Plants and nutrients

What essential elements do plants use?

TABLE 5.1 Tissue levels of essential elements required by most plants

Element	Chemical symbol	Concentration in dry matter (% or ppm)[a]	Relative number of atoms with respect to molybdenum
Obtained from water or carbon dioxide			
Hydrogen	H	6	60,000,000
Carbon	C	45	40,000,000
Oxygen	O	45	30,000,000
Obtained from the soil			
Macronutrients			
Nitrogen	N	1.5	1,000,000
Potassium	K	1.0	250,000
Calcium	Ca	0.5	125,000
Magnesium	Mg	0.2	80,000
Phosphorus	P	0.2	60,000
Sulfur	S	0.1	30,000
Silicon	Si	0.1	30,000
Micronutrients			
Chlorine	Cl	100	3,000
Iron	Fe	100	2,000
Boron	B	20	2,000
Manganese	Mn	50	1,000
Sodium	Na	10	400
Zinc	Zn	20	300
Copper	Cu	6	100
Nickel	Ni	0.1	2
Molybdenum	Mo	0.1	1

Source: Epstein 1972, 1999.

[a]The values for the nonmineral elements (H, C, O) and the macronutrients are percentages. The values for micronutrients are expressed in parts per million.

What do they use them for?

TABLE 5.2 Classification of plant mineral nutrients according to biochemical function

Mineral nutrient	Functions
Group 1	**Nutrients that are part of carbon compounds**
N	Constituent of amino acids, amides, proteins, nucleic acids, nucleotides, coenzymes, hexosamines, etc.
S	Component of cysteine, cystine, methionine. Constituent of lipoic acid, coenzyme A, thiamine pyrophosphate, glutathione, biotin, 5′-adenylylsulfate, and 3′-phosphoadenosine.
Group 2	**Nutrients that are important in energy storage or structural integrity**
P	Component of sugar phosphates, nucleic acids, nucleotides, coenzymes, phospholipids, phytic acid, etc. Has a key role in reactions that involve ATP.
Si	Deposited as amorphous silica in cell walls. Contributes to cell wall mechanical properties, including rigidity and elasticity.
B	Complexes with mannitol, mannan, polymannuronic acid, and other constituents of cell walls. Involved in cell elongation and nucleic acid metabolism.
Group 3	**Nutrients that remain in ionic form**
K	Required as a cofactor for more than 40 enzymes. Principal cation in establishing cell turgor and maintaining cell electroneutrality.
Ca	Constituent of the middle lamella of cell walls. Required as a cofactor by some enzymes involved in the hydrolysis of ATP and phospholipids. Acts as a second messenger in metabolic regulation.
Mg	Required by many enzymes involved in phosphate transfer. Constituent of the chlorophyll molecule.
Cl	Required for the photosynthetic reactions involved in O_2 evolution.
Zn	Constituent of alcohol dehydrogenase, glutamic dehydrogenase, carbonic anhydrase, etc.
Na	Involved with the regeneration of phosphoenolpyruvate in C_4 and CAM plants. Substitutes for potassium in some functions.
Group 4	**Nutrients that are involved in redox reactions**
Fe	Constituent of cytochromes and nonheme iron proteins involved in photosynthesis, N_2 fixation, and respiration.
Mn	Required for activity of some dehydrogenases, decarboxylases, kinases, oxidases, and peroxidases. Involved with other cation-activated enzymes and photosynthetic O_2 evolution.
Cu	Component of ascorbic acid oxidase, tyrosinase, monoamine oxidase, uricase, cytochrome oxidase, phenolase, laccase, and plastocyanin.
Ni	Constituent of urease. In N_2-fixing bacteria, constituent of hydrogenases.
Mo	Constituent of nitrogenase, nitrate reductase, and xanthine dehydrogenase.

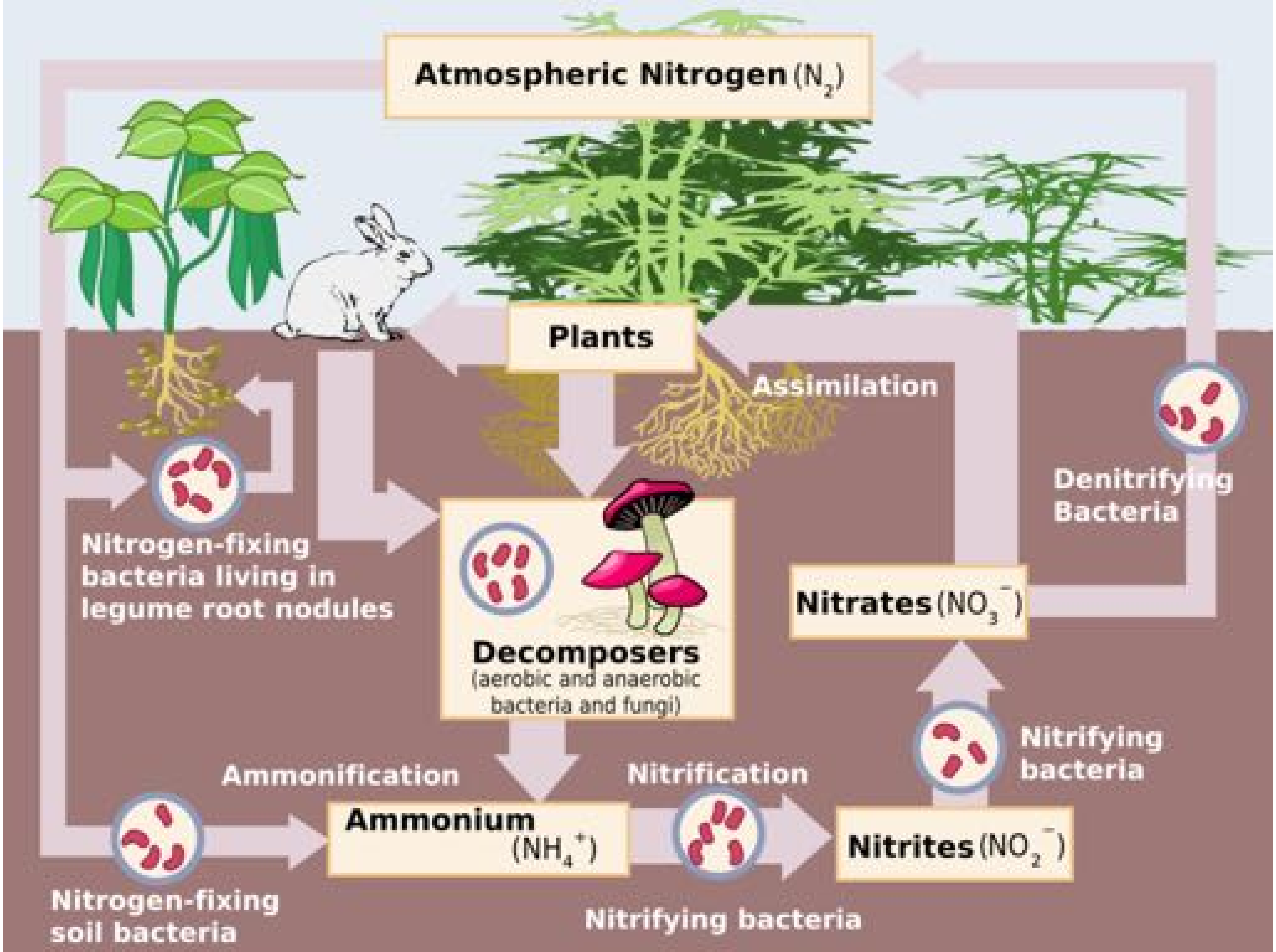
Source: After Evans and Sorger 1966 and Mengel and Kirkby 2001.

How do nutrients get into the soil?

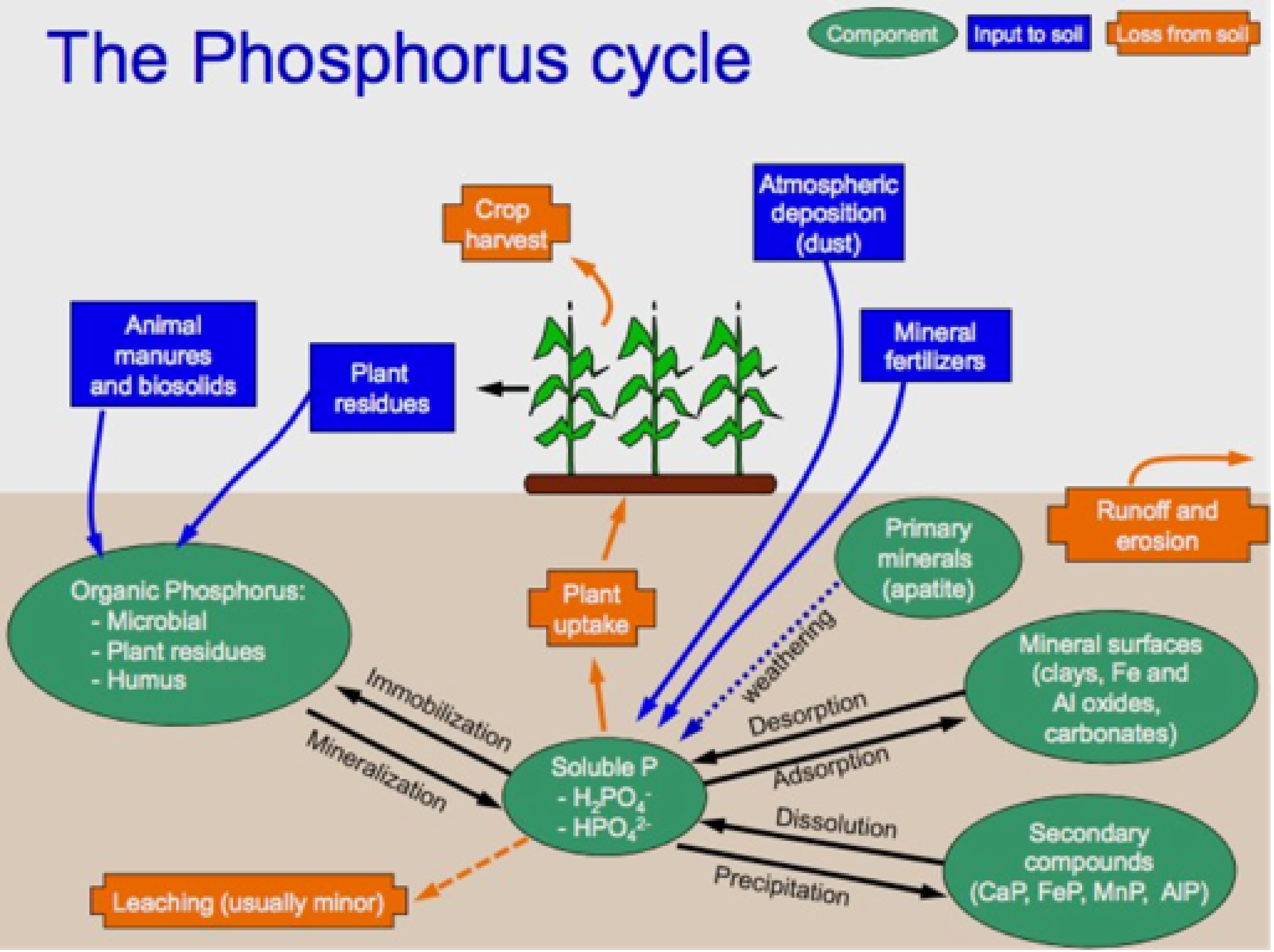
Table 1. Major sources of available nutrients that enter the soil.

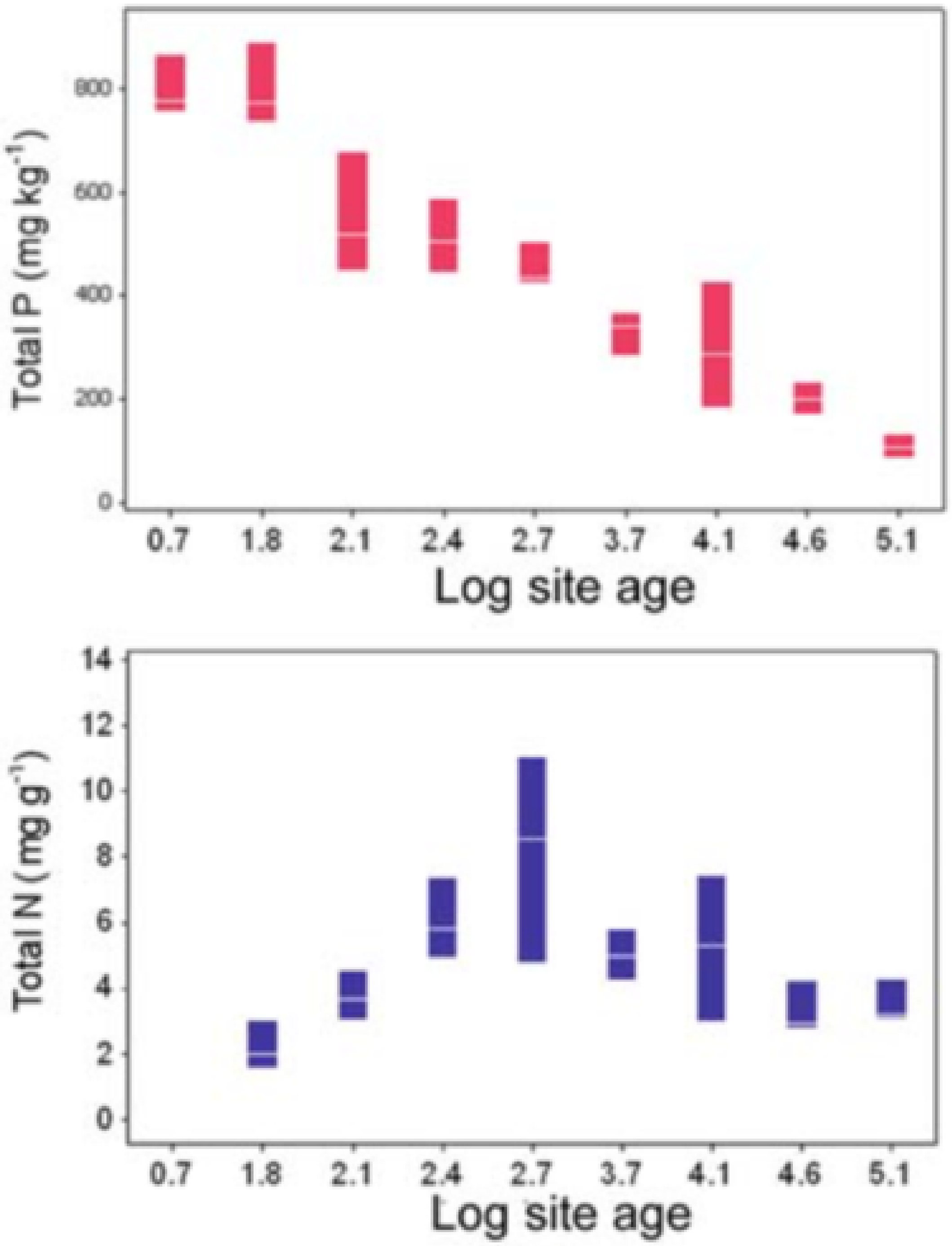
	Source of nutrient (% of total)		
Nutrient	Atmosphere	Weathering	Recycling
Temperate forest			
N	7	0	93
P	1	<10?	>89
K	2	10	88
Ca	4	31	65
Arctic tundra			
N	4	0	96
P	4	<1	96

Source: Chapin 1991.



Atmospheric Nitrogen (N_2)
Plants
Assimilation
Denitrifying Bacteria
Nitrogen-fixing bacteria living in legume root nodules
Decomposers
(aerobic and anaerobic bacteria and fungi)
Nitrates (NO_3^-)
Nitrifying bacteria
Ammonification
Nitrification
Ammonium (NH_4^+)
Nitrites (NO_2^-)
Nitrogen-fixing soil bacteria
Nitrifying bacteria


The Phosphorus cycle
Component
Input to soil
Loss from soil
Crop harvest
Atmospheric deposition (dust)
Animal manures and biosolids
Plant residues
Mineral fertilizers
Runoff and erosion
Primary minerals (apatite)
Plant uptake
Organic Phosphorus:
- Microbial
- Plant residues
- Humus
weathering
Mineral surfaces (clays, Fe and Al oxides, carbonates)
Immobilization
Desorption
Mineralization
Adsorption
Soluble P
- $H_2PO_4^-$
- HPO_4^{2-}
Dissolution
Secondary compounds (CaP, FeP, MnP, AlP)
Precipitation
Leaching (usually minor)



What could explain these trends?

Nutrition impacts: NPP

N addition increases NPP by 29% (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 $P < 0.05$.

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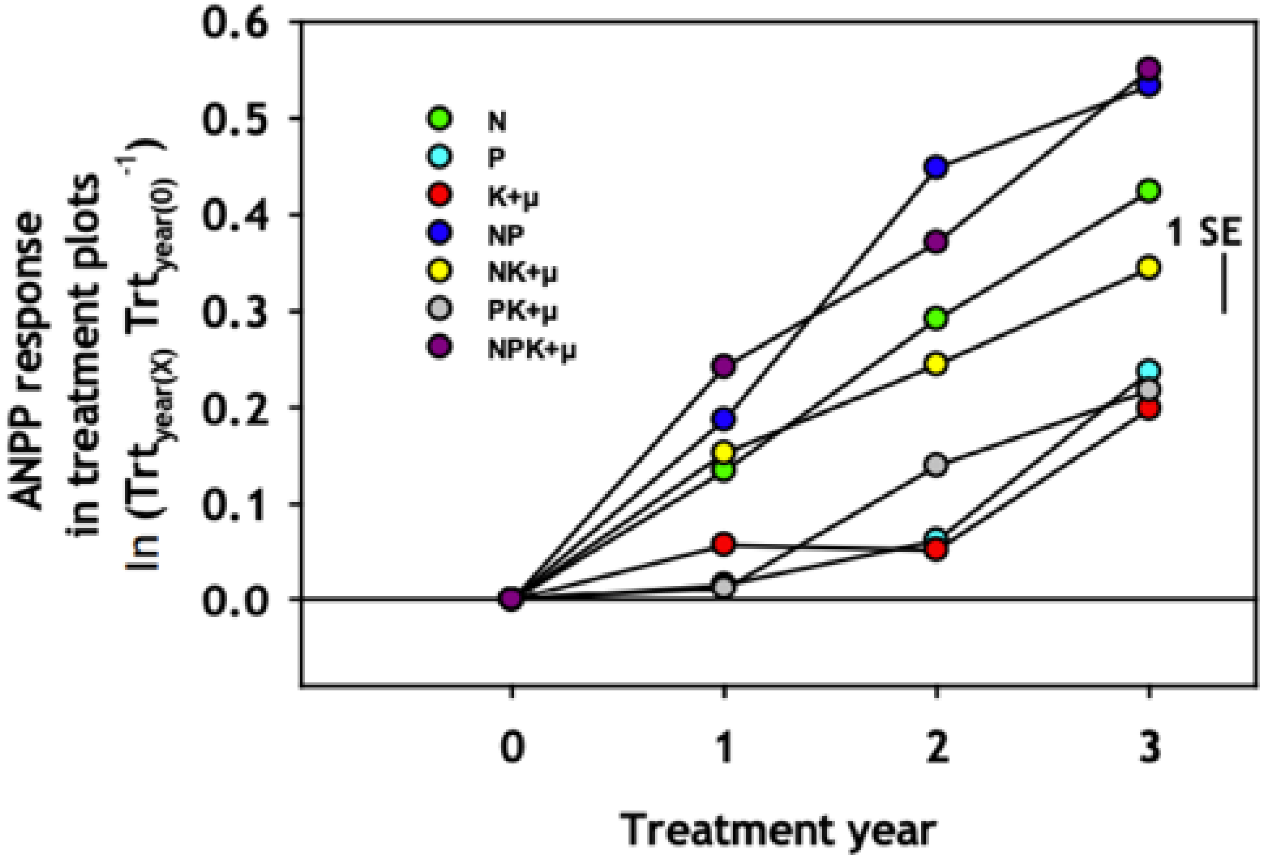
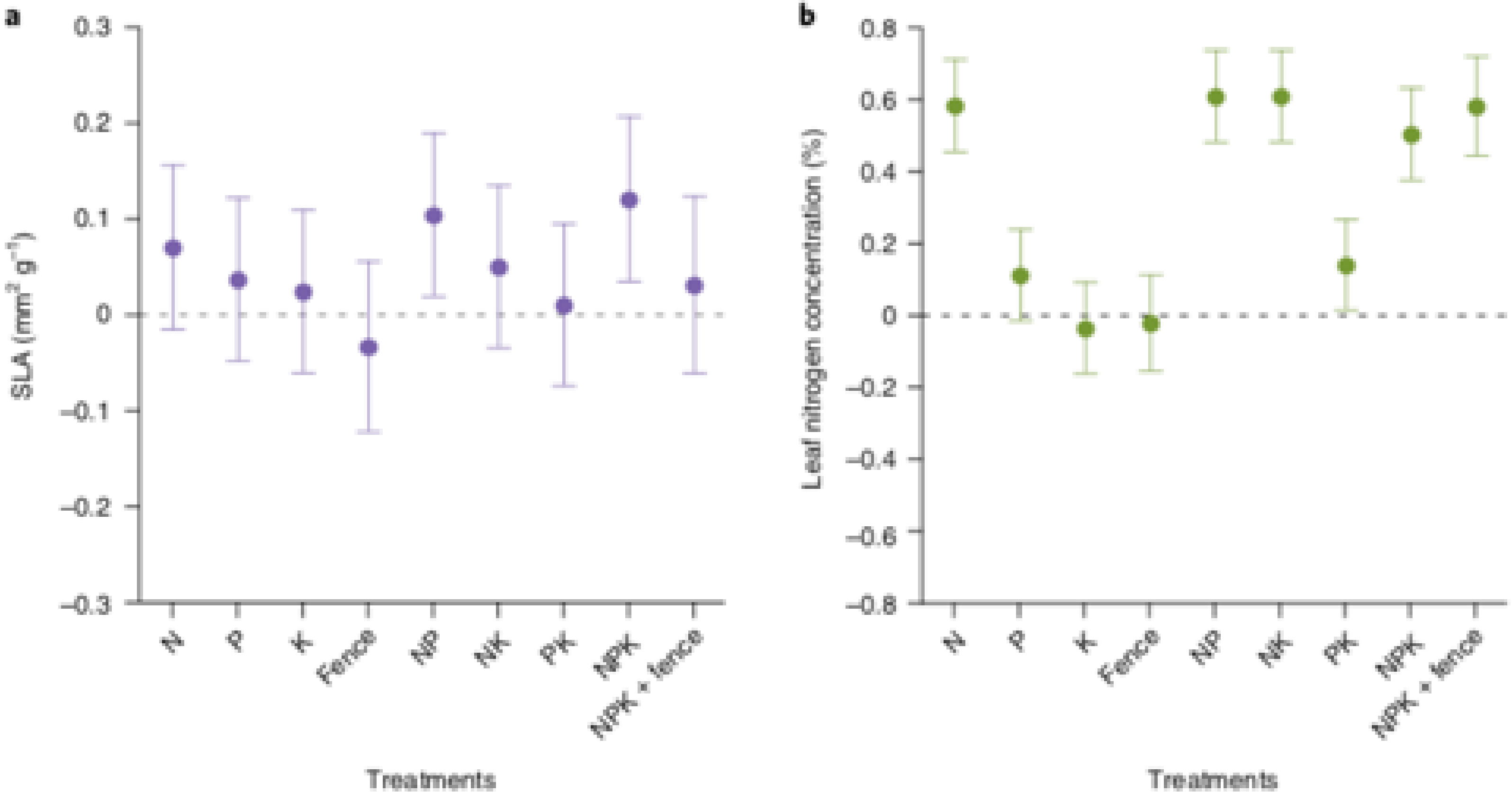
What could explain this effect?

Biomass can be limited by multiple nutrients



Fay et al. (2015)

Nutrition impacts: leaf physiology



Leaves are basically the same shape, but get packed with more N

Firn et al. (2019)

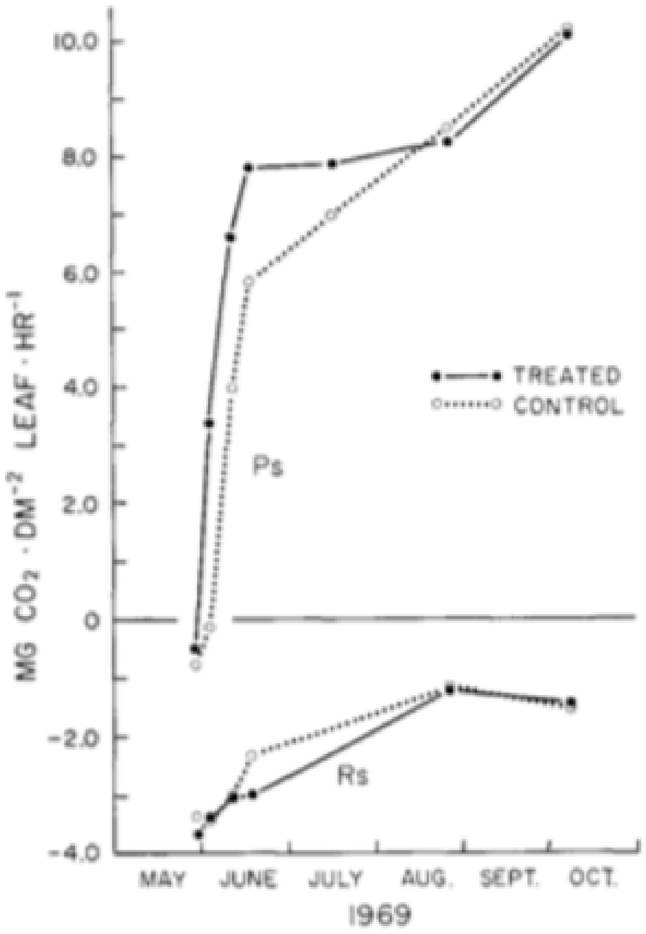
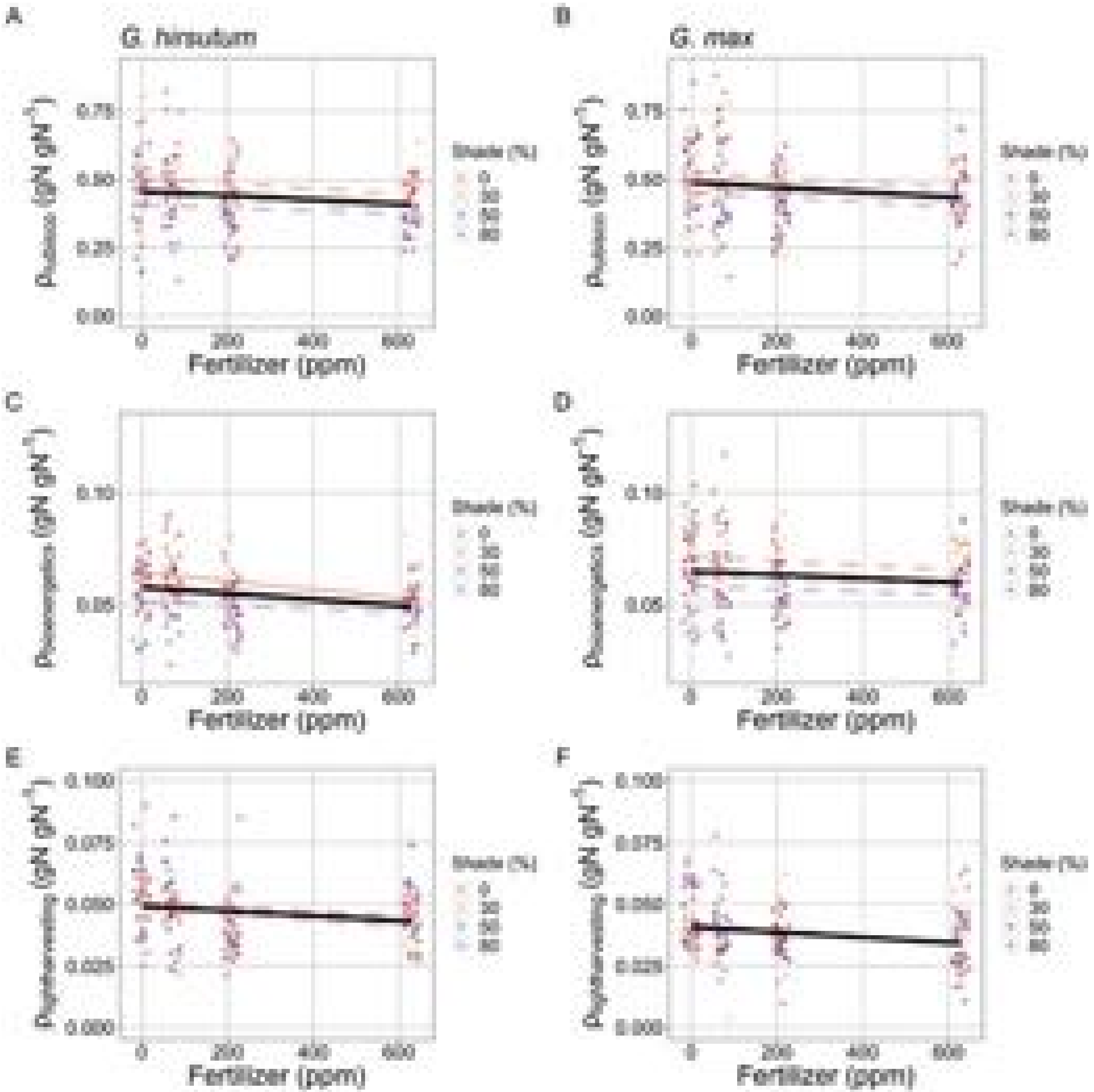


FIGURE 3. *Net photosynthesis (Ps) and dark respiration (Rs) in 1969 for current shoots of Douglas-fir trees treated April 1968.*

Not necessarily doing more photosynthesis though…

Brix (1971)



The relative amount of N used for photosynthesis is reduced with added N

Waring et al. (2023)

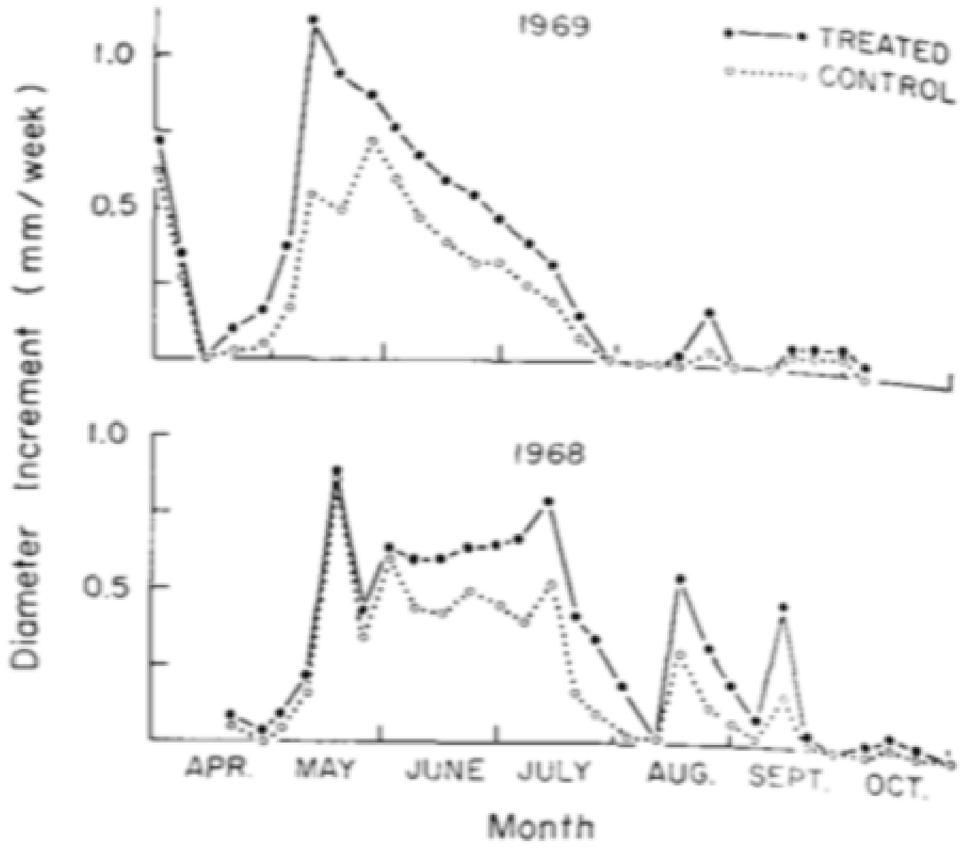
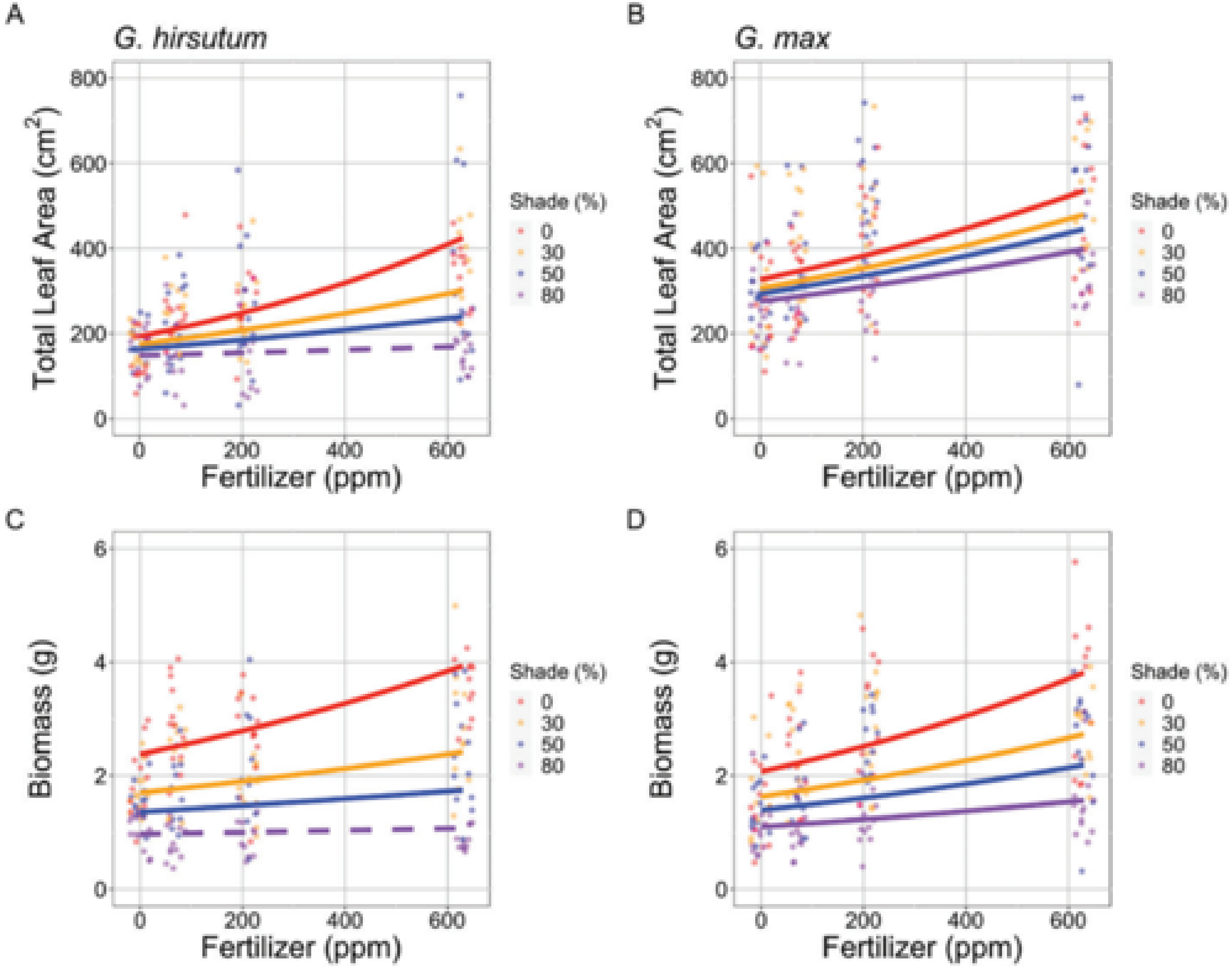


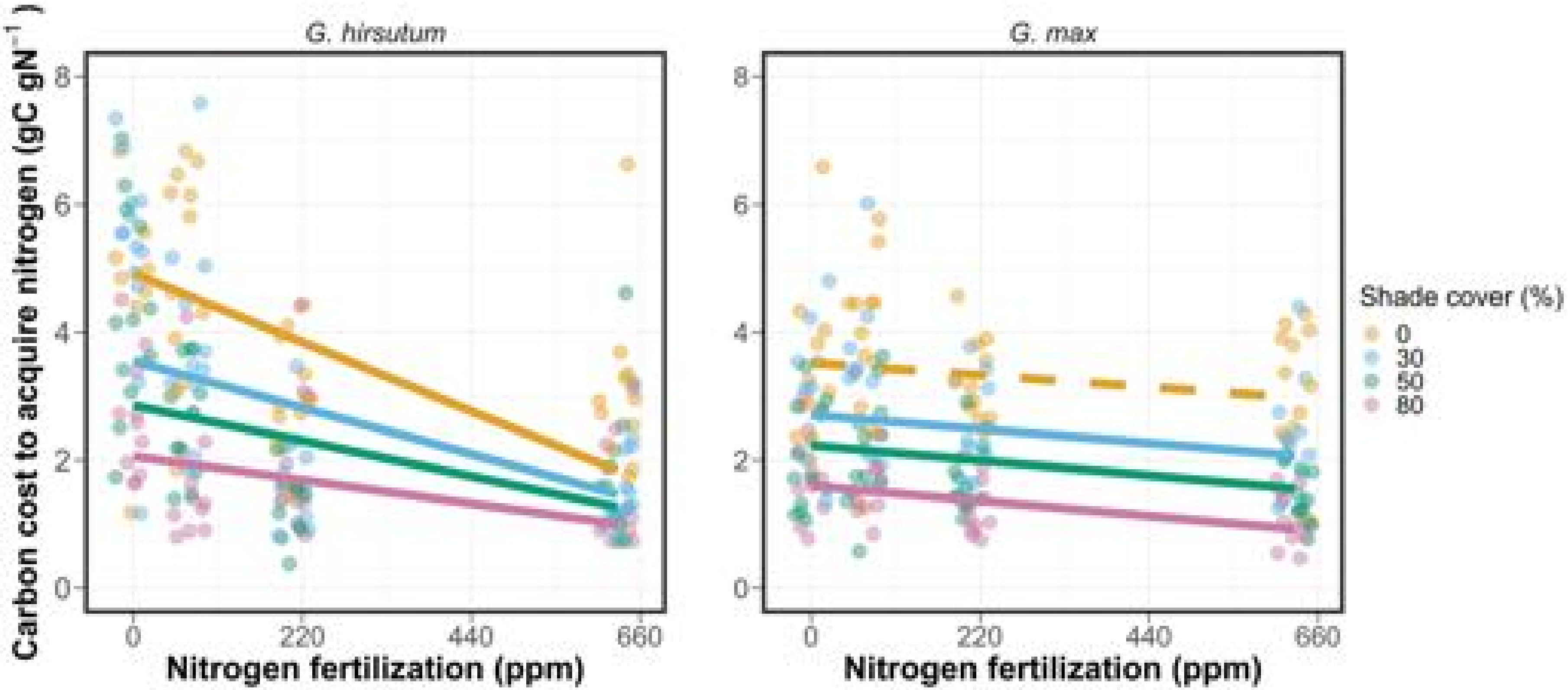
FIGURE 1. *Rates of weekly diameter growth for Douglas-fir in the 2 years following fertilization in April 1968.*

But plants are growing!

Brix (1971)

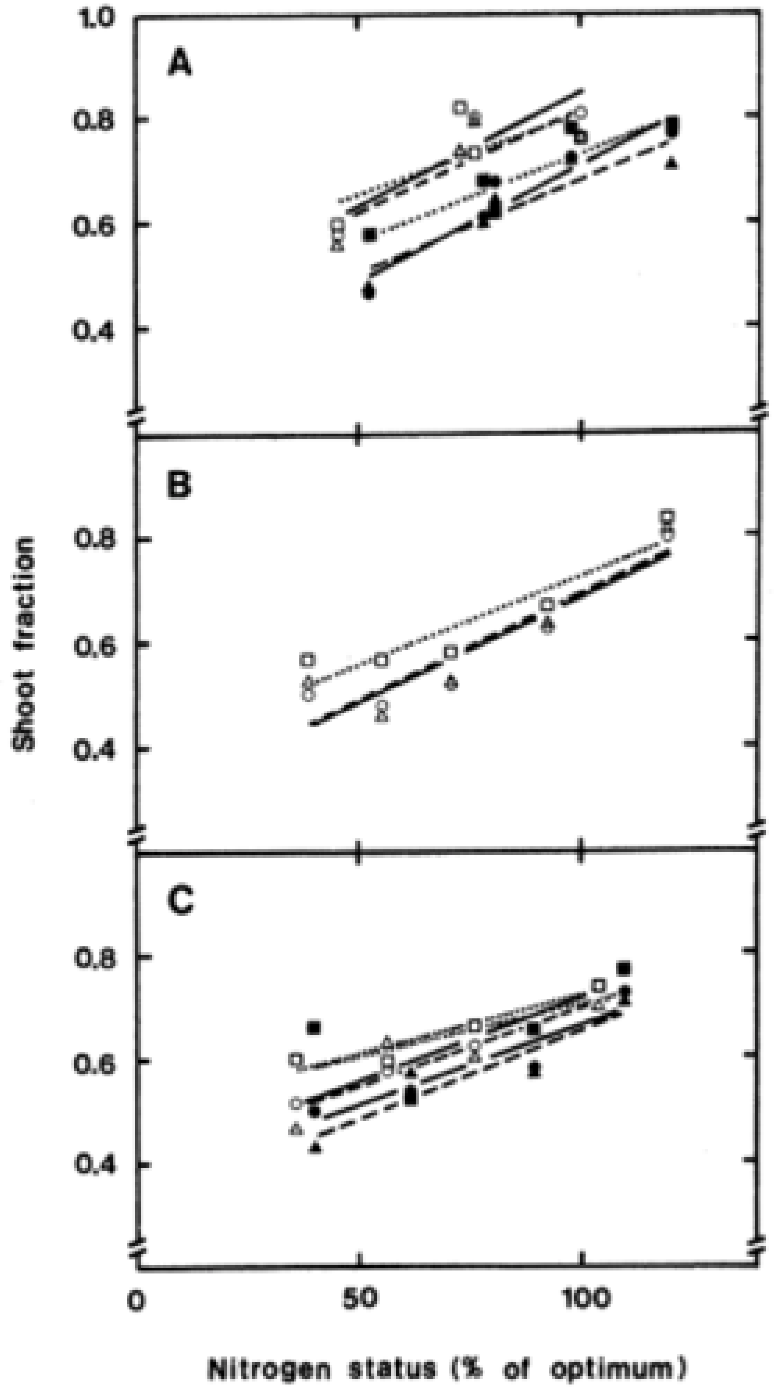


Waring et al. (2023)



Because it is less costly for the plant to get nutrients

Perkowski et al. (2021)



More leaves and shoots are produced at the expense of roots

Ingested et al. (1991)

Nutrition effects on physiological processes

- Growth: increases
- Storage: increases
- Photosynthesis: not heavily impacted
- Allocation: shift to aboveground

Nutrition effects on physiological processes

- Growth: increases
- Storage: increases
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- Allocation: shift to aboveground

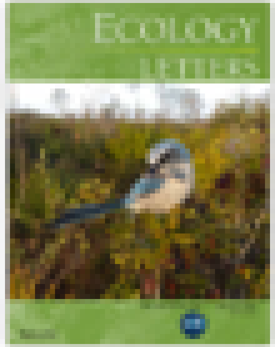
Why?

Nutrition effects on physiological processes

- Growth: increases
- Storage: increases
- Photosynthesis: not heavily impacted
- Allocation: shift to aboveground

What might influence this?

ECOLOGY LETTERS



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LETTER | Full Access

Soil Nitrogen Supply Exerts Largest Influence on Leaf Nitrogen in Environments with the Greatest Leaf Nitrogen Demand

Alissar Cheaib, Elizabeth F. Waring, Risa McNellis, Evan A. Perkowski, Jason P. Martina, Eric W. Seabloom, Elizabeth T. Borer, Peter A. Wilfahrt, Ning Dong, Iain Colin Prentice .... See all authors

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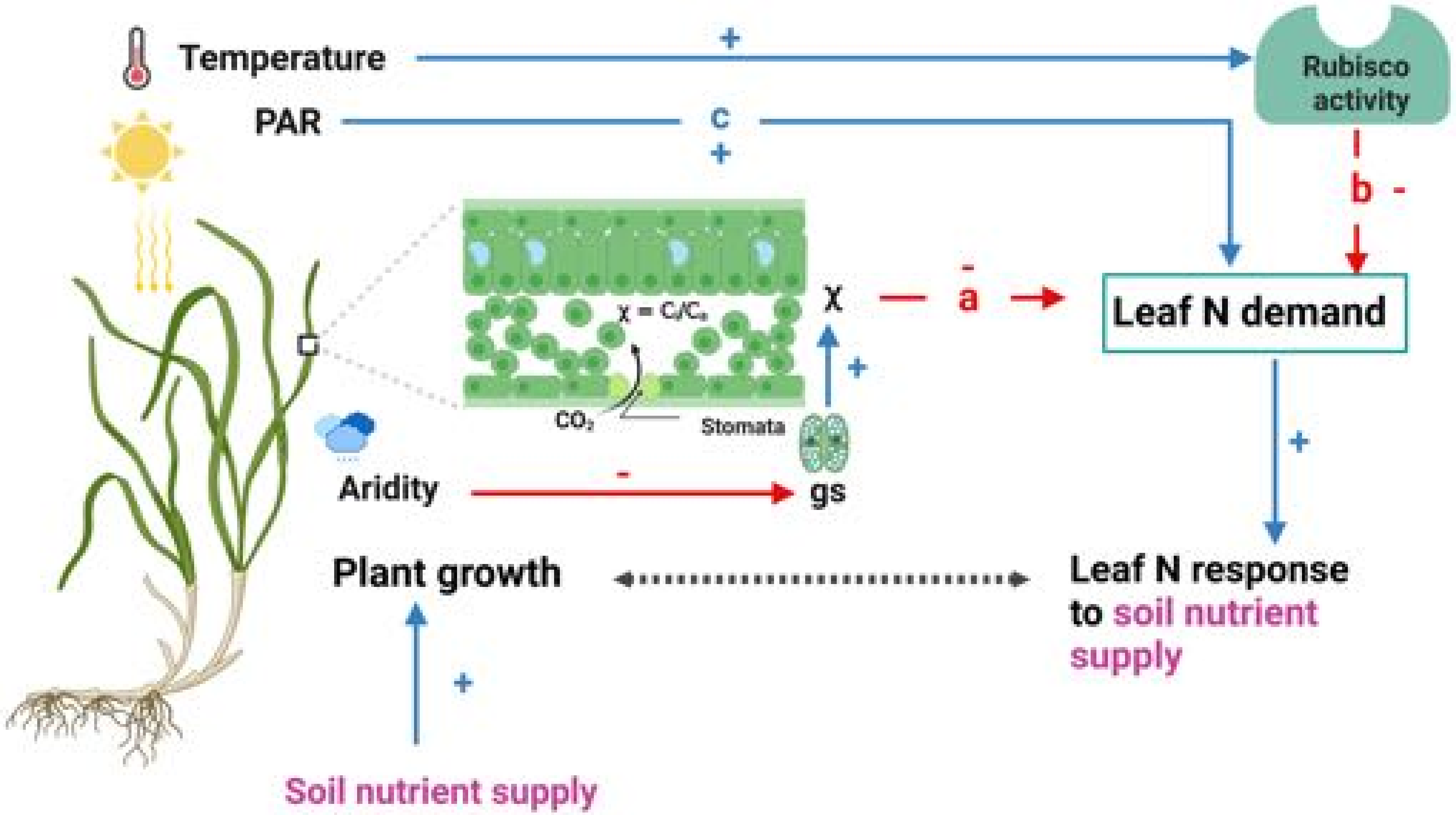
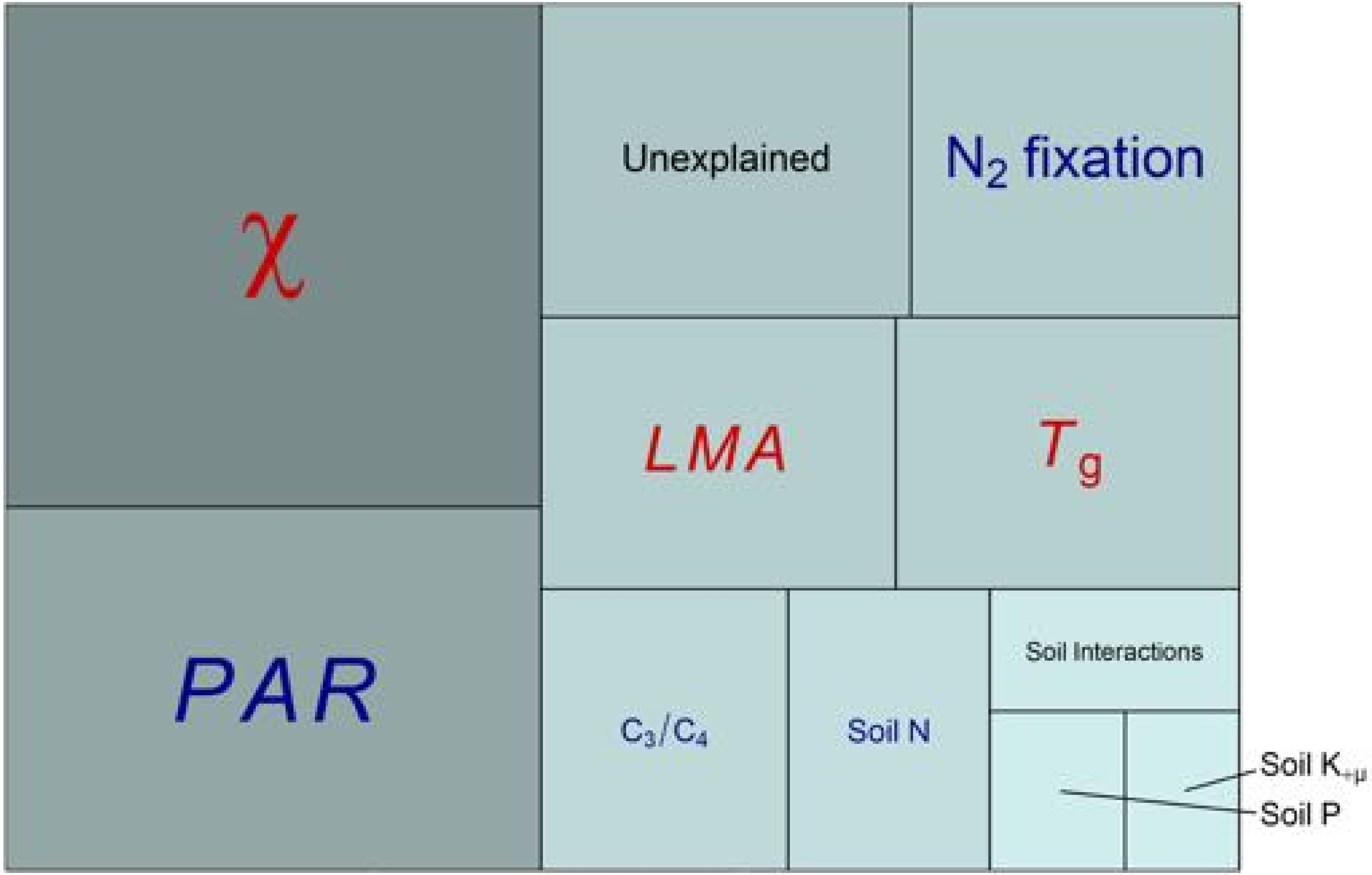
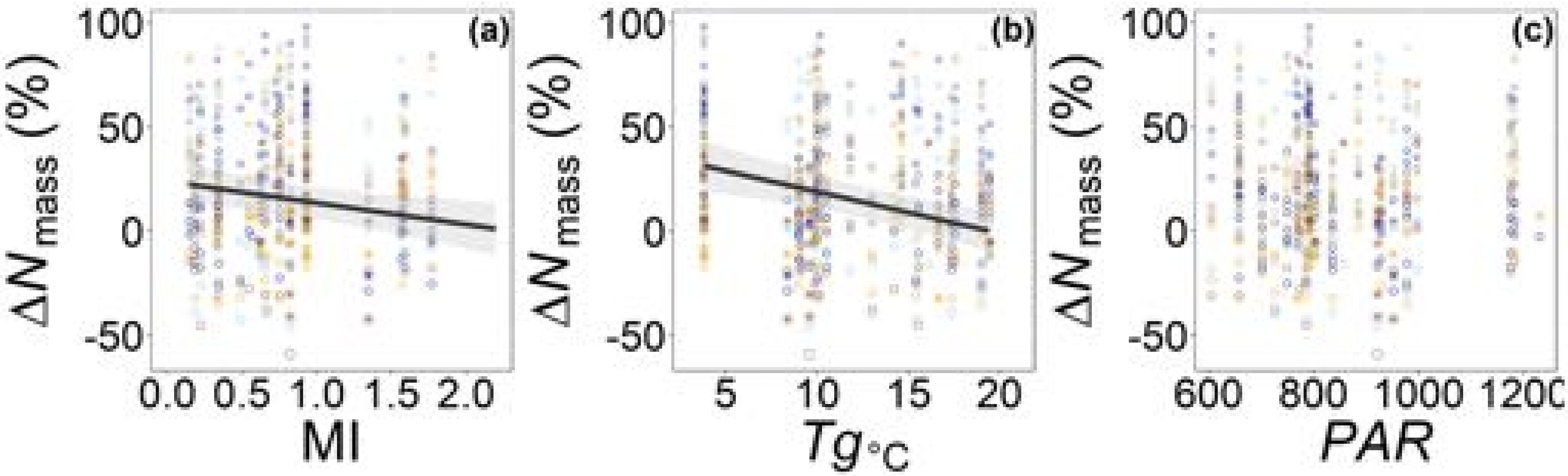


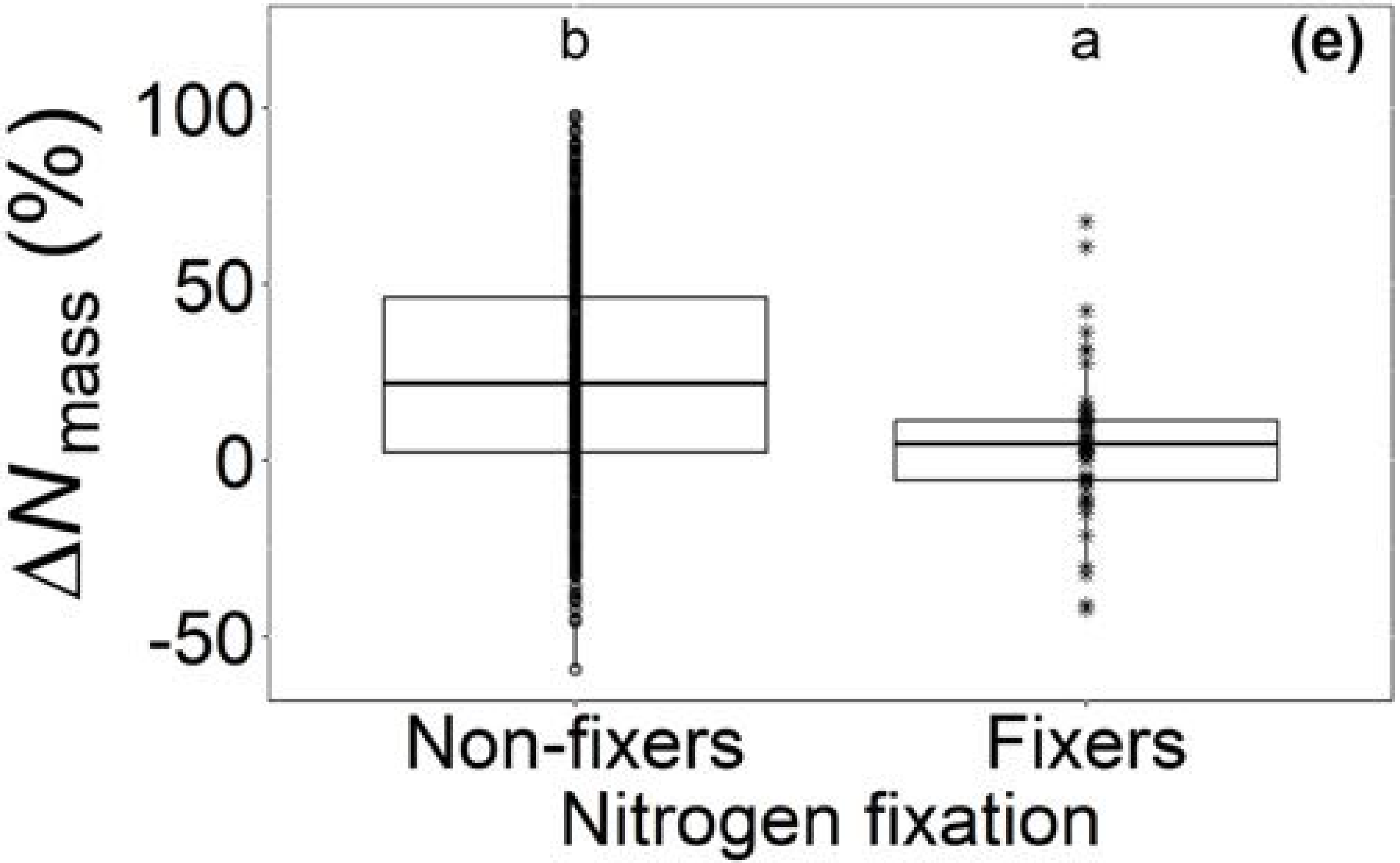
Cheaib et al. (2025)



Cheaib et al. (2025)



Cheaib et al. (2025)

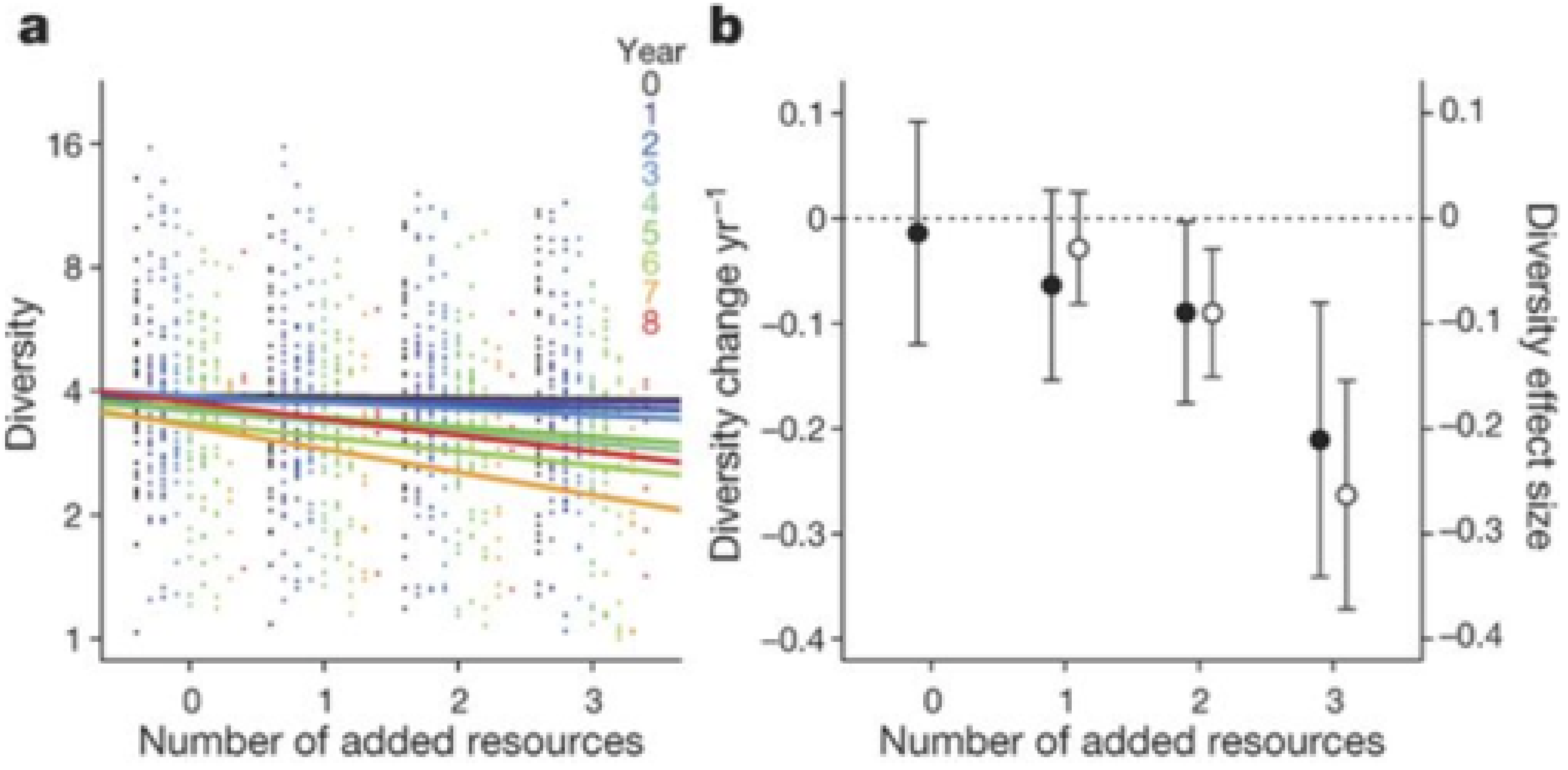


Cheaib et al. (2025)

Takehome from Cheaib et al. (2025)

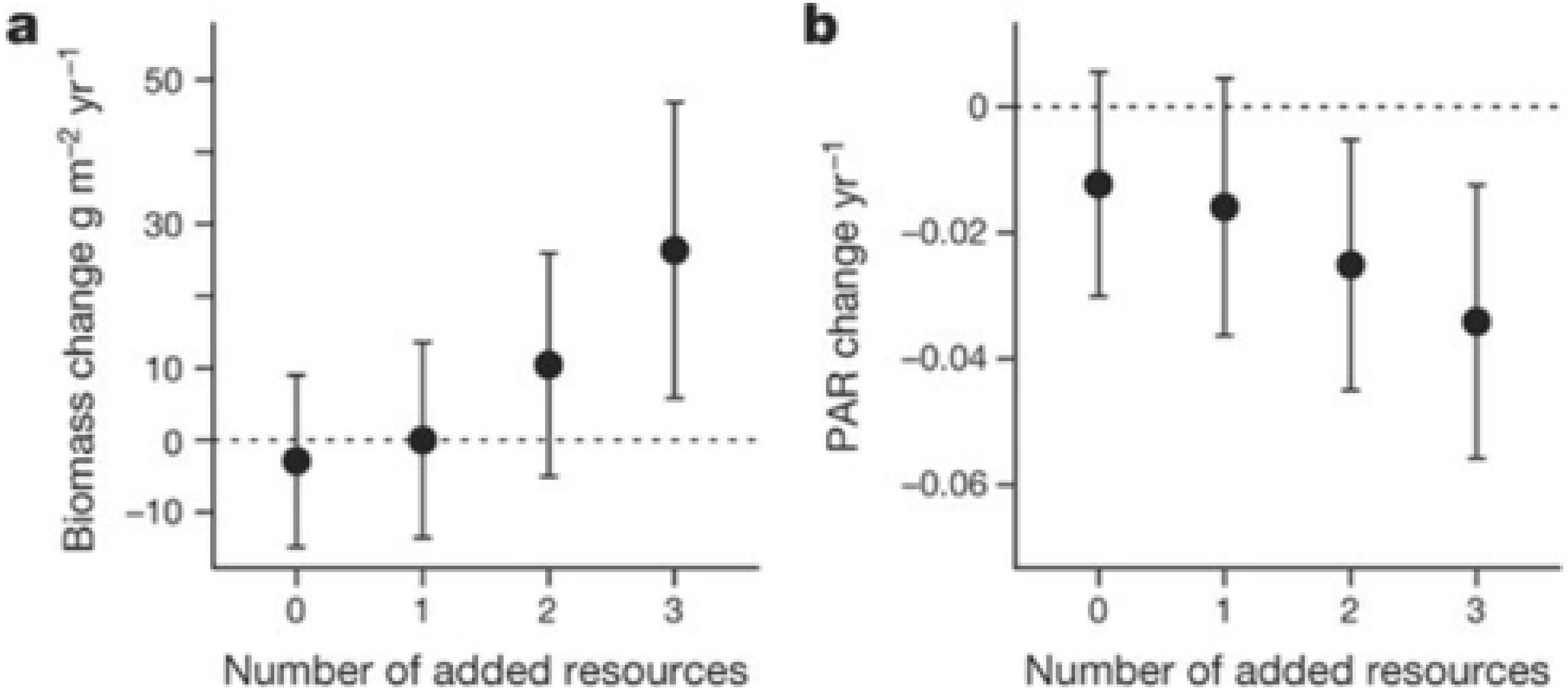
Plant-nutrient interactions involve the interplay between nutrient demand and nutrient availability

Nutrition impacts: Diversity



Why would adding nutrients reduce diversity?

Harpole et al. (2016)



A shift in the importance of other limitations!

Harpole et al. (2016)

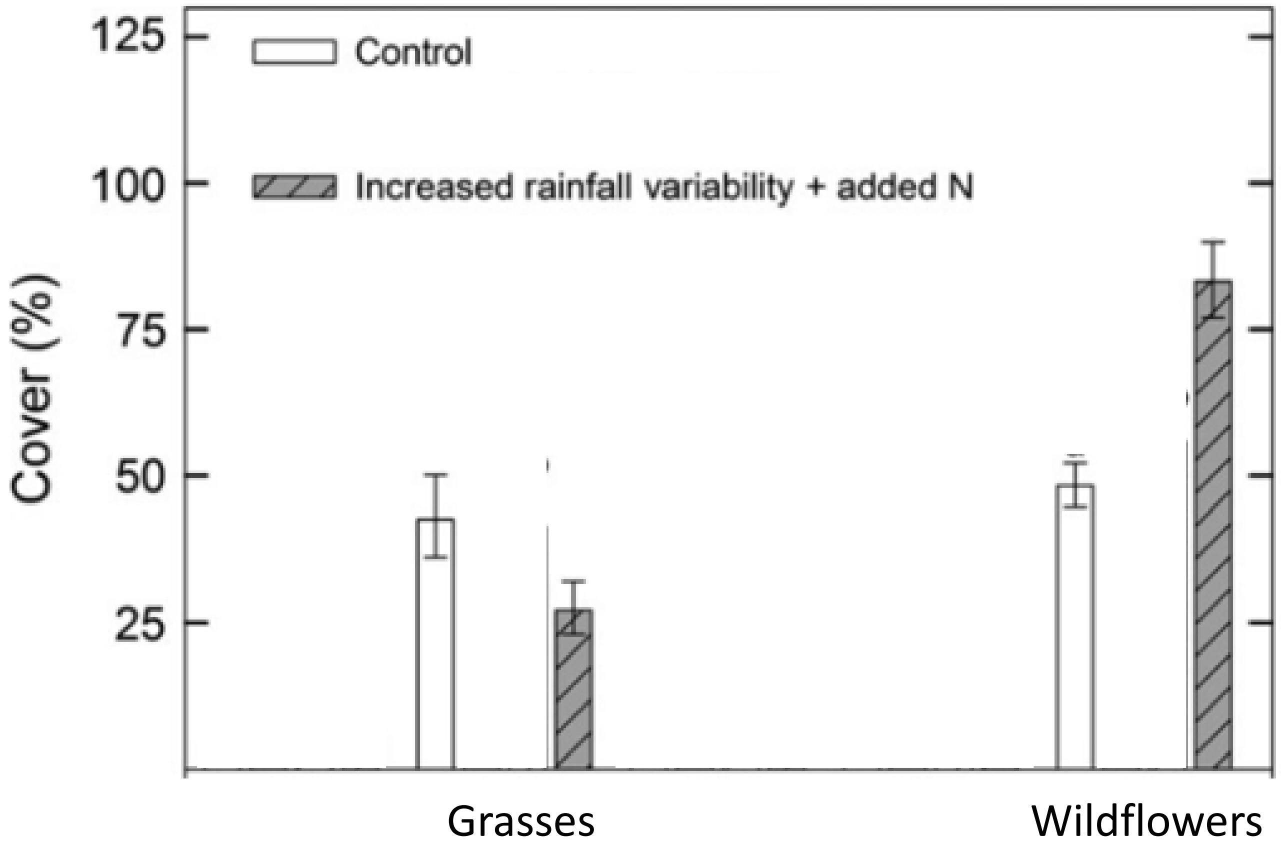
Competition example: tallgrass prairie

Competition example: tallgrass prairie

Wildflowers
- C3
- Fast growing
- Use a lot of resources (e.g., Nitrogen)

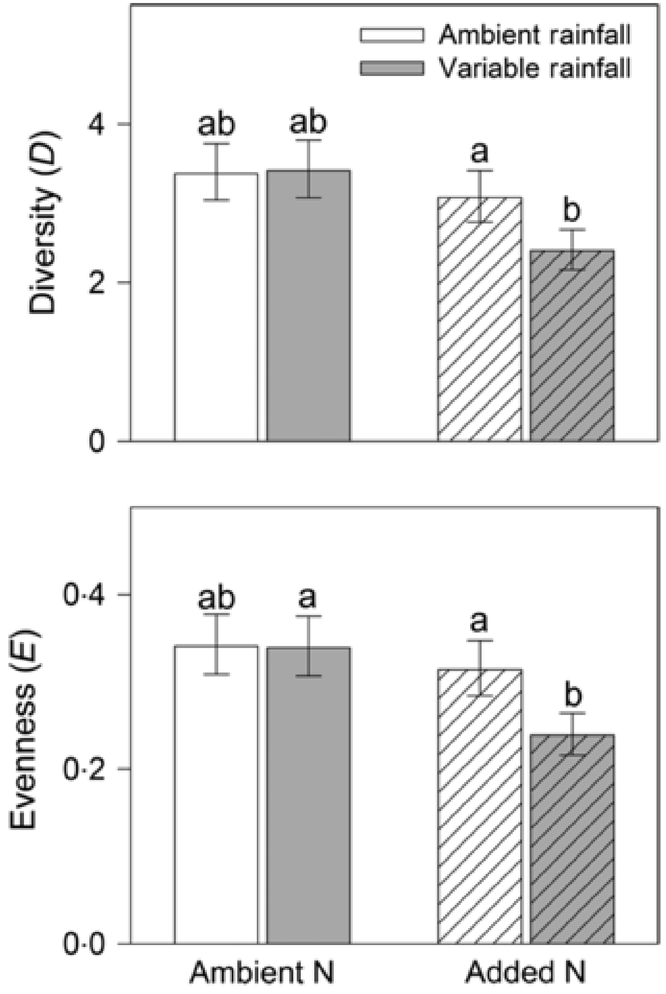
Grasses
- C4
- Slow growing
- Efficient resource use

Competition example: tallgrass prairie



Smith et al. (2016)

Competition example: tallgrass prairie

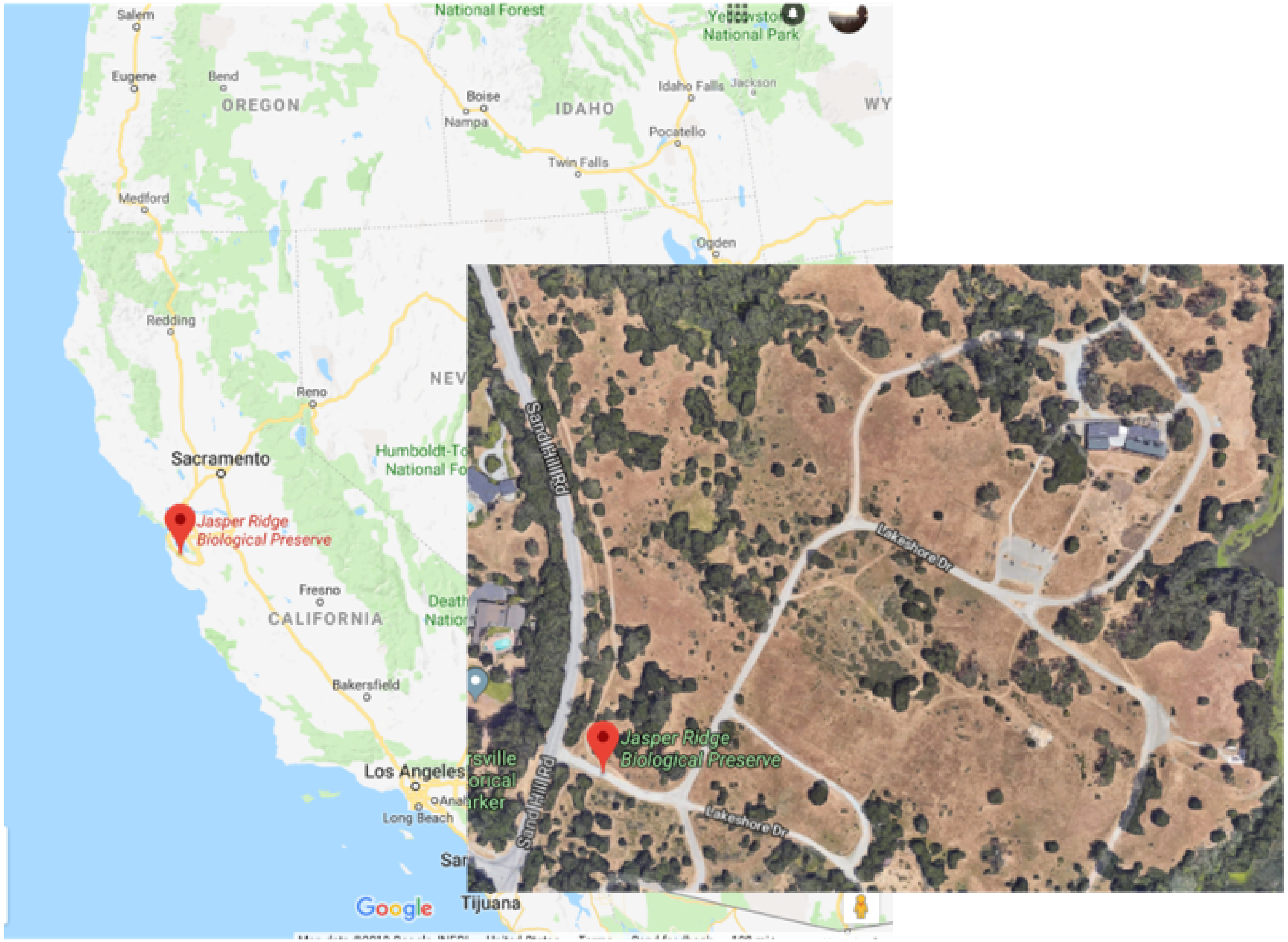


Smith et al. (2016)

Tying together global change

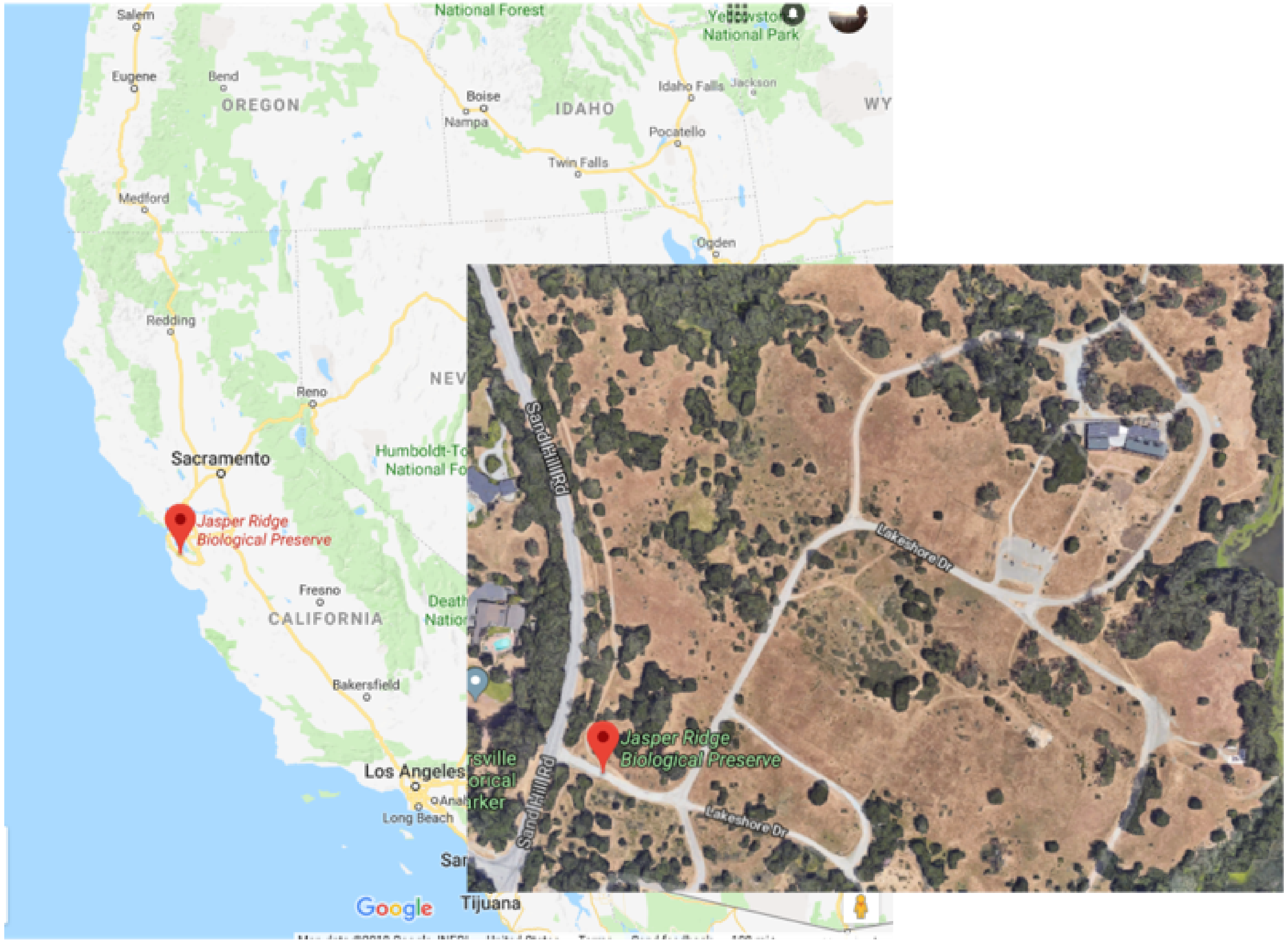
The Jasper Ridge Global Change Experiment

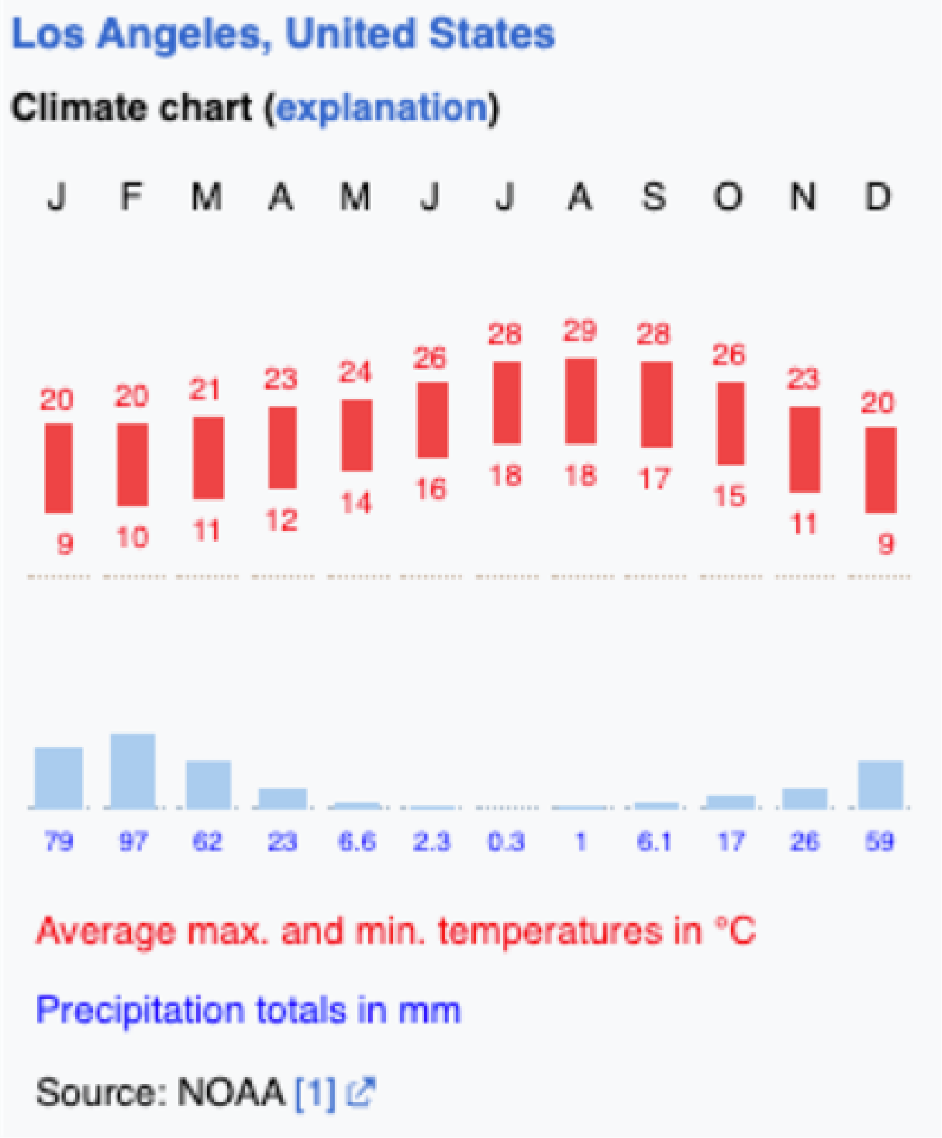
The Jasper Ridge GCE: location



Annual grassland
Mediterranean climate

The Jasper Ridge GCE: location





The Jasper Ridge GCE: treatments

CO_2 (FACE)
1. Ambient
2. 680 ppm

Temperature (heaters)
1. Ambient
2. Ambient + 1°C

Precipitation (sprinklers)
1. Ambient
2. 150% Ambient

Nitrogen (fertilizer)
1. None
2. +5 g m^{-2} yr^{-1}

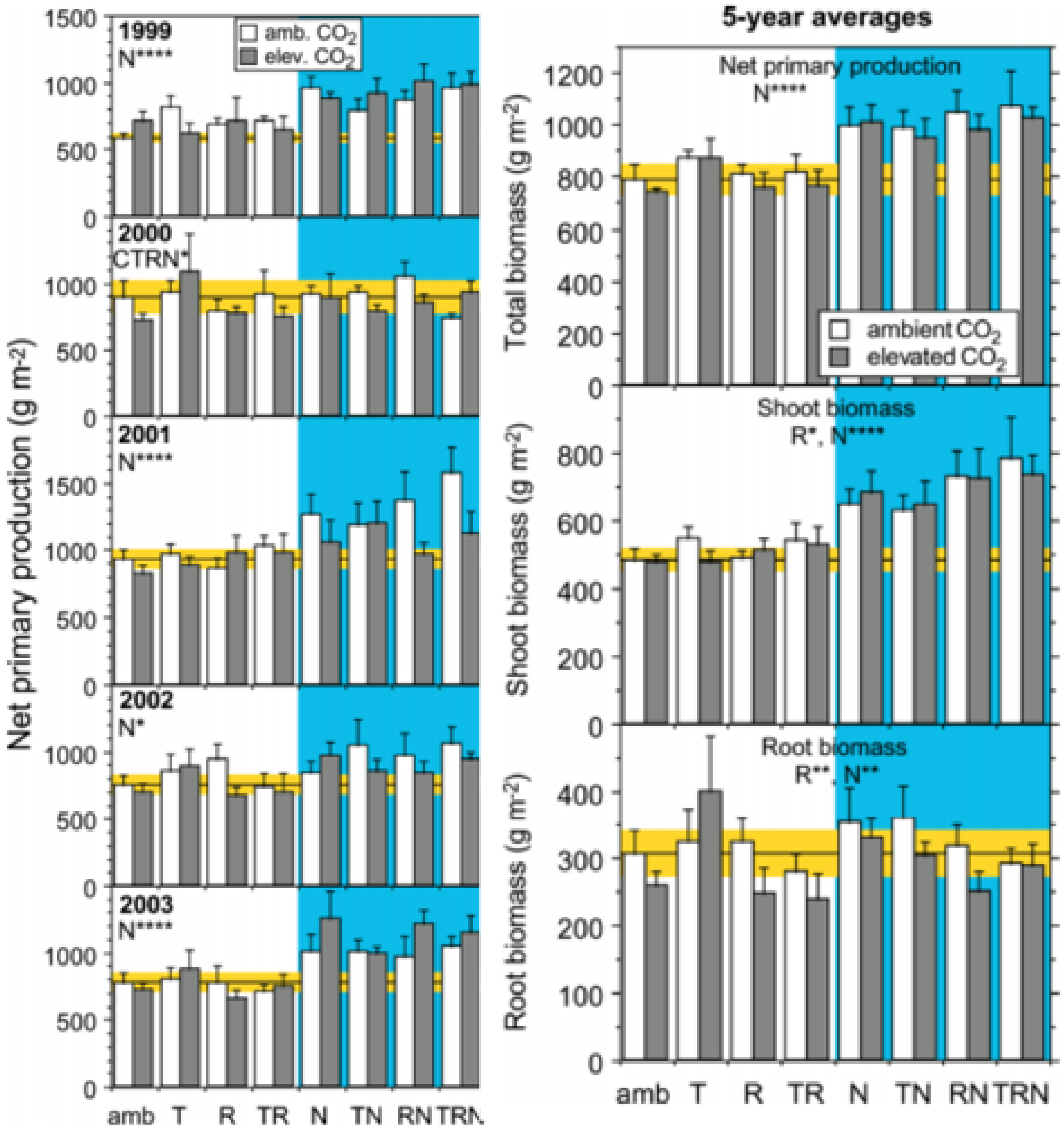
Treatments included all combinations

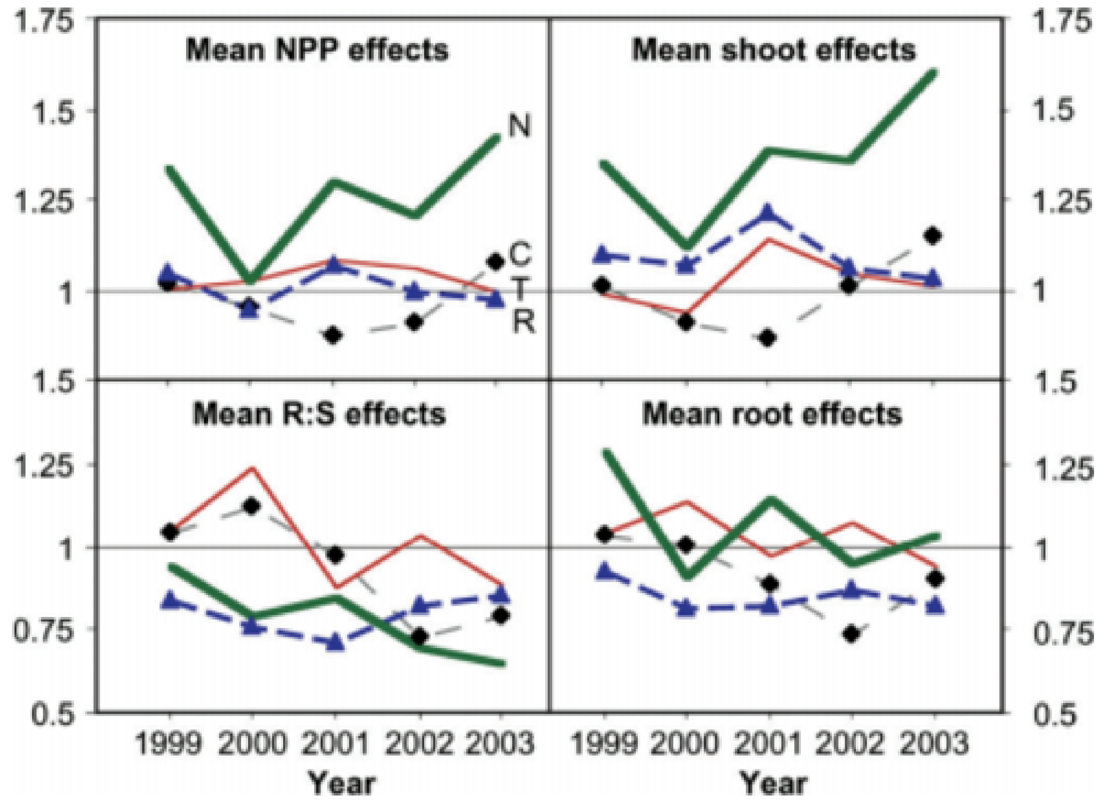
The Jasper Ridge GCE: measurements

- Root and shoot biomass
- Plant community diversity

Assignment: develop a hypothesis for how you would expect the treatments to impact plant biomass and diversity. Use a systems diagram to explain your hypothesis.

Biomass





Dukes et al. (2005)

Diversity

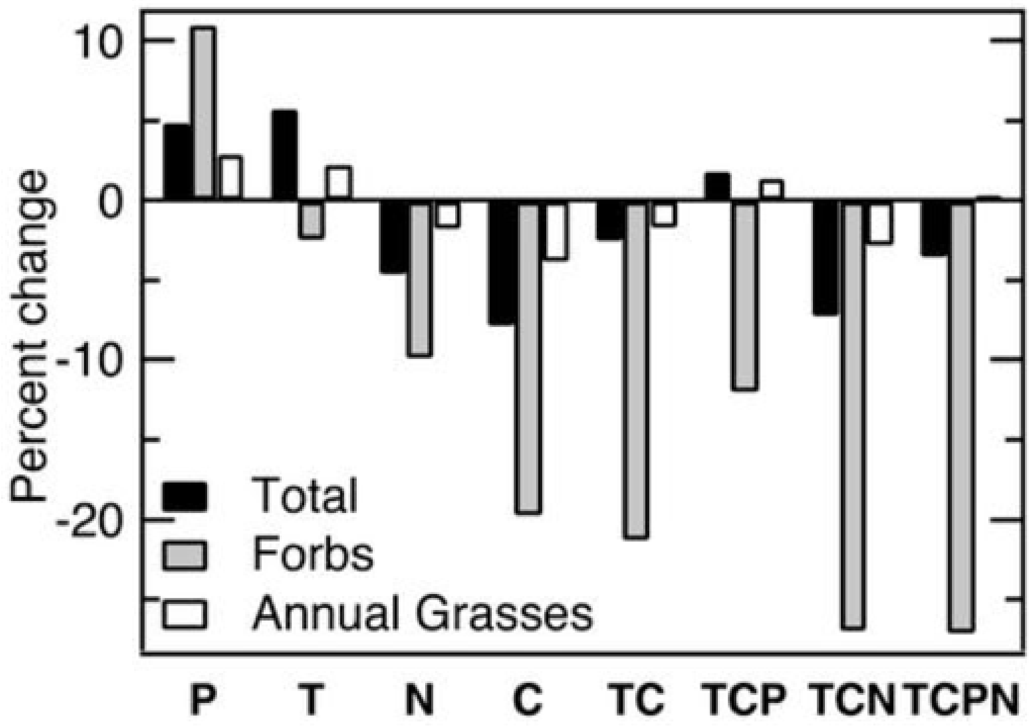


Table 1.

Plant diversity responses to single and combined global change treatments

Treatment	Level	*n*	Annual grasses	Forbs	Perennial grasses	Total
C	Low	64	6.0	4.0	0.35	10.5
	High	64	5.7	3.2*	0.47	9.7**
T	Low	64	5.8	3.6	0.34	9.8
	High	64	5.9	3.5	0.47	10.4
N	Low	64	5.9	3.8	0.39	10.3
	High	64	5.8	3.4***	0.43	9.8*
P	Low	64	5.7	3.4	0.42	9.8
	High	64	5.9	3.8*	0.39	10.3*
C + T	Low	32	5.9	4.1	0.36	10.3
	High	32	5.8	3.2***	0.59**	10.0
C + T + N	Low	16	5.9	4.4	0.24	10.7
	High	16	5.7	3.2	0.57	9.9
C + T + P	Low	16	5.9	3.8	0.62	10.5
	High	16	6.0	3.4	0.48	10.6
C + T + N + P	Low	8	5.9	4.3	0.35	10.4
	High	8	5.9	3.1*	0.54**	10.0

Diversity shown in mean number of species. Diversity means are ANCOVA-adjusted for preexisting differences among plots. C, elevated CO_2; T, elevated temperature; N, N deposition; P, precipitation. *, $P = 0.05$. **, $P = 0.10$. ***, $P = 0.01$.

Zavaleta et al. (2003)