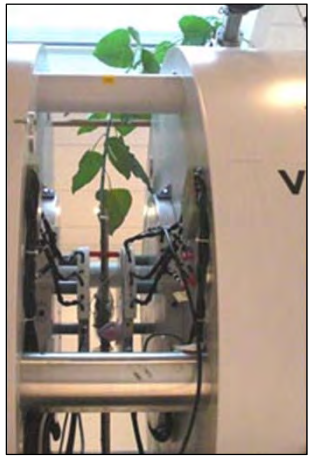
Does photosynthesis drive growth?

Hendrik Poorter
Plant Sciences, FZJ

Research center Jülich (Germany):

Focusing on high-throughput phenotyping

at a range of integration levels



Light

↓

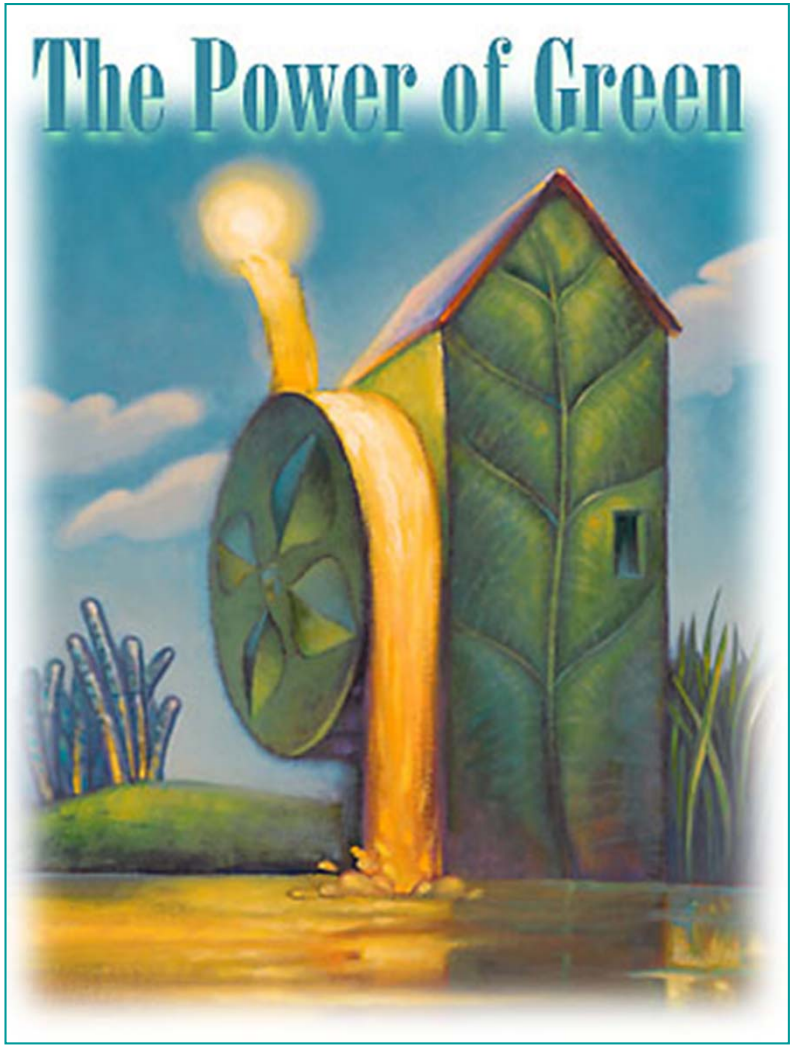
CO_2 fixation

↓

Sugars

↓

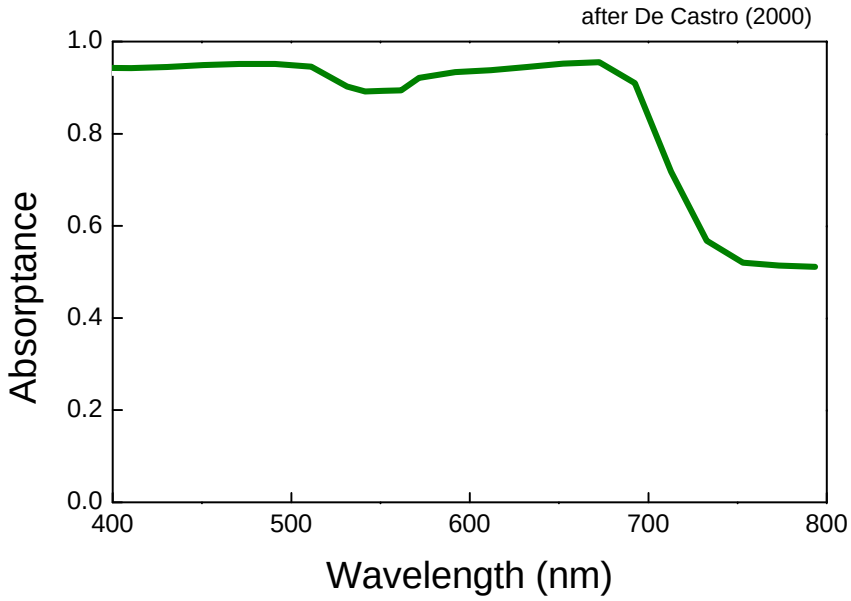
Growth

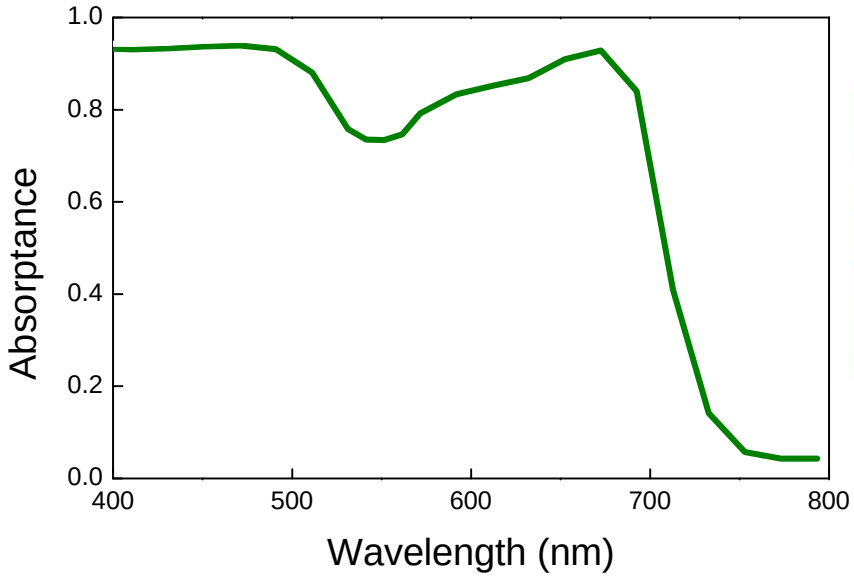


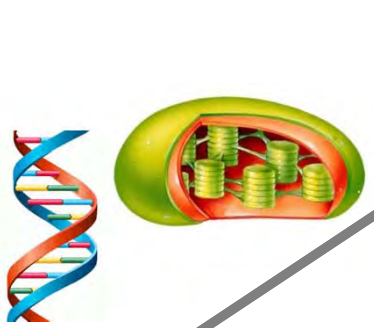
No growth without photosynthesis!

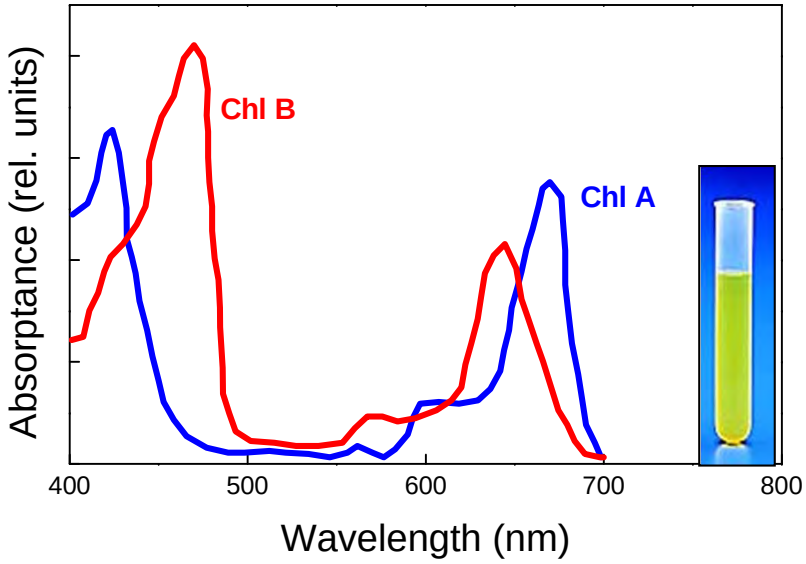
drawing: Michael Hagelberg

What is true at the subcellular scale is not necessarily true at the ecological scale:









To what extent does an
Δ photosynthesis

leads to a
Δ growth ?

Both terms are ambiguous:

photosynthesis:

/area, /mass ?

one leaf, whole plant ?

growth light, saturating light, CO_2, both ?

middle of the day, after a rain event ?

how long into treatment, ontogeny ?

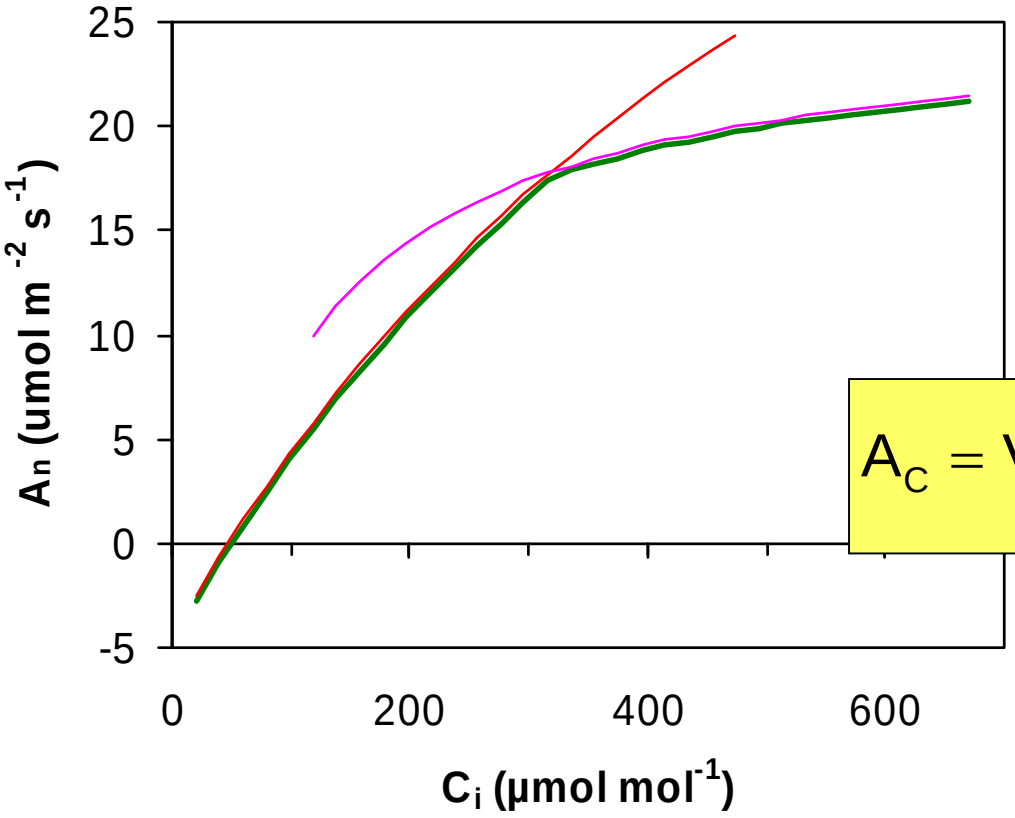
growth:

vegetative biomass, yield ?

above-ground, below-ground, both?

LER, AGR, RGR ?

Capturing photosynthesis:

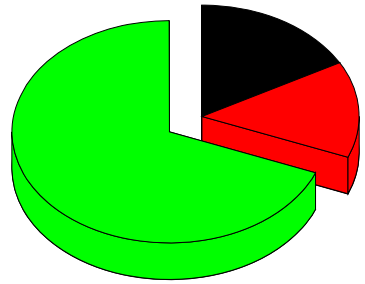


$$A_C = V_{CMAX} \cdot \frac{C - \Gamma_*}{C + K_C(1 + O/K_O)} - R_d$$

$$A_J = J \cdot \frac{C - \Gamma_*}{4C + 8\Gamma_*} - R_d$$

Von Caemmerer & Farquhar(1981) Planta

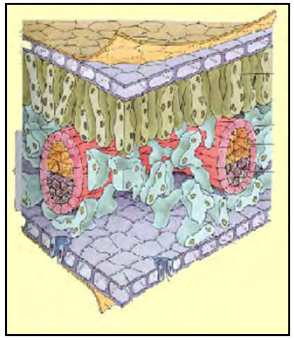
Capturing the C-budget:

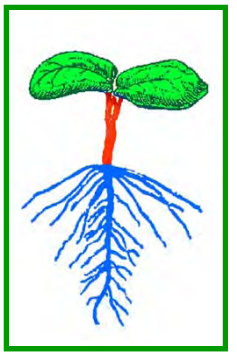


$$RGR = \left\{ + PS_A \,.\, SLA \,.\, LMF \; - LR \,.\, LMF \; - SR \,.\, SMF \; - RR \,.\, RMF \right\} / C_p$$

Poorter & Van der Werf (1998) Book chapter

A more simple equation:



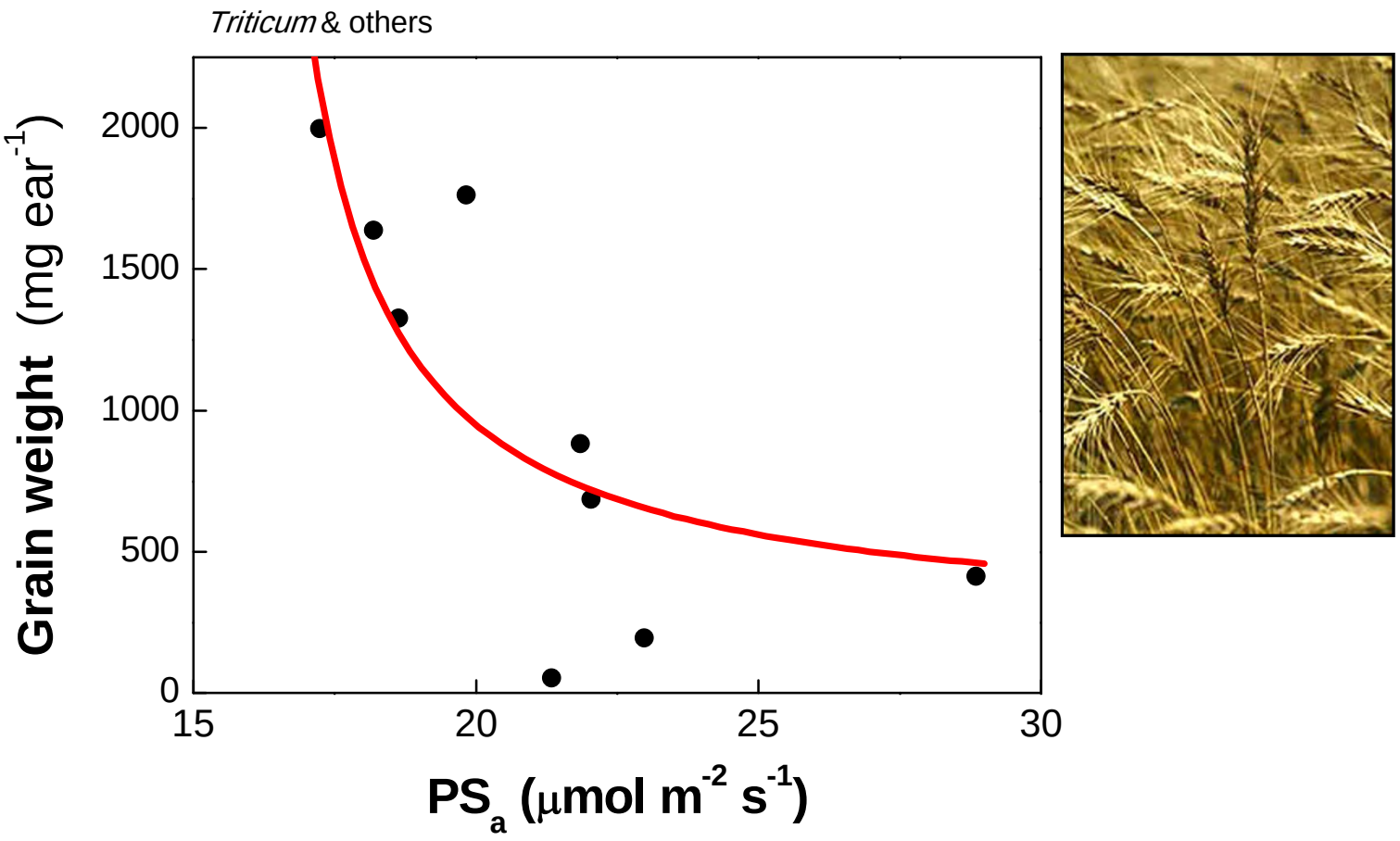


$$RGR = \frac{PS_A \,.\, FCI}{[C]} \,.\, SLA \,.\, LMF$$

$$RGR = ULR \,.\, SLA \,.\, LMF$$

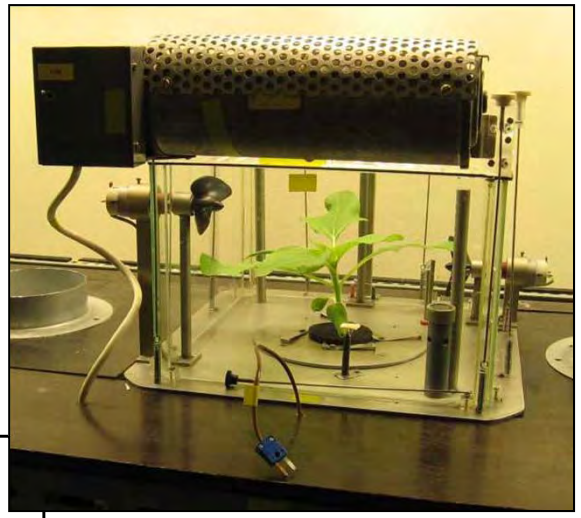
Poorter (2002) Encyclopedia of Life Sciences

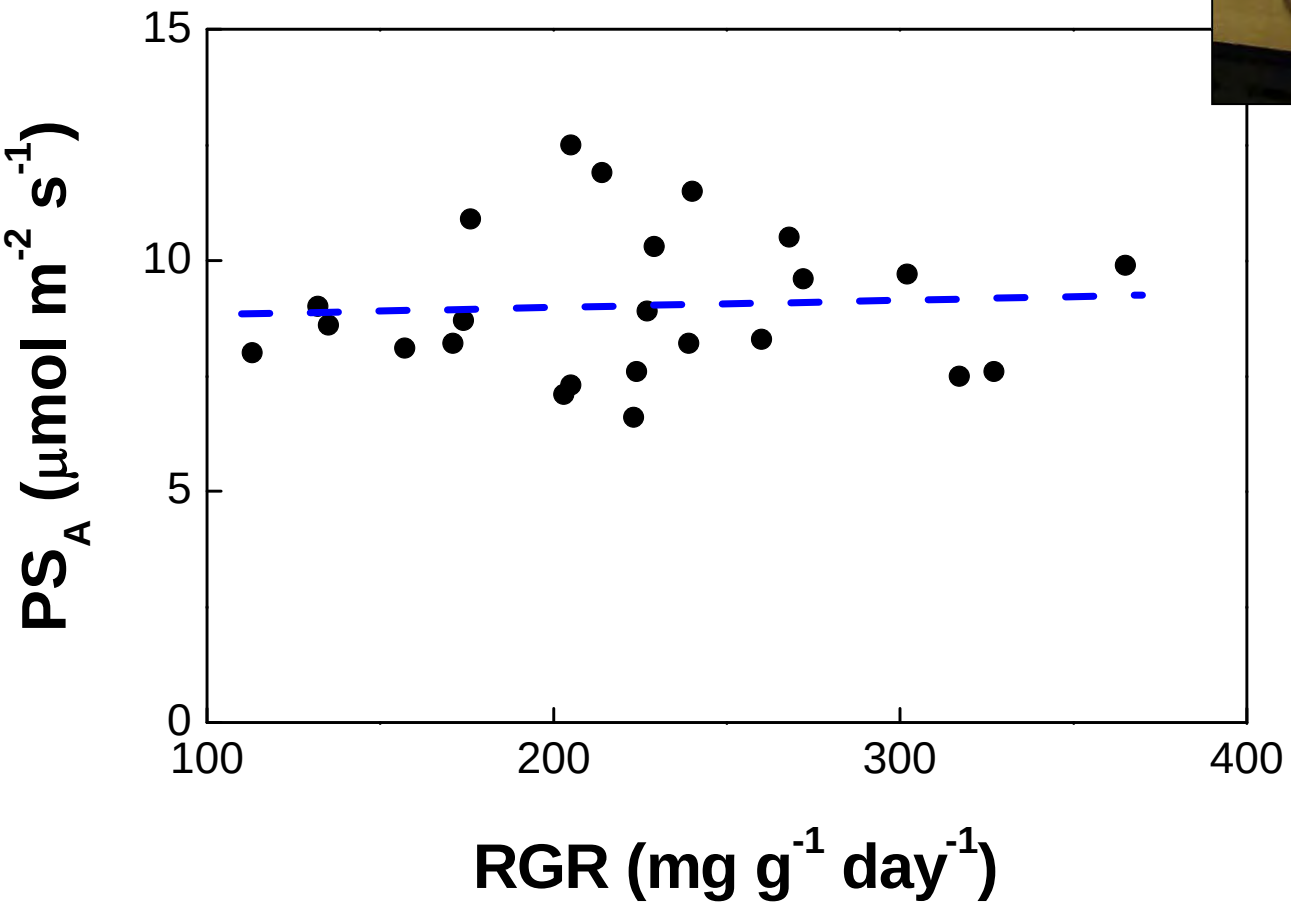
1. The case of differences between species or genotypes:



Evans & Dunstone (1970) Aust. J. Plant Physiol.

1b. Differences between species:





Poorter et al. (1990) Plant Physiol.

1c. Growth Response Coefficients summarise the relative change in growth parameters relative to RGR, and normally add up to 1.0; SLA most important factor:

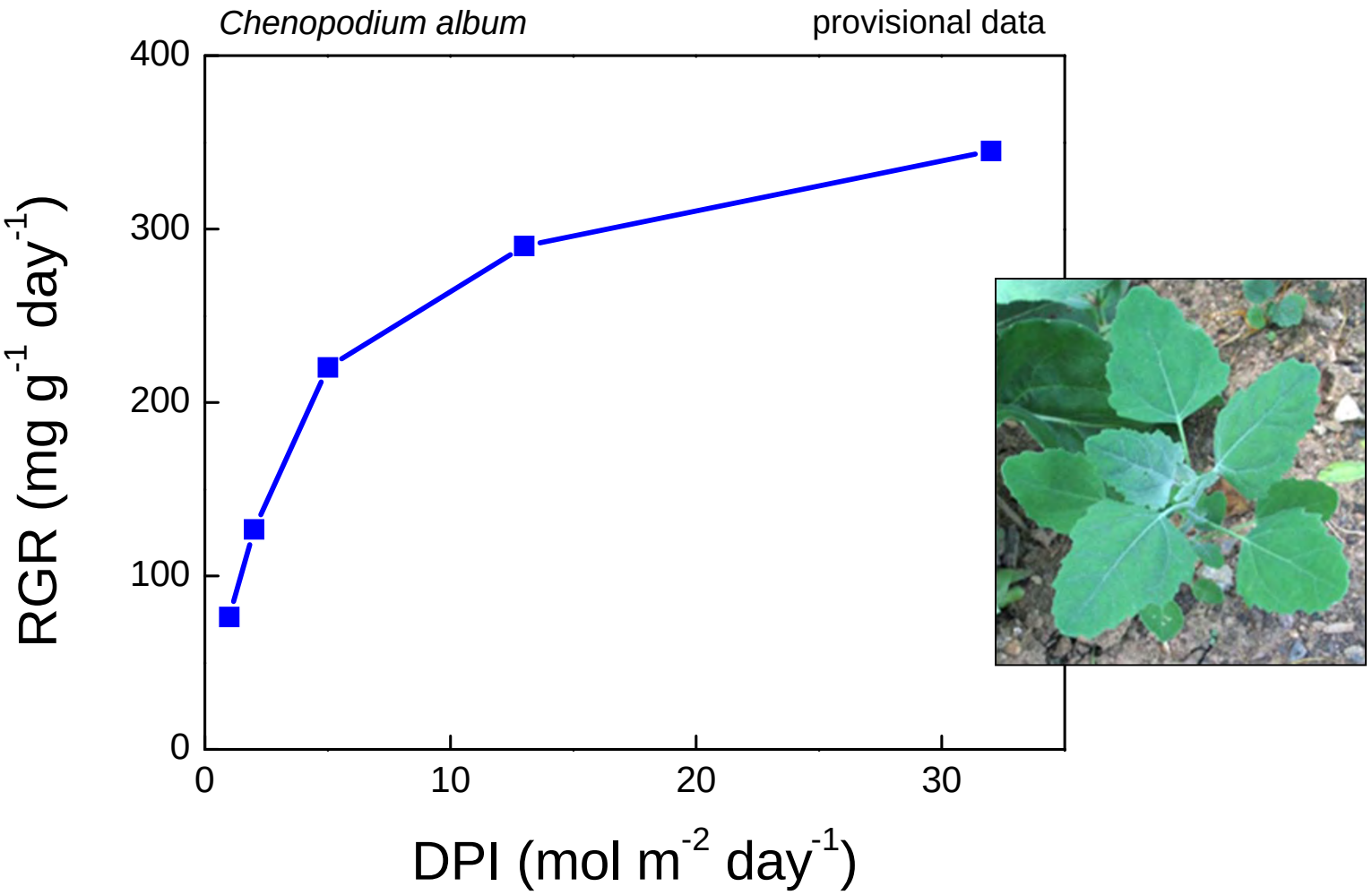
$$RGR = \frac{PS_A \,.\, FCI}{[C]} \,.\, SLA \,.\, LMF$$

$$GRC_X = \frac{\frac{dX}{X}}{\frac{dRGR}{RGR}}$$

	GRC 24 species	GRC meta analysis
PS_A	0.05	
FCI	0.29	0.24
[C]	(-) 0.10	
SLA	0.53	0.66
LMF	0.28	0.11

Poorter & Van der Werf (1998) Book

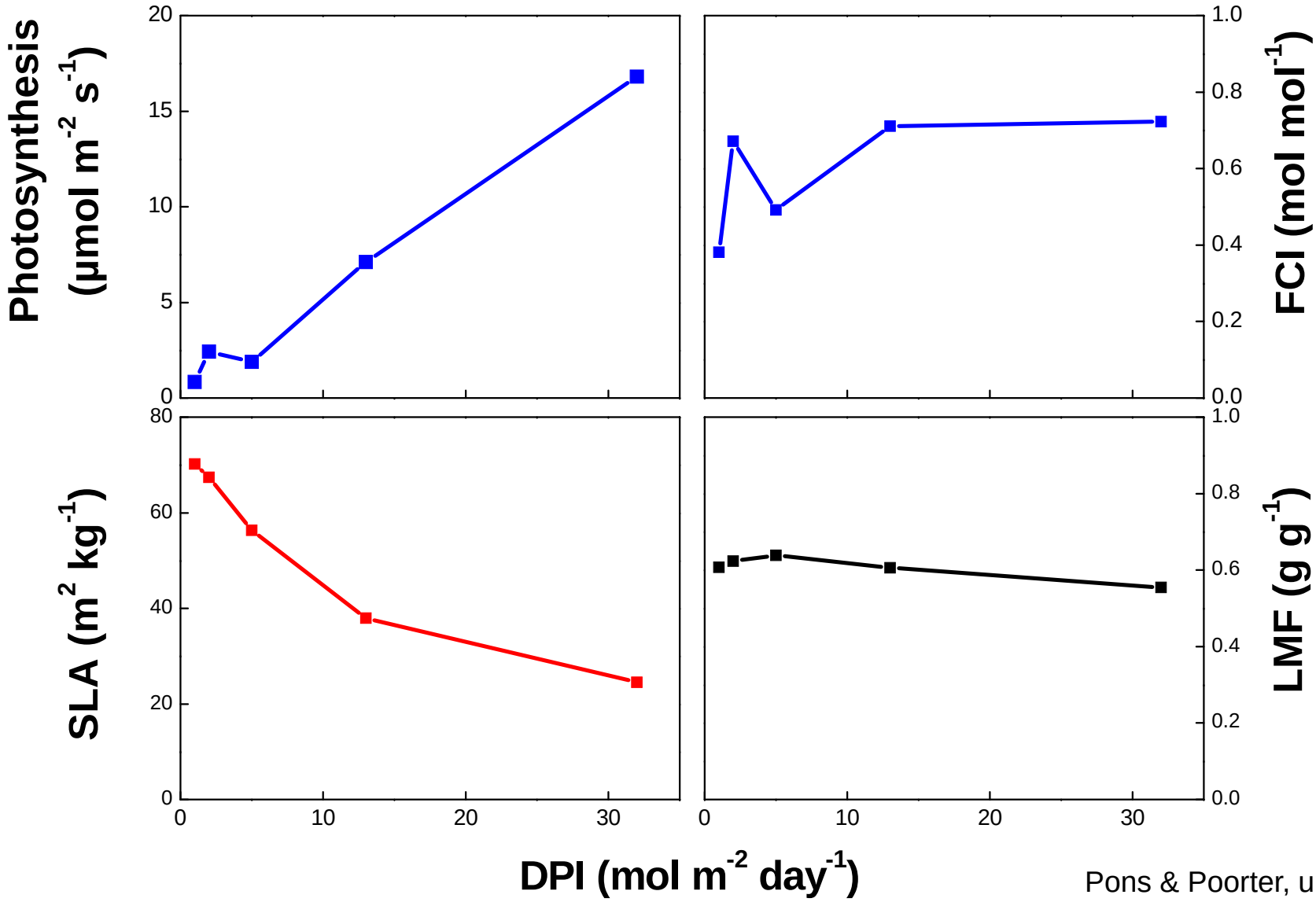
2. The case of light intensity:



Pons & Poorter, unpubl.

2b. The effect of light on RGR-components:

(provisional data)



Pons & Poorter, unpubl.

2c. Growth Response Coefficients for light-induced variation, PSa most important positive factor, SLA most negative factor:

$$RGR = \frac{PS_A \,.\, FCI}{[C]} \,.\, SLA \,.\, LMF$$

$$GRC_X = \frac{\frac{dX}{X}}{\frac{dRGR}{RGR}}$$

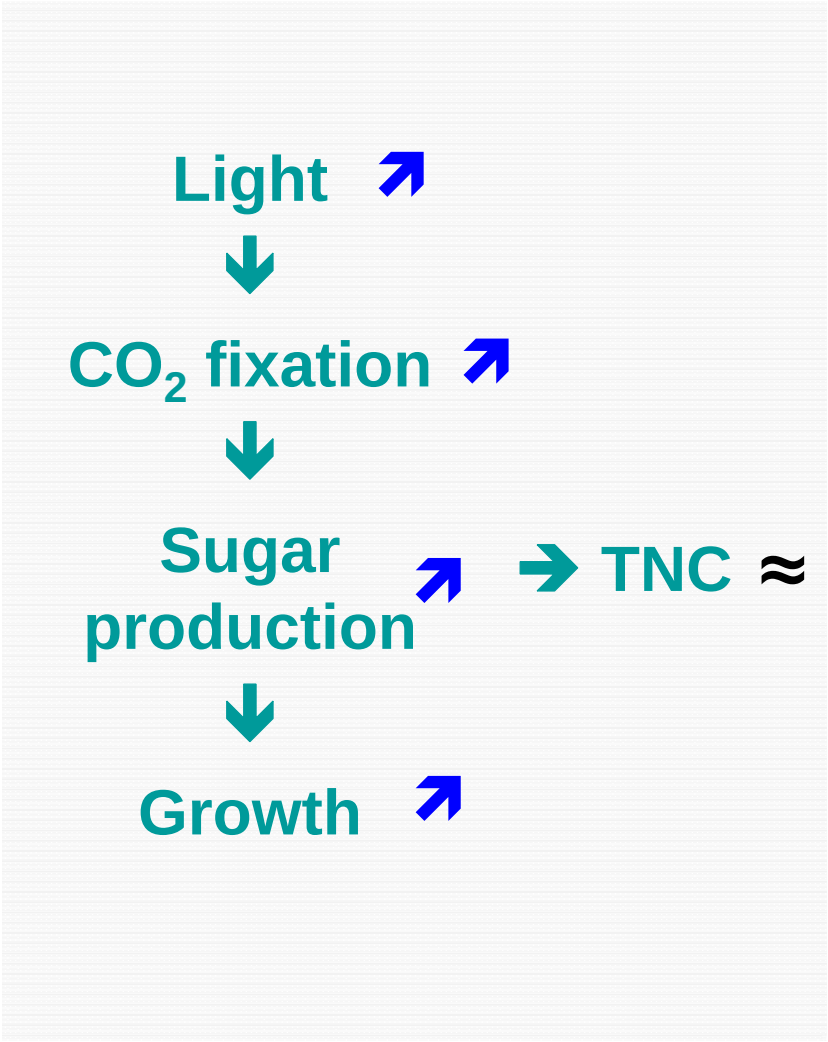
	GRC 5 species	GRC meta anal.
PS_A	2.03	
FCI	0.36	2.15
[C]	0.09	
SLA	-0.85	-1.18
LMF	0.00	-0.12

Poorter & Van der Werf (1998) Book chapter

Effect of light on chemical composition:

	Low Light	High Light
Protein	300	279
TNC	51	53
Lignin	134	208

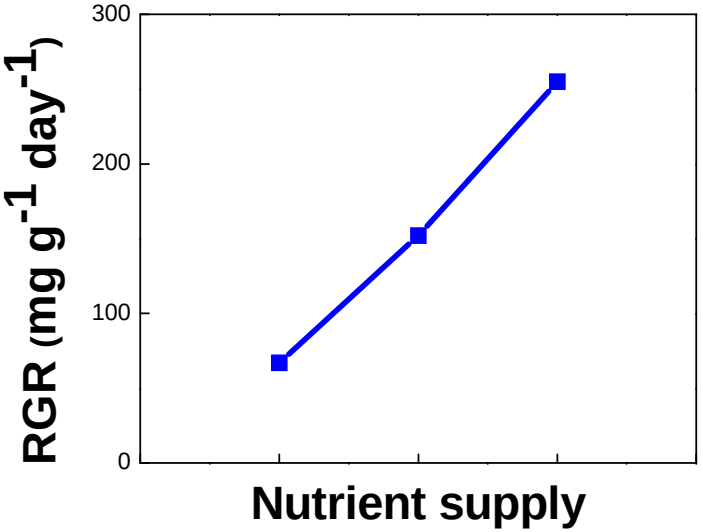
Salix aquatica



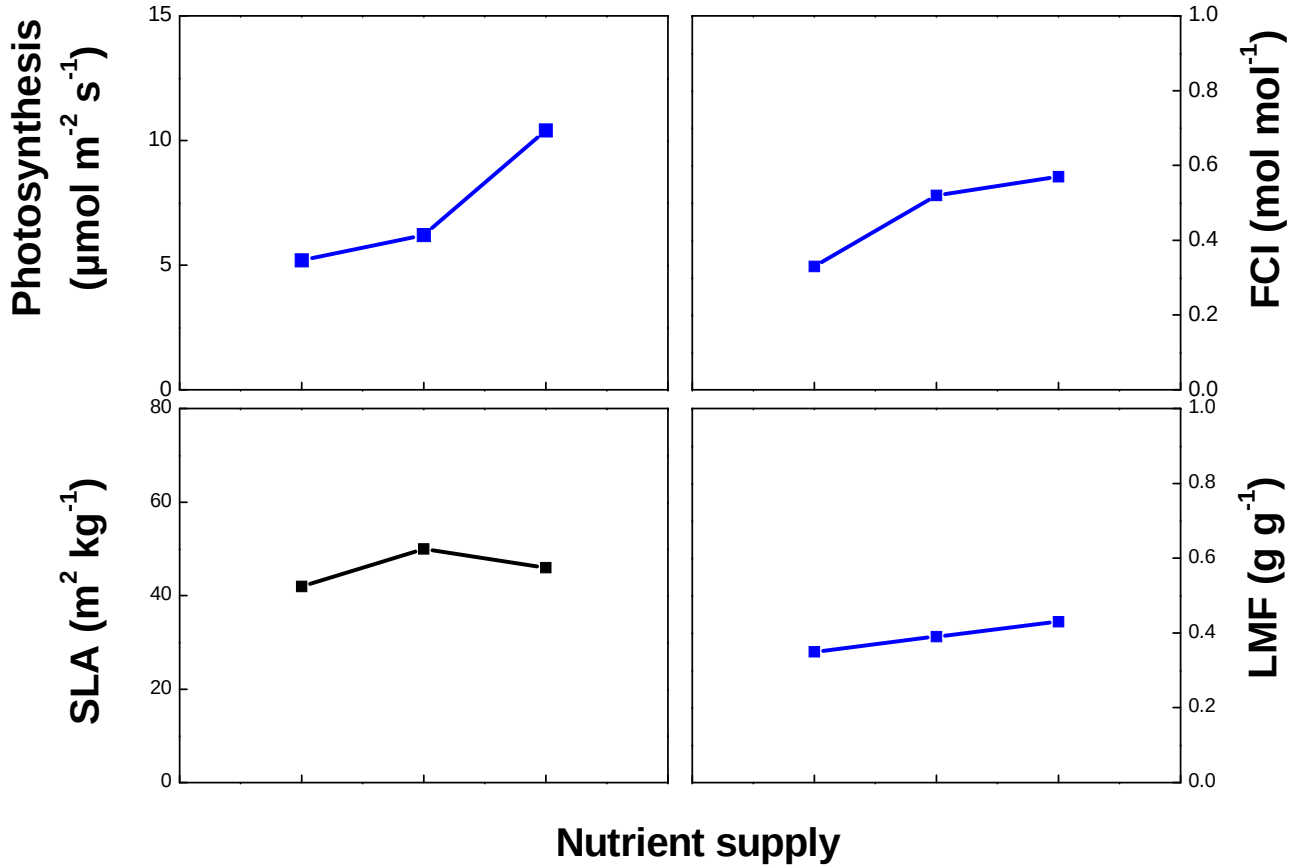
Waring et al. (1985) Oecologia

3a. The case of nutrients:

Poorter et al. (1995) Plant & Soil



Holcus lanatus



3b. GRC's for nutrients, most important decrease is in PSa:

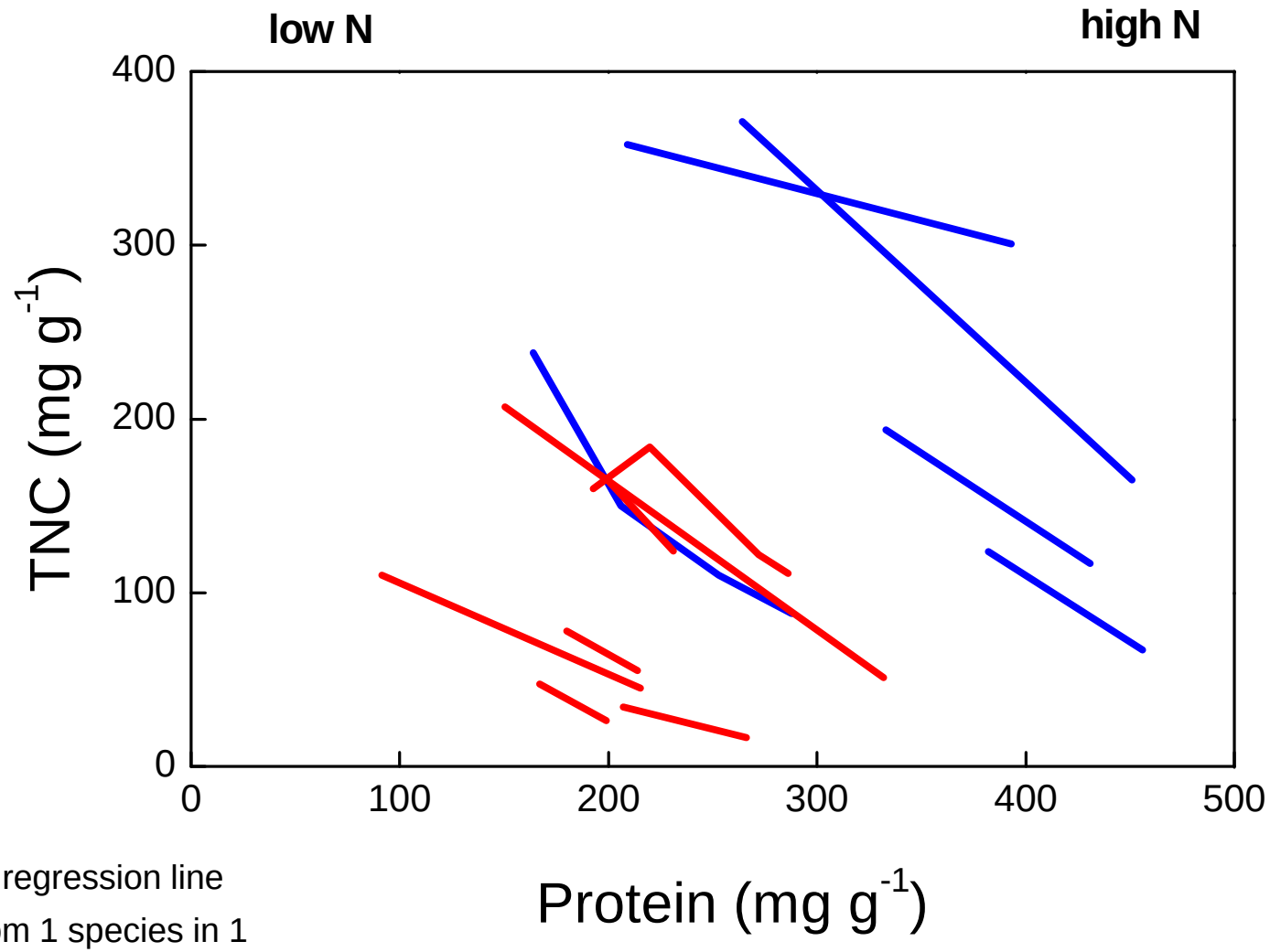
$$RGR = \frac{PS_A \,.\, FCI}{[C]} \,.\, SLA \,.\, LMF$$

$$GRC_X = \frac{\frac{dX}{X}}{\frac{dRGR}{RGR}}$$

	GRC
PS_A	0.45
FCI	0.41
[C]	-0.02
SLA	0.08
LMF	0.30

Provisional data

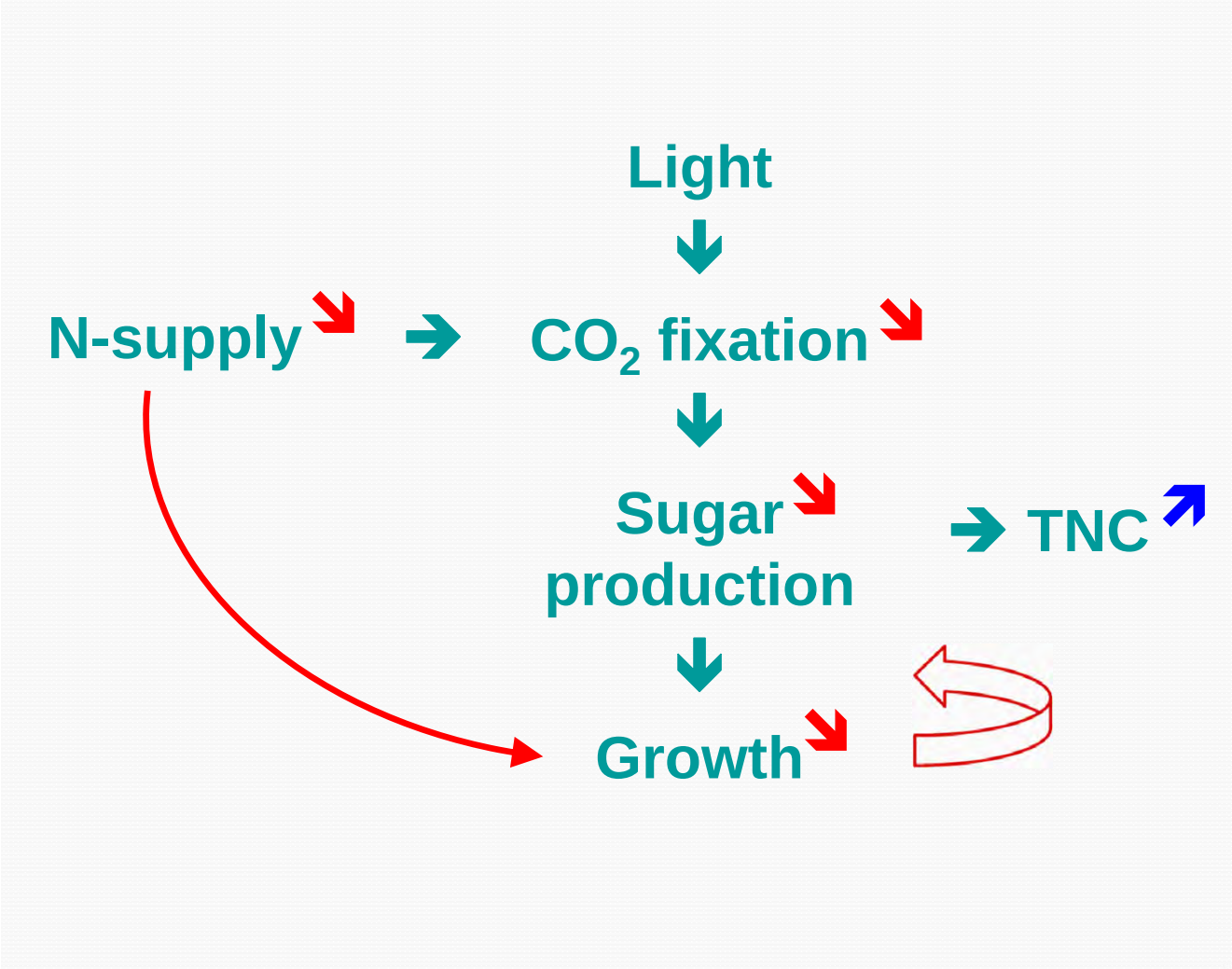
3c. But: in every experiment considered Total Nonstructural Carbohydrates rather than proteins accumulate in the leaves at low N. So, is there a limitation by photosynthesis?:



Each line is the regression line through data from 1 species in 1 experiment; red = woody species

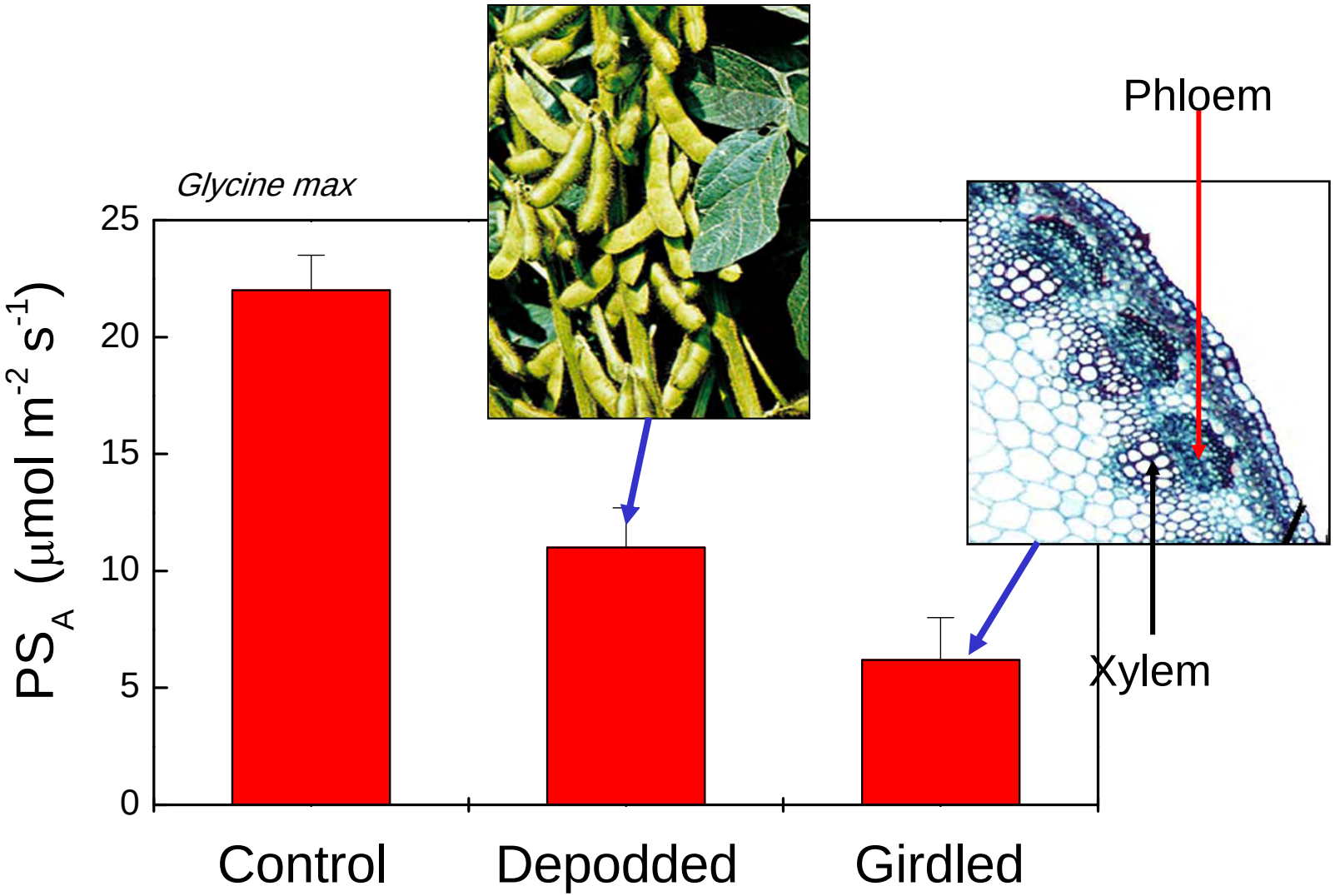
Poorter & Villar (1997) Book chapter

3d. Negative effect of low nutrients on photosynthesis, but more on growth ➔ TNC accumulation:



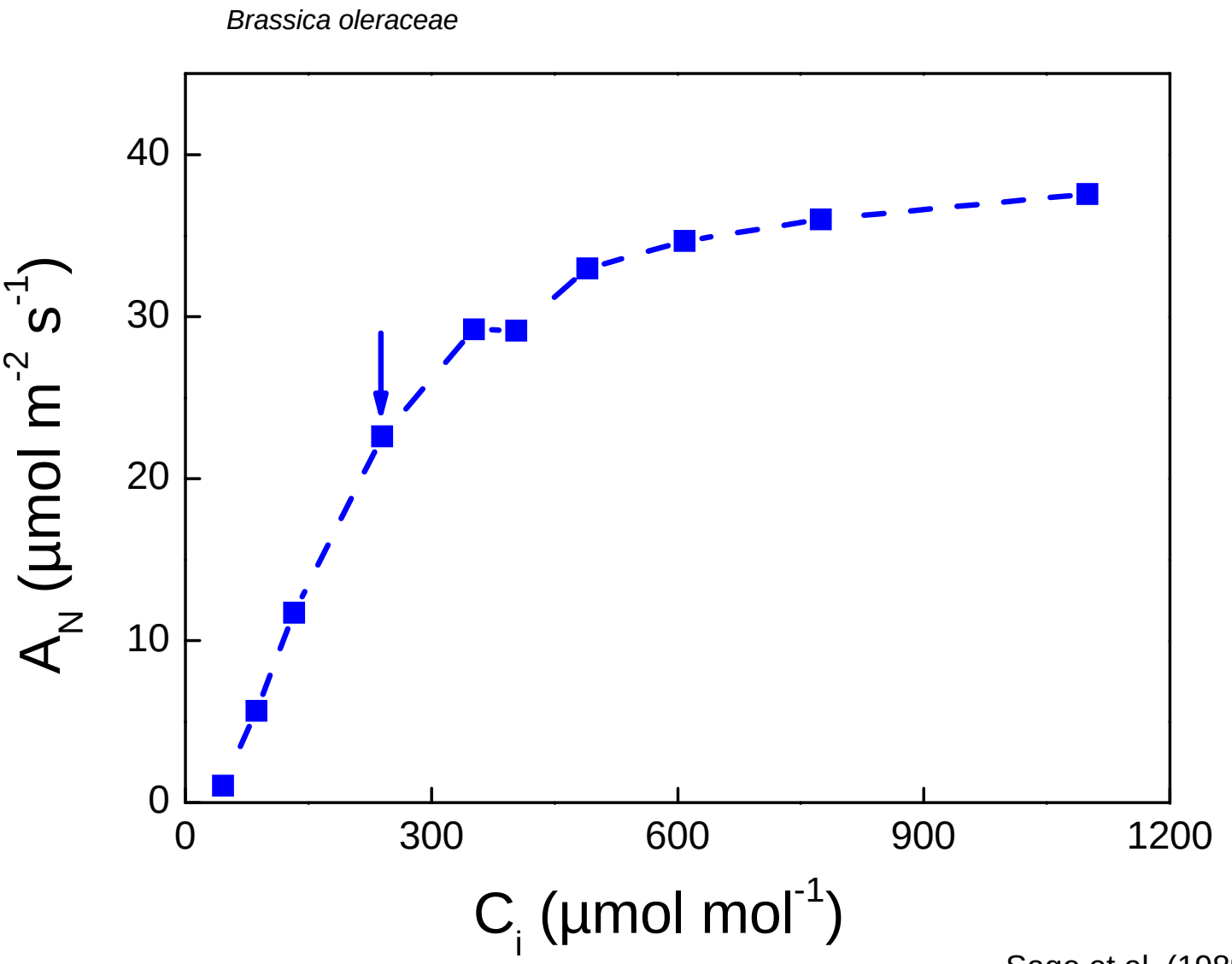
3e. How do we perceive a plant?

3f. Reduced demand from the sinks, or limited export out of the leaf has a negative feedback on photosynthesis:



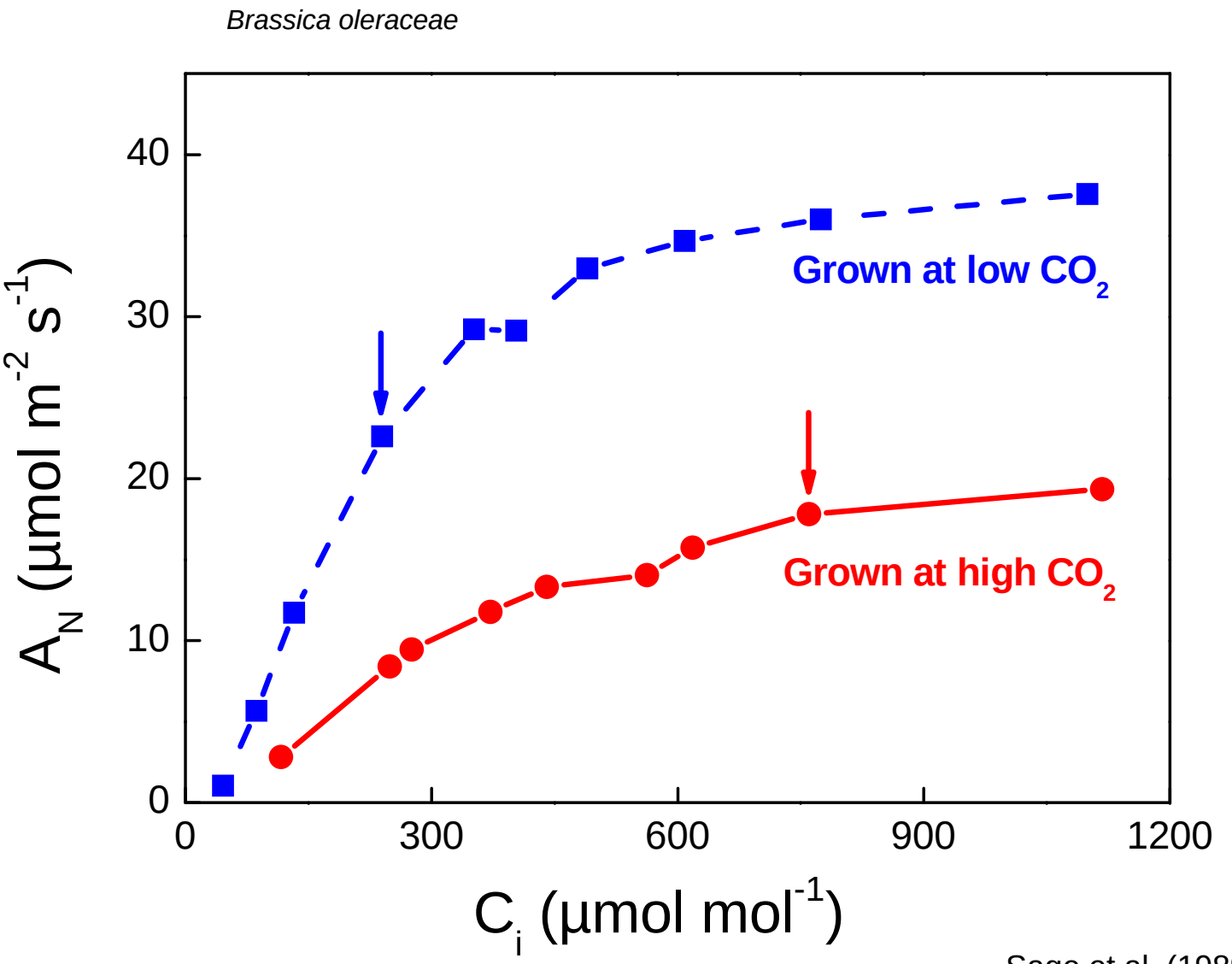
Setter et al. (1980) Plant Physiol.

4. A short-term response curve of photosynthesis with respect to CO_2:



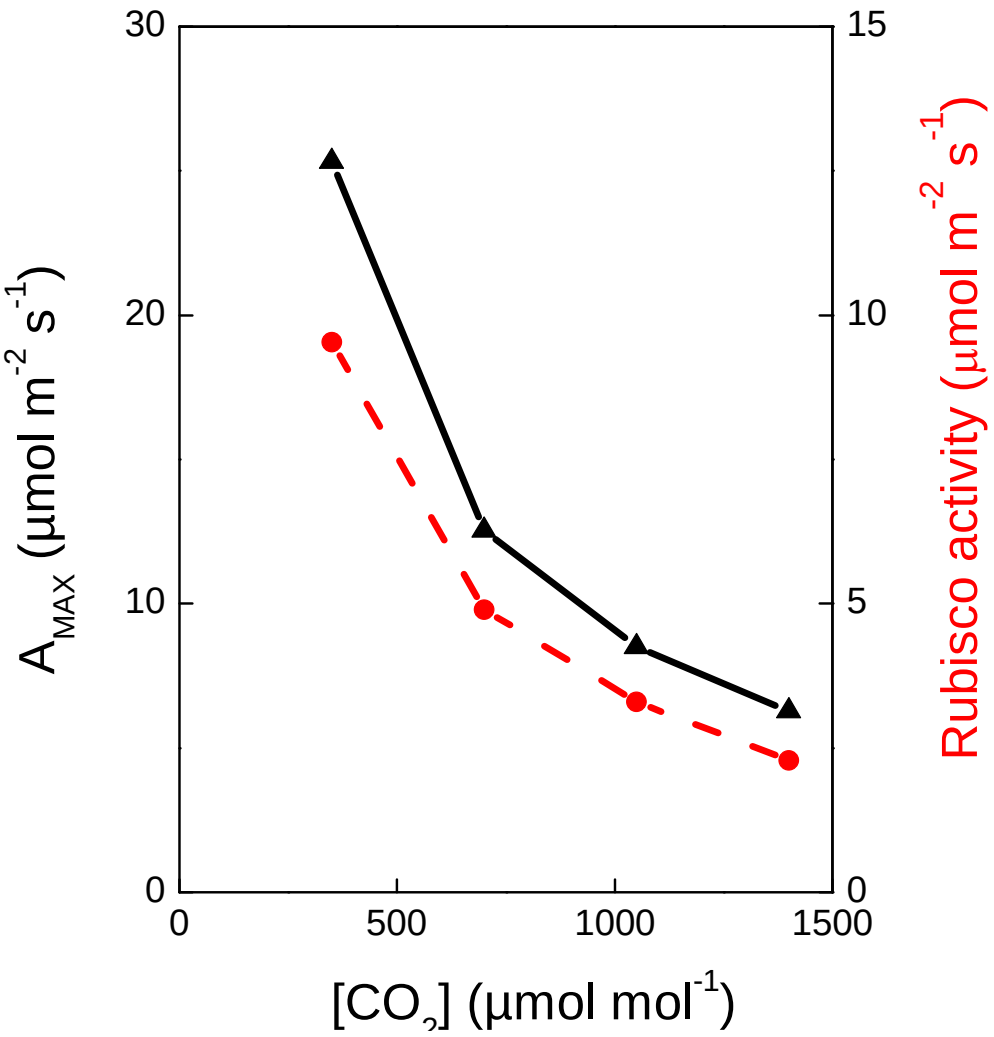
Sage et al. (1989) Plant Physiol.

4b. A-c_i curves of plants grown for longer time at low- and high CO_2



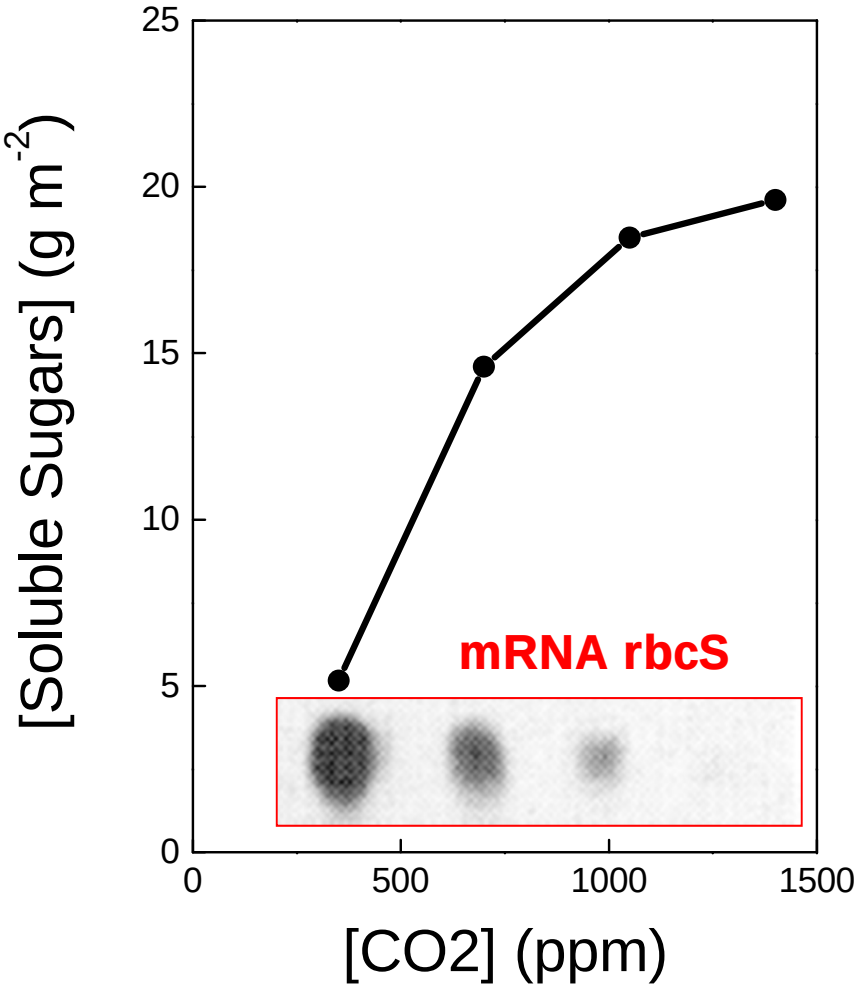
Sage et al. (1989) Plant Physiol.

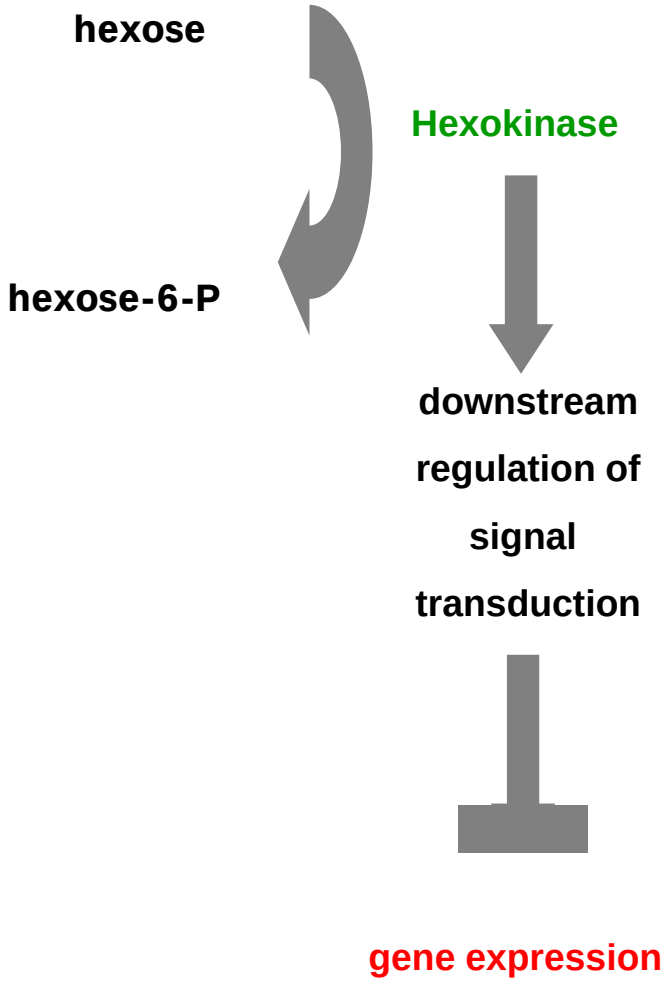
4c. Another example of strong feedback:
The higher the growth [CO_2], the lower Amax !?!



Van Oosten et al. (1995) New Phytol.

4d. Decreased transcription of rbcS genes, most likely because of high [soluble sugars]:

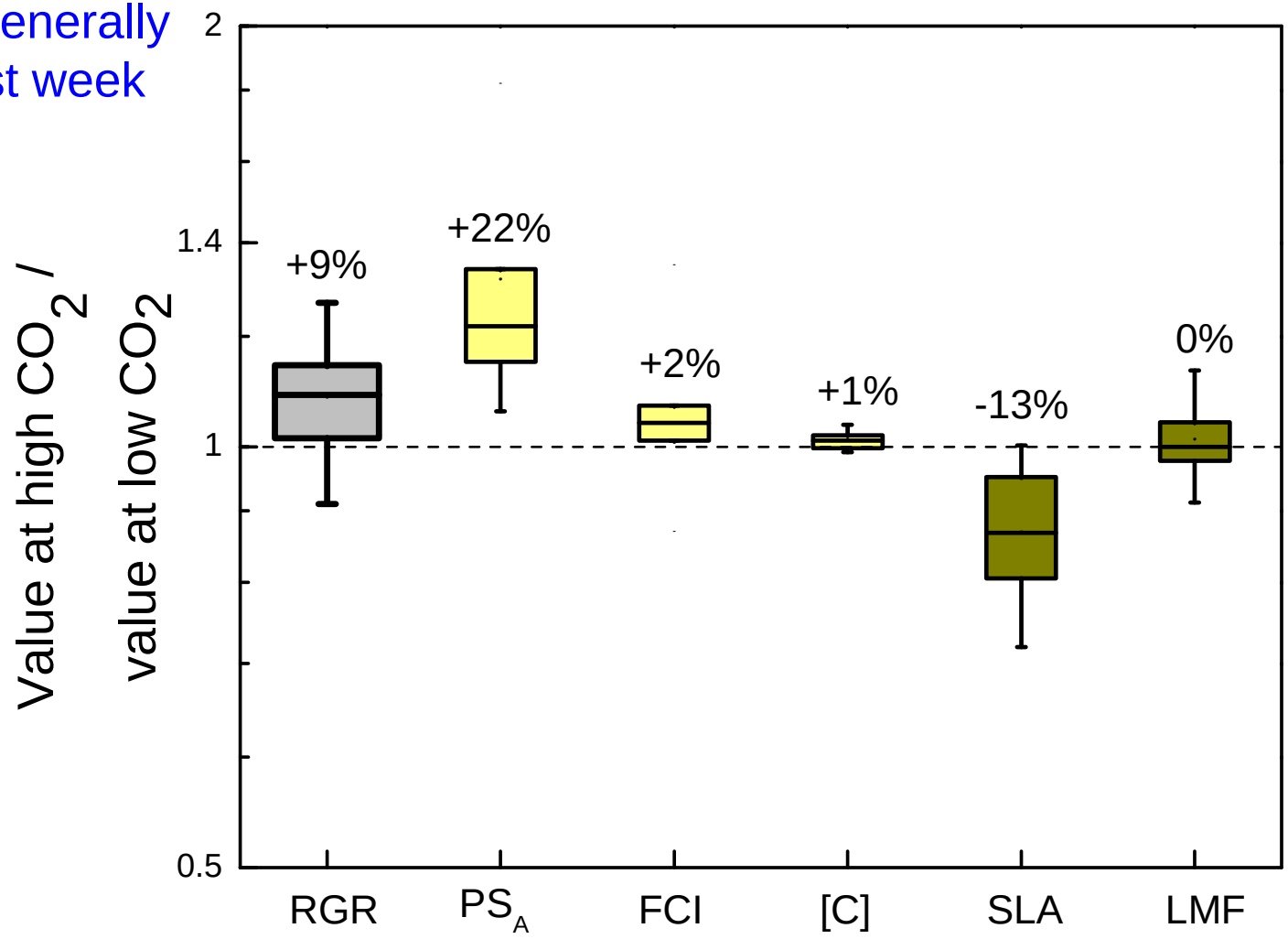




Van Oosten et al. (1995) New Phytol.

4e. Effect of elevated CO_2 on growth components, a meta-analysis: photosynthesis increase, SLA decrease, RGR generally stimulated the first week

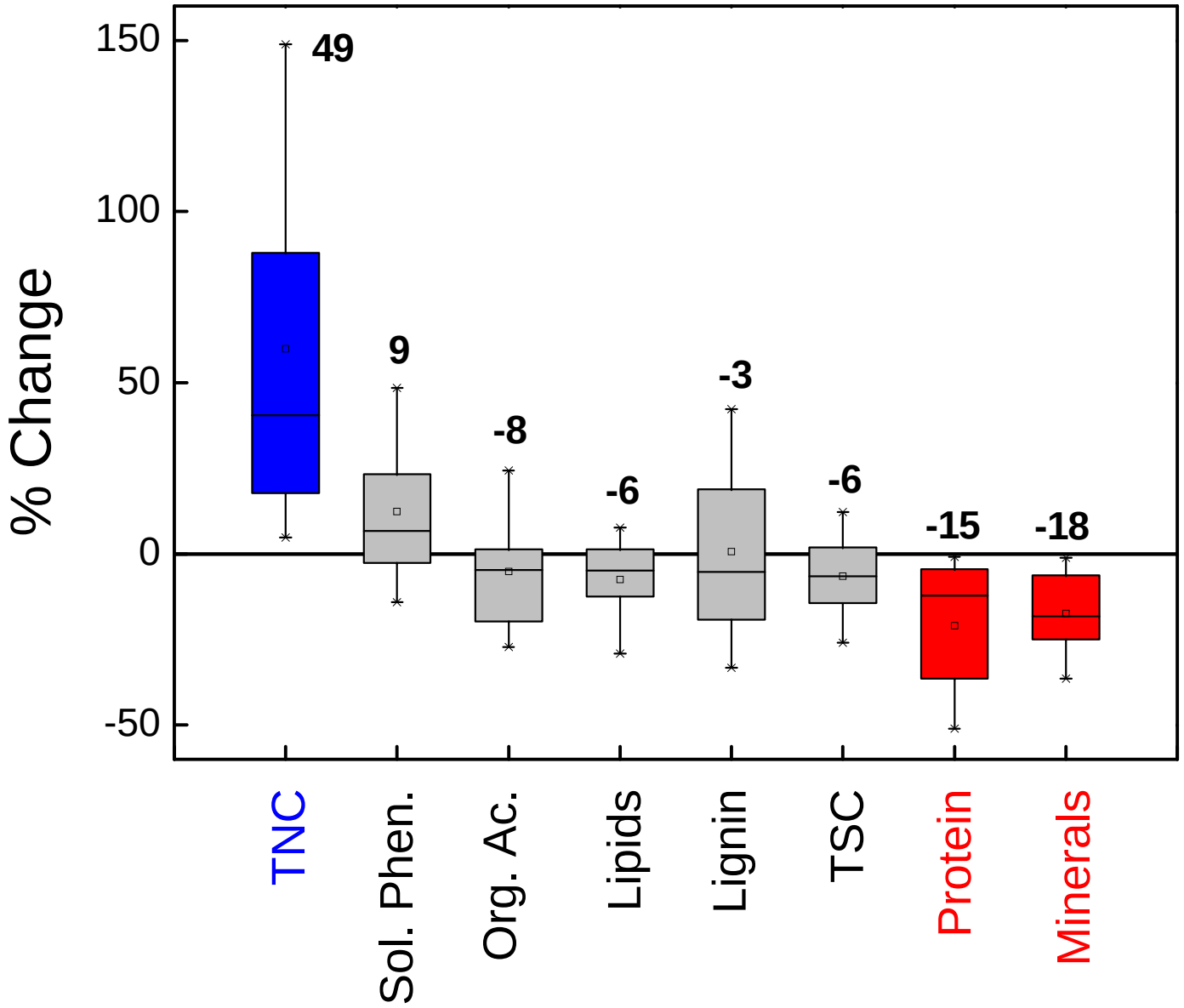
	GRC
PS_A	2.28
FCI	0.23
[C]	0.11
SLA	-1.63
LMF	0.00



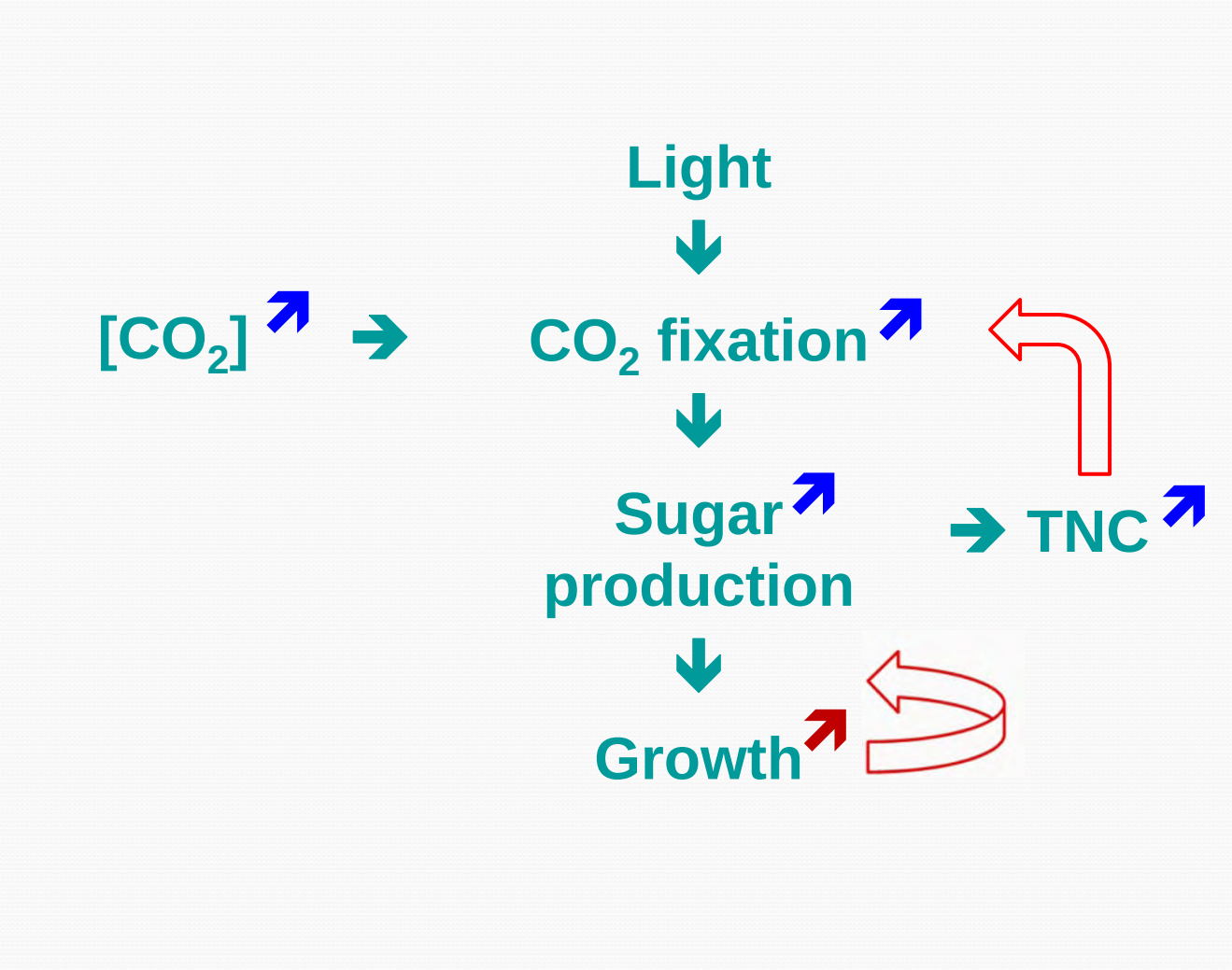
after Poorter & Navas (2003) New Phytol.

4f. High CO_2 affects chemical composition: lower [protein] and [minerals], much higher TNC

Poorter et al. (1997) PCE.



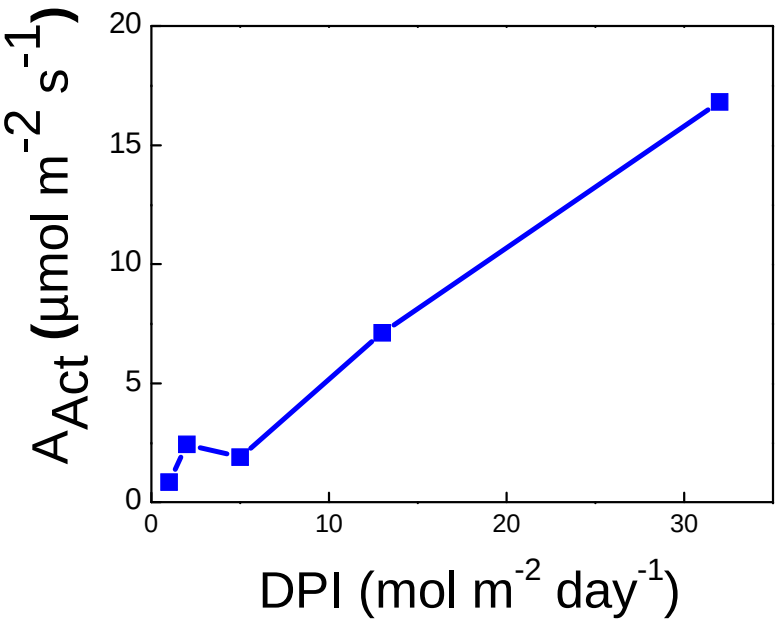
4g. Effect of elevated CO_2: photosynthesis increases more than growth ➔ TNC accumulation



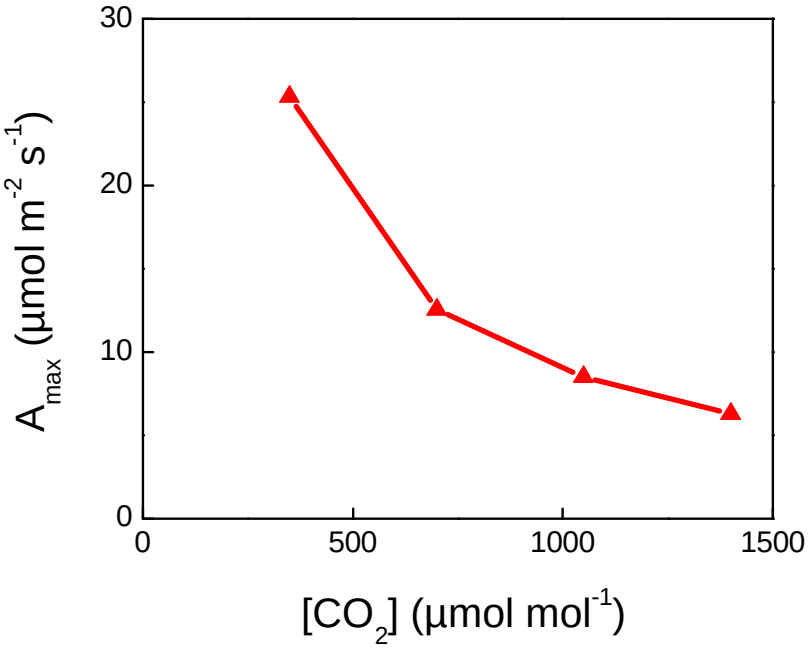
So, are all sugars equally valuable for a plant?

Plants have quite similar GRC's for light and CO_2 , but photosynthetic capacity response to high light is different from high CO2:

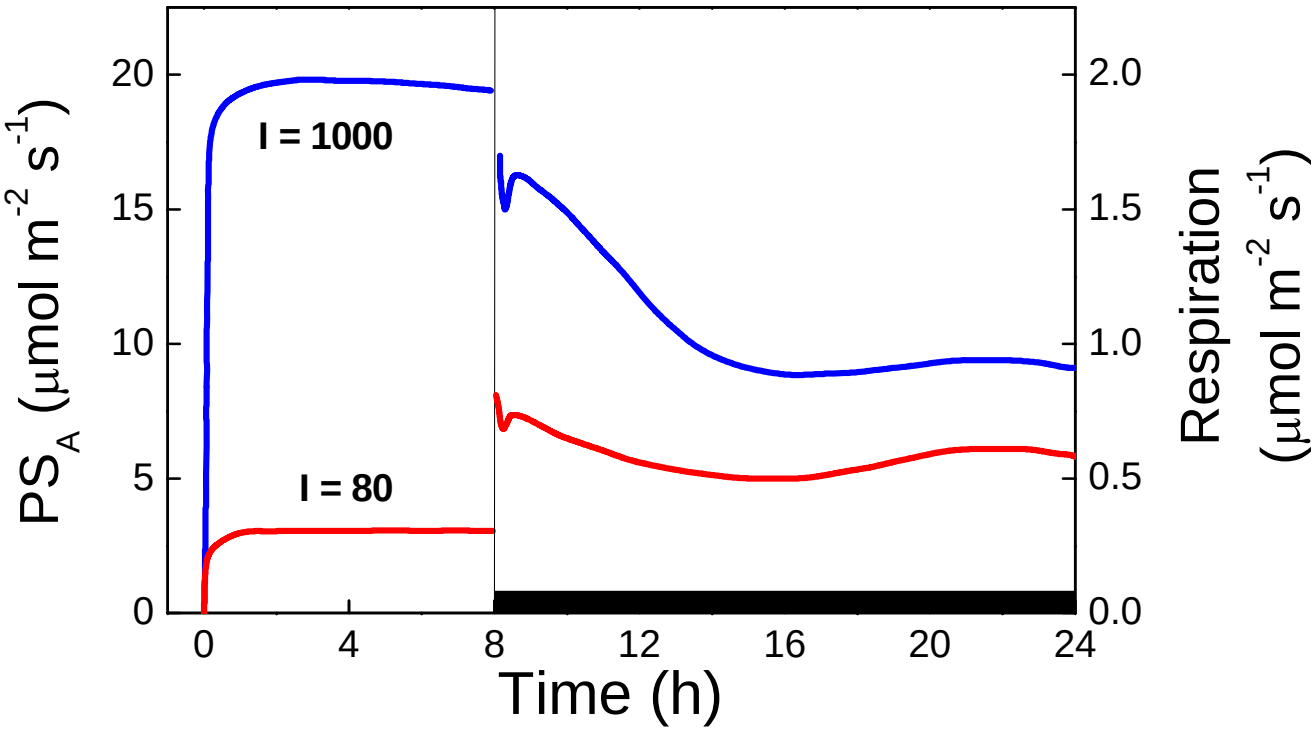
Light:



CO_2:

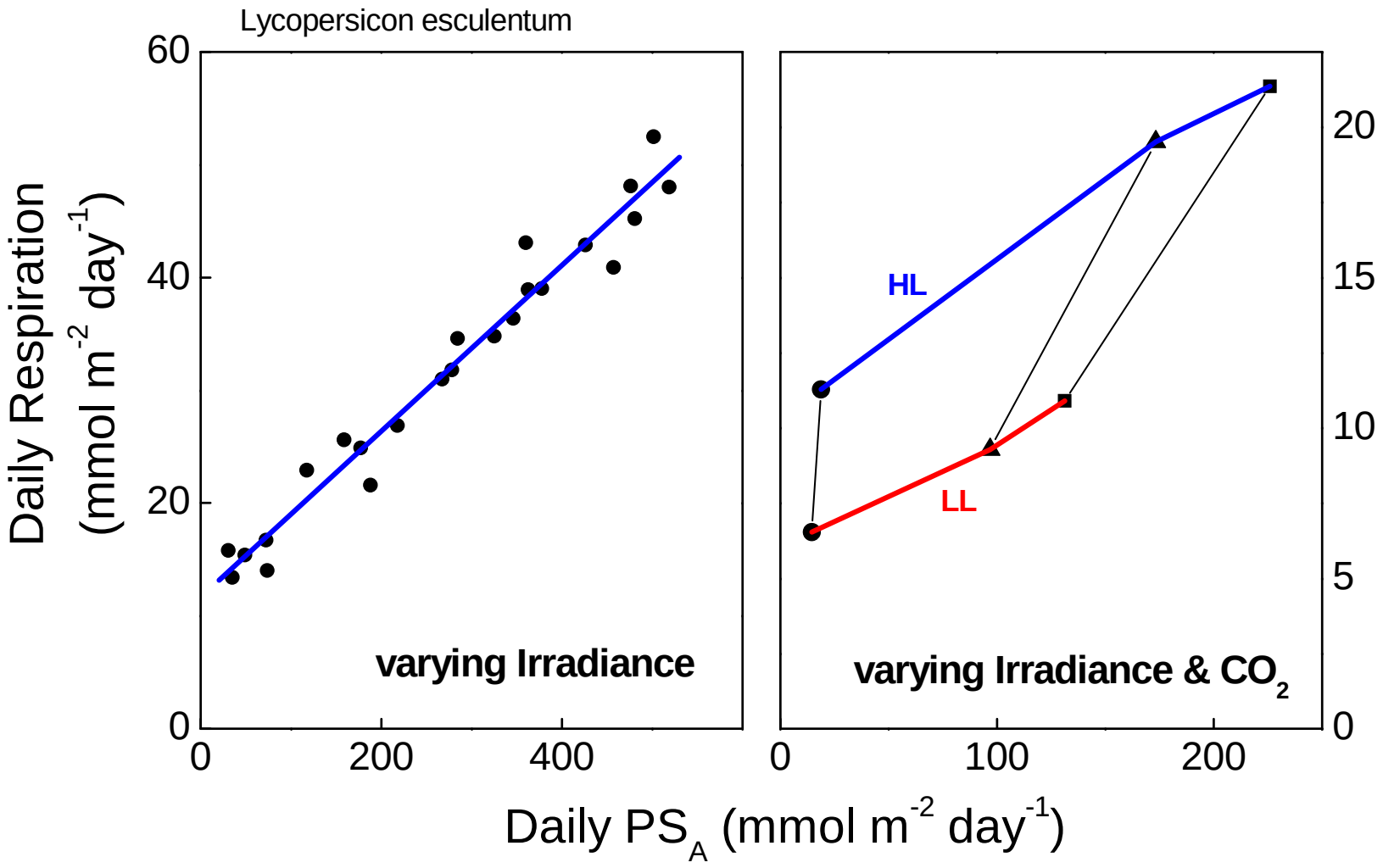


5b. Increasing light for 1 day for a tomato leaf increases respiration the night after:



Ludwig et al. (1975) Book chapter.

5c. LR_A is positively correlated with PS_A, but….



Ludwig et al. (1975) Book chapter.

5d. Meta-Phenomics:

Meta-Phenomics: summarising, by means of a meta-analysis of a wide array of literature data, the phenome of a plant,

Aim: constructing dose-response curves for 12 environmental variables, 40 traits, 20 species ‘groups’

So far: >8000 records (each record consists of all observations of 1 species in 1 experiment grown under 1 condition), for > 800 species in a total of >800 experiments.

More info: www.metaphenomics.org, and J. Exp. Bot. 61: 2043-2055

5e. Meta-Phenomics:

The environmental factors, traits, and characteristics of the species involved:

Stress box

1. Light quantity
2. Light quality
3. UV-B
4. CO_2
5. O_3
6. Nutrient supply
7. Drought stress
8. Waterlogging
9. Submergence
10. Temperature
11. Salinity
12. Soil compaction

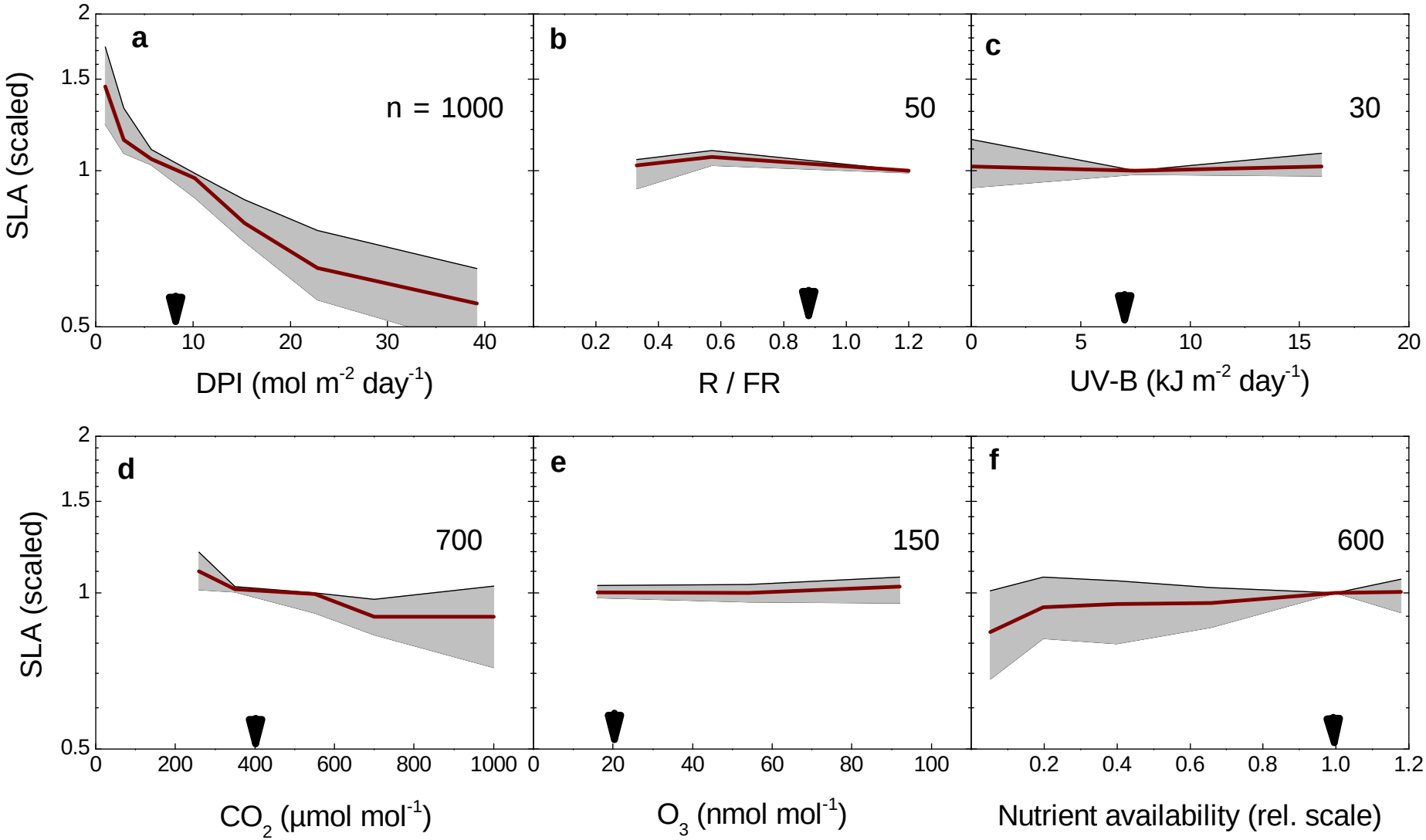
Trait box

- RGR, ULR, SLA, LMF, SMF, RMF
- TPM, Yield, HI
- A_{Act}, A_{Max}, Respiration, J/V_{MAX}
- Transpiration, g_s, c_i/c_a, $\delta^{13}C$
- height, leaf size
- leaf thickness, density, DMC
- [C], [N], [P]
- Starch, Fructan, Sol. Sugars
- Minerals, Ash, Nitrate, Org. Acids
- Lignin, (Hemi-)Cellulose
- Protein, Org. N, Chlorophyll
- Sol. Phenolics, Tannin, Anthocya.
- Rubisco, other enzymes
- mRNA

Species box

- woody / herbaceous
- deciduous / evergreen
- shrub / tree
- annual / perennial
- N_2 fixing yes / no
- C_3 / C_4 / CAM
- Phylogeny
- Sun / Shade
- Dry / Wet
- Cold / Warm
- Non-saline / Saline

5f. An example: SLA responses to light, gases, and nutrients, including normal ranges



Poorter et al. (2010) J. Exp. Bot.

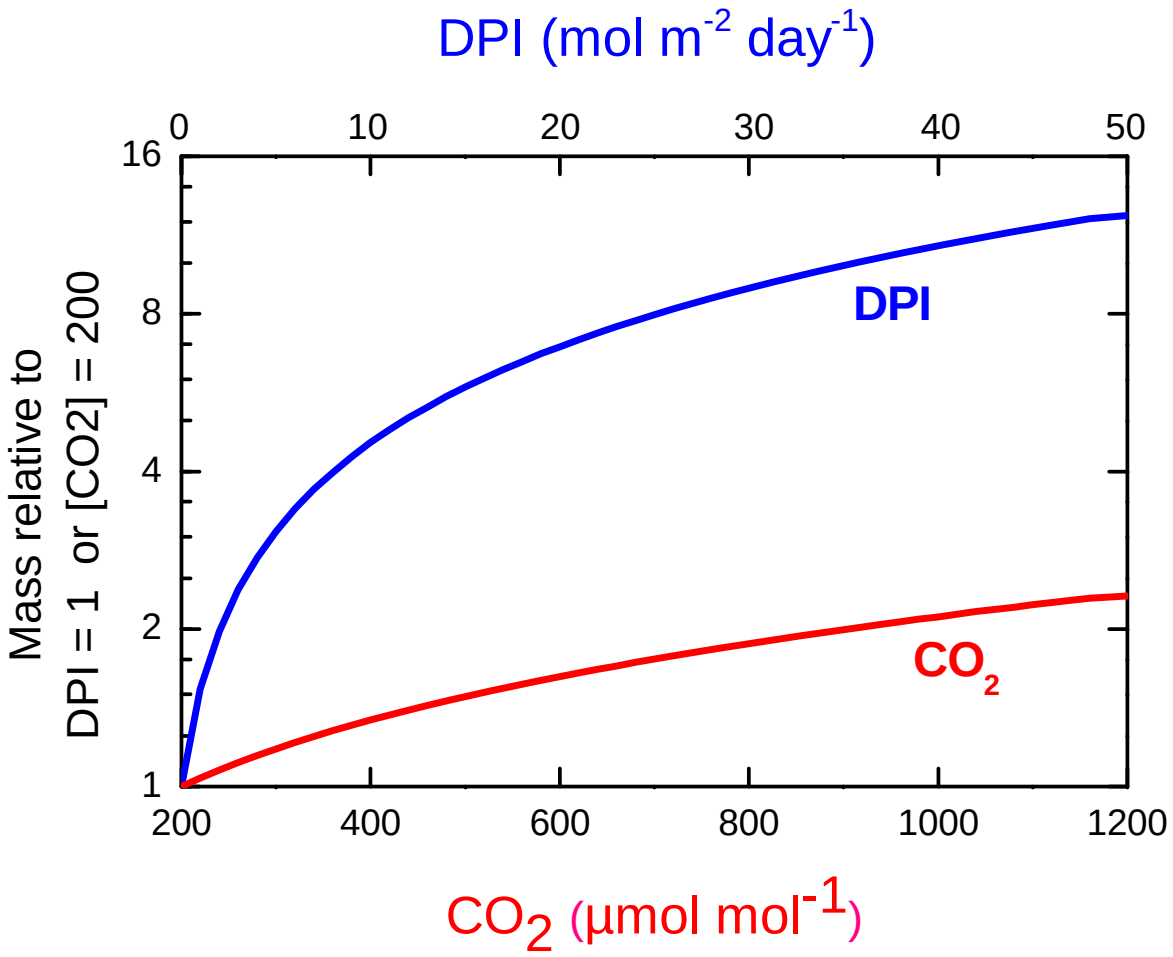
5g. Plasticity in SLA and LMF, based on fitted curves:

	Range		PI SLA
Irradiance	1 – 50	mol m^{-2} day^{-1}	**3.03**
CO_2	200 – 1200	µmol mol^{-1}	1.40
Compaction	1.0 – 1.6	g cm^{-3}	1.18
Salinity	0 – 100	% seawater	1.16
Waterlogging	- – +		1.14

R : FR	0.2 – 1.2	mol mol^{-1}	1.00
UV-B	1 – 20	kJ m^{-2} day^{-1}	1.00
O_3	5 – 100	nmol mol^{-1}	1.00

Water	0.05 – 1	rel. units	1.27
Nutrients	0.05 – 1	rel. units	1.29
Submergence	- – +		**1.80**
Temperature	5 – 35	^oC	**2.07**

5h. Is growth equally sensitive to ìncreased photosythesis due to light and CO_2 ?

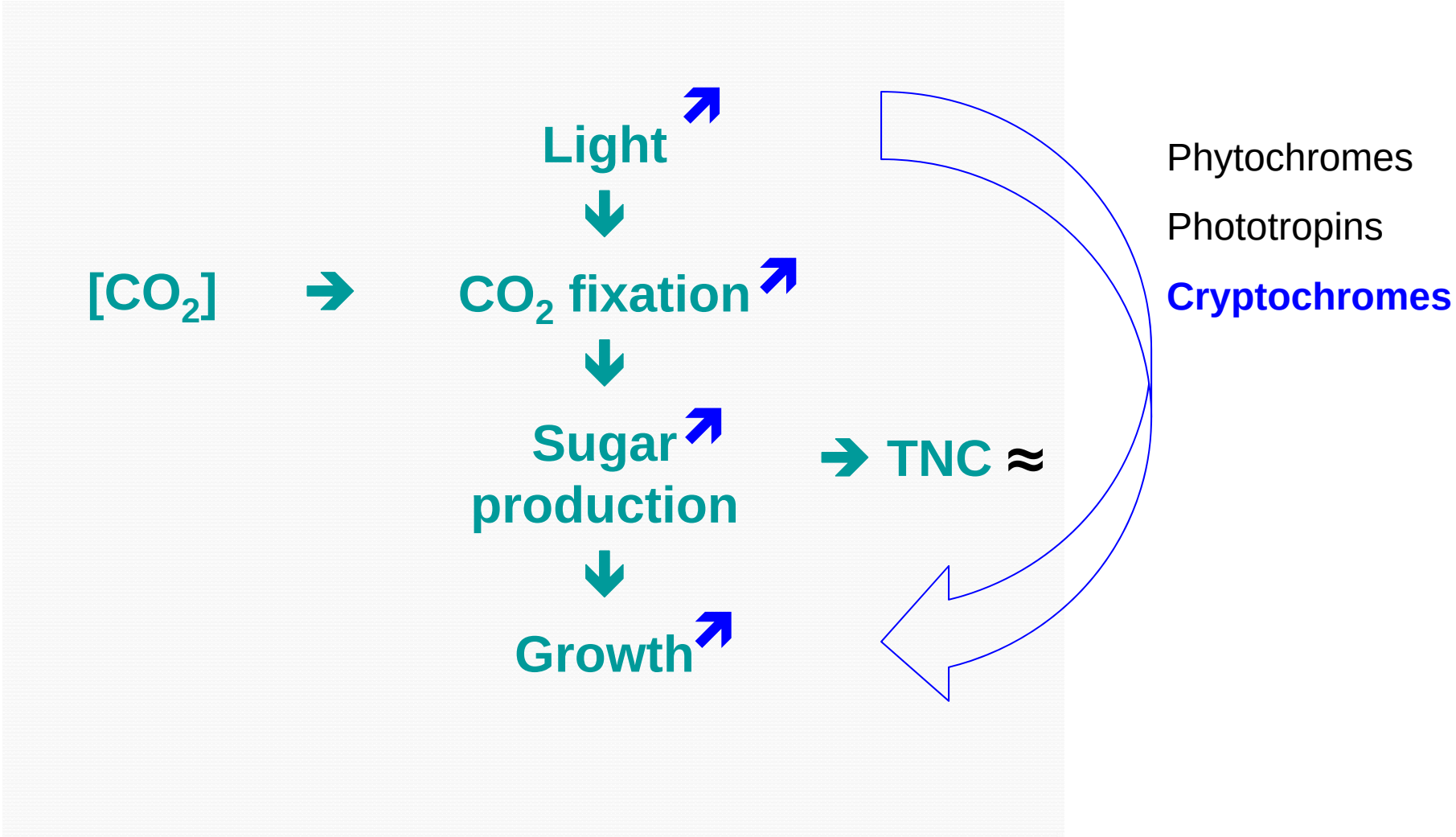


DPI: 8 ➔ 16
+57%

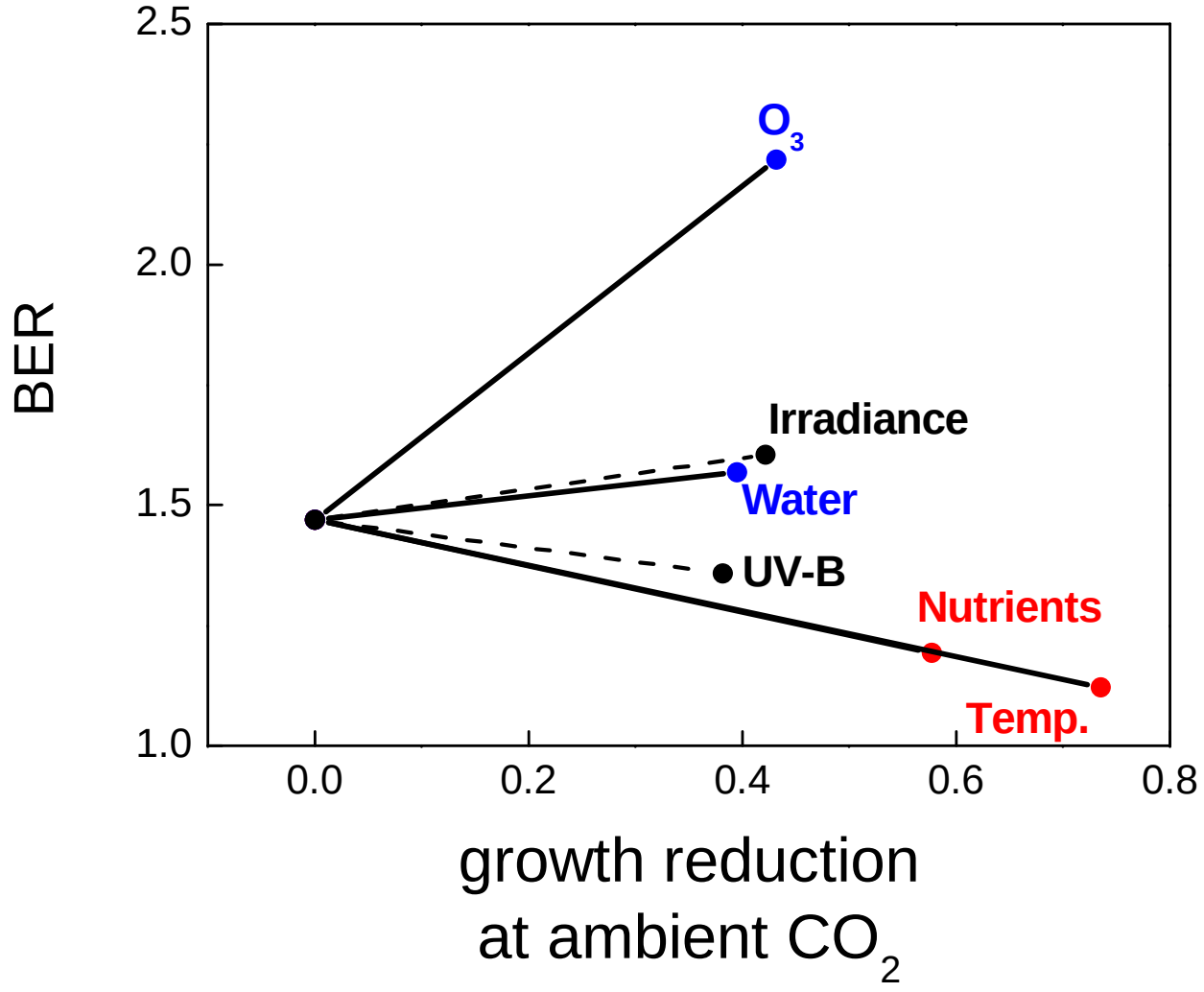
CO_2: 360 ➔ 720
+39%

Poorter, provisional data

5i. Why might the effect of elevated CO_2 be different from high light?



Smallest growth reduction when TNC is accumulating?



Poorter & Perez-Soba (2002) EGEC.

Conclusions:

1. No growth without C-fixation
2. But PS_A is not the only driver (SLA!)
3. Most likely growth needs C
   and some (light) signal
4. Strongest interaction of high CO_2
   with low T and low nutrients.

More info:

Meta-Phenomics:

- www.metaphenomics.org

- Poorter H, Niinemets U, Walter A, Fiorani F, Schurr U (2010) A method to construct dose-response curves for a wide range of environmental factors and plant traits by means of a meta-analysis of phenotypic data. *J. Exp. Bot*. **61**: 2043-2055.

Methods GRC:

- Renton M, Poorter H (2011). Using log-log scaling slope analysis for determining the contributions to variability in biological variables such as leaf mass per area (LMA): why it works, when it works and how it can be extended. *New Phytol.* **190**: 5-8.

Growth analysis:

- Poorter H & Van der Werf A (1998). Is inherent variation in RGR determined by LAR at low irradiance and by NAR at high irradiance? A review of herbaceous species. In: Inherent Variation in Plant Growth. Physiological Mechanisms and Ecological Consequences. Lambers H, Poorter H & Van Vuuren MMI (eds). Backhuys Publishers, Leiden, The Netherlands, pp. 309-336.