Photosynthetic least-cost optimality theory

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Photosynthetic acclimation

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We know that plants adjust photosynthetic traits to changes in environmental conditions

CO_2: Bazzaz (1990)

Annu. Rev. Ecol. Syst. 1990. 21:167–96

THE RESPONSE OF NATURAL ECOSYSTEMS TO THE RISING GLOBAL CO_2 LEVELS

F. A. Bazzaz

Light: Boardman (1977)

Ann. Rev. Plant Physiol. 1977. 28:355–77

COMPARATIVE PHOTOSYNTHESIS OF SUN AND SHADE PLANTS

N. K. Boardman
Division of Plant Industry, CSIRO, Canberra City, A.C.T. 2601, Australia

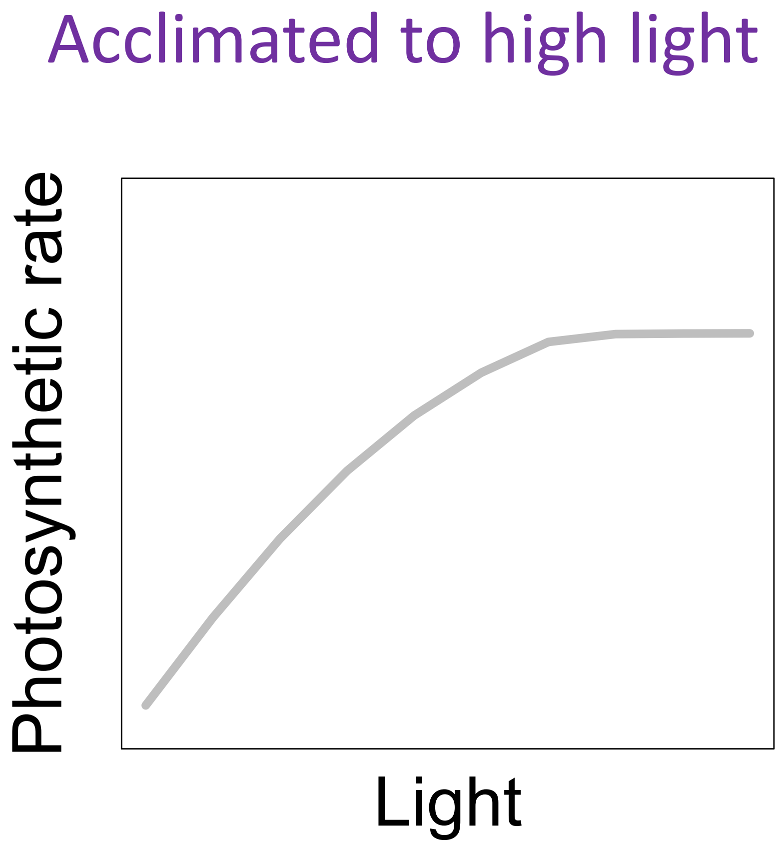
Temperature: Berry & Björkman (1980)

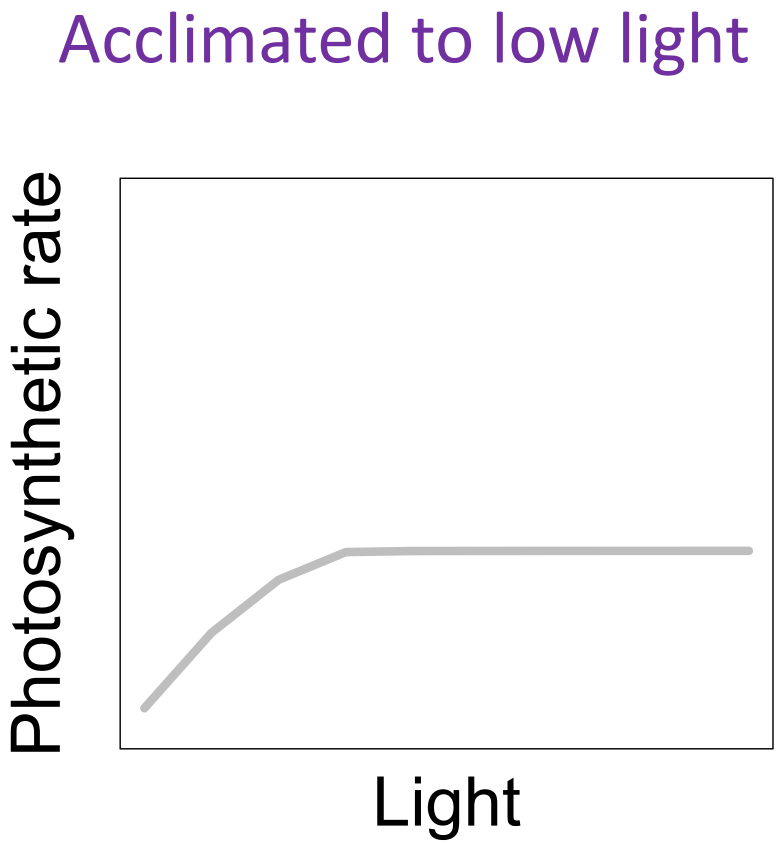
Ann. Rev. Plant Physiol. 1980. 31:491–543

PHOTOSYNTHETIC RESPONSE AND ADAPTATION TO TEMPERATURE IN HIGHER PLANTS

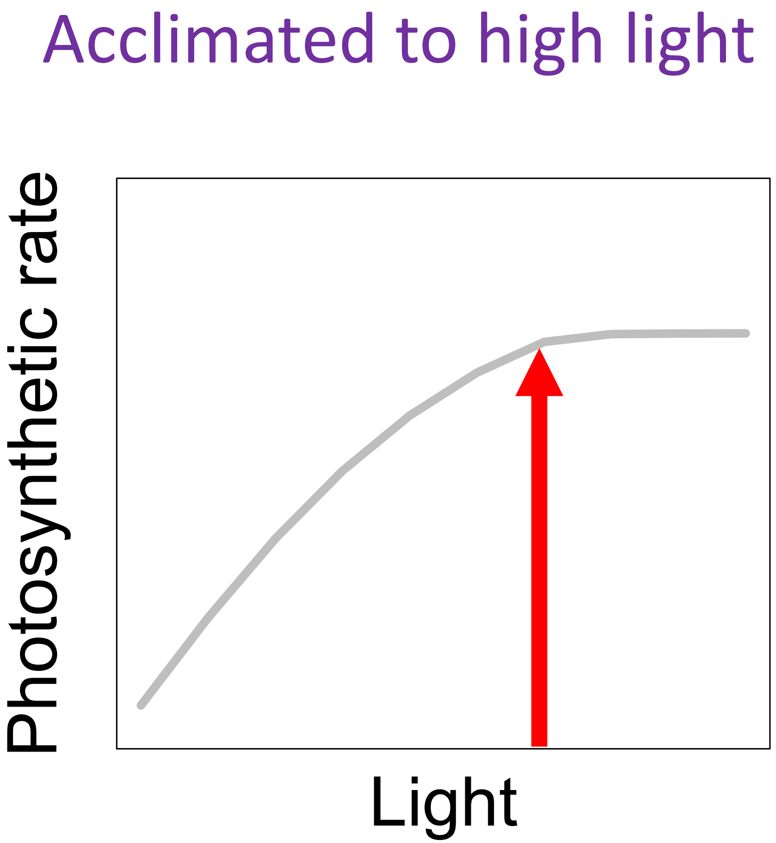
Joseph Berry and Olle Björkman[1]

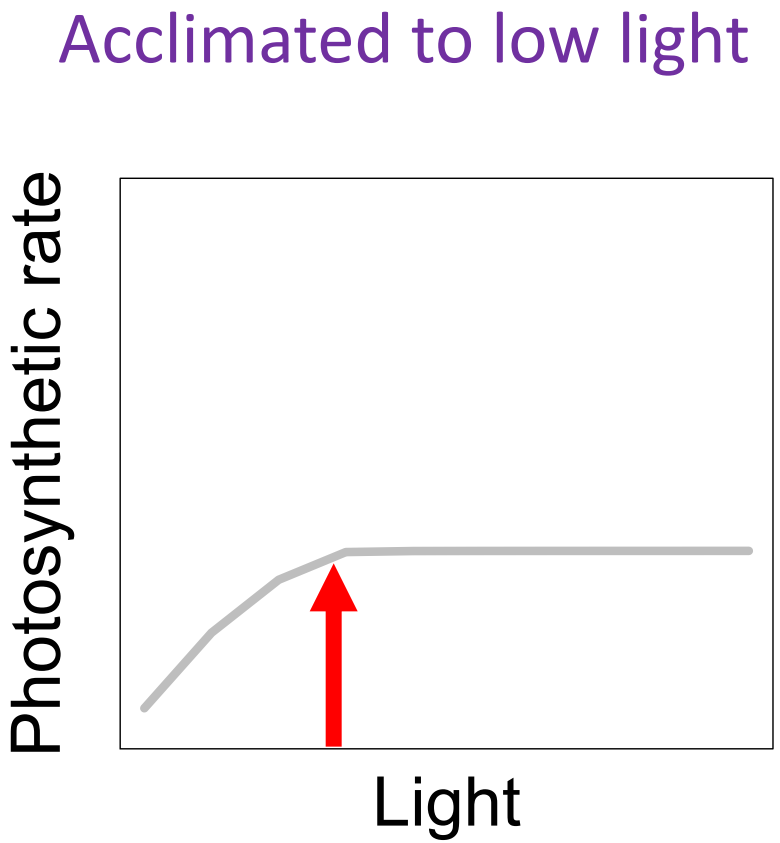
Acclimation: an example





Acclimation: an example





Photosynthesis peaks a light level close to the level the leaf is acclimated to

A general theory to explain photosynthetic acclimation: photosynthetic least cost theory

Least-Cost Input Mixtures of Water and Nitrogen for Photosynthesis

Ian J. Wright,[1,*] Peter B. Reich,[2,†] and Mark Westoby[1,‡]

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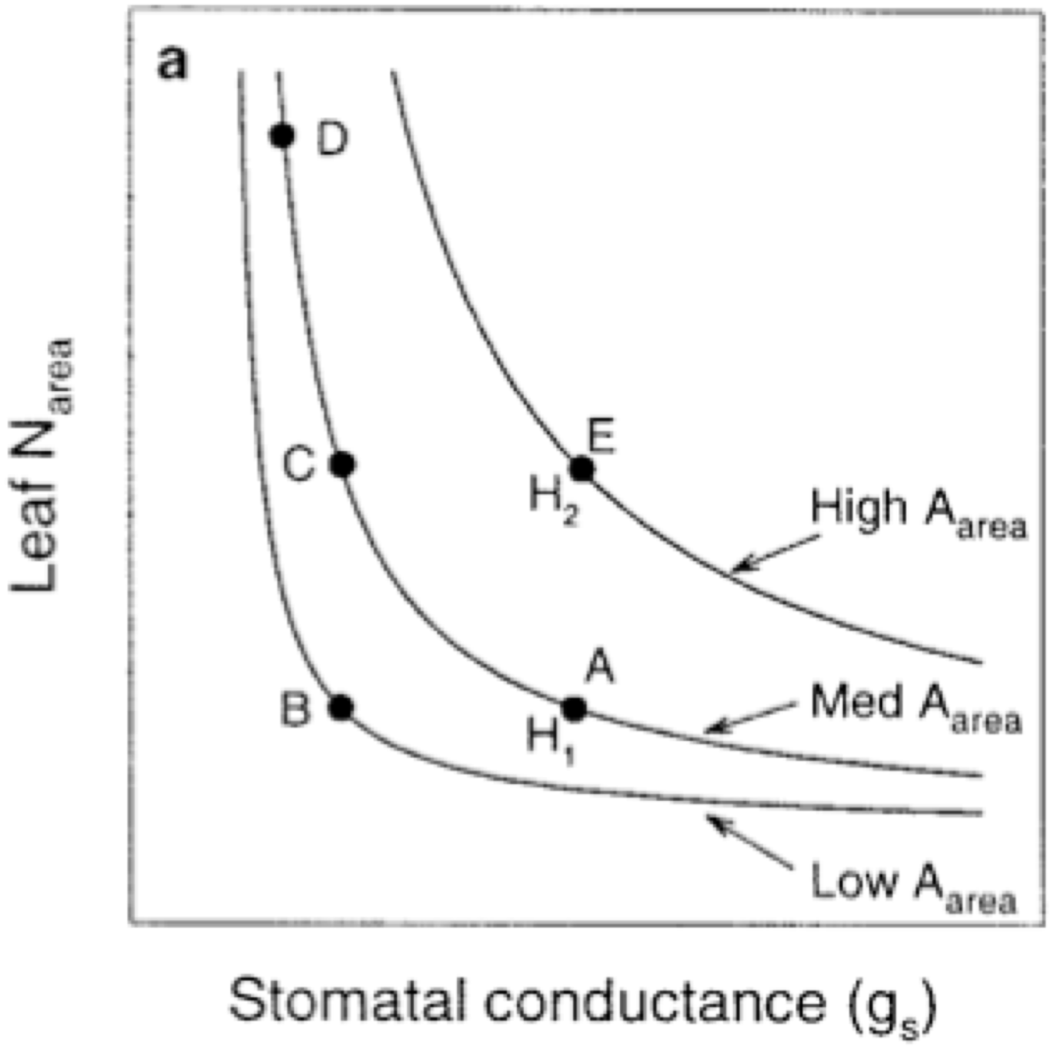
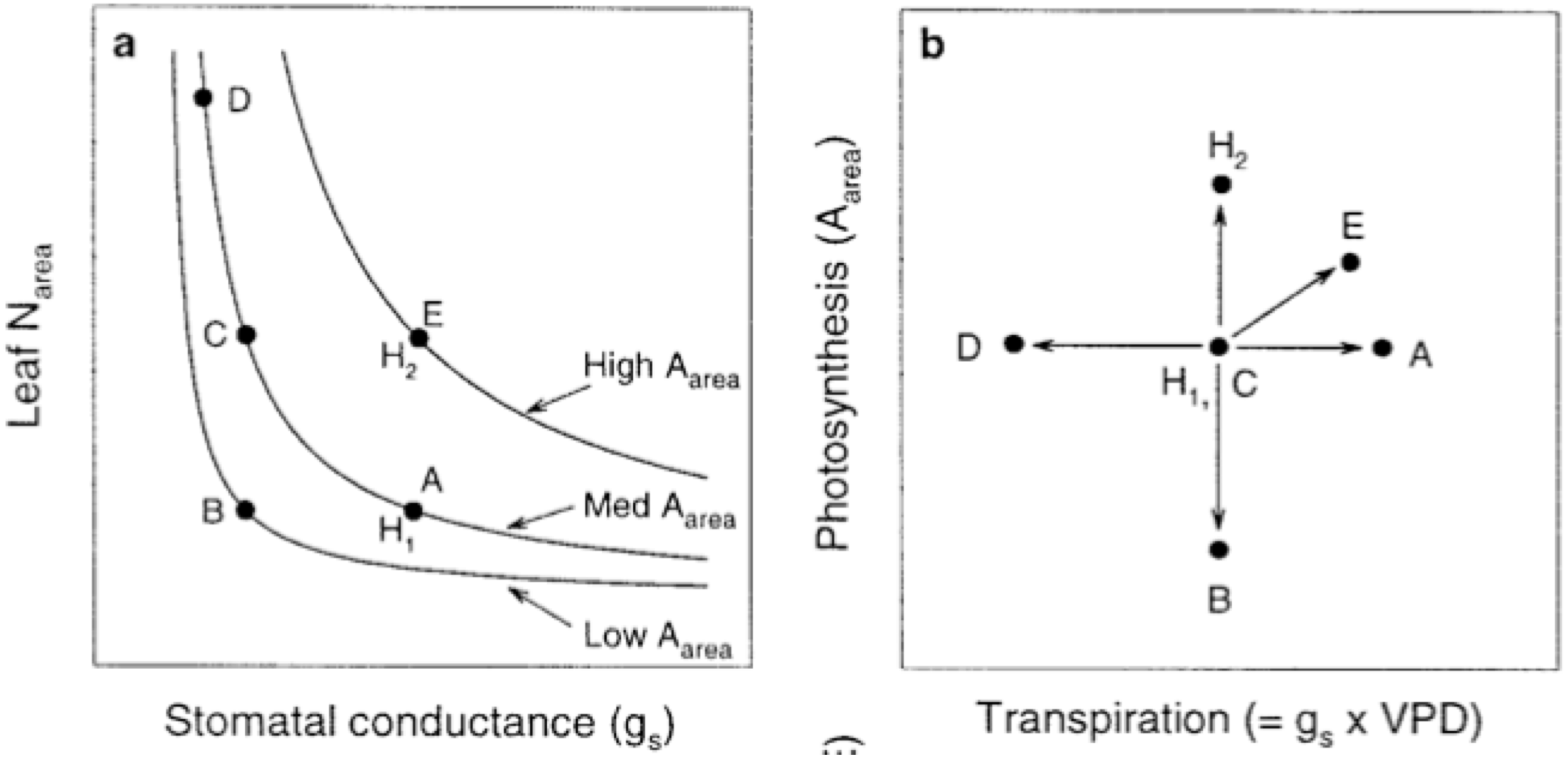
1998). When the stomates are open to allow CO_2 to diffuse into the leaf, water is inevitably lost in transpiration. Also, water is split during photosynthesis, the hydrogen being incorporated in sugar intermediates, and water is the medium in which nutrients and photoassimilates are transported around the plant.

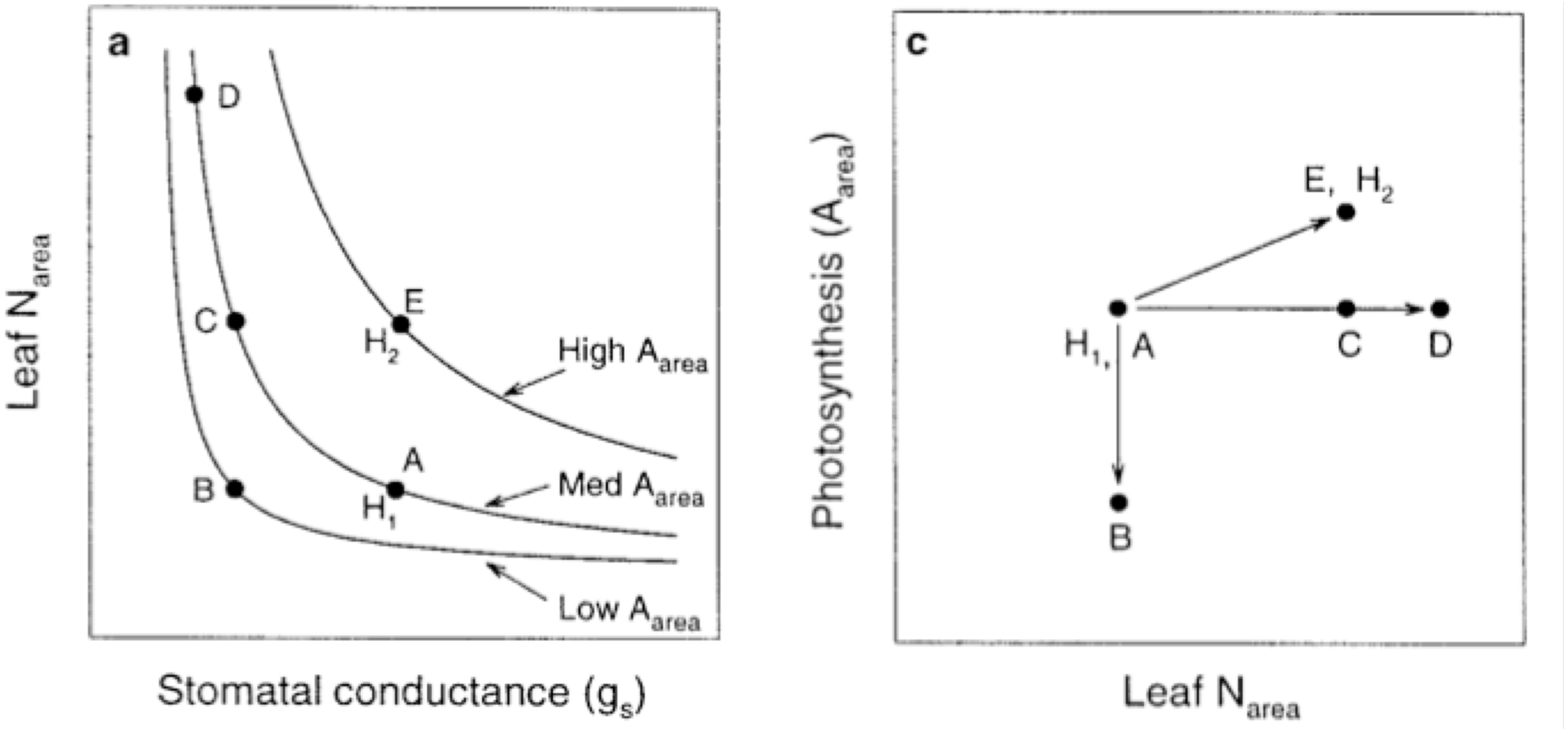
Economic analogies have often been used to describe the way plants operate, with resources such as water, ni-

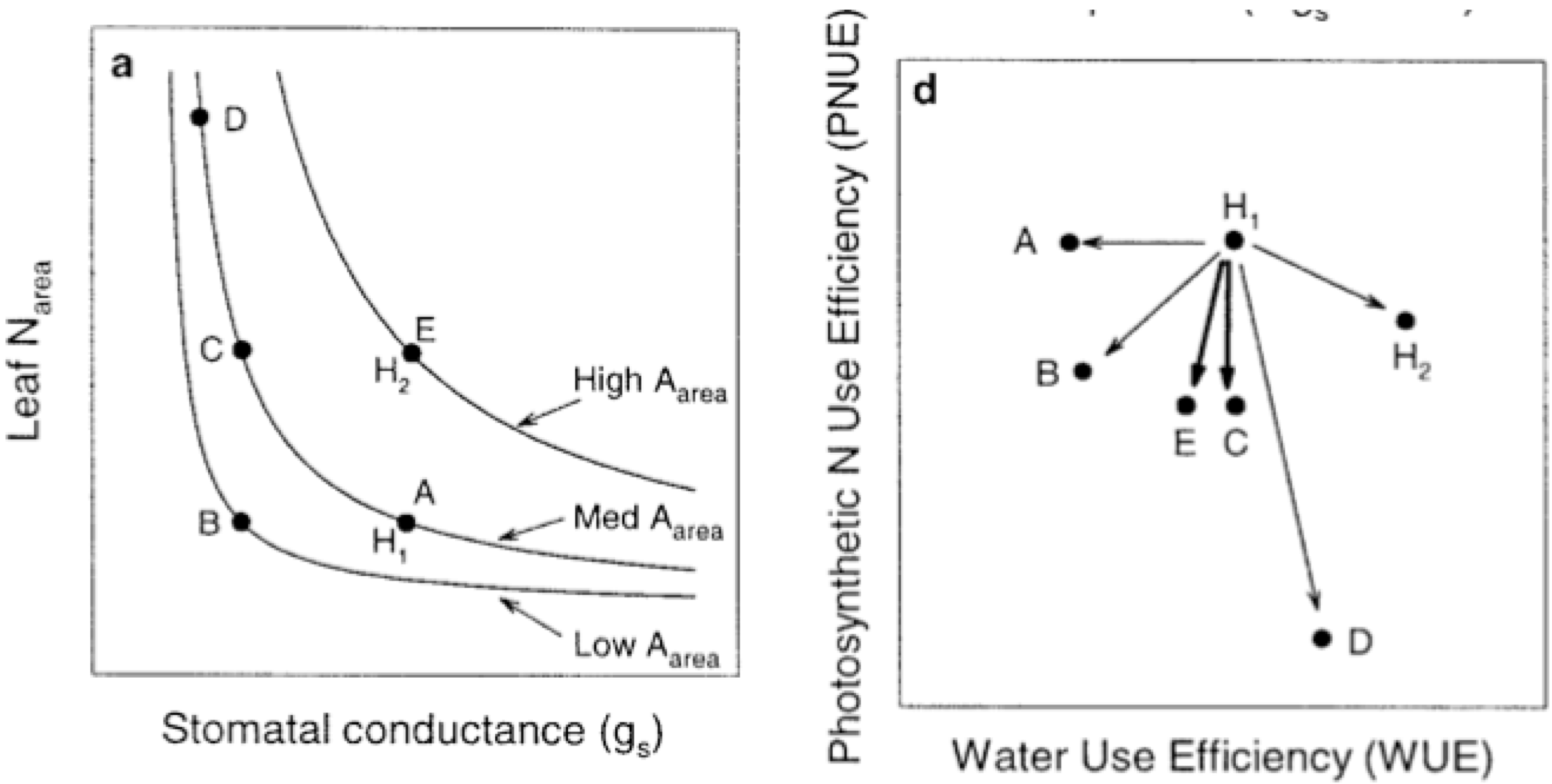


A = f{enzymes} * f{Ci}

A ~ N * gs


a
D
C
E
H2
High Aarea
A
B
H1
Med Aarea
Low Aarea
Leaf Narea
Stomatal conductance (gs)
b
H2
E
D
A
H1, C
B
Photosynthesis (Aarea)
Transpiration (= gs x VPD)


a
D
C
E
H2
High A area
A
Med A area
B
H1
Low A area
Leaf N area
Stomatal conductance (gs)
c
Photosynthesis (A area)
E, H2
H1, A
C
D
B
Leaf N area



a
D
C
E
H2
High A_area
A
B
H1
Med A_area
Low A_area
Leaf N_area
Stomatal conductance (g_s)
d
H1
A
B
E
C
H2
D
Photosynthetic N Use Efficiency (PNUE)
Water Use Efficiency (WUE)

ECOLOGY LETTERS

Ecology Letters, (2014) **17**: 82–91 doi: 10.1111/ele.12211

LETTER

Balancing the costs of carbon gain and water transport: testing a new theoretical framework for plant functional ecology

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[2]*AXA Chair of Biosphere and Climate Impacts, Department of Life Sciences and Grantham Institute for Climate Change, Imperial College, Silwood Park, Ascot, SL5 7PY, UK*

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Abstract

A novel framework is presented for the analysis of ecophysiological field measurements and modelling. The hypothesis '*leaves minimise the summed unit costs of transpiration and carboxylation*' predicts leaf-internal/ambient CO_2 ratios (c_i/c_a) and slopes of maximum carboxylation rate (V_{cmax}) or leaf nitrogen (N_{area}) *vs.* stomatal conductance. Analysis of data on woody species from contrasting climates (cold-hot, dry-wet) yielded steeper slopes and lower mean c_i/c_a ratios at the dry or cold sites than at the wet or hot sites. High atmospheric vapour pressure deficit implies low c_i/c_a in dry climates. High water viscosity (more costly transport) and low photorespiration (less costly photosynthesis) imply low c_i/c_a in cold climates. Observed site-mean c_i/c_a shifts are predicted quantitatively for temperature contrasts (by photorespiration plus viscosity effects) and approximately for aridity contrasts. The theory explains the dependency of c_i/c_a ratios on temperature and vapour pressure deficit, and observed relationships of leaf $\delta^{13}C$ and N_{area} to aridity.

Keywords

Aridity, nitrogen, optimality, photosynthesis, plant functional traits, stable isotopes, stomatal conductance, temperature, transpiration, viscosity.

Ecology Letters (2014) **17**: 82–91

Principles

A value of χ that satisfies the optimisation criterion (χ_o) must satisfy the following:

$$a.\partial(E/A)/\partial\chi + b.(V_{cmax}/A)/\partial\chi = 0 \quad (1)$$

Given that $E = 1.6g_sD$ and $A = g_sc_a(1 - \chi)$, and assuming that $A >> R_d$ (day respiration) and $c_i >> \Gamma^*$ (the photorespiratory compensation point), it is shown below that the optimum is obtained for $\chi = \chi_o$ where

$$\boxed{\chi_o = \xi/(\xi + \sqrt{D}) \quad (2)}$$

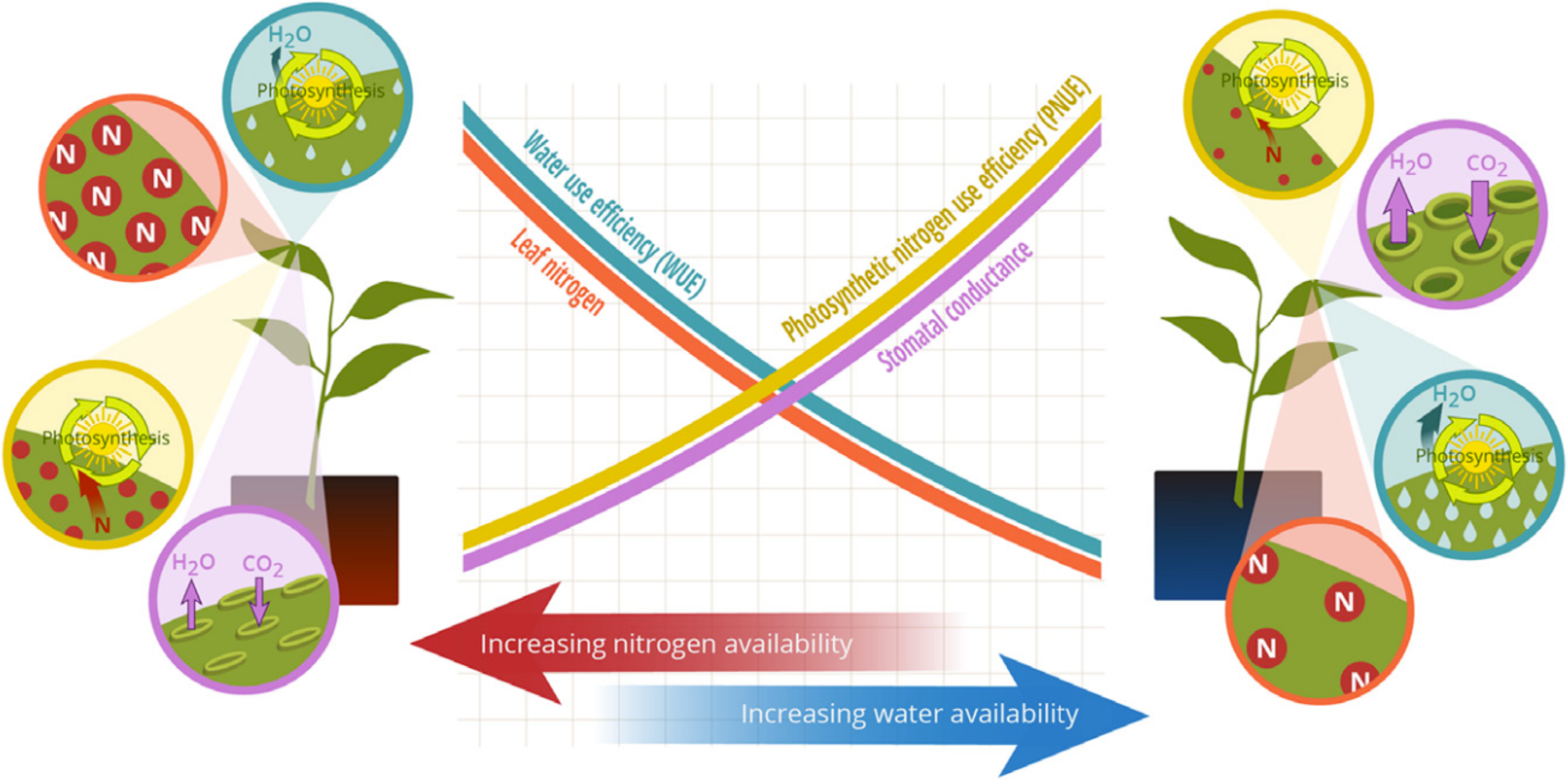
and $\xi = \sqrt{(bK/1.6a)}$, where K is the Michaelis–Menten coefficient for Rubisco-limited photosynthesis at a pO_2 of 21 kPa.

χ = ratio of CO_2 inside to outside the leaf

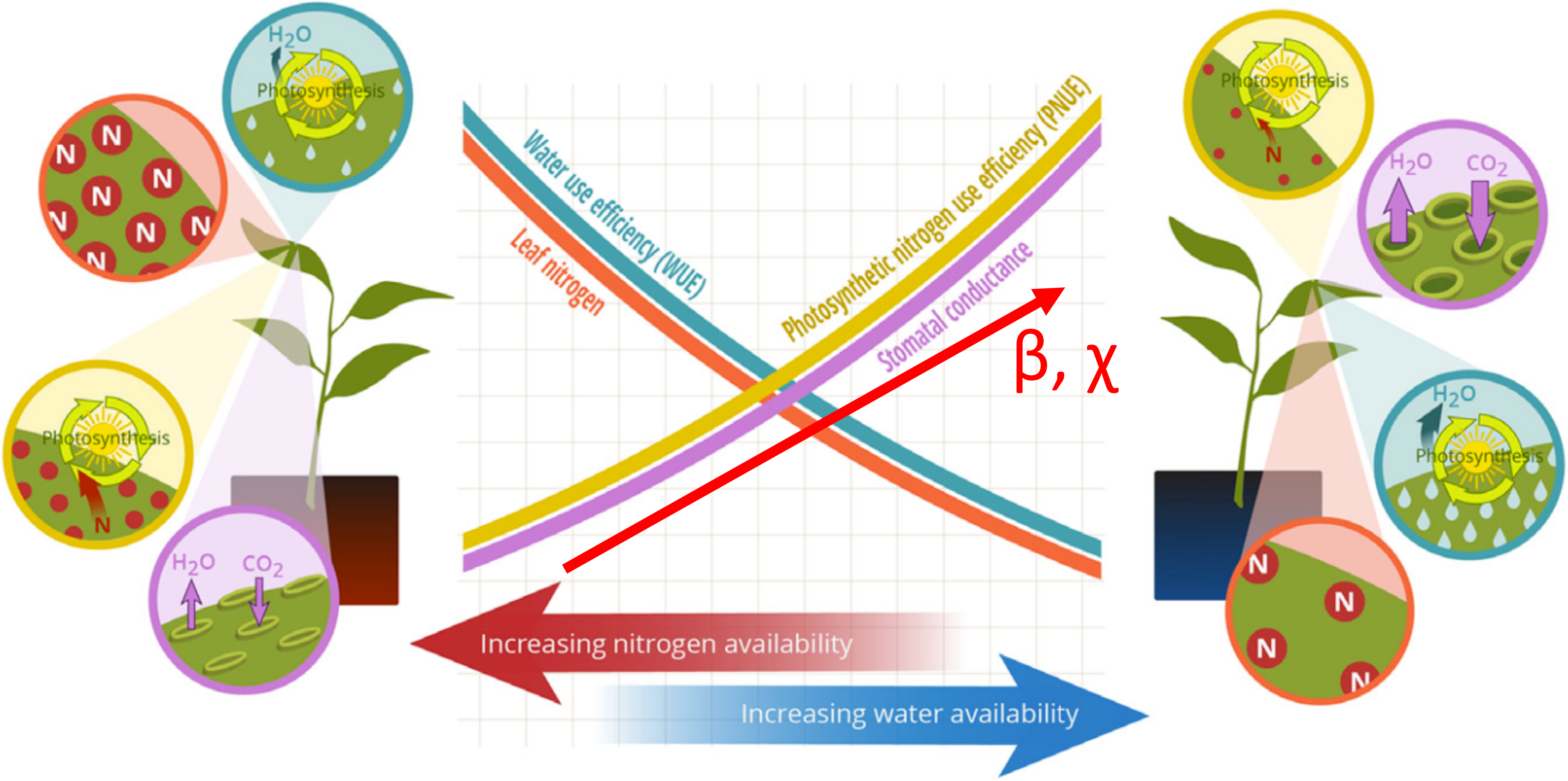
a = carbon cost of maintaining transpiration to support photosynthesis

b = carbon cost of maintaining photosynthetic enzymes

β = b/a



Bialic-Murphy et al. (2021)



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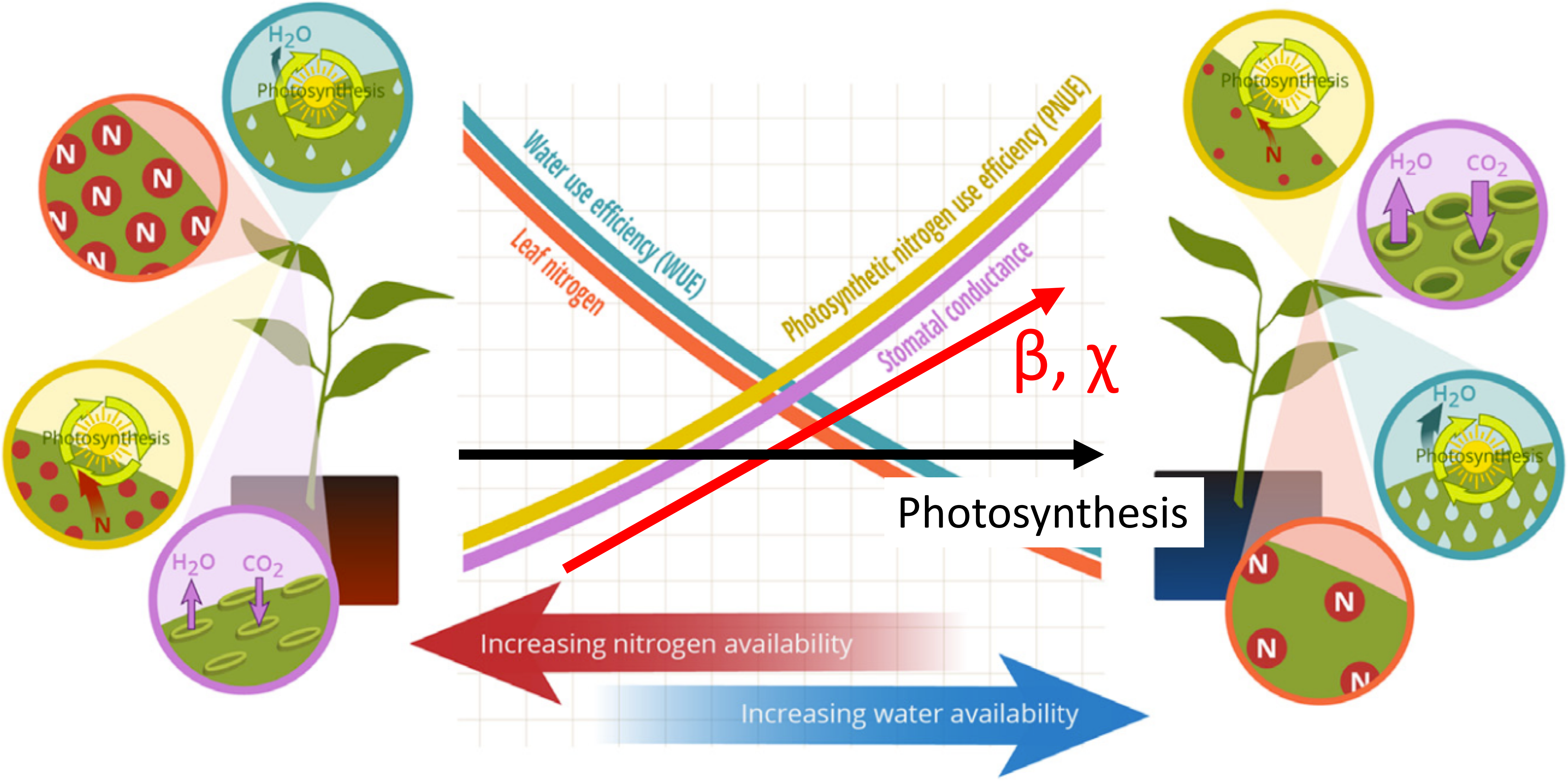

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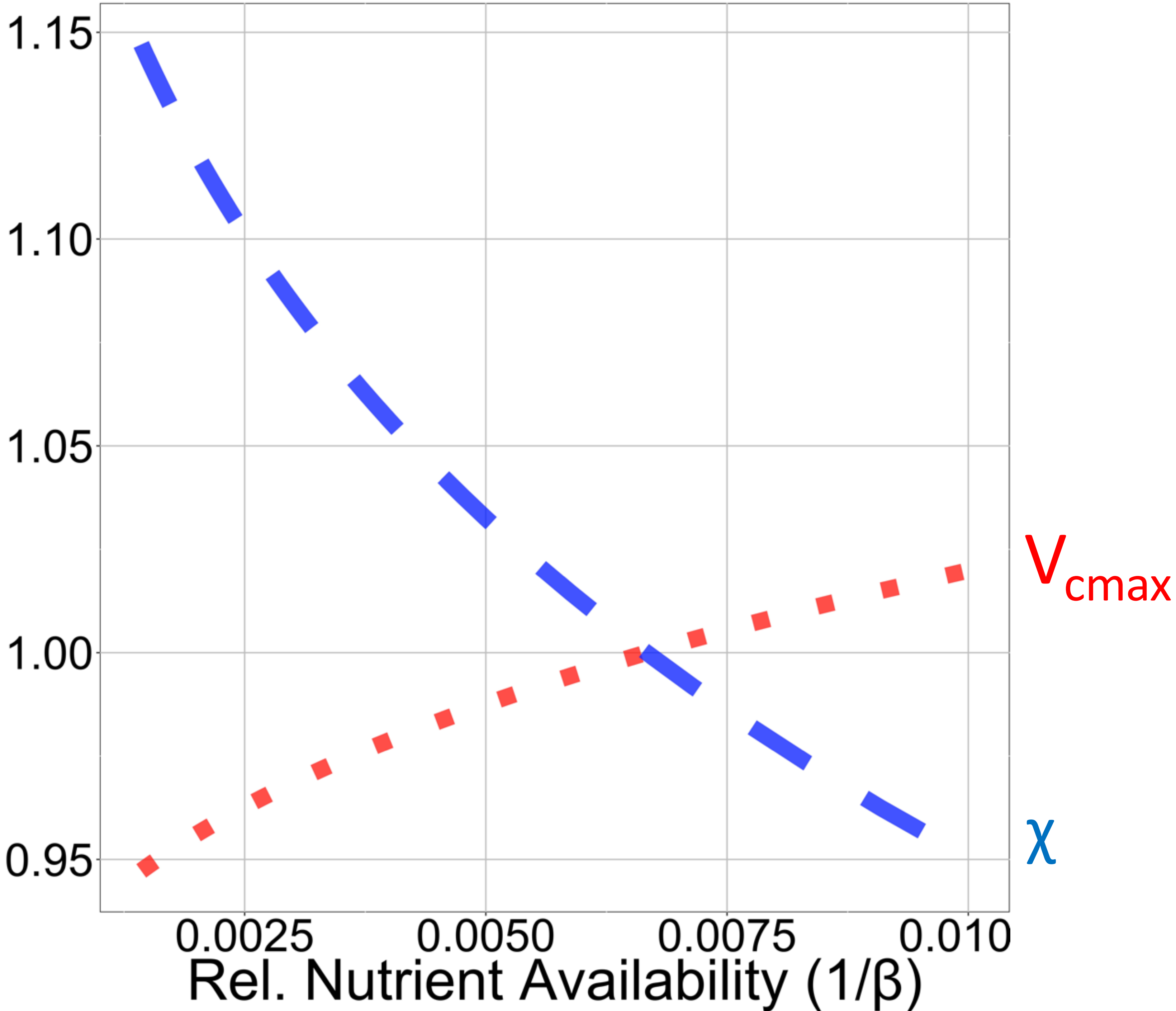
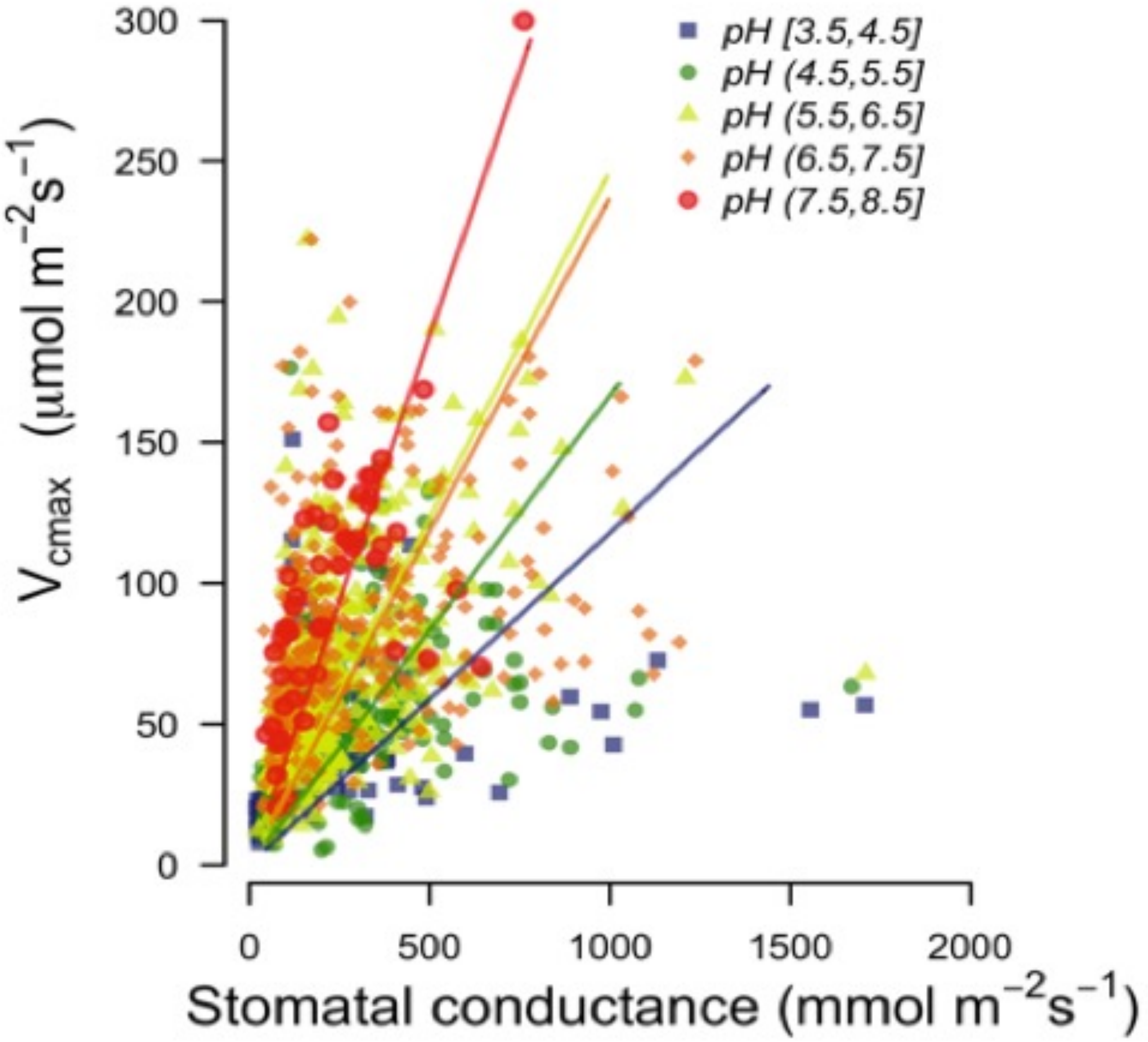
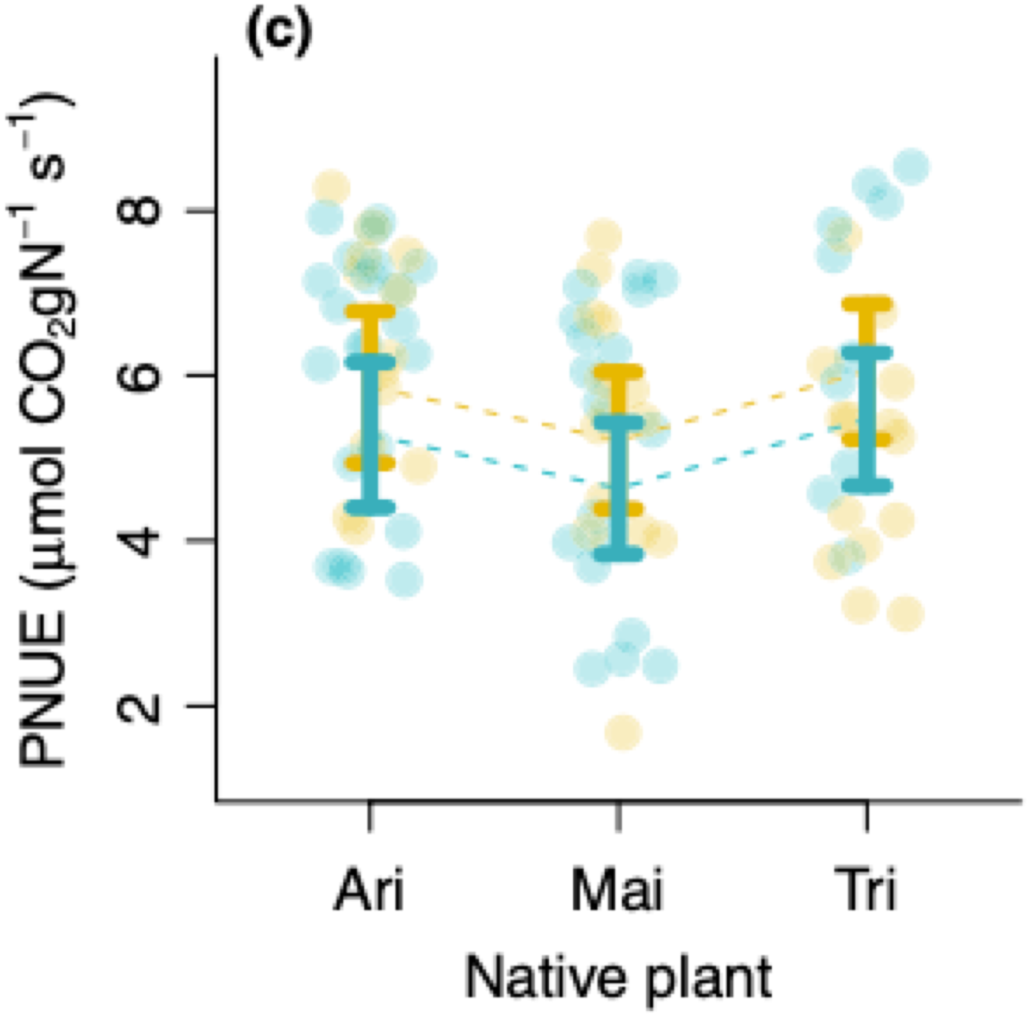


1.15
1.10
1.05
1.00
0.95
0.0025
0.0050
0.0075
0.010
Rel. Nutrient Availability (1/β)
V_{cmax}
χ

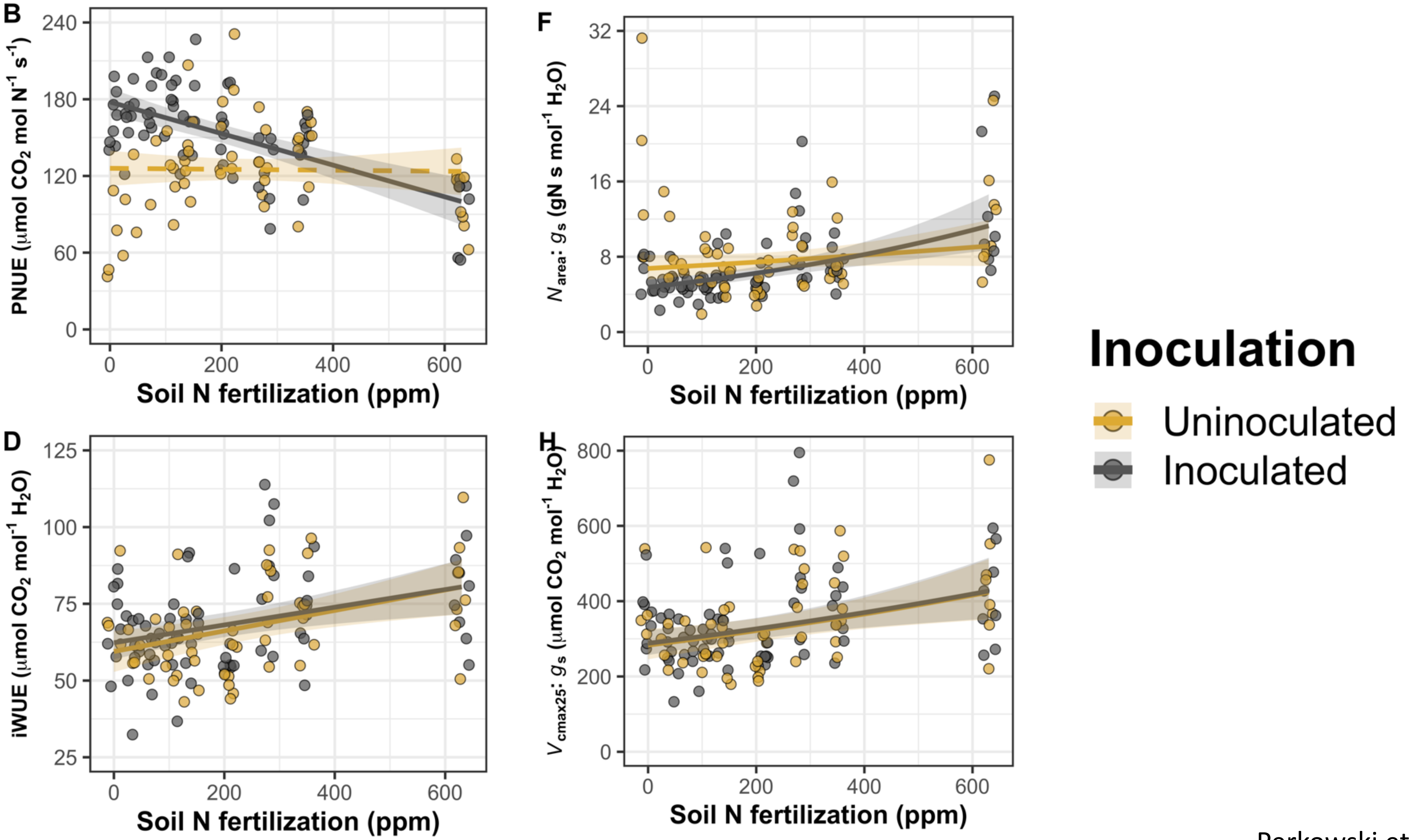
Does it work?



Paillassa et al. (2020)



Bialic-Murphy et al. (2021)



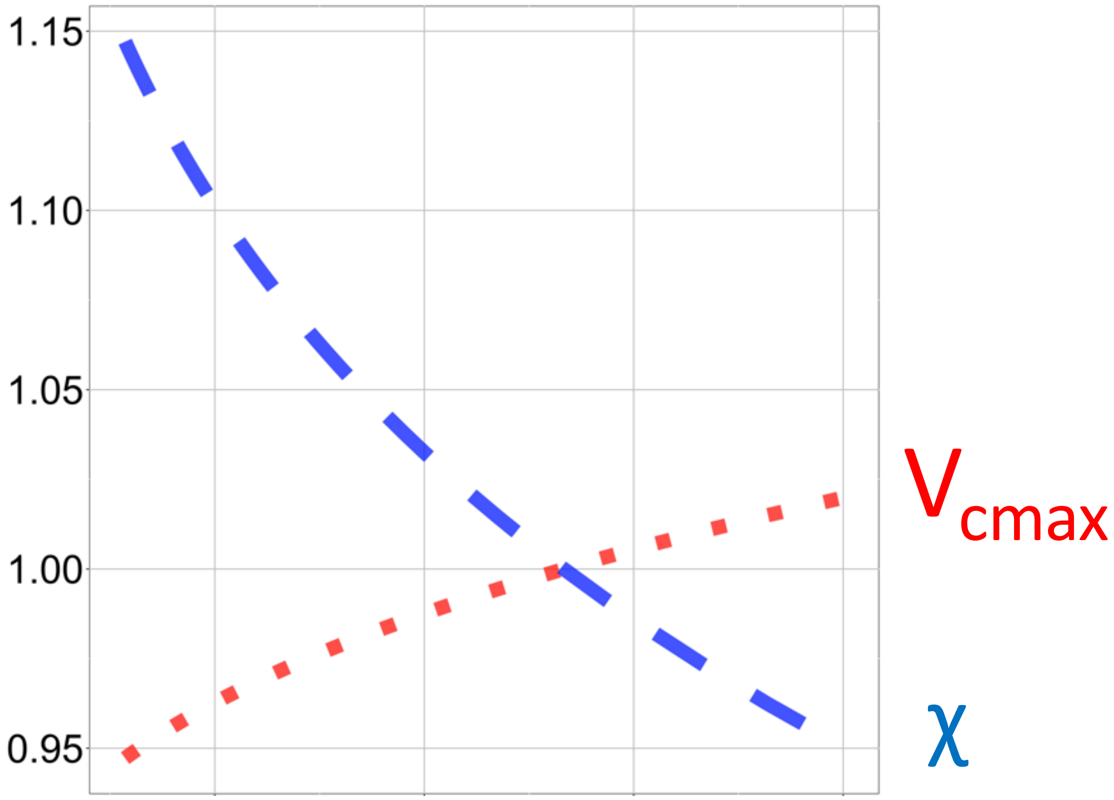
Perkowski et al. (in prep)

Why does it matter for our project?

IntBio implications

- Provides a framework for understanding how Alliaria invasion-induced disruptions in mycorrhizal networks impacts plant physiology
- Can predict that antibi plants in invaded plots will have:
  - Higher β
  - Higher χ
  - Lower V_{cmax}
  - Lower leaf N and P
  - Higher costs for uptaking N and P

IntBio implications



Decreasing invasion

Some yet unresolved questions

- What really is β?
- Are there leaf-whole plant tradeoffs?
- What are implications for vital rates and demography?
- Are there species-specific responses? Why?

Presentation available at:
www.github.com/SmithEcophysLab/seminar/2023_intbio