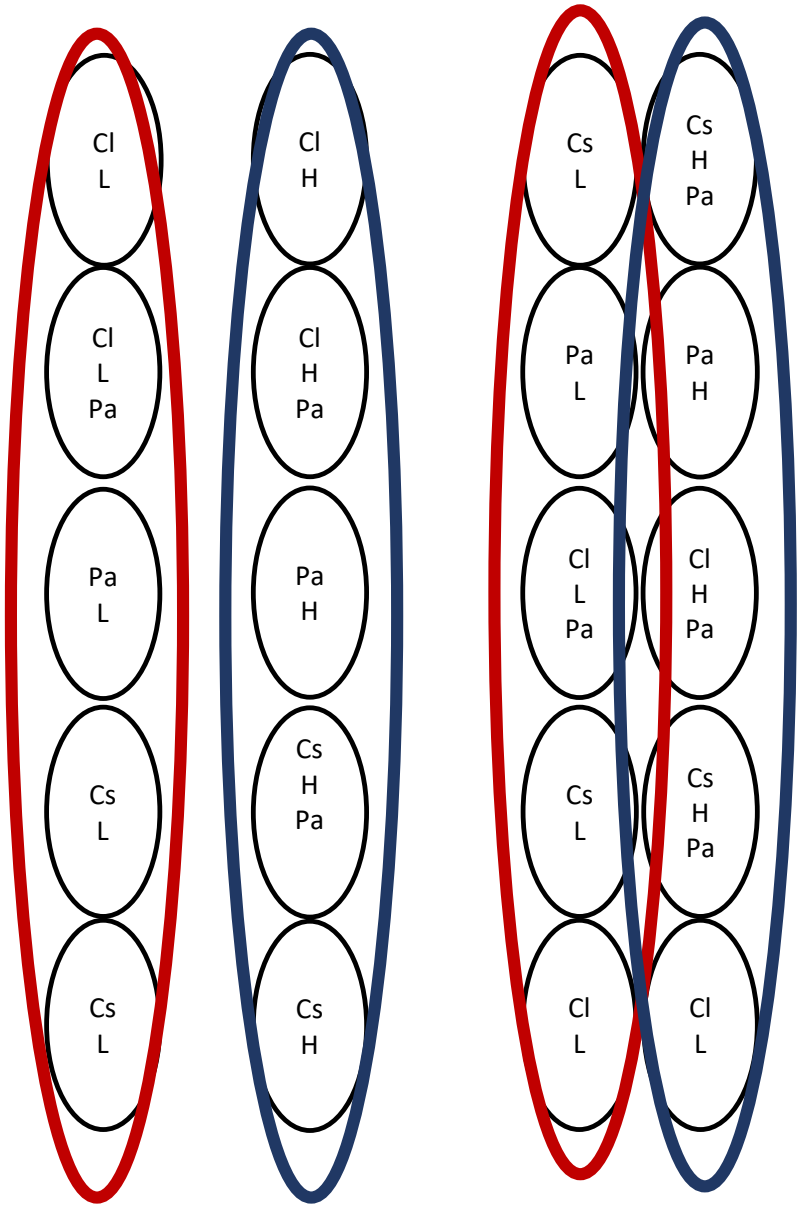
- 70-L mesocosms
- Pea gravel topped with N-free turface
- Fertilized twice a week (1 L per mesocosms)
  - Two strengths- High Low

Door	Wall


Cl L
Cl L Pa
Pa L
Cs L
Cs L
Cl H
Cl H Pa
Pa H
Cs H Pa
Cs H
Cs L
Pa L
Cl L Pa
Cs L
Cl L
Cs H Pa
Pa H
Cl H Pa
Cs H Pa
Cl L



Door	Wall


Cl L
Cl L Pa
Pa L
Cs L
Cs L
Cl H
Cl H Pa
Pa H
Cs H Pa
Cs H
Cs L
Pa L
Cl L Pa
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Cl L
Cs H Pa
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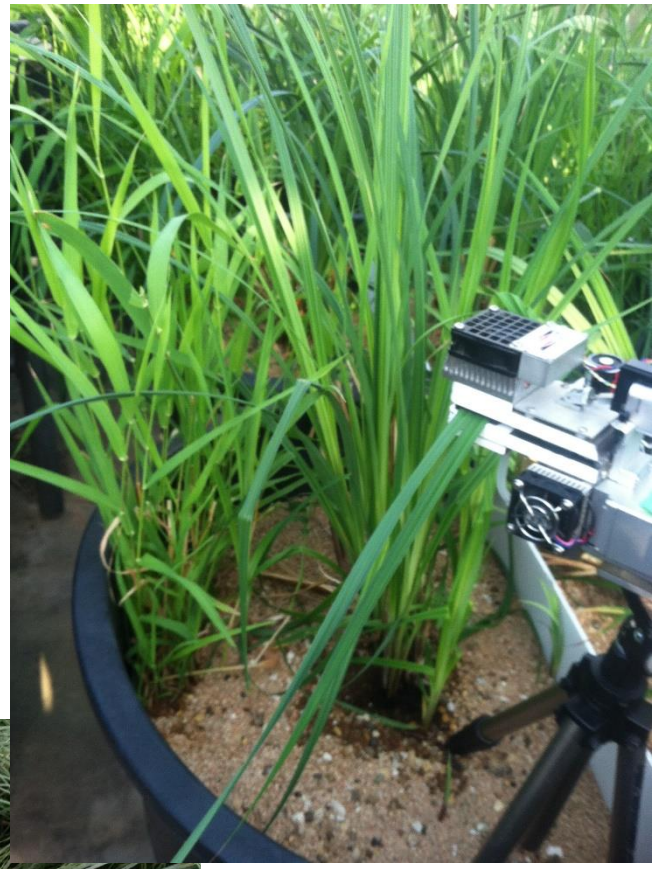
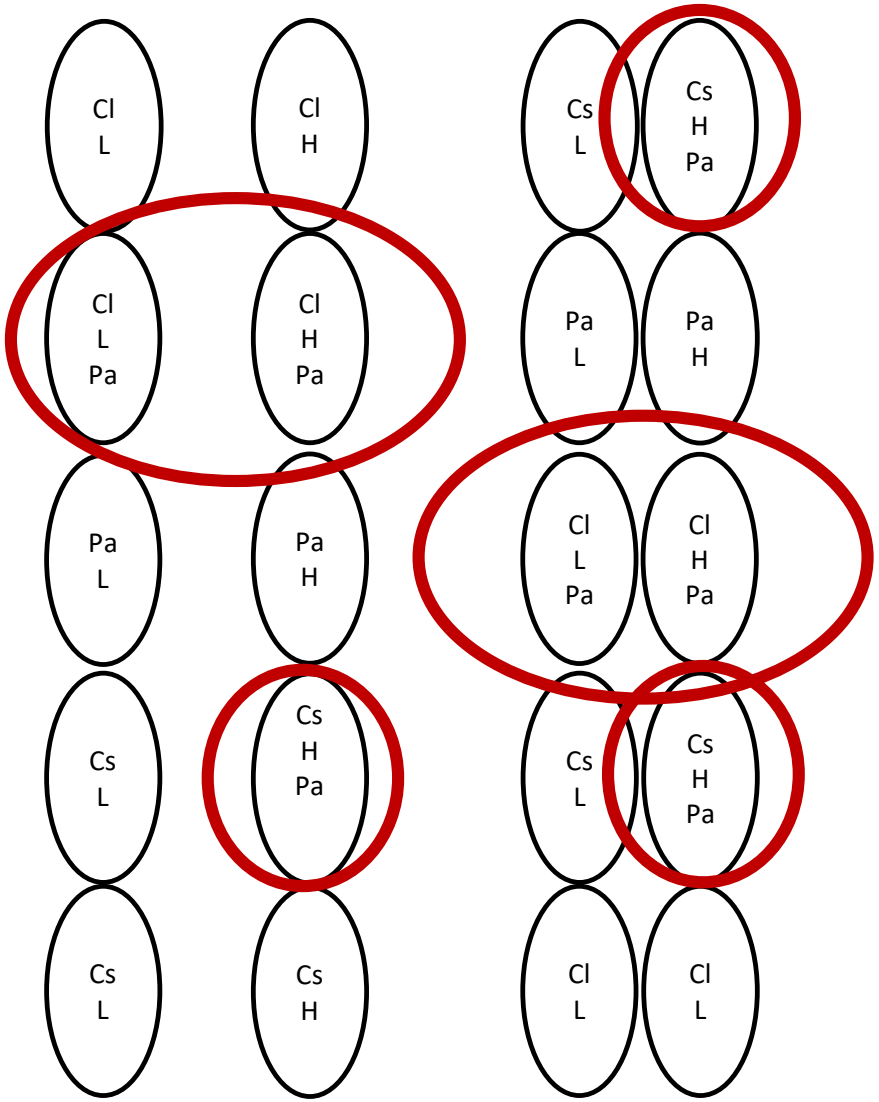
Cl H Pa
Cs H Pa
Cl L



Door	Wall


Cl L
Cl H
Cs L
Cs H Pa
Cl L Pa
Cl H Pa
Pa L
Pa H
Pa L
Pa H
Cl L Pa
Cl H Pa
Cs L
Cs H Pa
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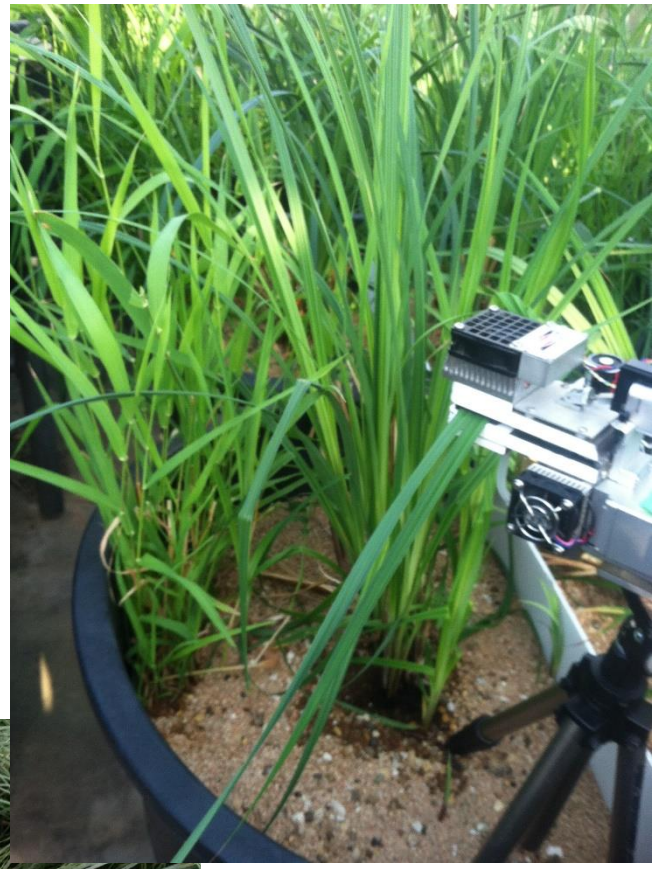
Cs L
Cs H
Cl L
Cl L



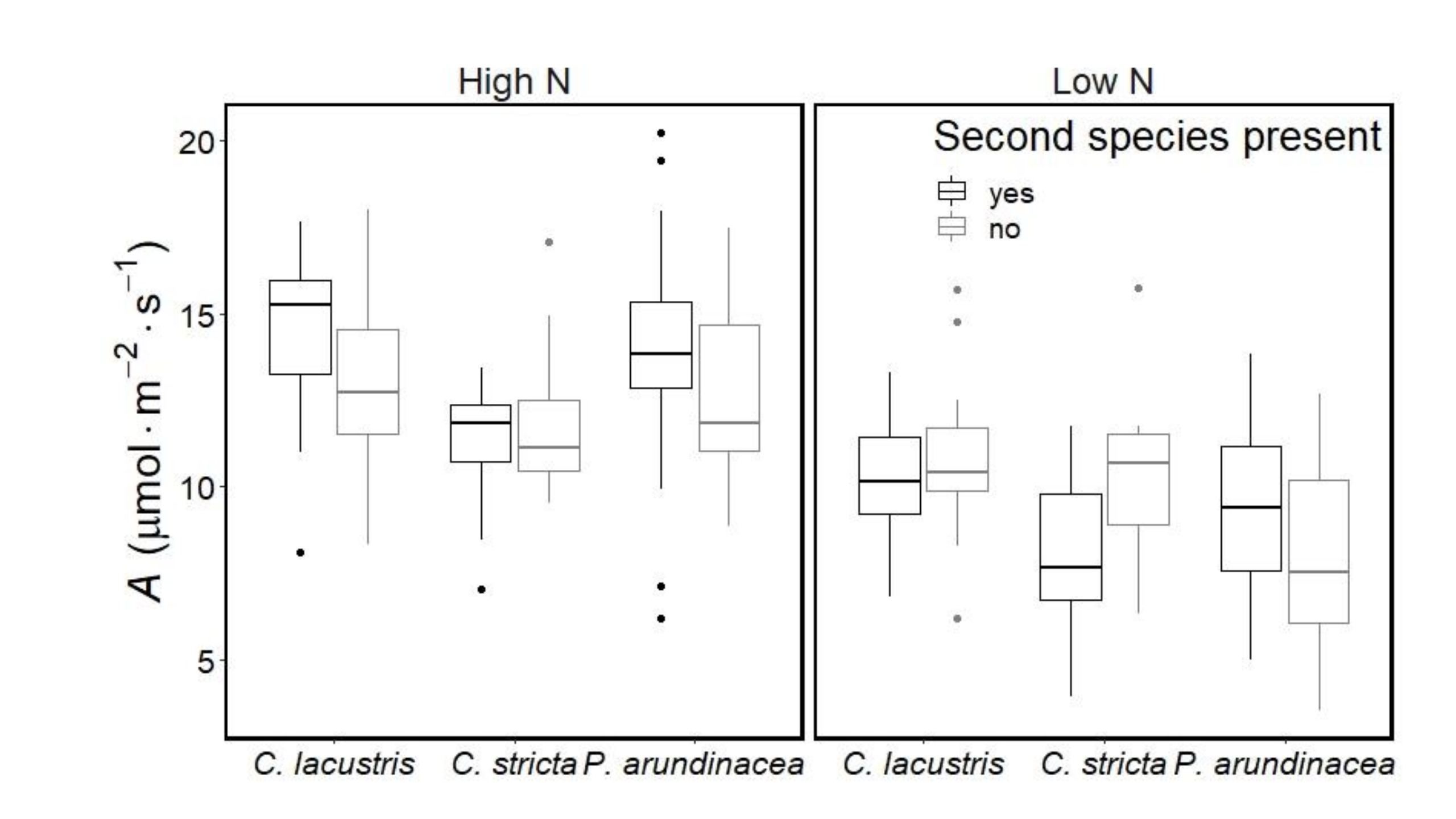
Methods

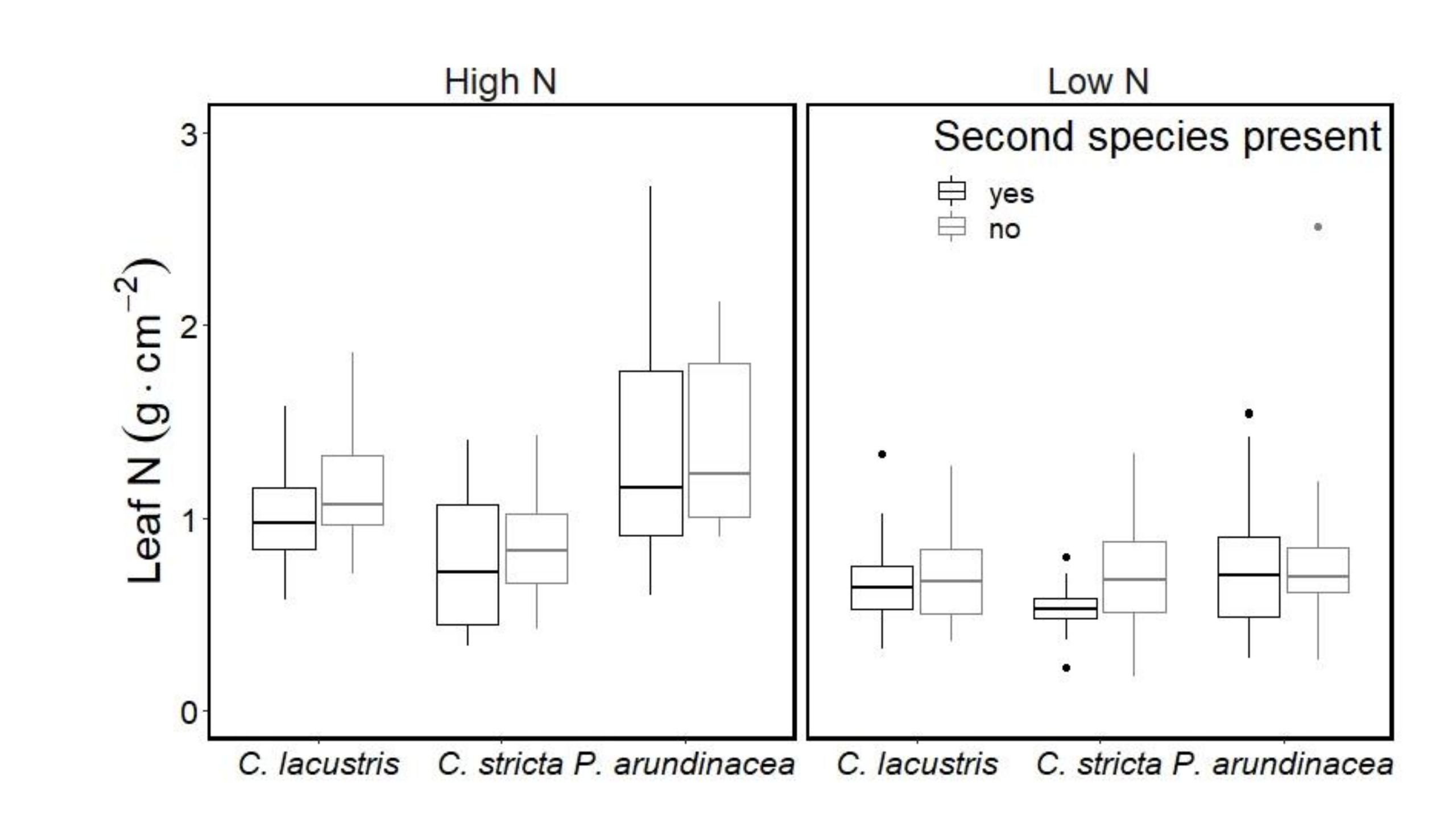
- 70-L mesocosms
- Pea gravel topped with N-free turface
- Fertilized twice a week (1 L per mesocosms)
  - Two strengths- High Low
- Measured every 4.5 weeks from May to October

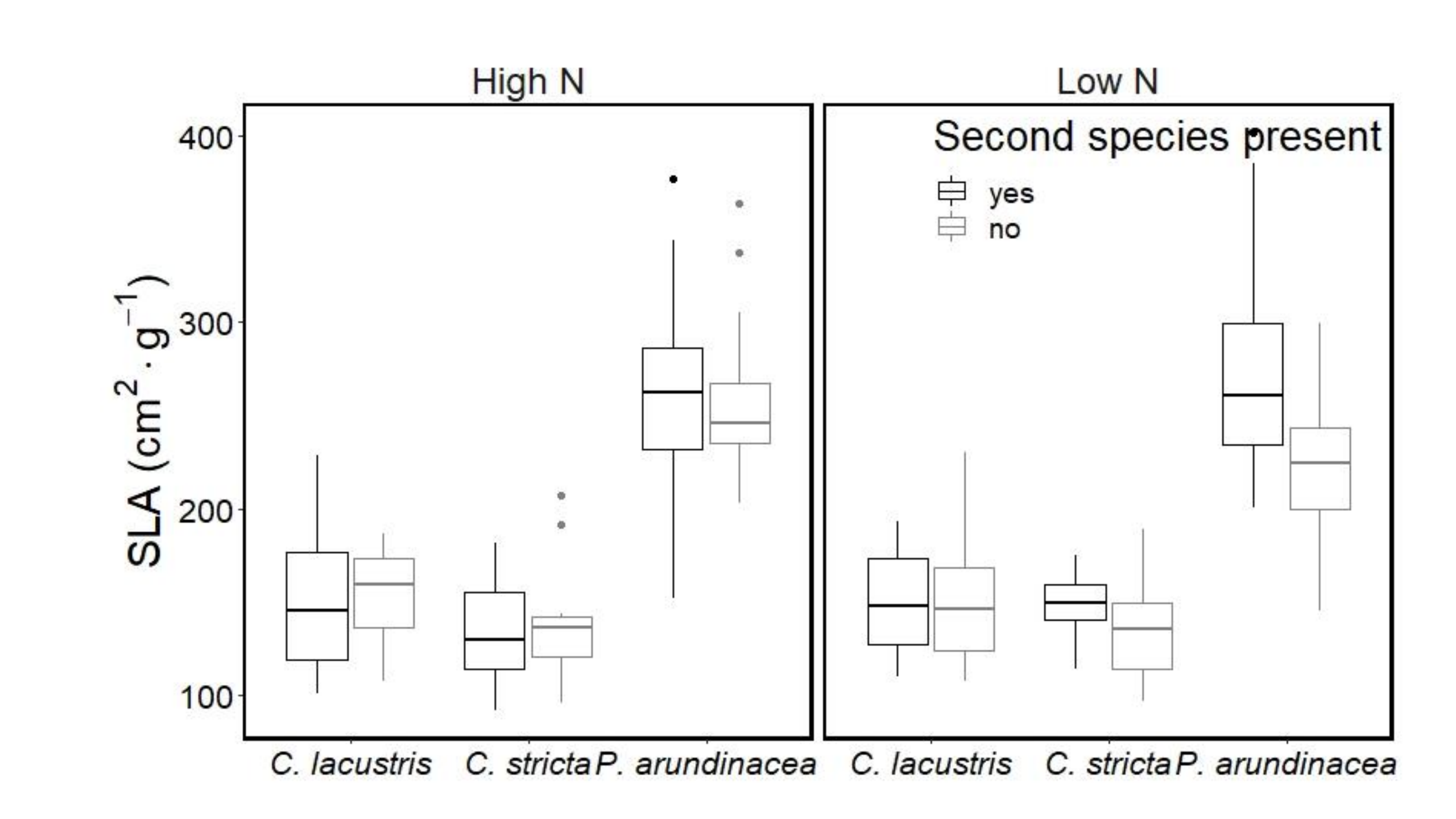
Methods

Licor 6400XT

- Leaves for elemental analysis
- SLA

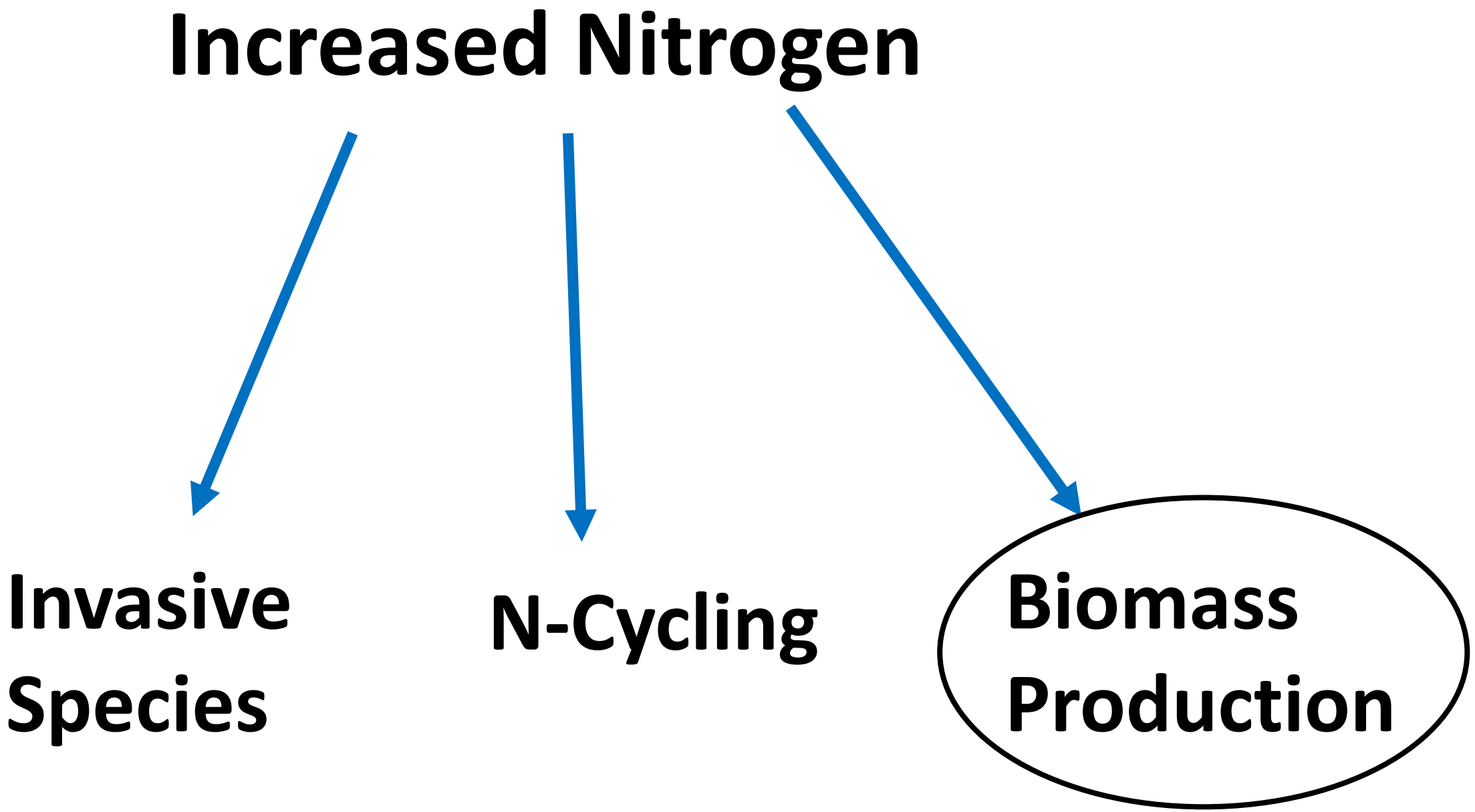

High N
Low N
Second species present
yes
no
20
15
10
5
A (μmol · m⁻² · s⁻¹)
C. lacustris
C. stricta
P. arundinacea
C. lacustris
C. stricta
P. arundinacea


High N
Low N
Second species present
yes
no
Leaf N (g · cm⁻²)
0
1
2
3
C. lacustris
C. stricta P. arundinacea
C. lacustris
C. stricta P. arundinacea


High N
Low N
Second species present
yes
no
SLA (cm^2 · g^{-1})
400
300
200
100
C. lacustris
C. stricta
P. arundinacea
C. lacustris
C. stricta
P. arundinacea

- the maintenance of high leaf N, leaf physiology, and a high SLA for a longer period part of *Phalaris* invasive success
- *P*. *arundinacea* is likely to respond to competition positively by raising *A*, leaf N, and SLA

- TAKE AWAY: Ability to use excess soil N only part of the story for *Phalaris* invasive success. Ability to respond positively to competition also part of its success.


Increased Nitrogen
Invasive Species
N-Cycling
Biomass Production

Increases in NPP due to fertilization

NPP=GPP-R_d

GPP = g C m^{-2} yr^{-1}

NPP = total biomass

LeBauer and Treseder

2008

TABLE 1. Effects of nitrogen on plant growth, overall and grouped by biome.

Grouping	*n*	*R*	95% CI	*Q*	*P*
Overall	126	1.29	1.22–1.35	1032	**<0.0001**
Biome	7			20.5	**0.0022**
Temperate forest	22	1.19	1.11–1.28		**<0.0001**
Tropical forest	16	1.60	1.30–1.97		**<0.0001**
Excluding young Hawaiian soils	8	1.20	1.04–1.40		**0.013**
Young Hawaiian soils	8	2.13	1.48–3.08		**<0.0001**
Tundra	10	1.35	1.12–1.64		**0.0018**
Tropical grassland	6	1.26	1.04–1.54		**0.021**
Desert	3	1.11	0.80–1.55		0.53
Temperate grassland	32	1.53	1.37–1.71		**<0.0001**
Wetland	36	1.16	1.00–1.34		**0.045**

Notes: The response ratio, *R*, is the ratio of estimated aboveground net primary productivity in the fertilized to the control plots. An $R > 1$ reflects a positive growth response to nitrogen and indicates nitrogen limitation as defined in *Methods*. The homogeneity statistic *Q* is used to assess homogeneity of effect sizes. Boldface type indicates responses that are significant at $P < 0.05$.

LeBauer and Treseder. *Ecology* (2008) Table 1

Increases in photosynthesis climate dependent

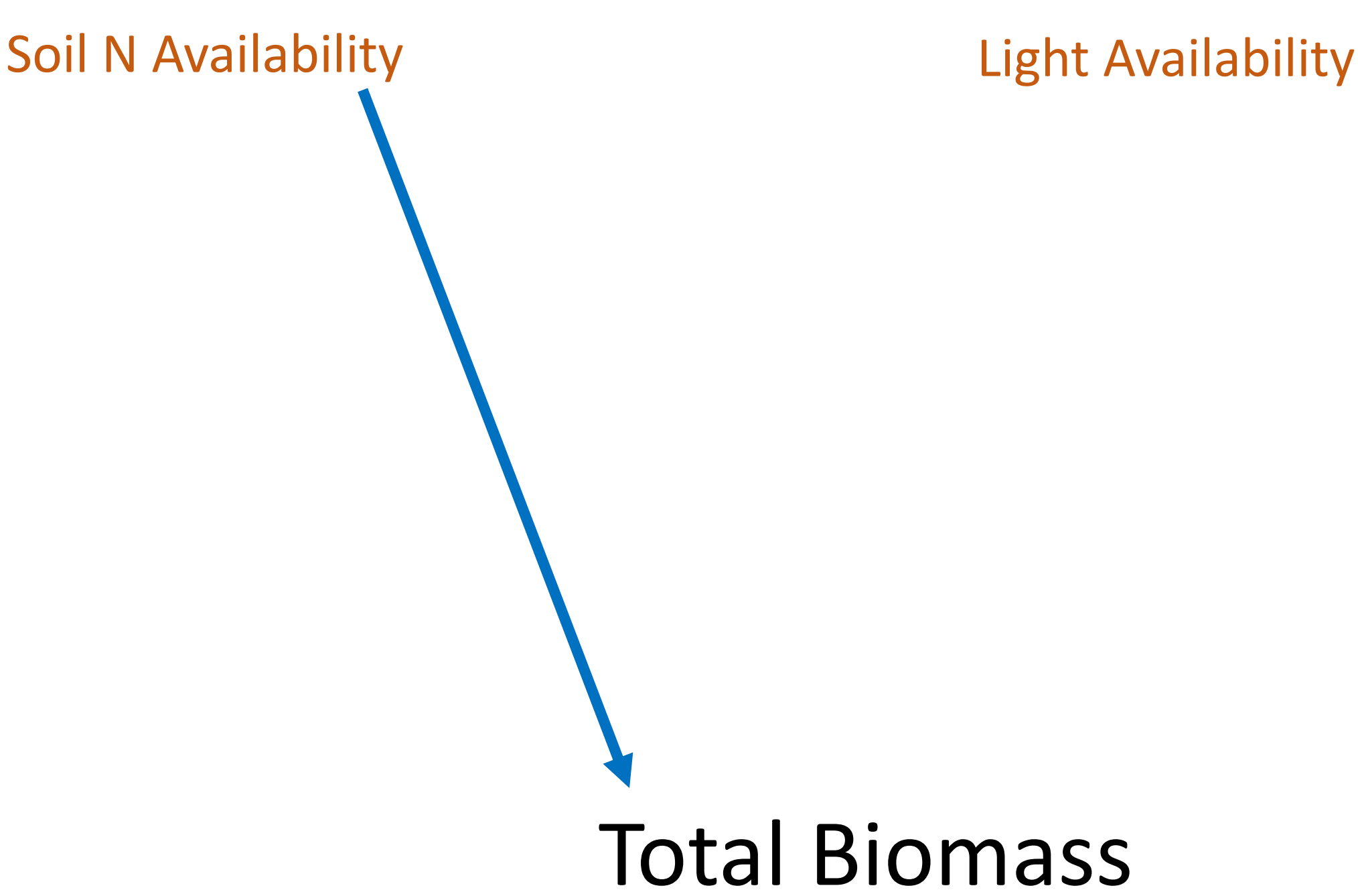
ECOLOGY LETTERS BNL-209496-2018-JAAM

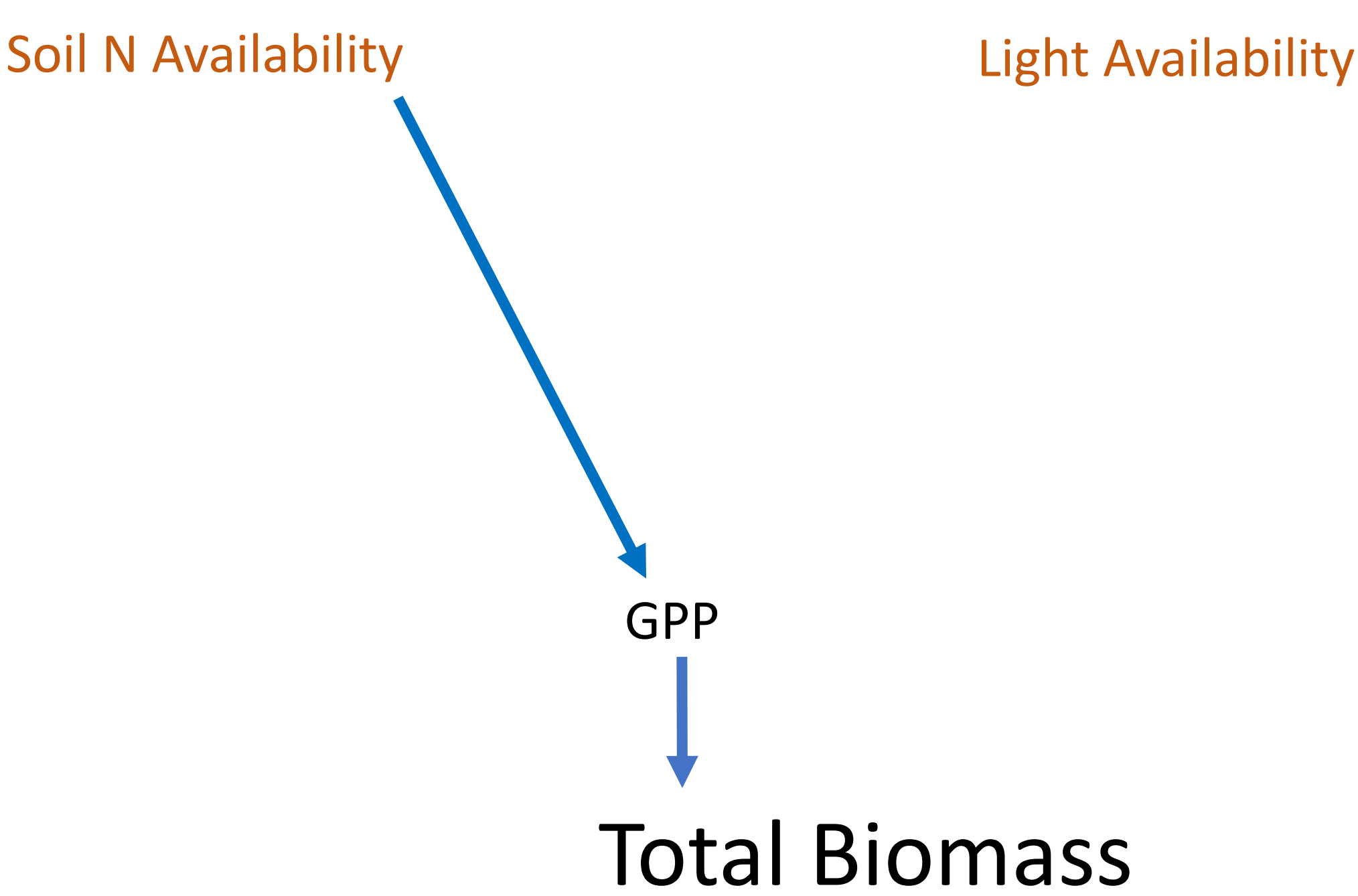
Ecology Letters, (2018) doi: 10.1111/ele.13210

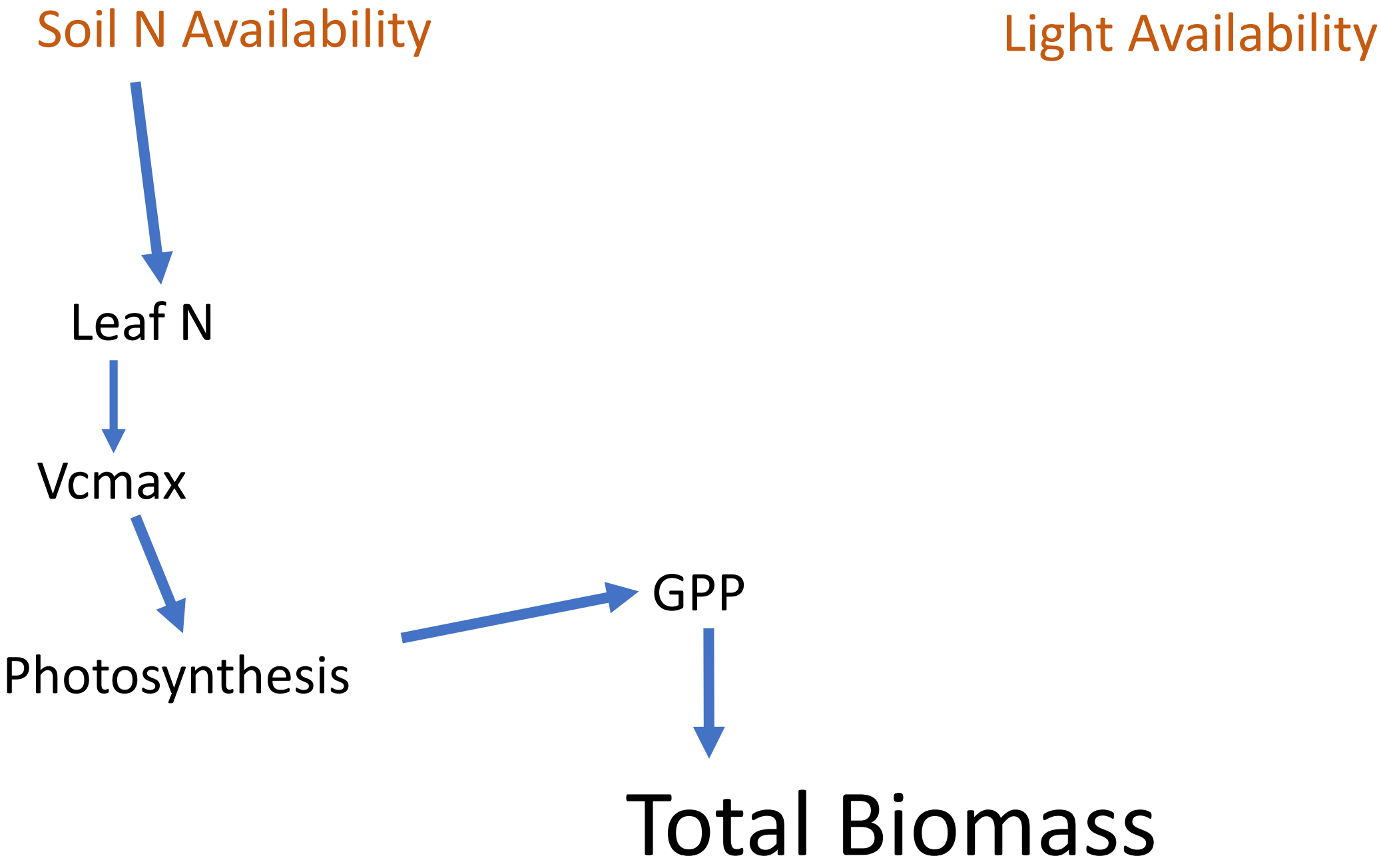
LETTER

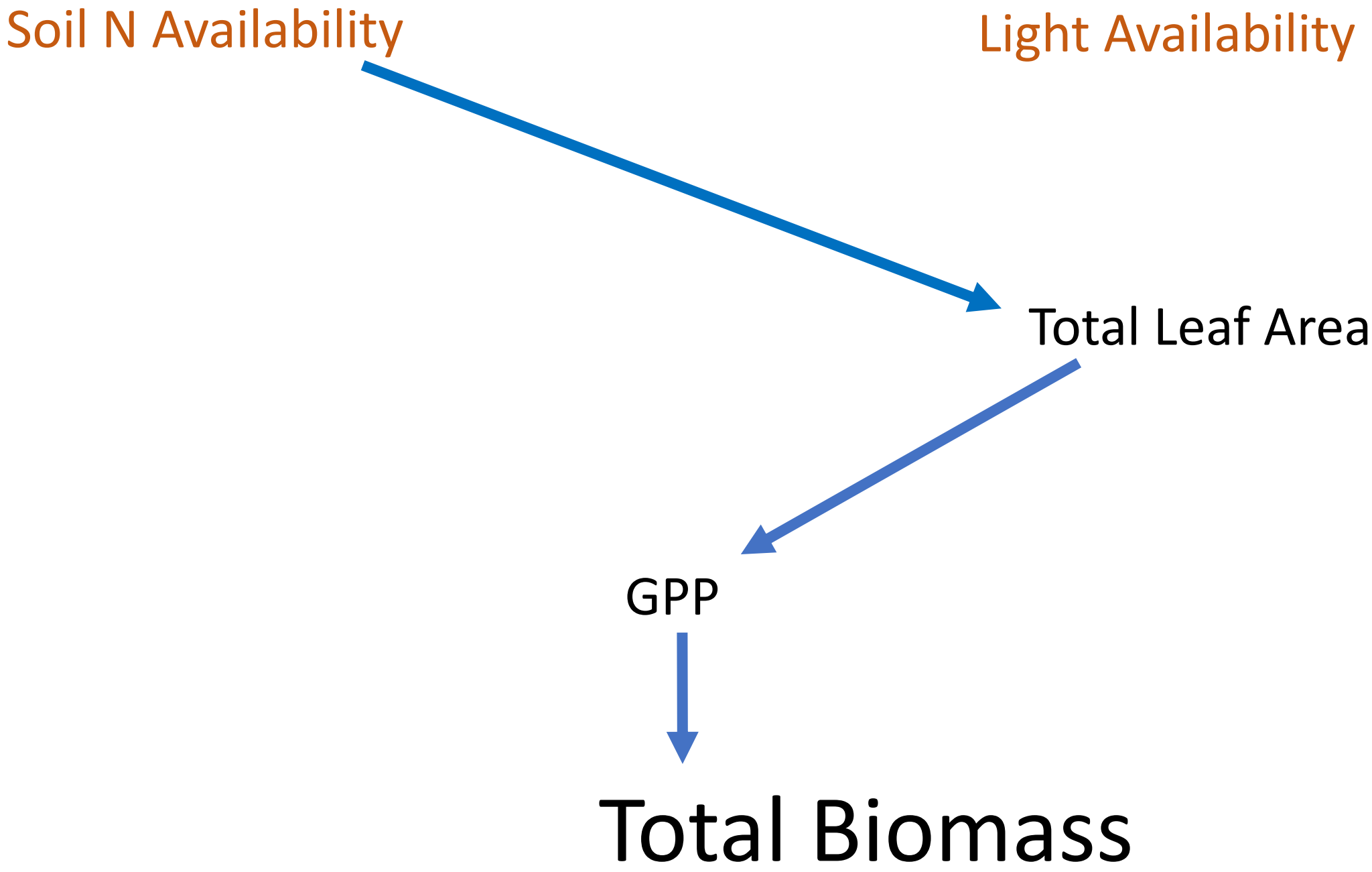
Global photosynthetic capacity is optimized to the environment

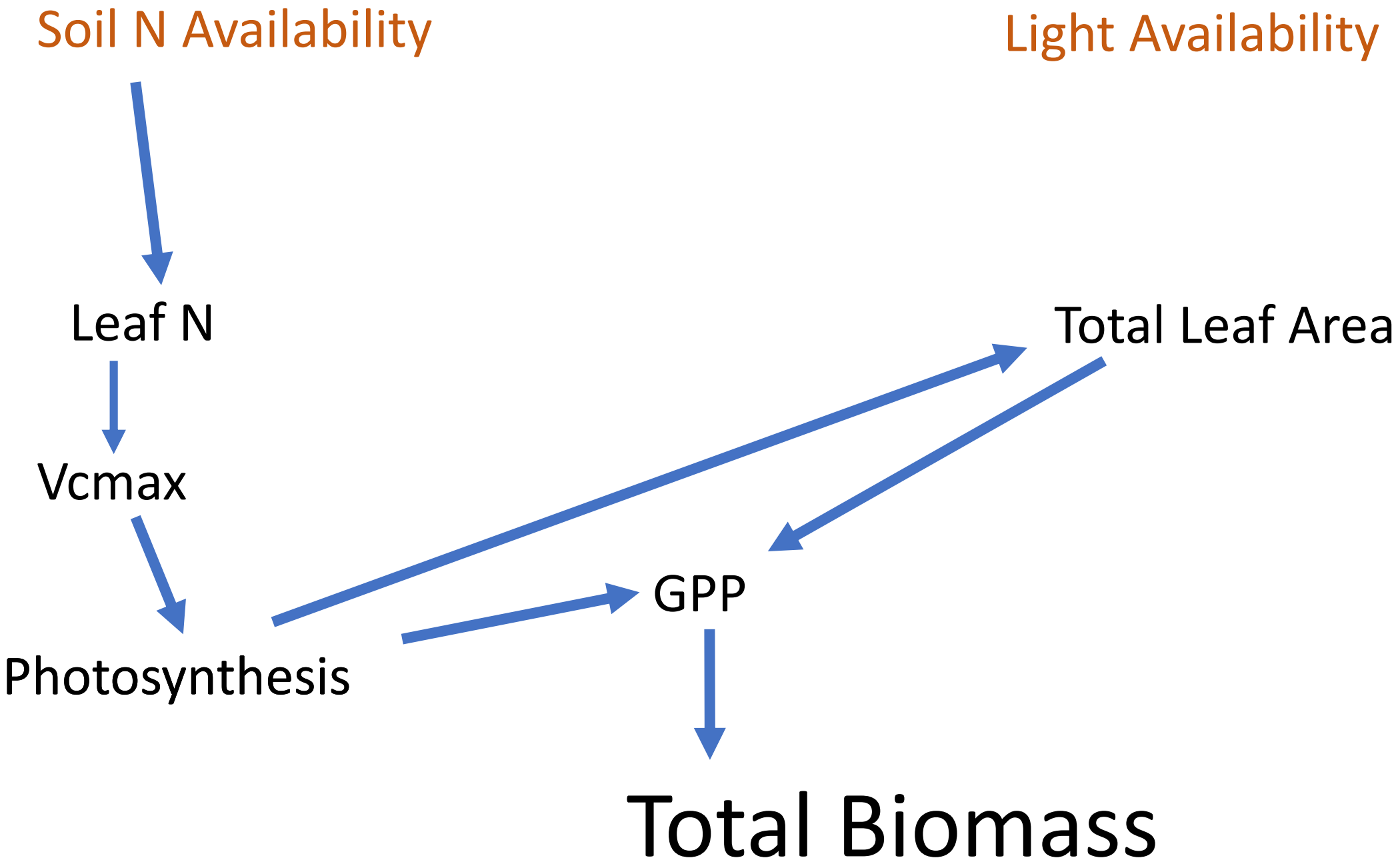
Smith et al.


Soil N Availability
Light Availability
Total Biomass


Soil N Availability
Light Availability
GPP
Total Biomass

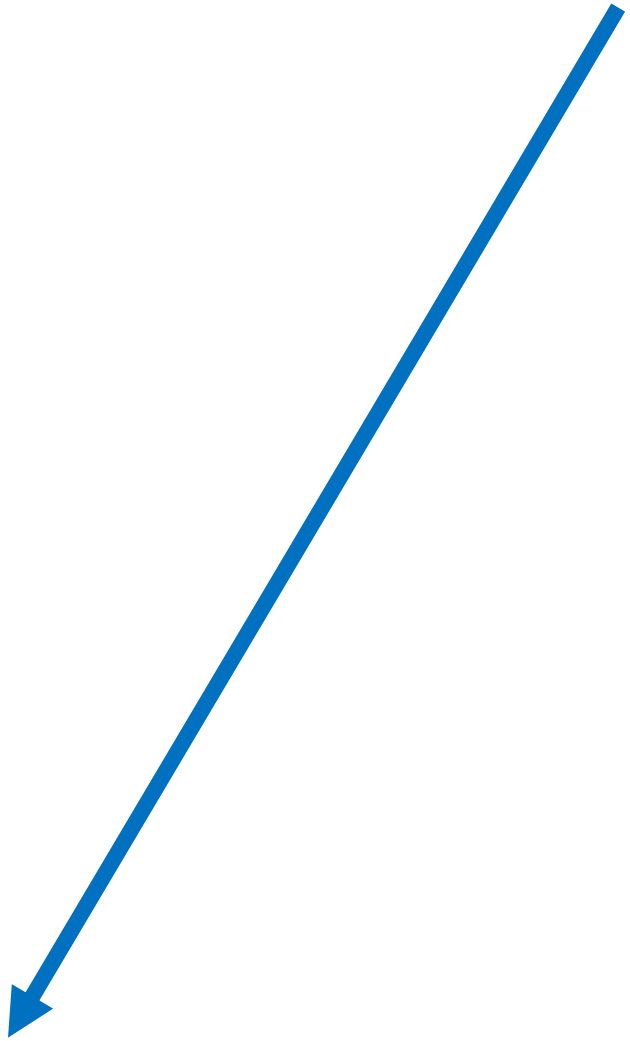

Soil N Availability
Light Availability
Leaf N
Vcmax
Photosynthesis
GPP
Total Biomass


Soil N Availability
Light Availability
Total Leaf Area
GPP
Total Biomass

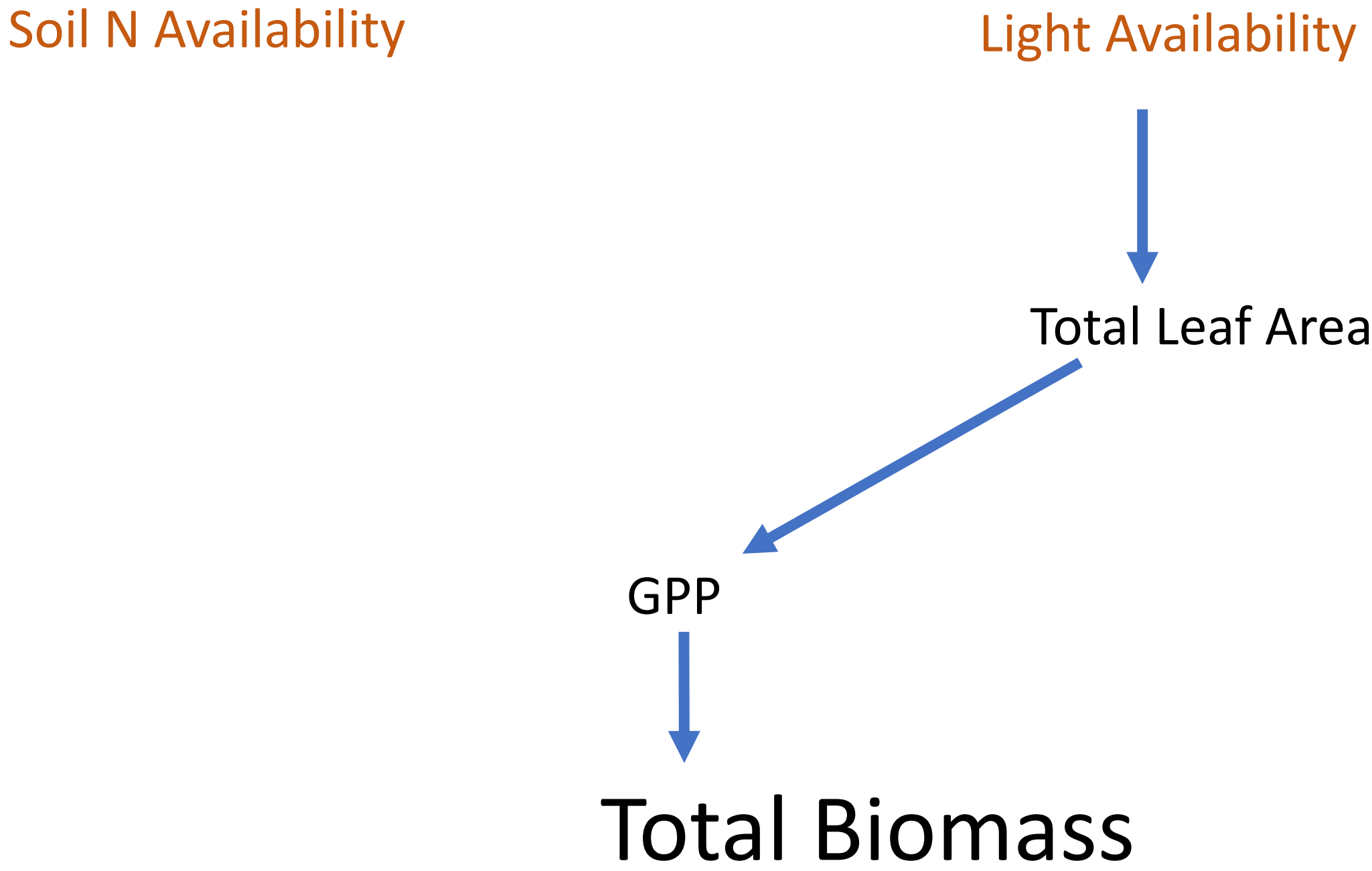

Soil N Availability
Light Availability
Leaf N
Total Leaf Area
Vcmax
GPP
Photosynthesis
Total Biomass

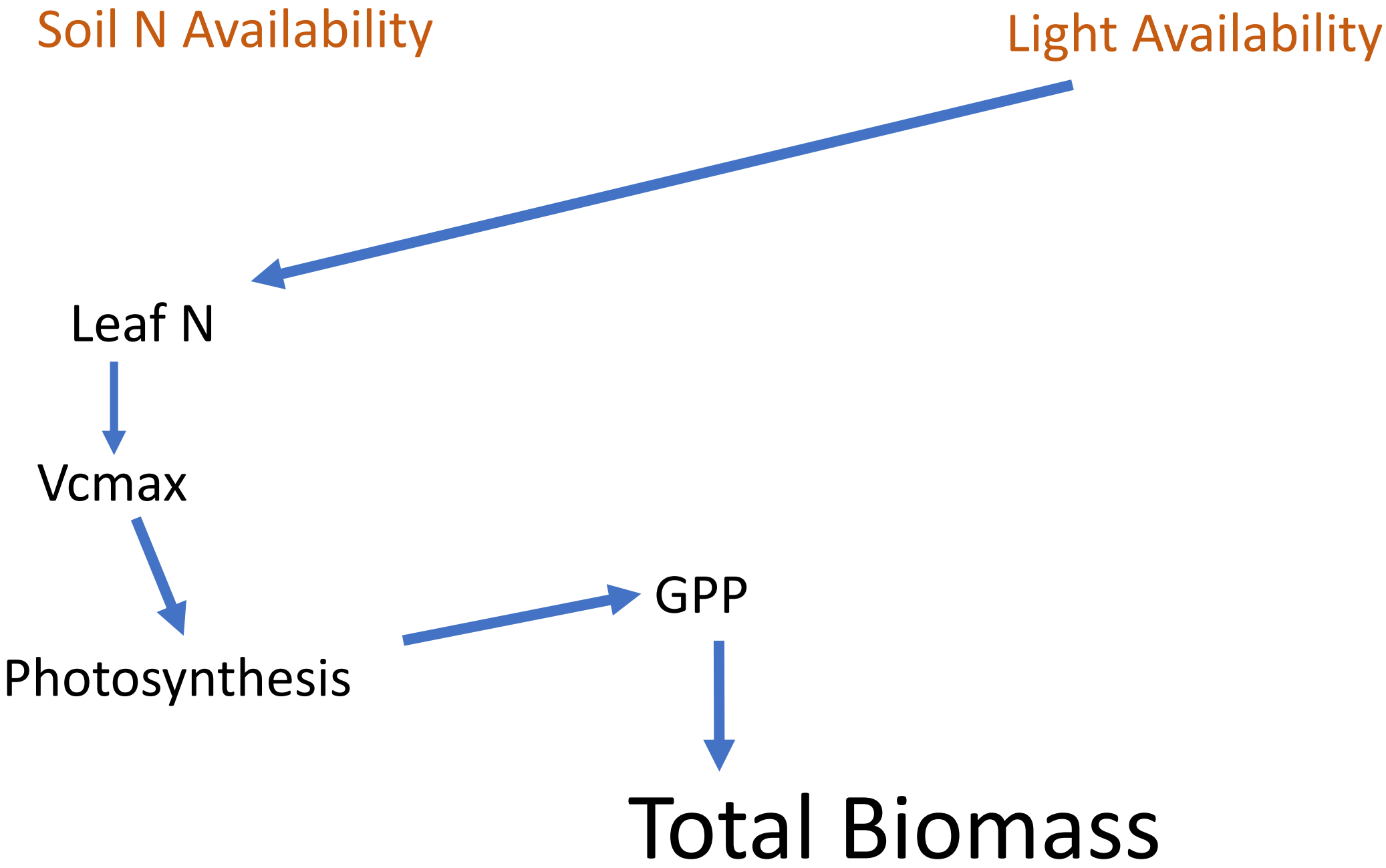
Soil N Availability

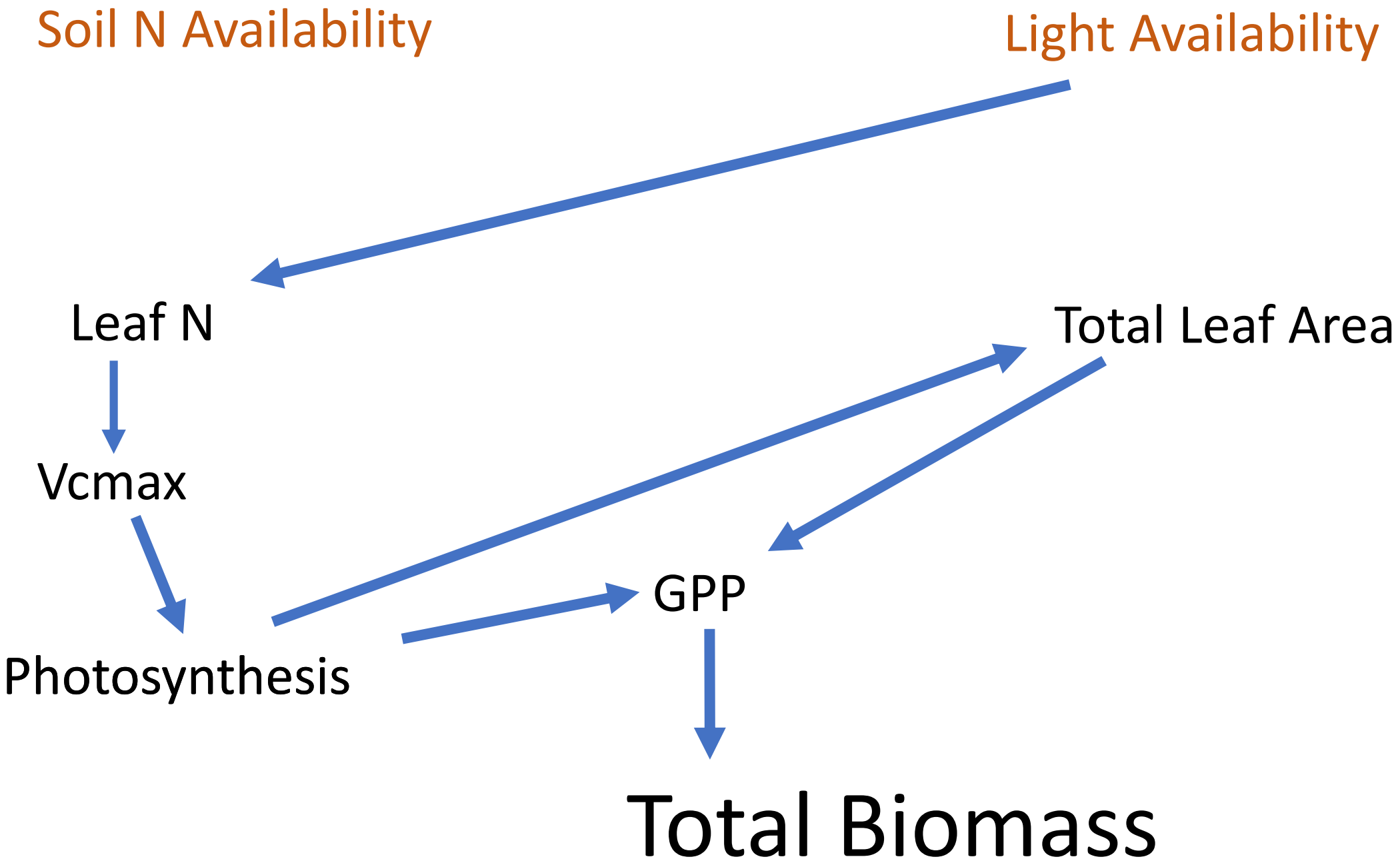
Light Availability

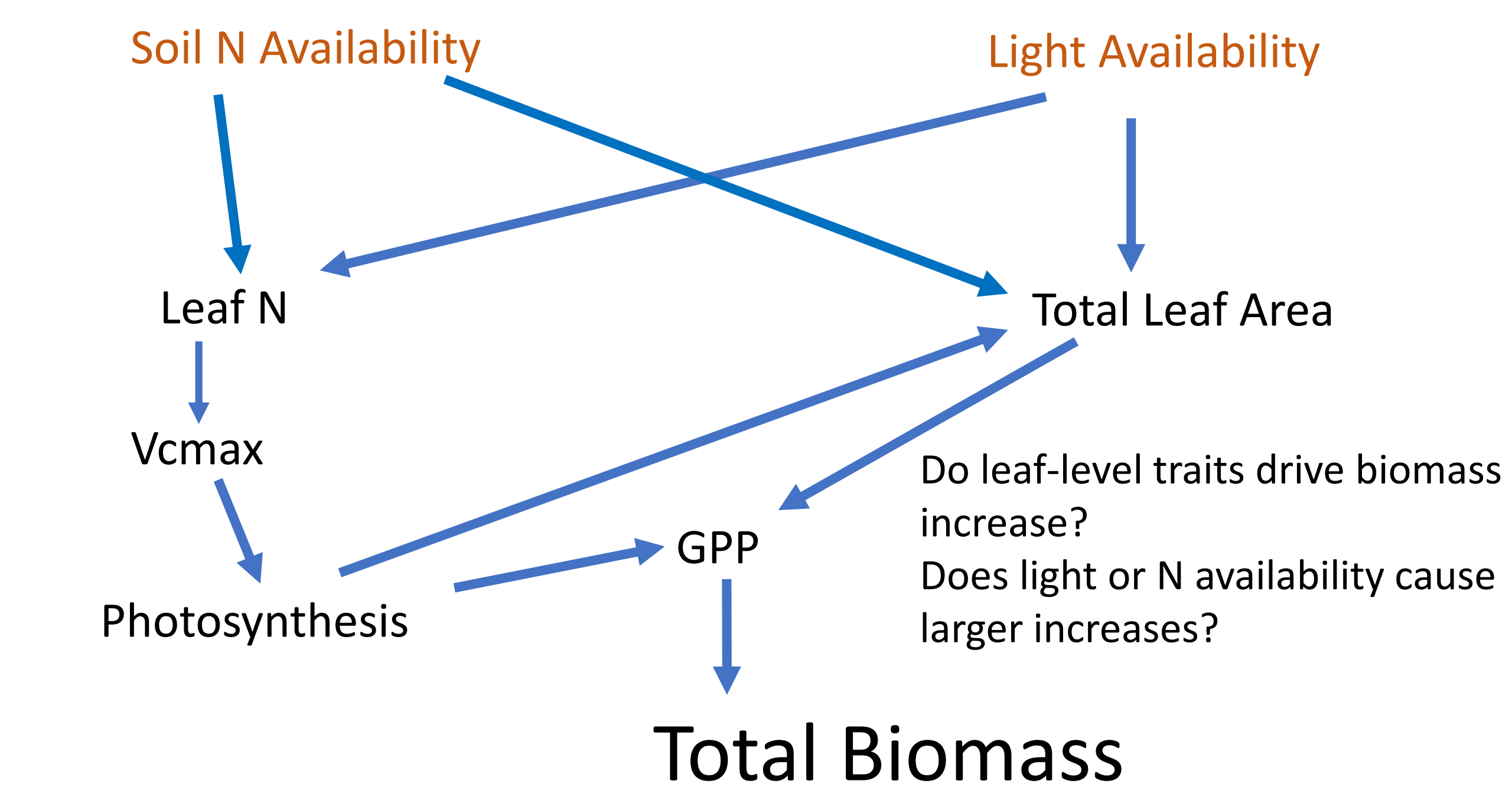


Total Biomass


Soil N Availability
Light Availability
Total Leaf Area
GPP
Total Biomass


Soil N Availability
Light Availability
Leaf N
Vcmax
Photosynthesis
GPP
Total Biomass


Soil N Availability
Light Availability
Leaf N
Total Leaf Area
Vcmax
GPP
Photosynthesis
Total Biomass

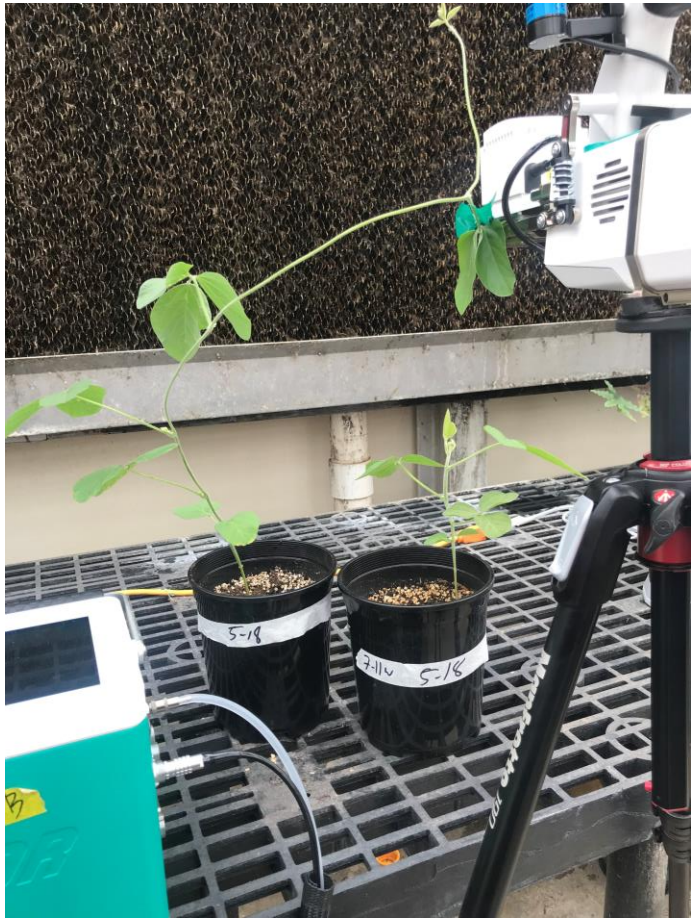

Soil N Availability
Light Availability
Leaf N
Total Leaf Area
Vcmax
Photosynthesis
GPP
Total Biomass
Do leaf-level traits drive biomass increase?
Does light or N availability cause larger increases?

How we are approaching light vs N issue

whole plant research

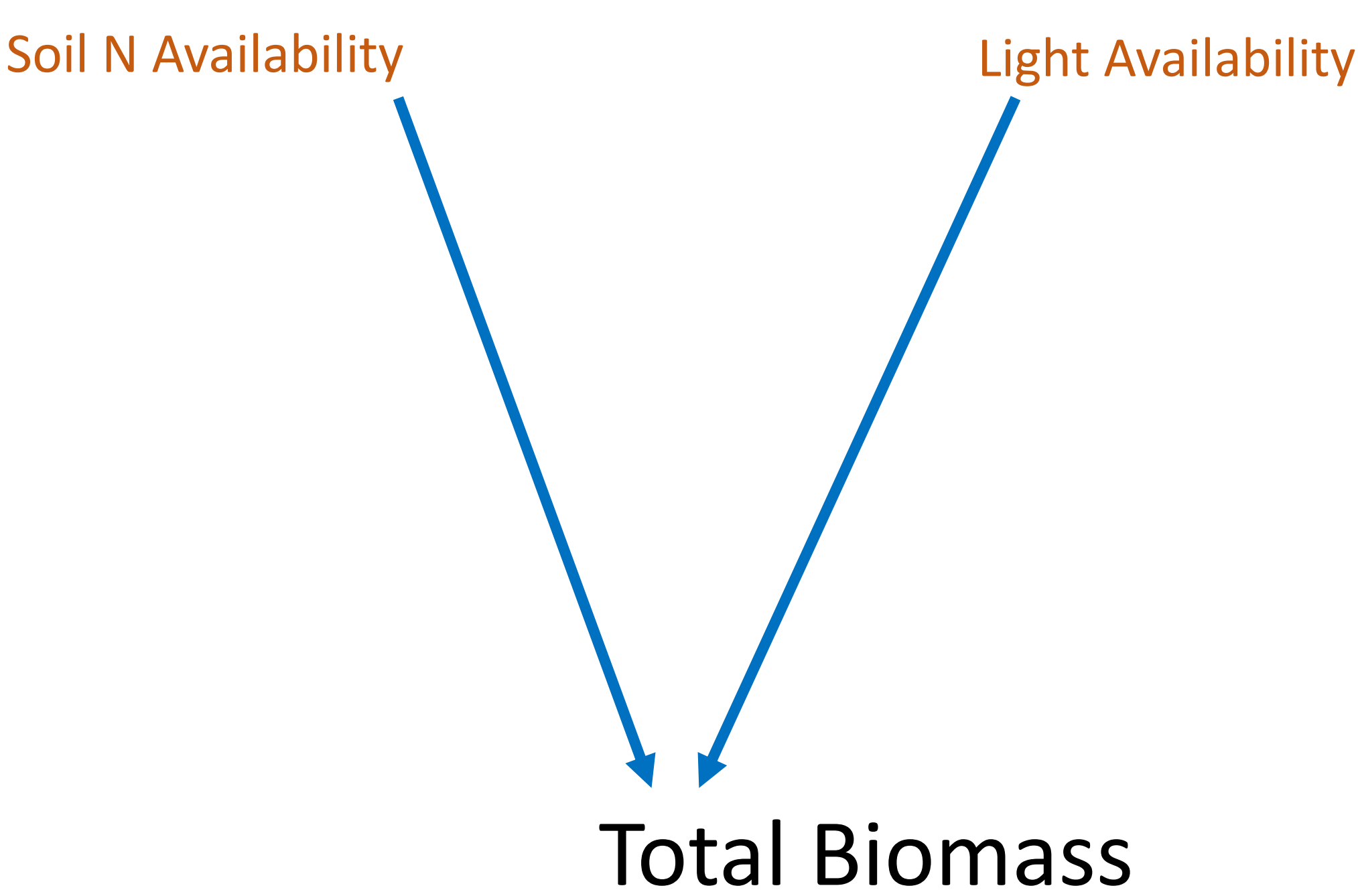
Greenhouse

- Li6800
- Biomass
- Area
- Elemental analysis



Greenhouse

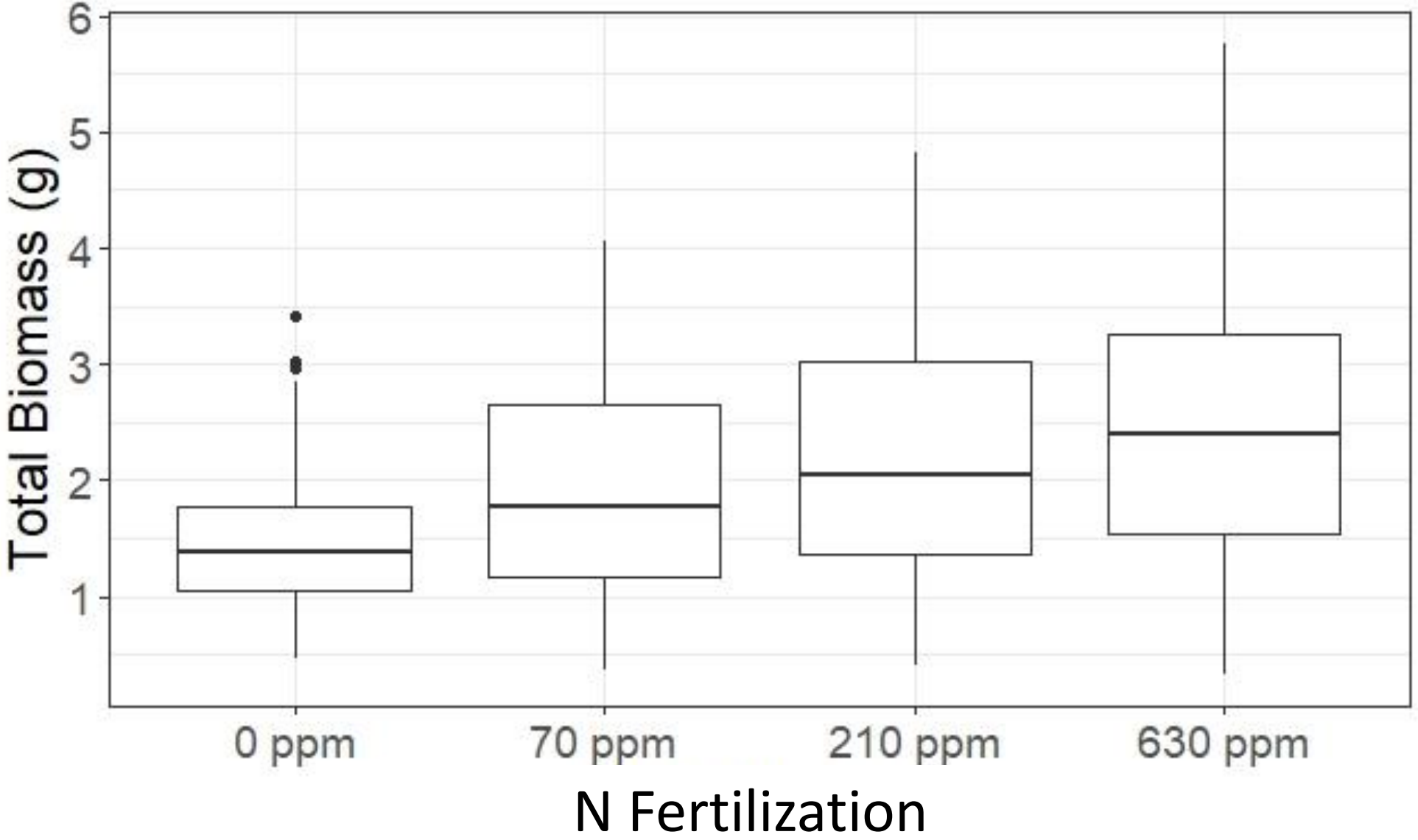
- Four light treatments
- Four N fertilization treatments
- Two species
  - Cotton
  - Soybean


Soil N Availability
Light Availability
Total Biomass

Greenhouse

70% increase

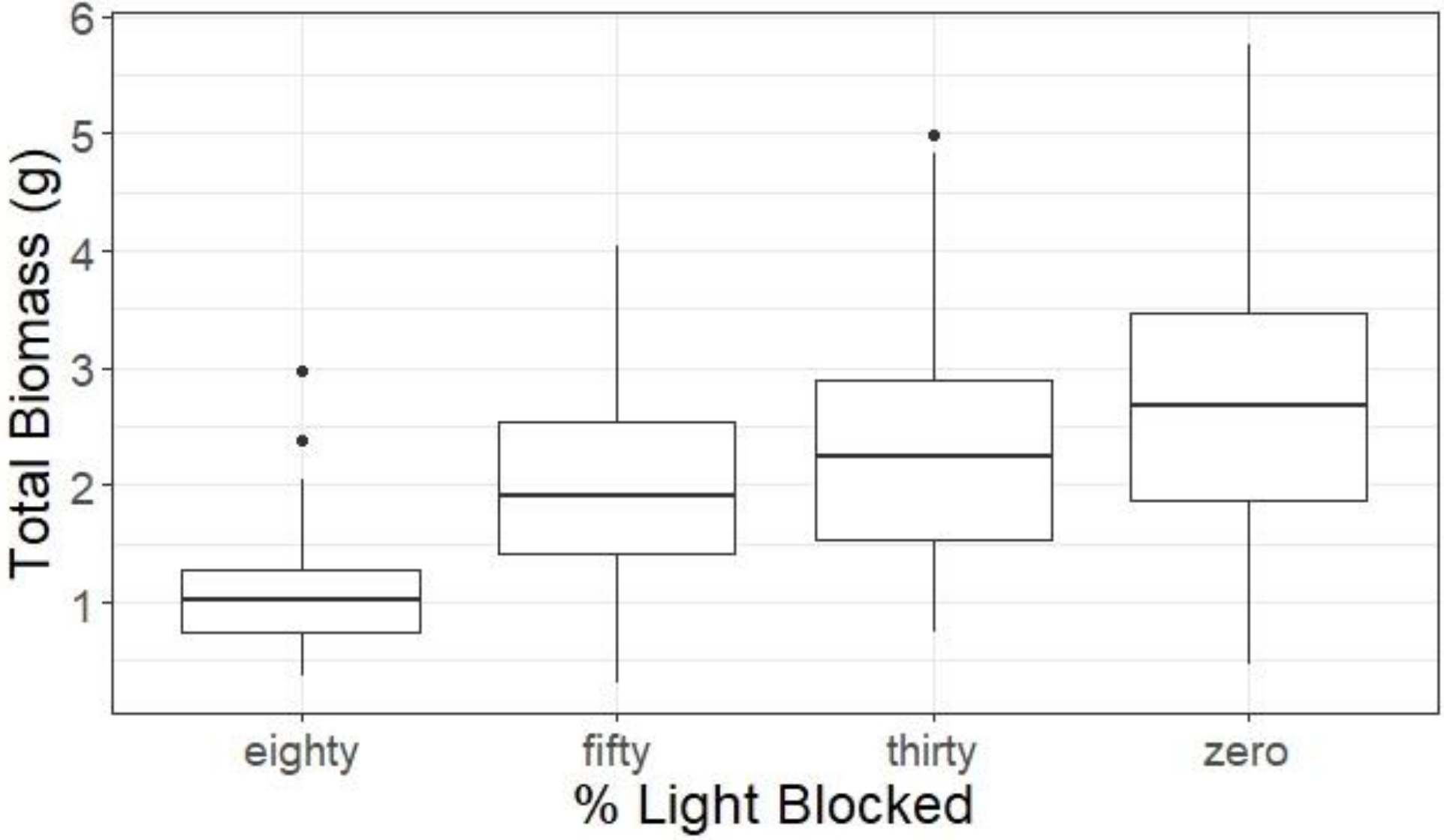
P=0.0213

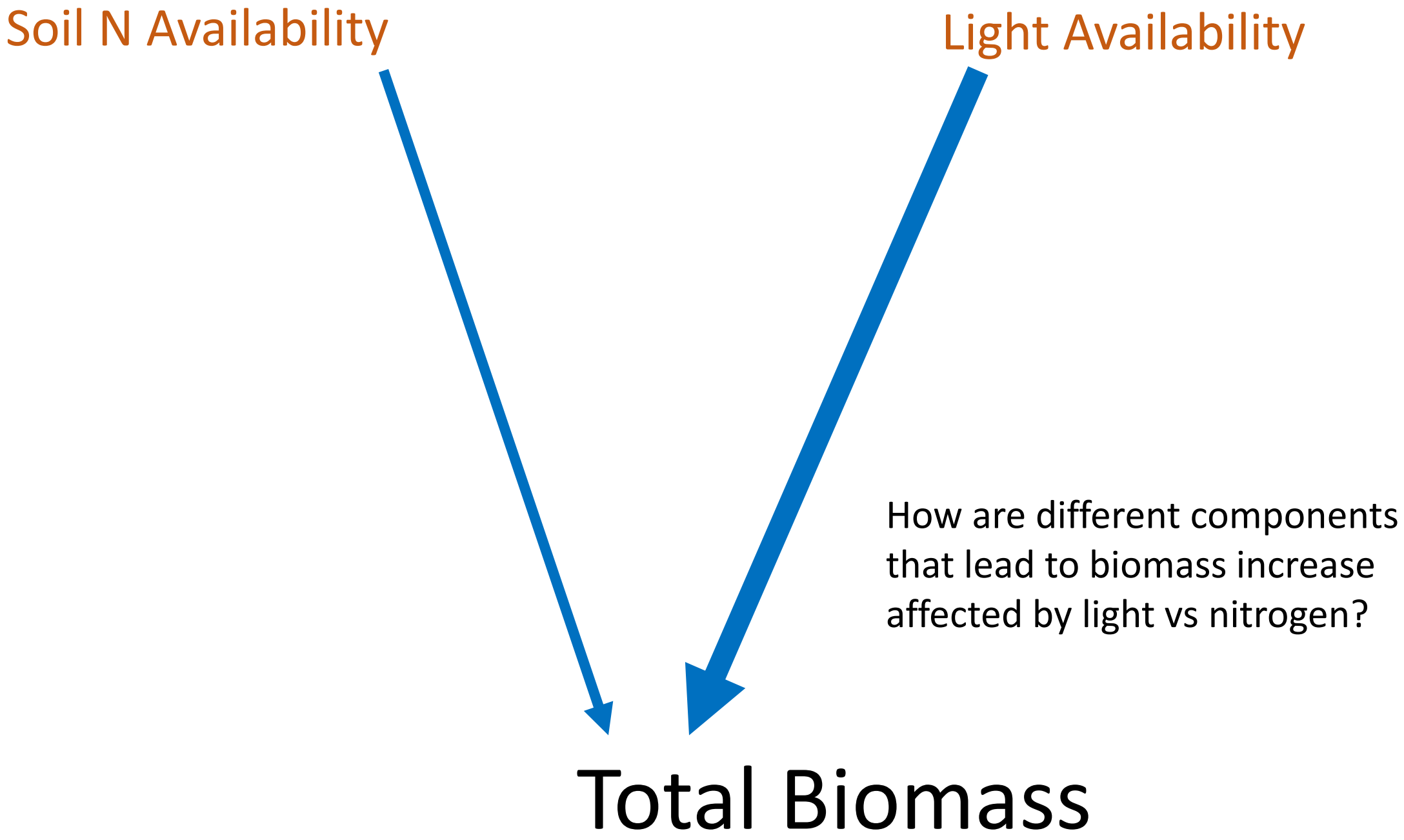


Greenhouse

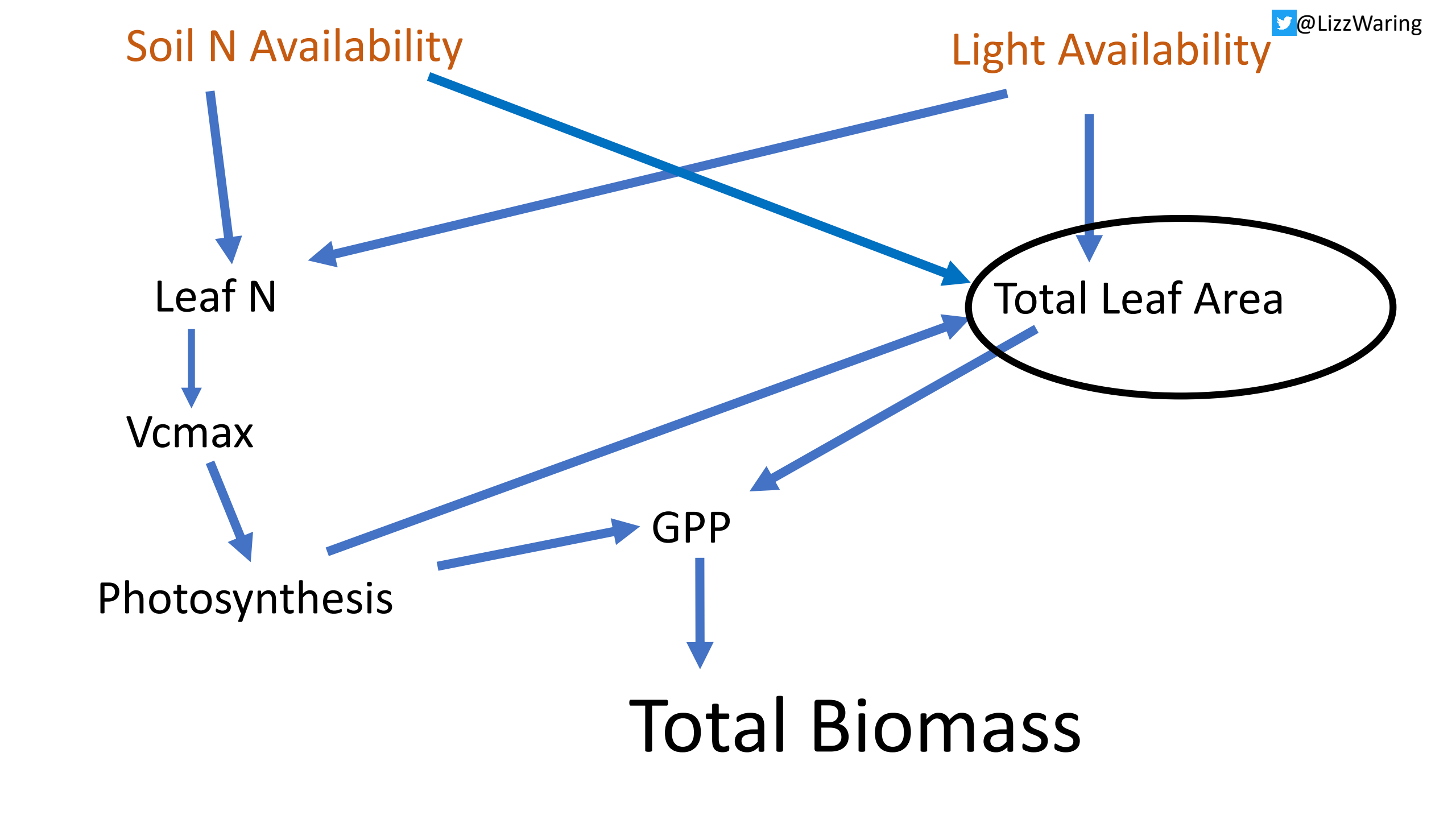
140% increase

P<0.0001





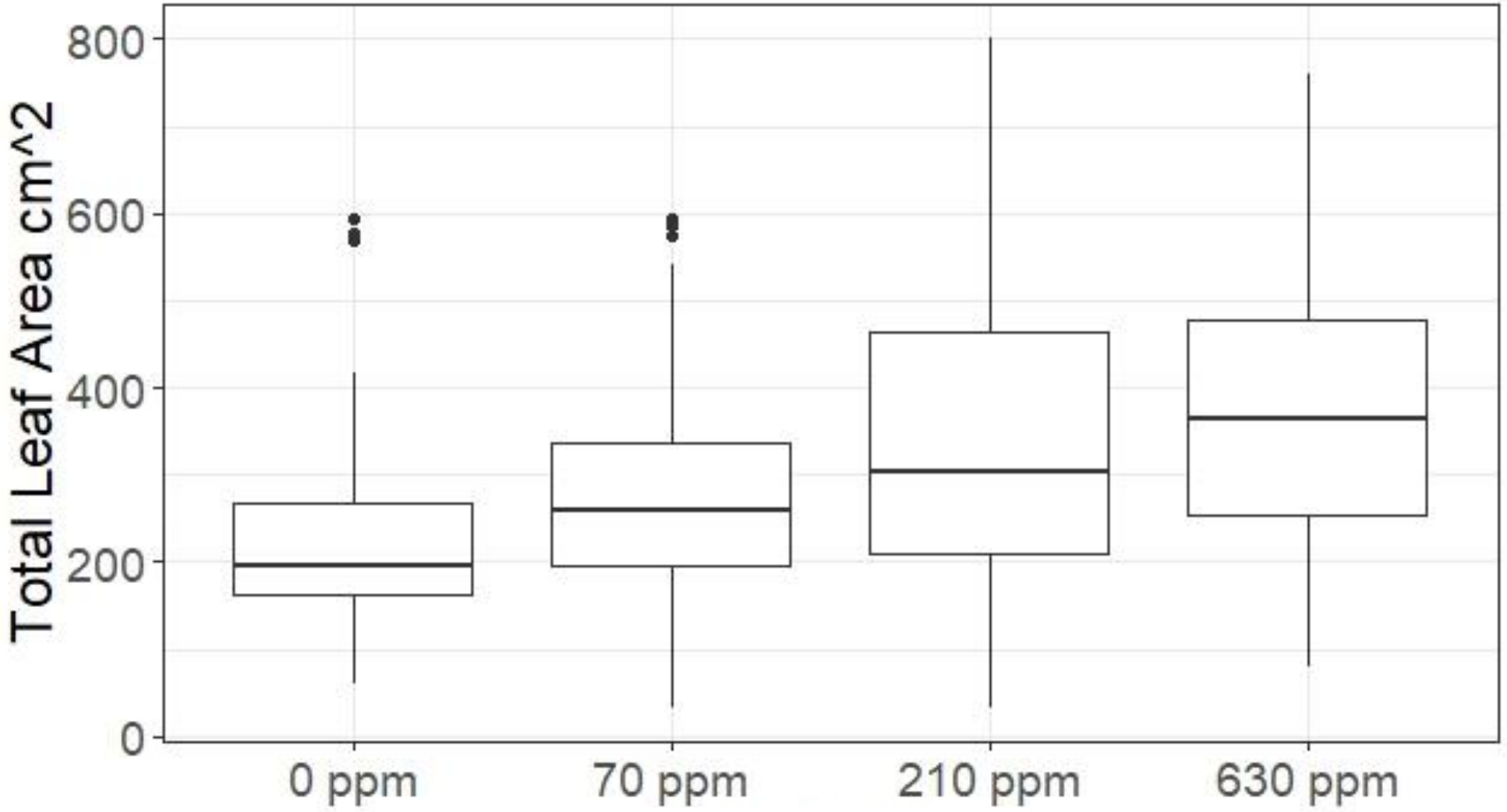
How are different components that lead to biomass increase affected by light vs nitrogen?


@LizzWaring
Soil N Availability
Light Availability
Leaf N
Total Leaf Area
Vcmax
GPP
Photosynthesis
Total Biomass

Greenhouse

70% increase

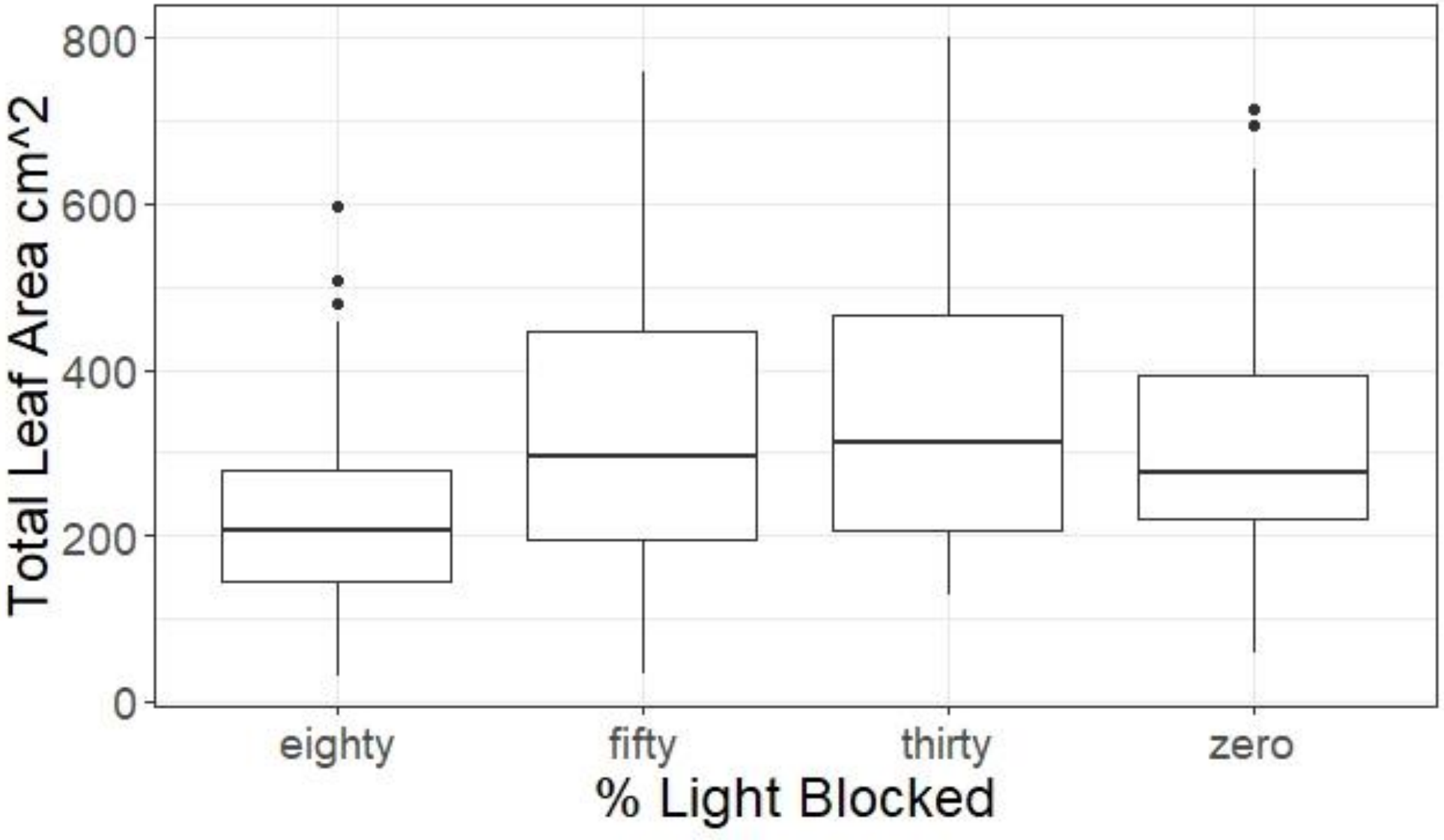
P<0.0001

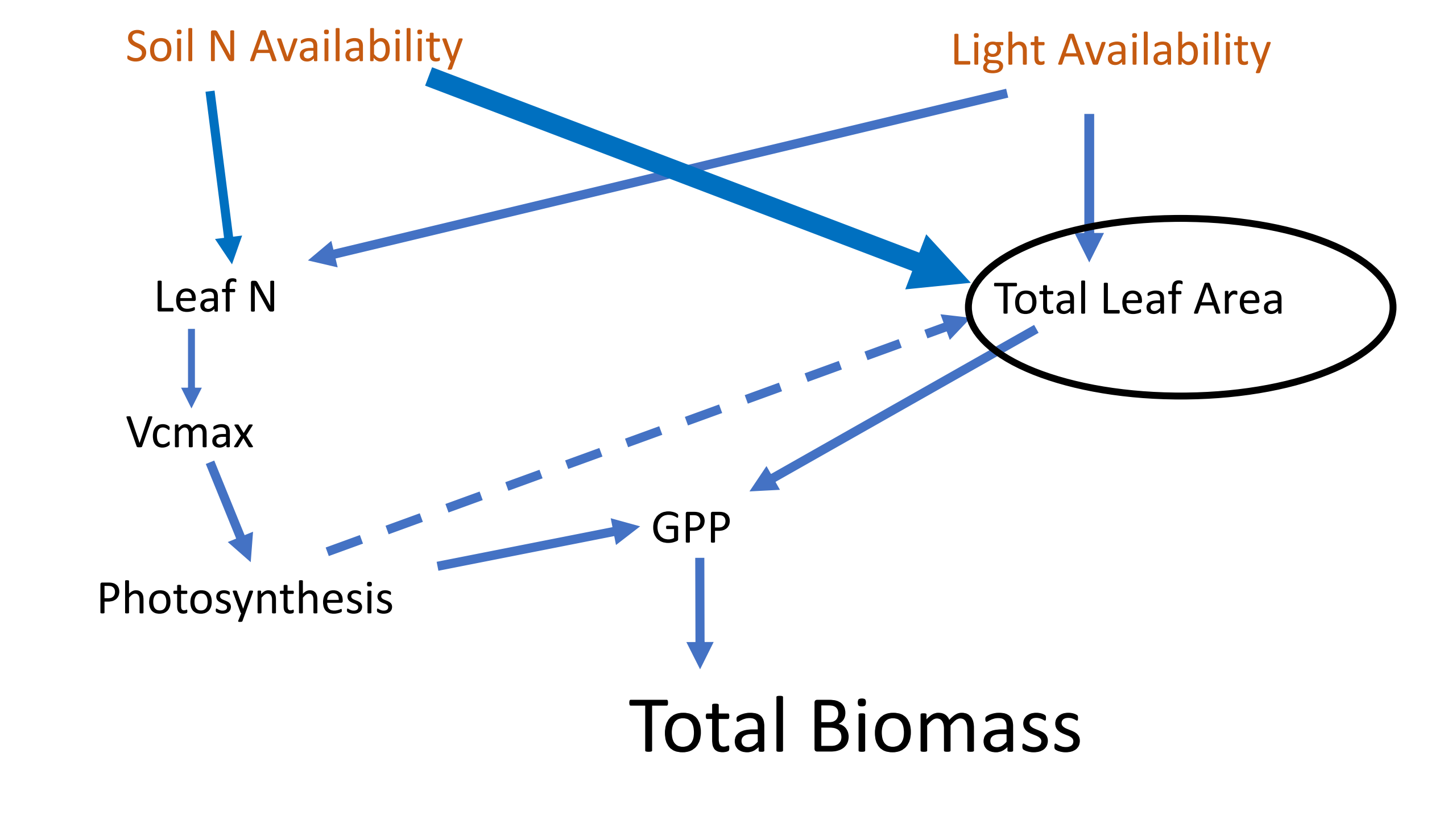


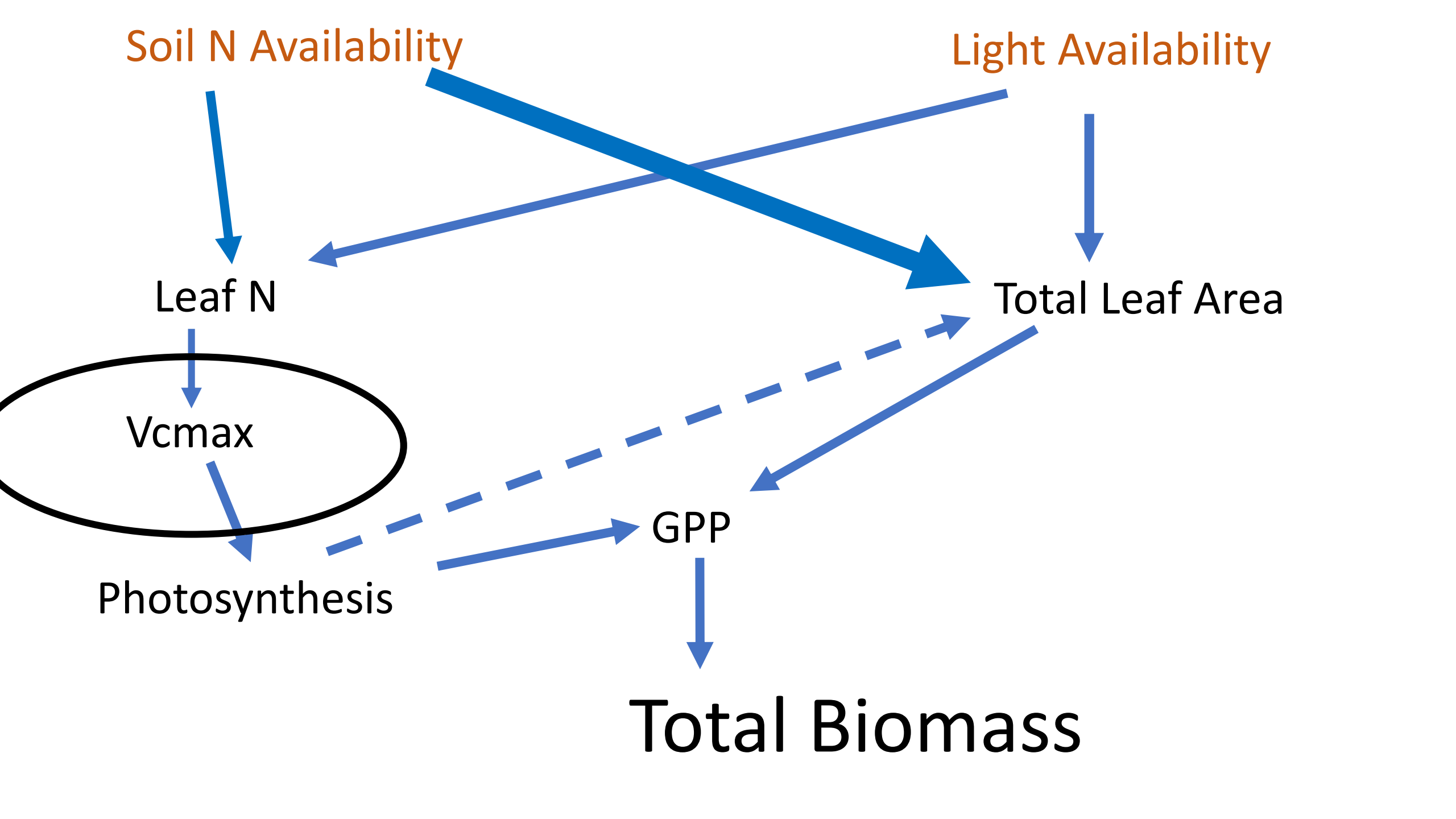
Greenhouse

40% increase

P<0.0001



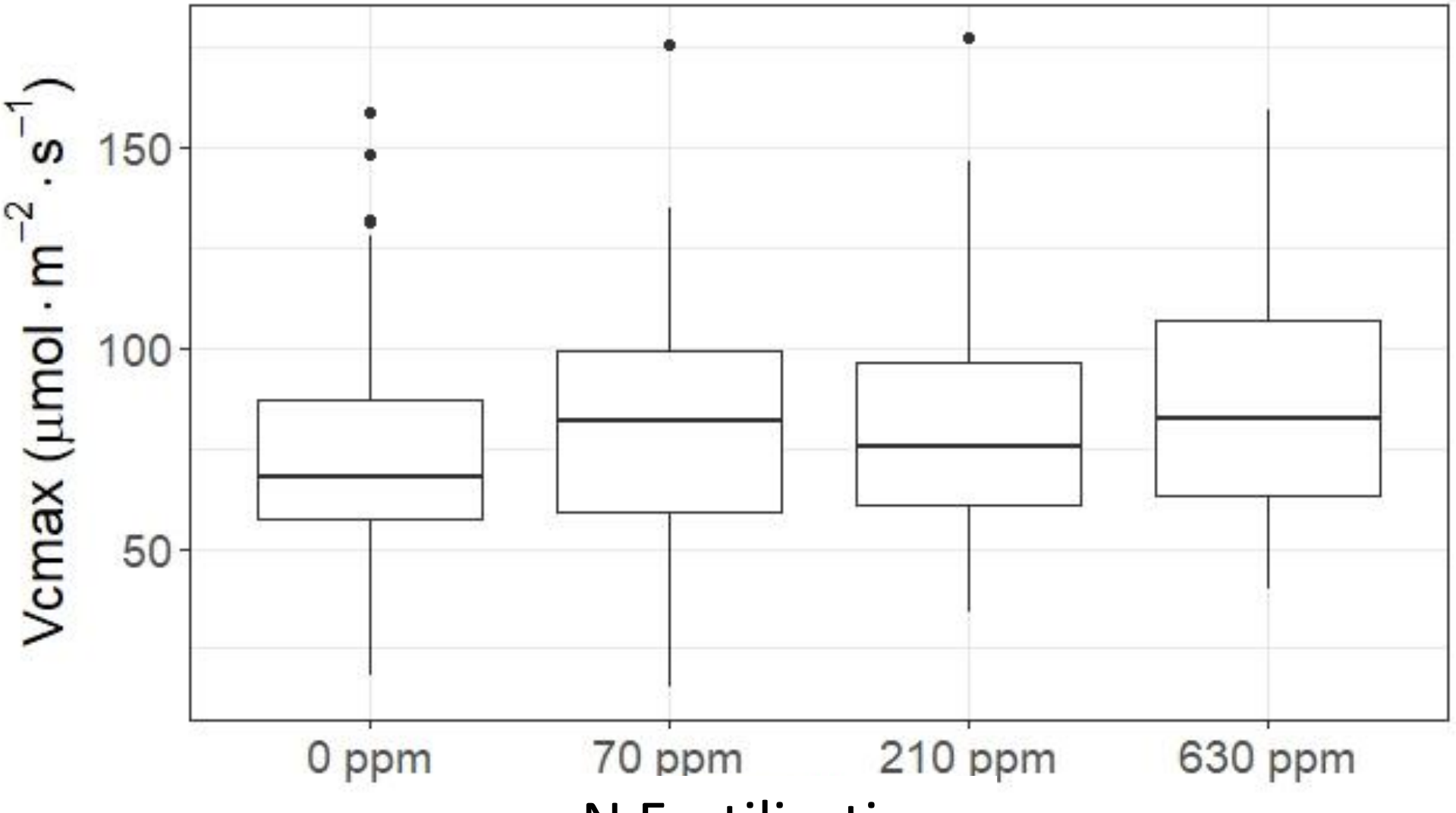

Soil N Availability
Light Availability
Leaf N
Total Leaf Area
Vcmax
GPP
Photosynthesis
Total Biomass


Soil N Availability
Light Availability
Leaf N
Total Leaf Area
Vcmax
Photosynthesis
GPP
Total Biomass

Greenhouse

15% increase

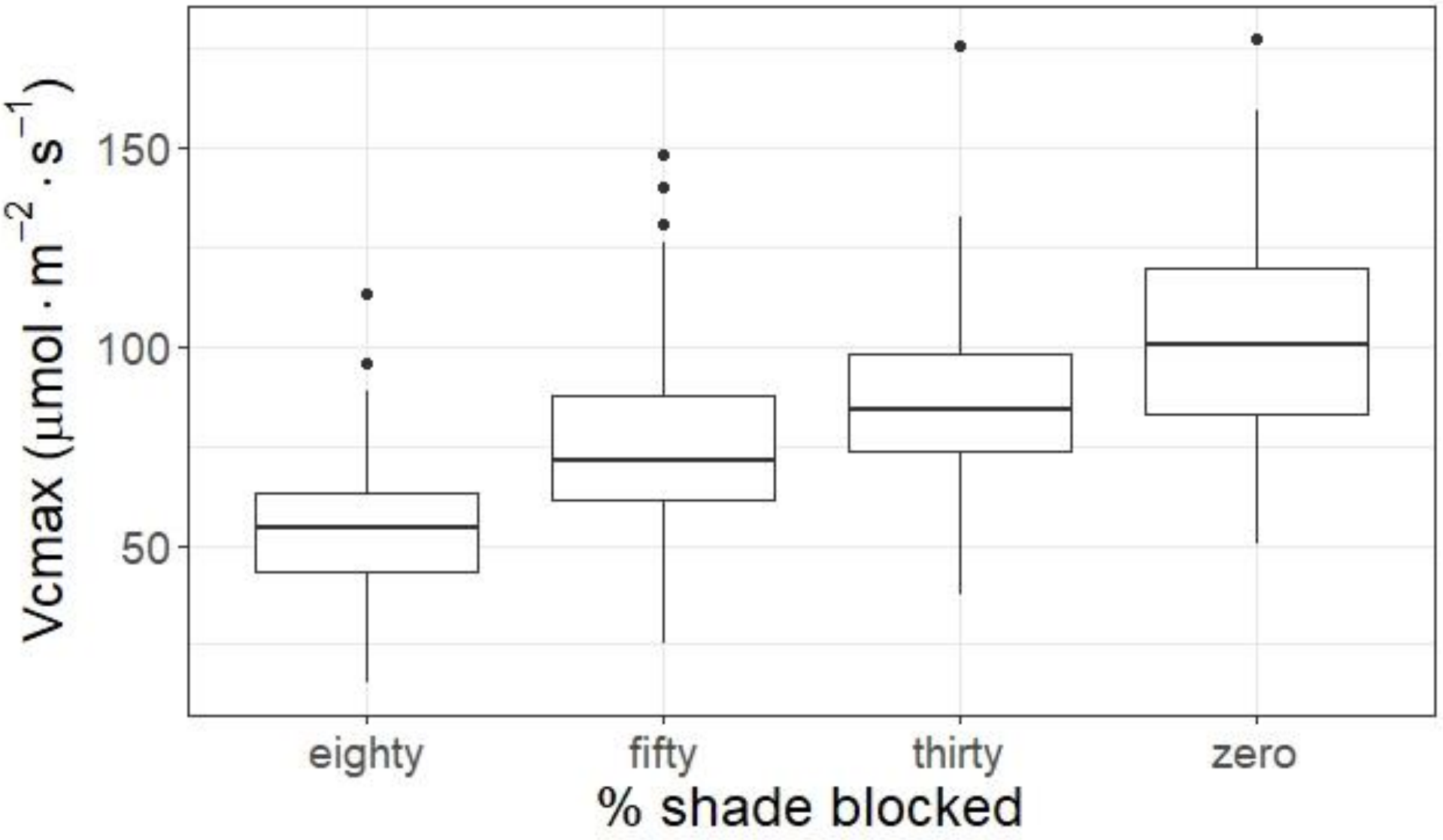
P=0.0022

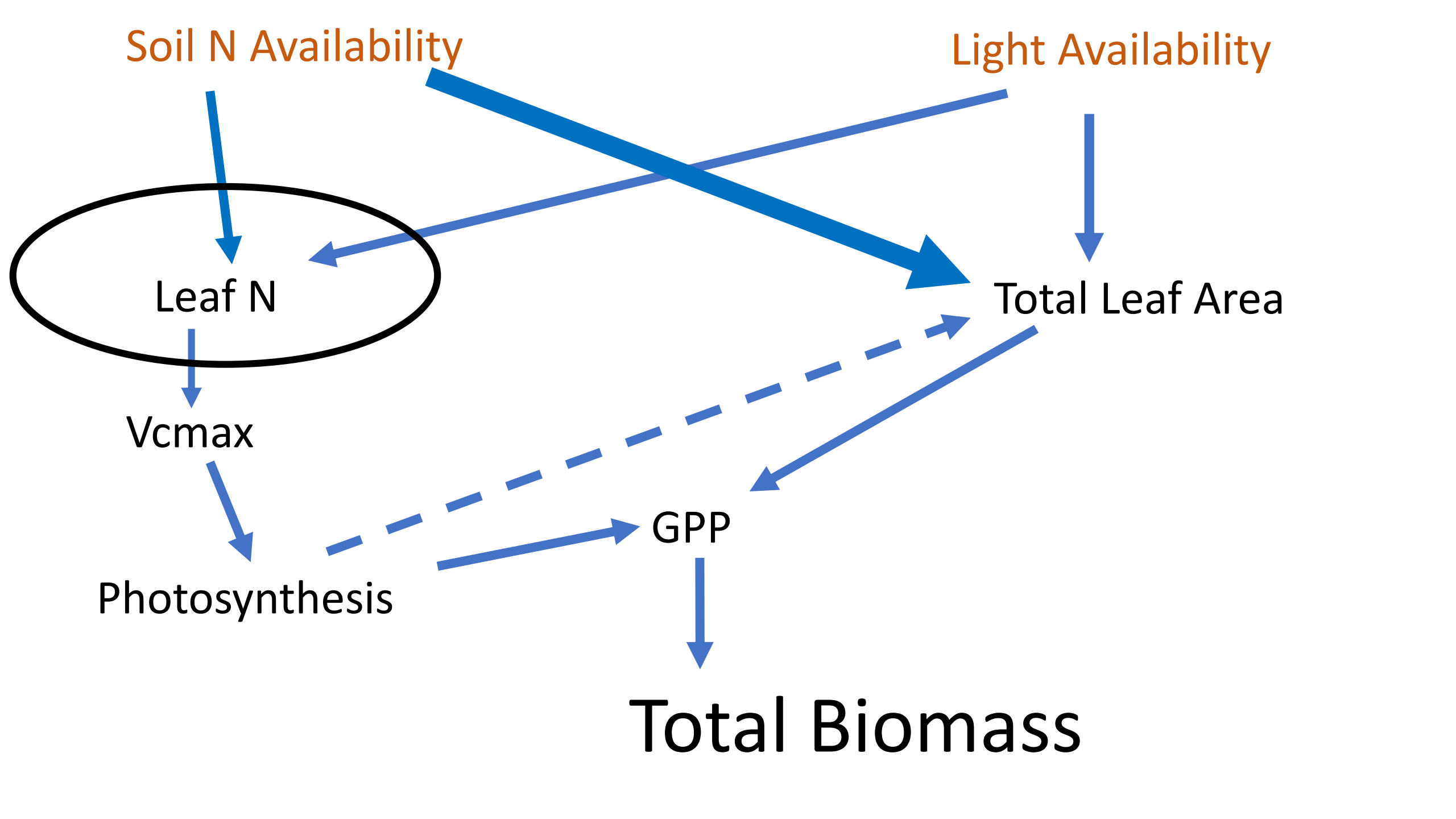


Greenhouse

87% increase

P<0.0001

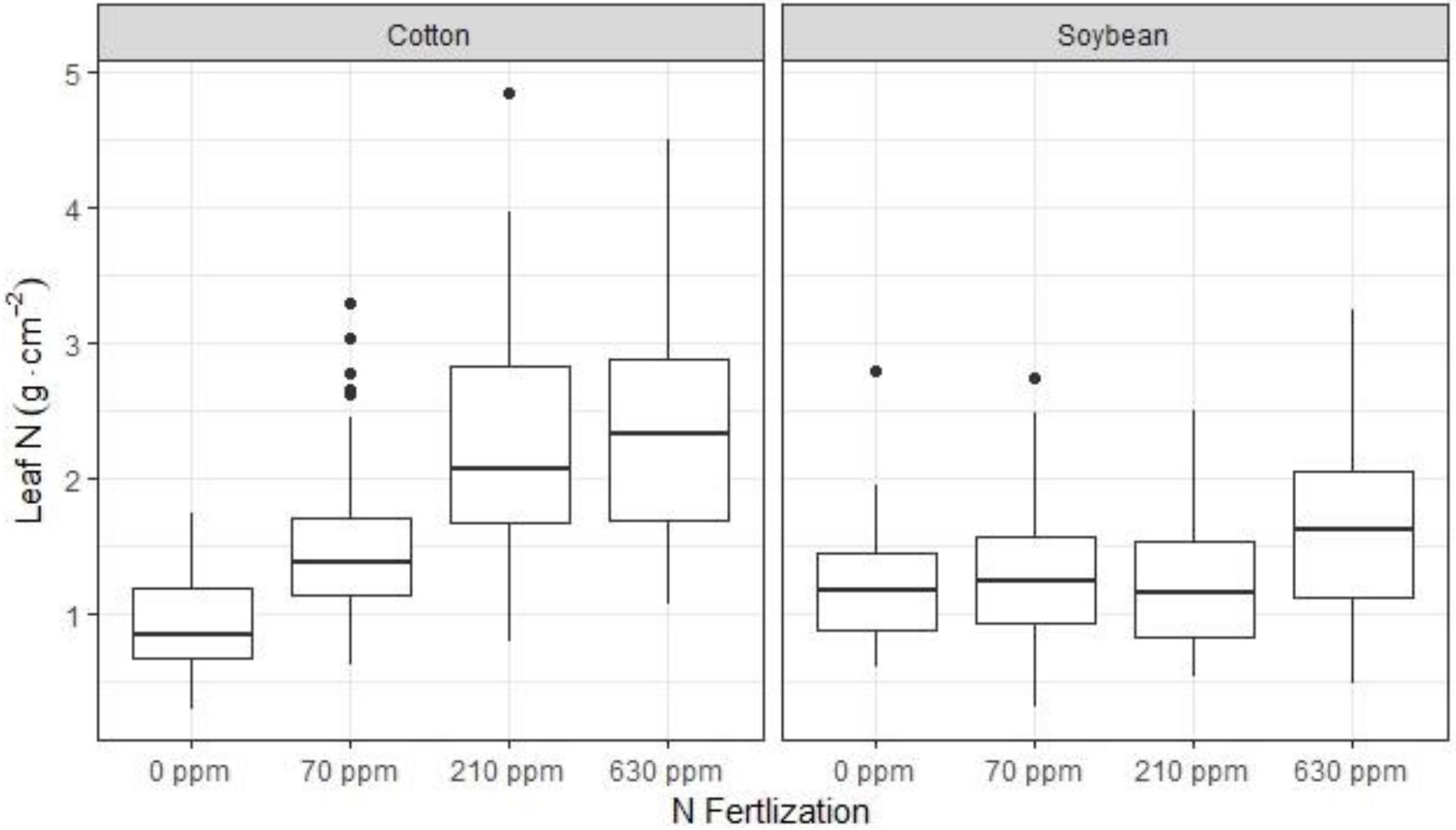



Soil N Availability
Light Availability
Leaf N
Total Leaf Area
Vcmax
GPP
Photosynthesis
Total Biomass

Greenhouse

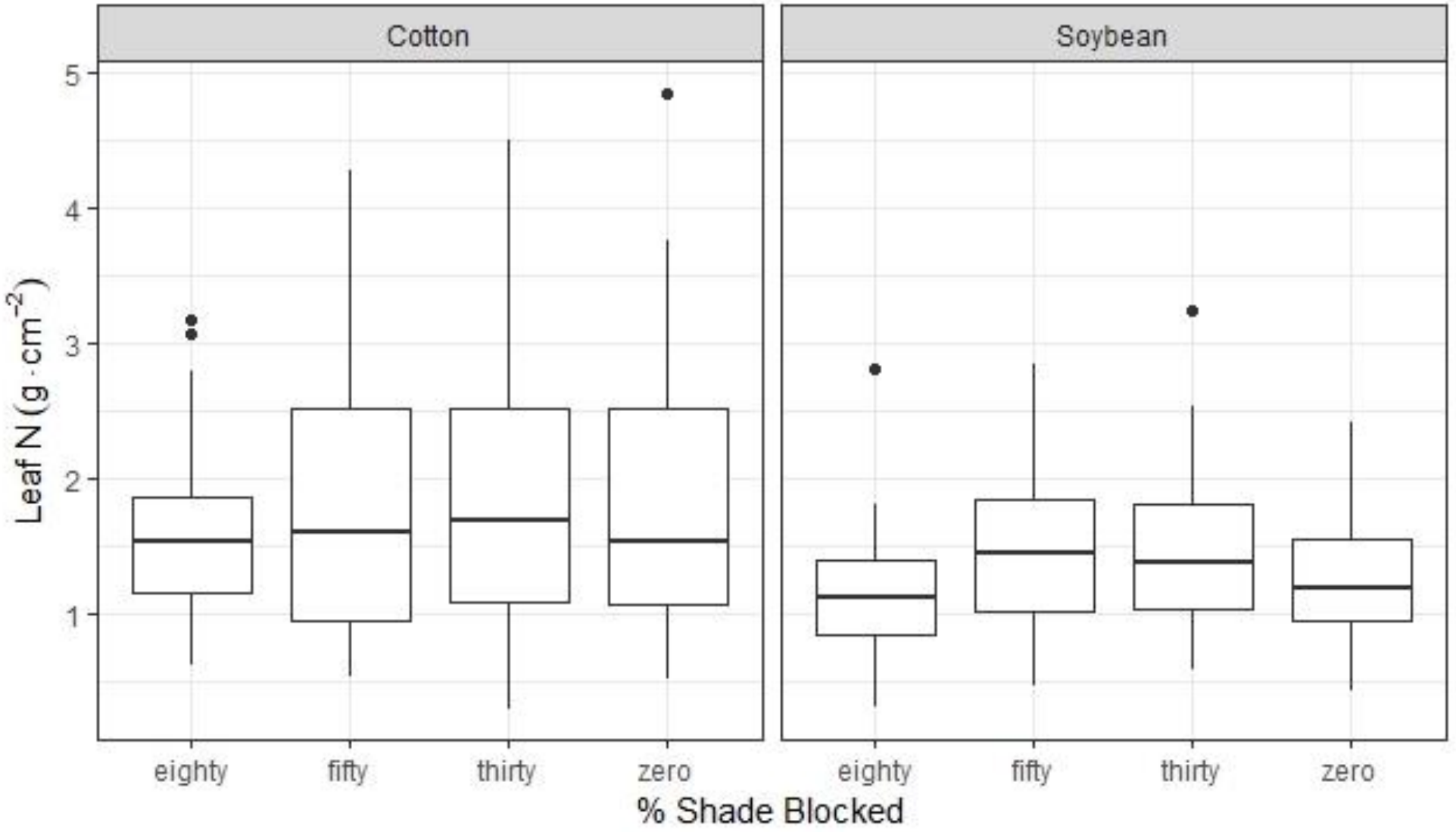
Cotton:
>150 %
increase

Soybean:
40 %
increase

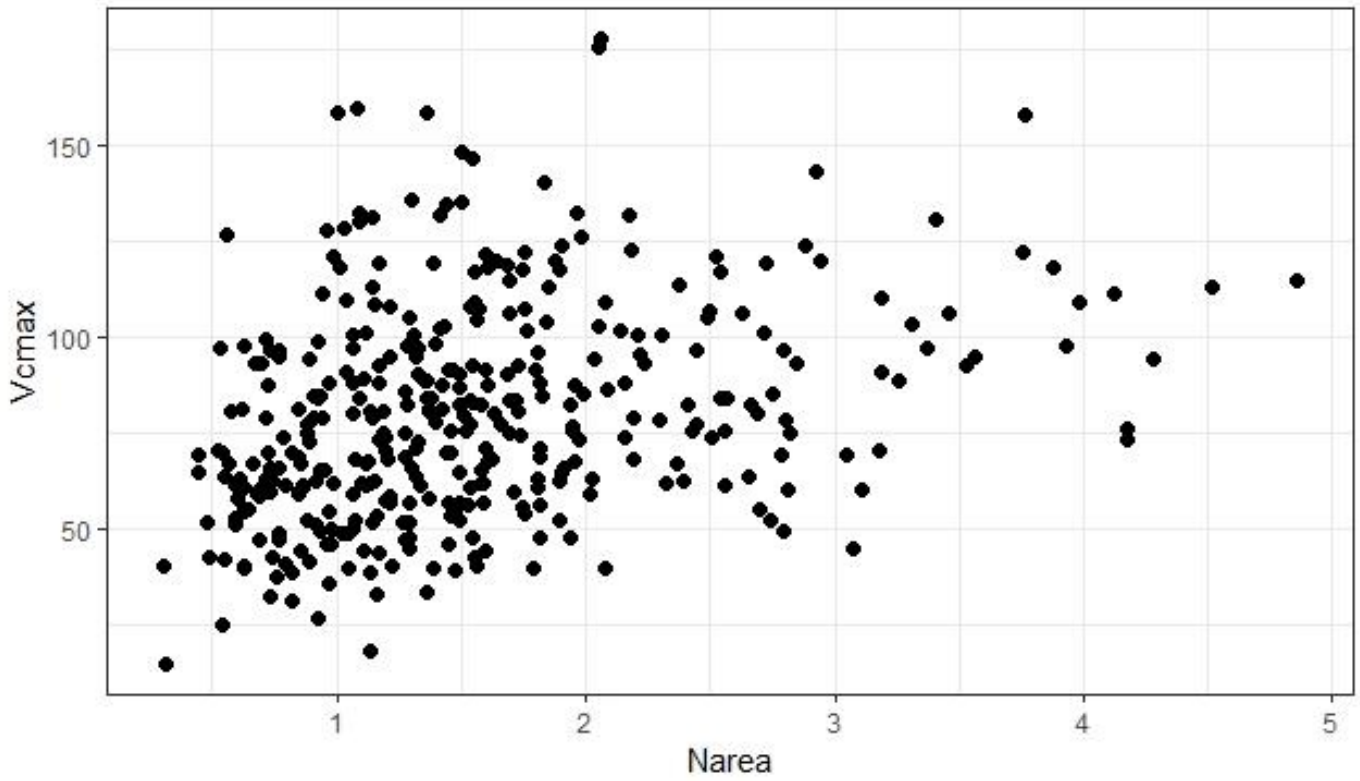


Greenhouse

No change



- N fertilization increase Leaf N
- Light increase photosynthesis
- Photosynthesis drives N demand, not other way around



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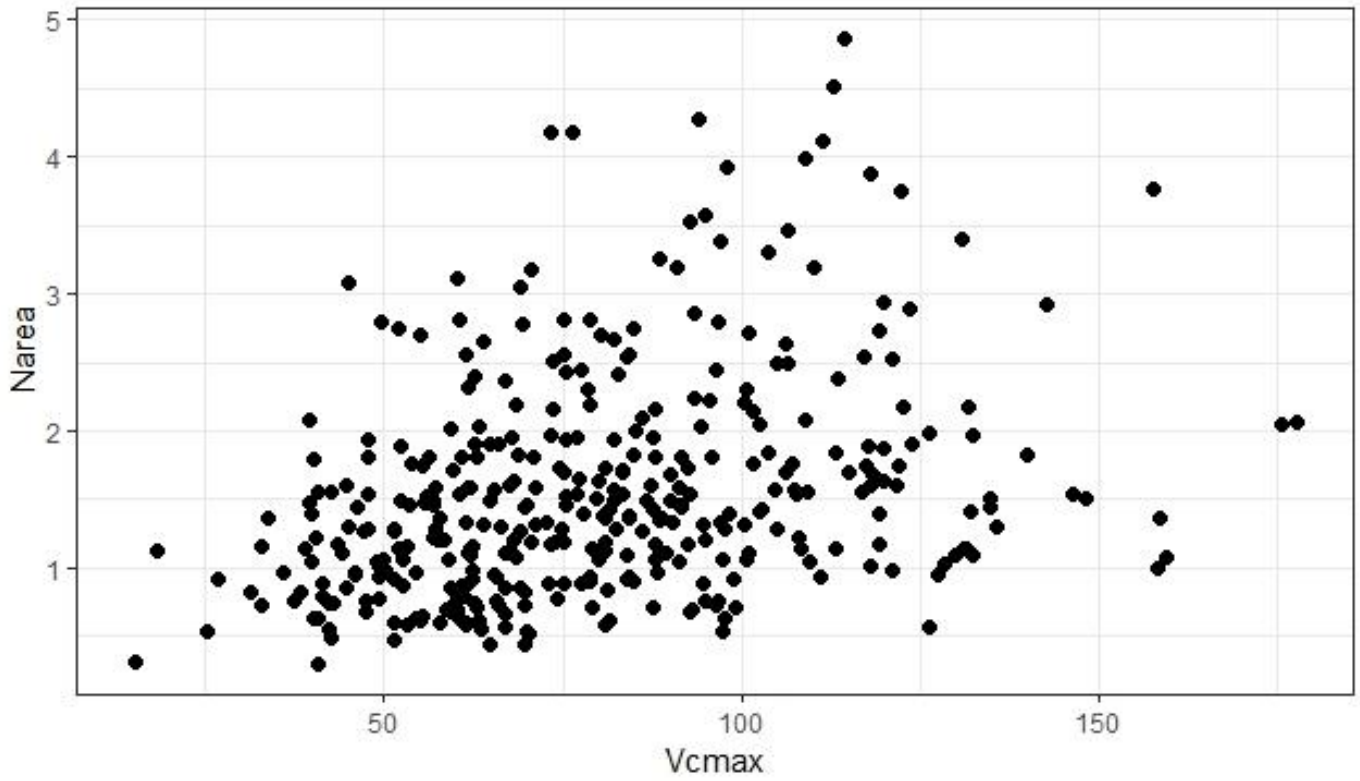
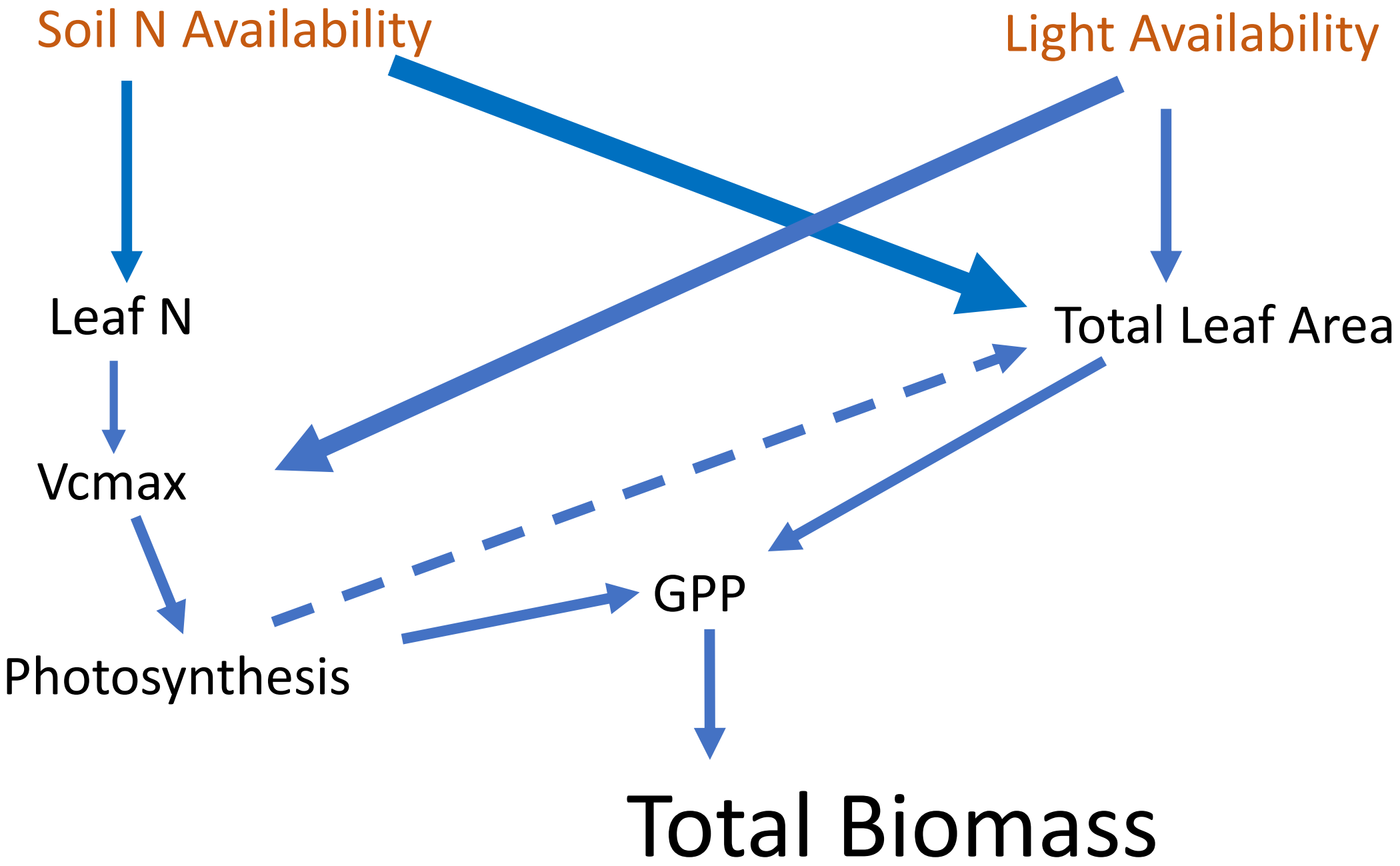
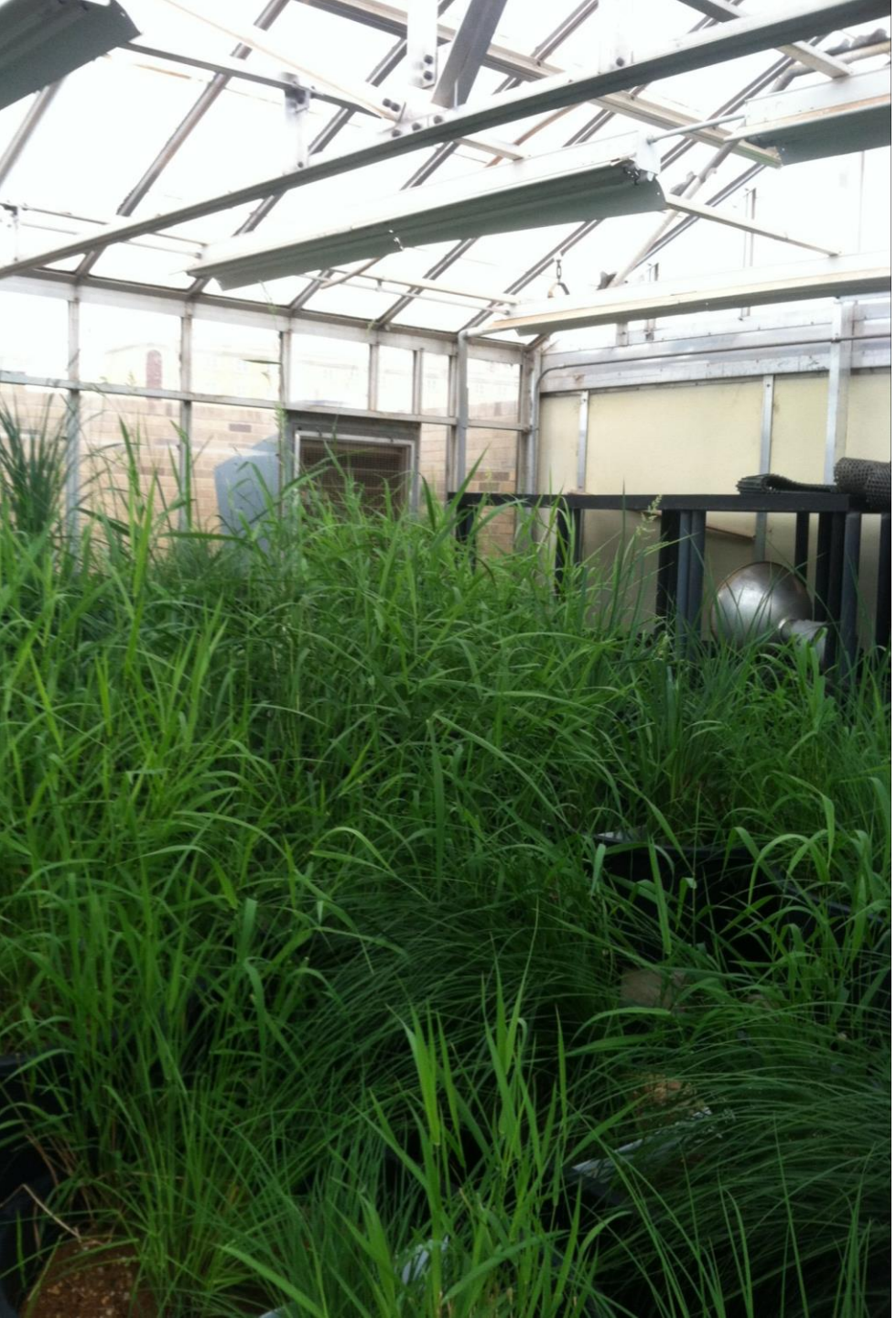



Soil N Availability
Light Availability
Leaf N
Total Leaf Area
Vcmax
GPP
Photosynthesis
Total Biomass

The Future!

- Are Earth system models getting these mechanics correct?

- Can we use these data to improve ESM



Concluding thoughts

- The story of N and photosynthesis is complicated!
- Future conditions favor *P. arundinacea*
- Increased biomass/NPP not explained by fertilization alone
- Flip the paradigm of N and Photosynthesis

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Questions?