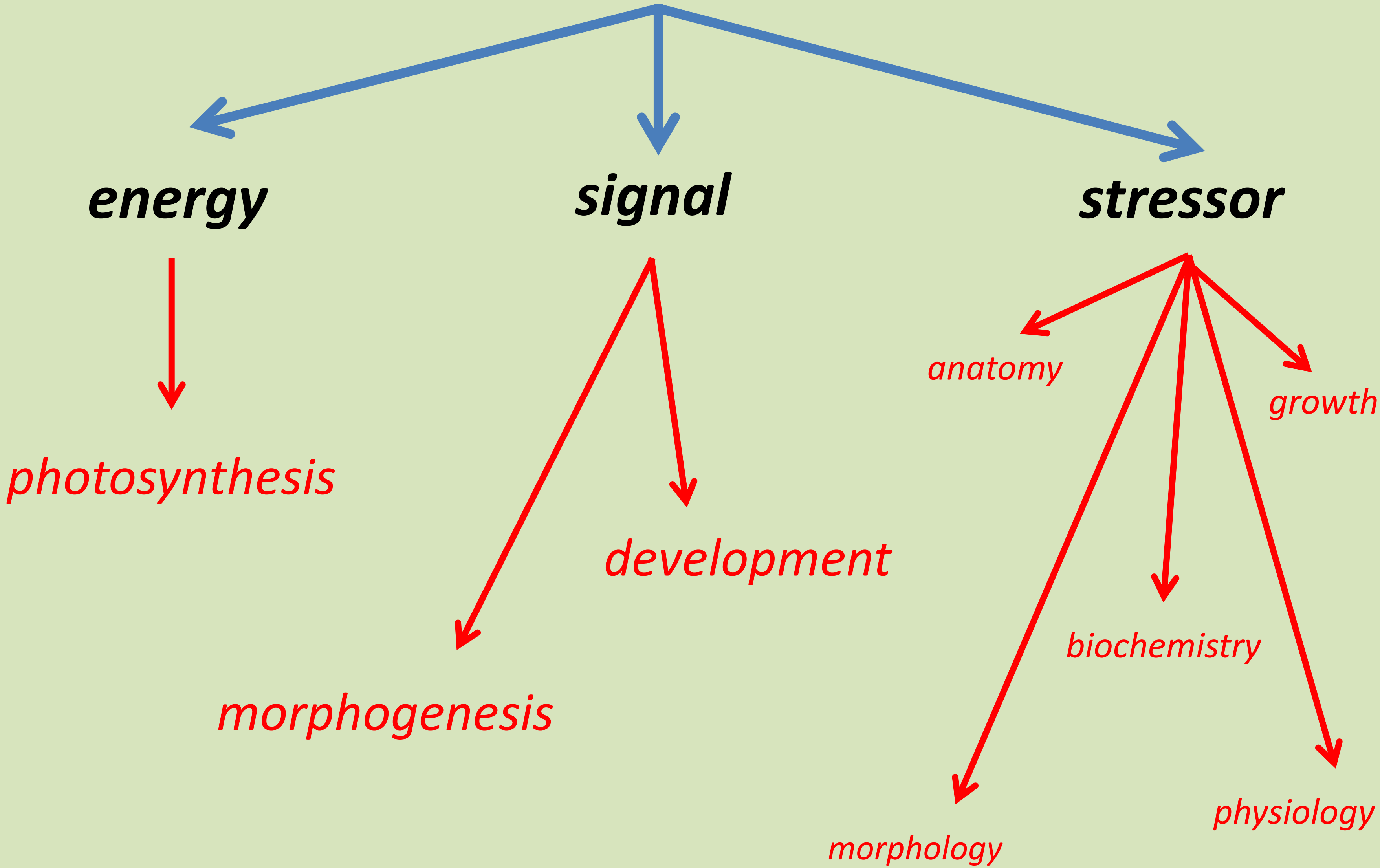
Plant responses to light

Efi Levizou
Assistant Professor in Plant Physiology
Dept of Agriculture Crop Production and Rural Environment
University of Thessaly

Light as environmental factor



light regulates numerous aspects of plant form and function throughout the life cycle

Plants respond to several different facets of their radiation environment

In order to respond, they have to sense

↓

Plants have developed a complex and sophisticated photosensory machinery that enables them to determine the

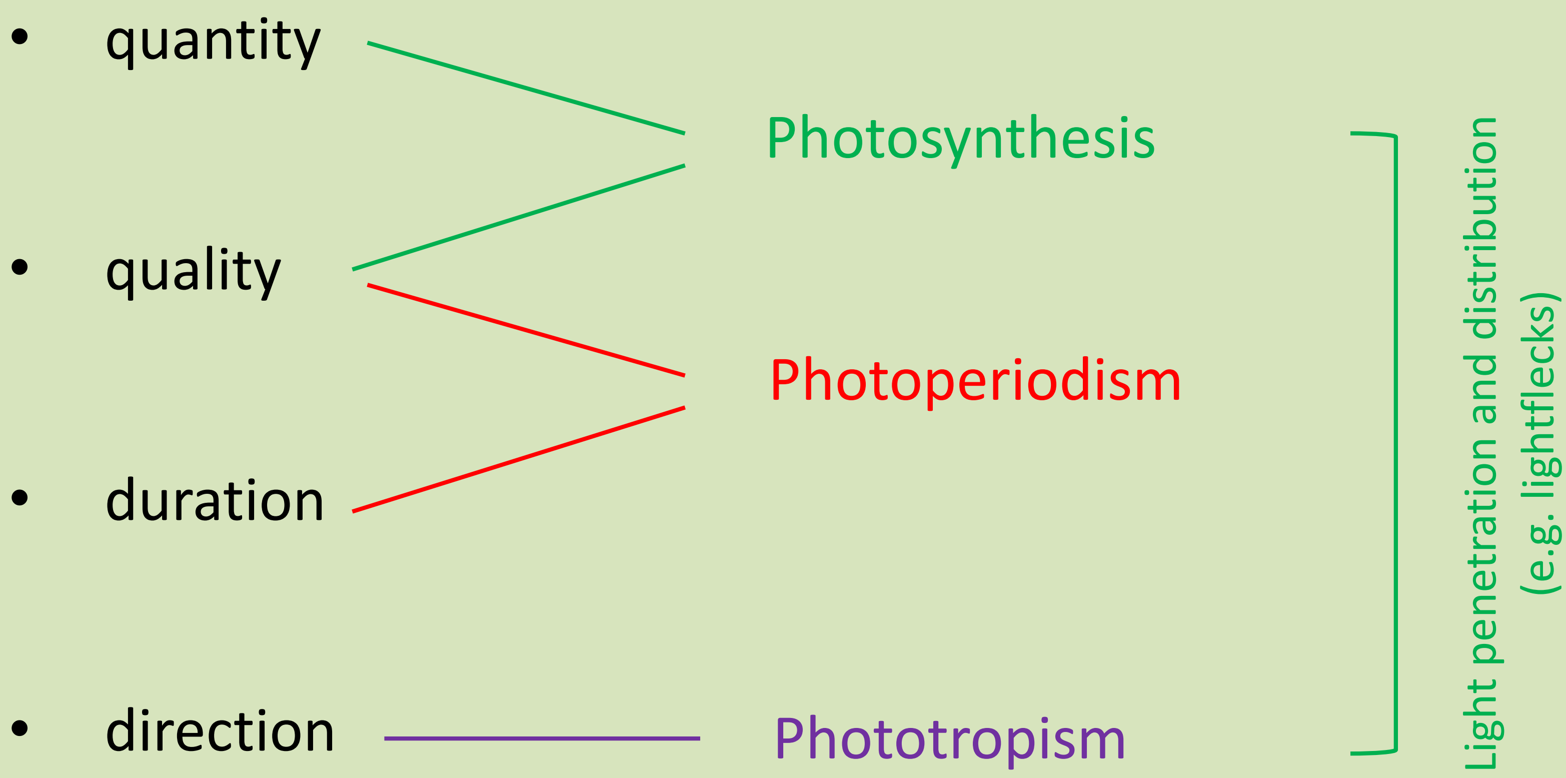
Daily and seasonal fluctuations

- quantity
- quality
- duration
- direction

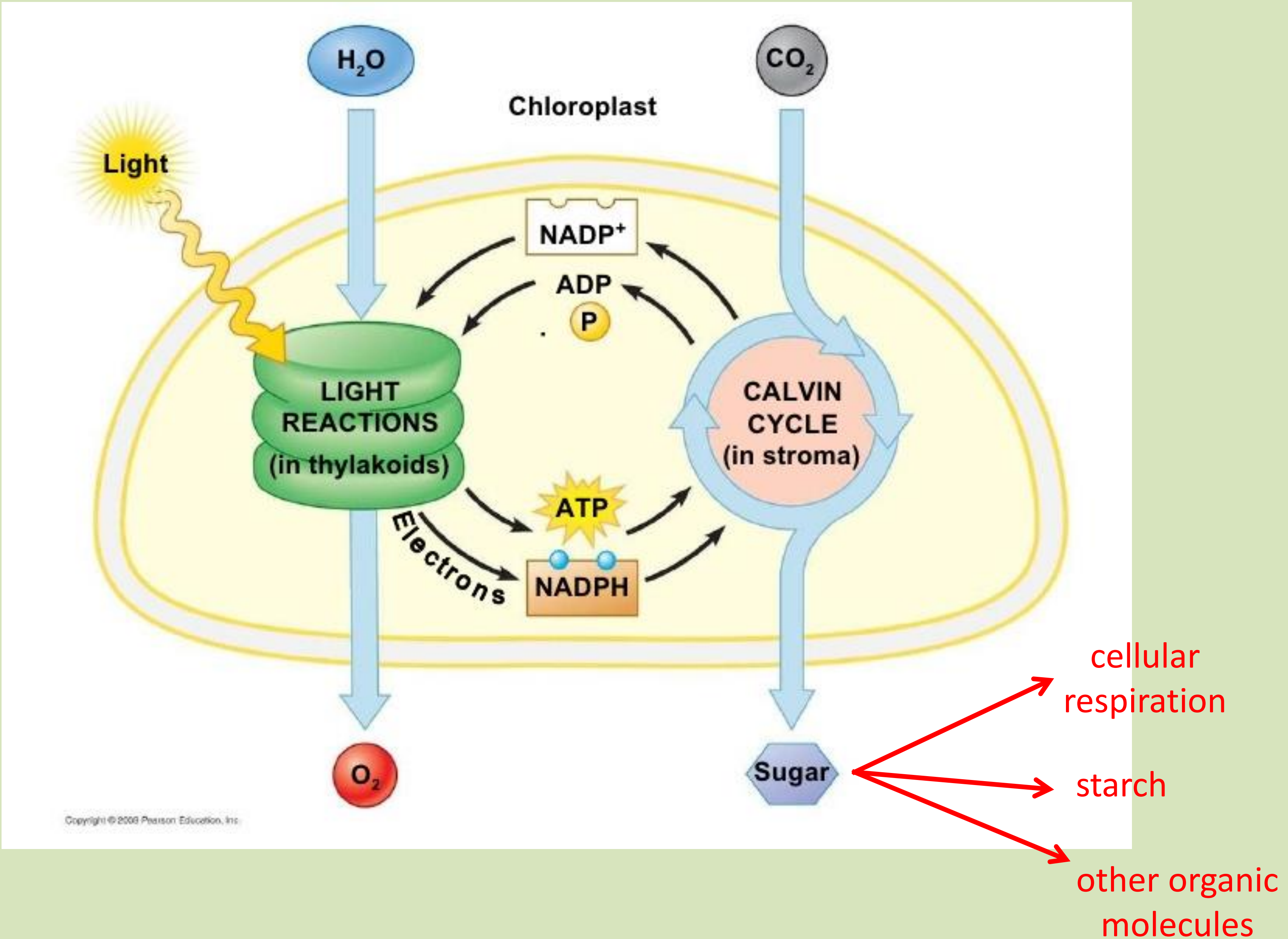
of light

To detect and respond to light, plants employ a suite of photoreceptors coupled to a network of signaling components and transcriptional effectors

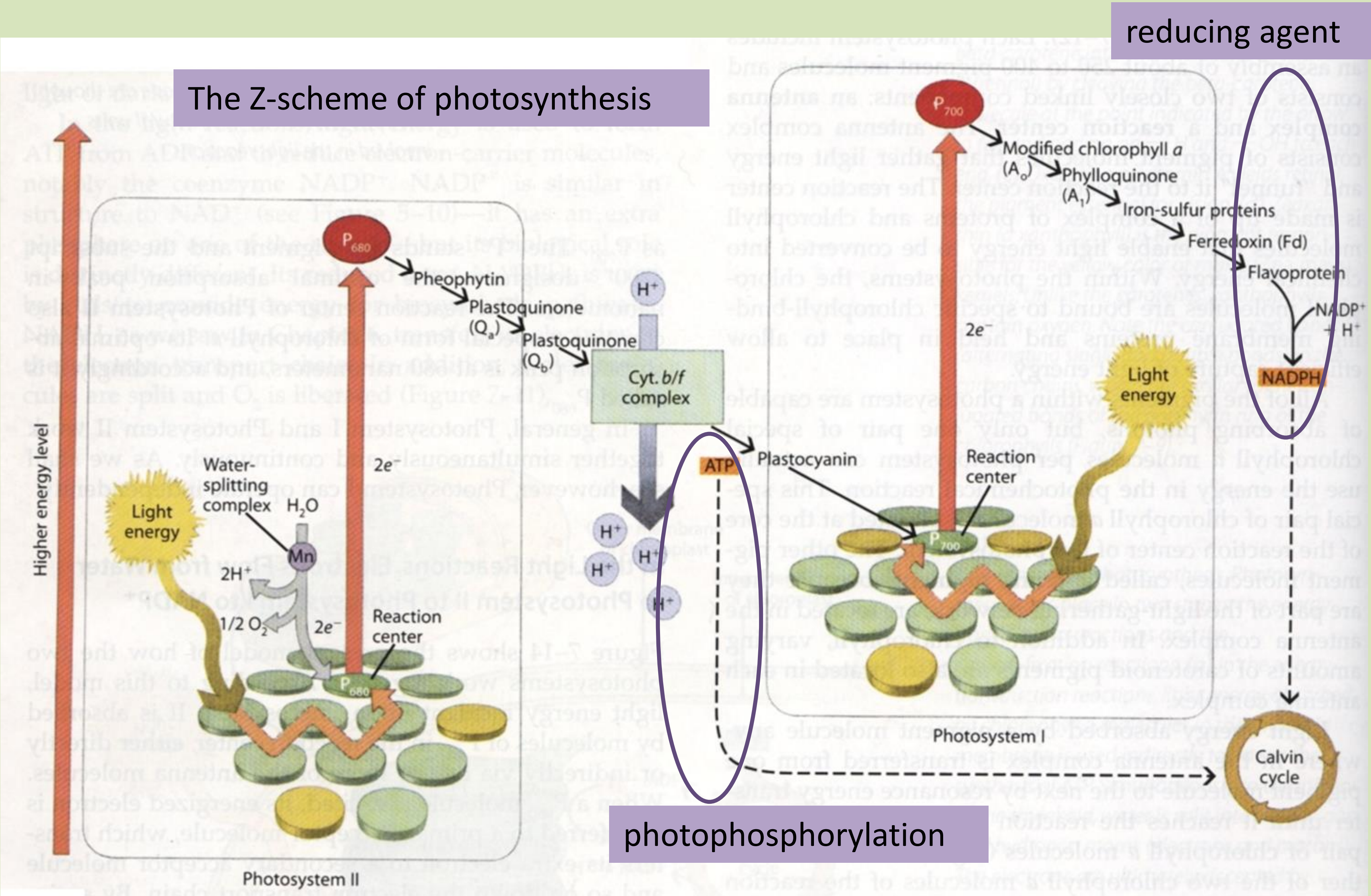
The ability of an organism to detect and measure day or night duration and respond to their relative length



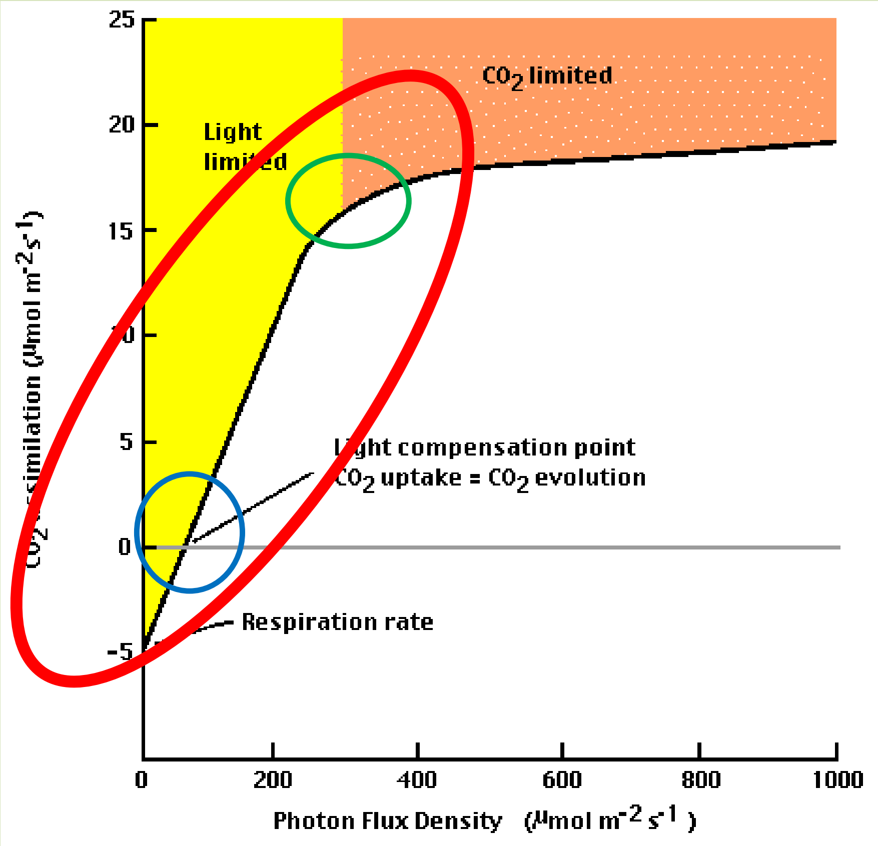
Light as energy input



Light as energy input



Photosynthesis responses to light quantity (intensity)



Saturation point: photosynthetic rate is limited by Calvin cycle biochemical reactions

Evolutionary compromise

The x-intercept: the intensity at which photosynthetic use is balancing the release of CO_2 by respiration

This specific profile indicates that

a) a small fraction of the high light energy is really used by the leaf and
b) on the contrary photosynthetic machinery is extremely efficient in utilizing low light

Plant responses to light fluctuations

During the evolution plants have developed an entire network of adaptation mechanisms to cope with fluctuations in the light environment.

These can be divided into two major groups:

A—adaptations to control light absorption capacity and

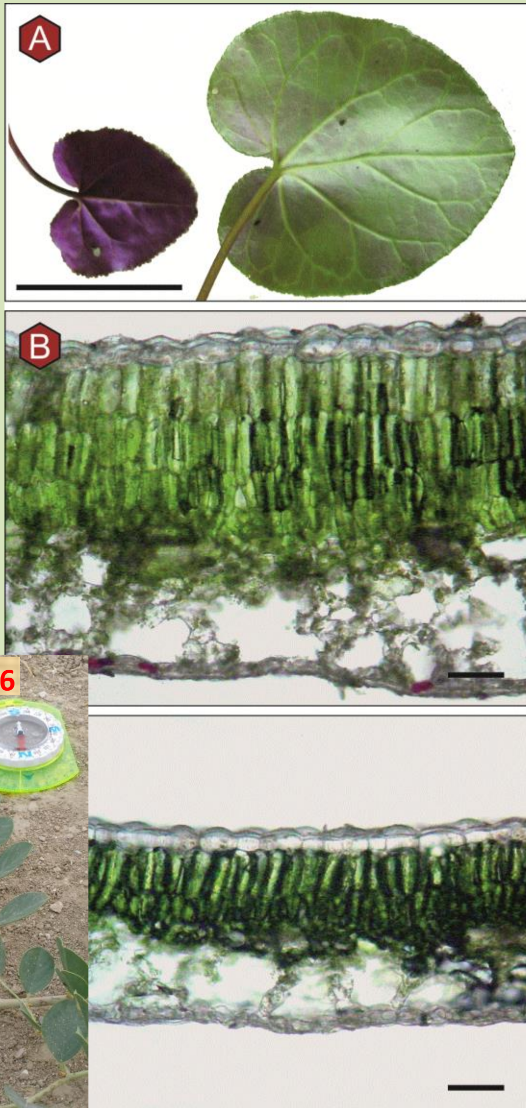
B—adaptations to deal with the light energy, which has been captured

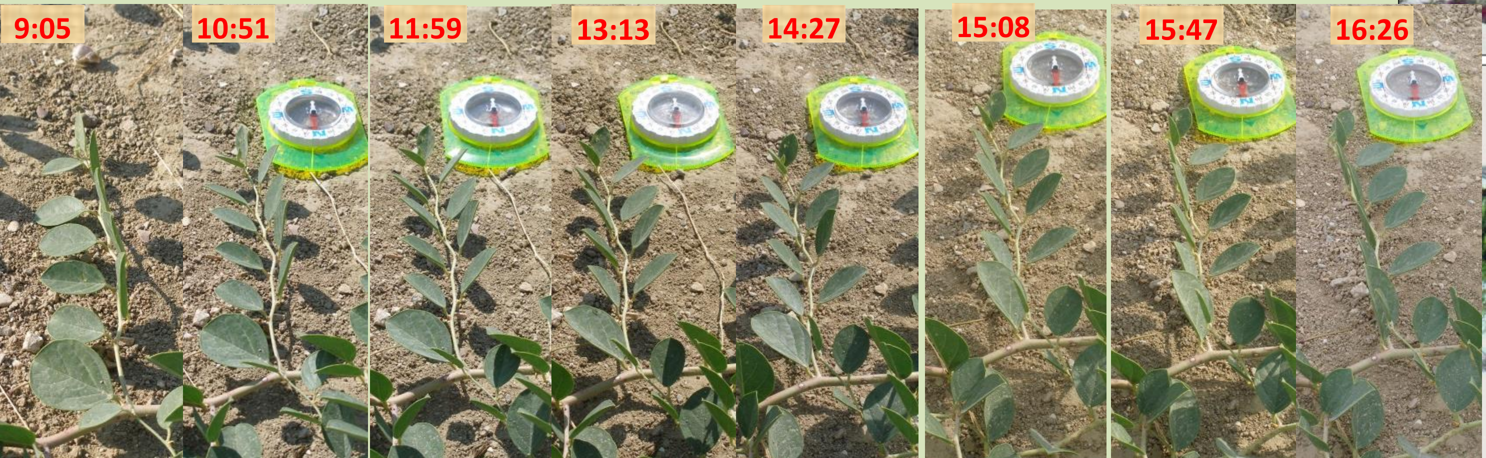
Plant responses to light fluctuations

adaptations to control light absorption capacity

Plants adapt to light in a number of different ways and on different levels of organization: **whole plant**, cellular and molecular

- Leaf movement
- Leaf anatomical adjustments



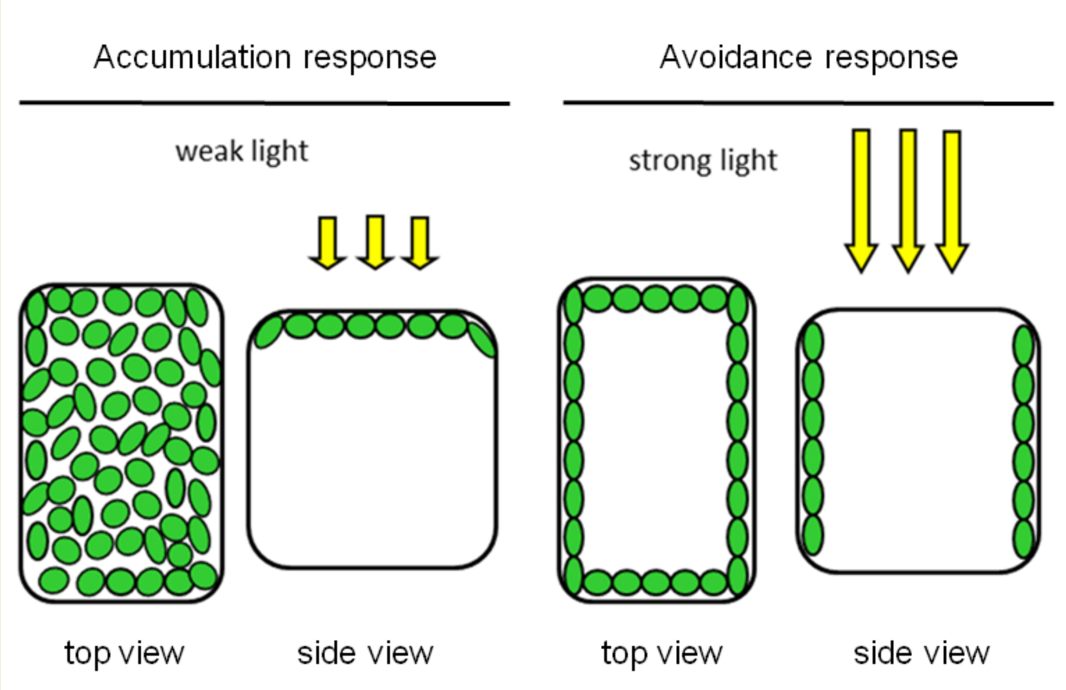


Plant responses to light fluctuations

adaptations to control light absorption capacity

Plants adapt to light in a number of different ways and on different levels of organization: whole plant, **cellular** and molecular

- Chloroplast movement

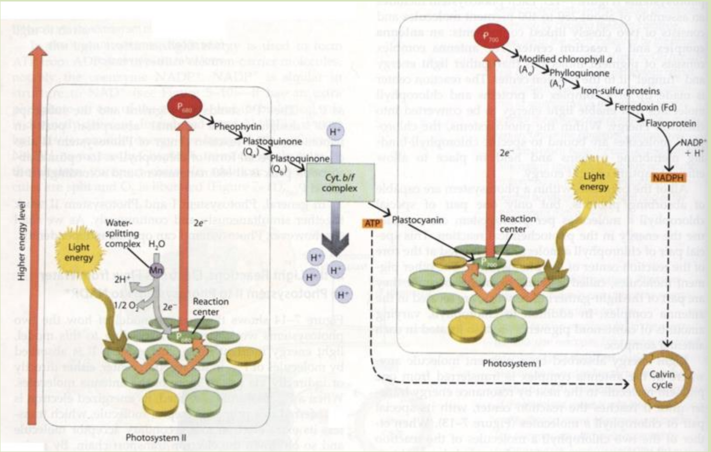


Plant responses to light fluctuations

adaptations to control light absorption capacity

Plants adapt to light in a number of different ways and on different levels of organization: whole plant, cellular and **molecular**

- control of chlorophyll content
- Modulation of PSII/PSI: ↑ in the shade
- dynamic changes in PSI and PSII light harvesting antenna size and efficiency



in plants grown under high light intensity the antenna is always smaller than in those grown in shade

↓

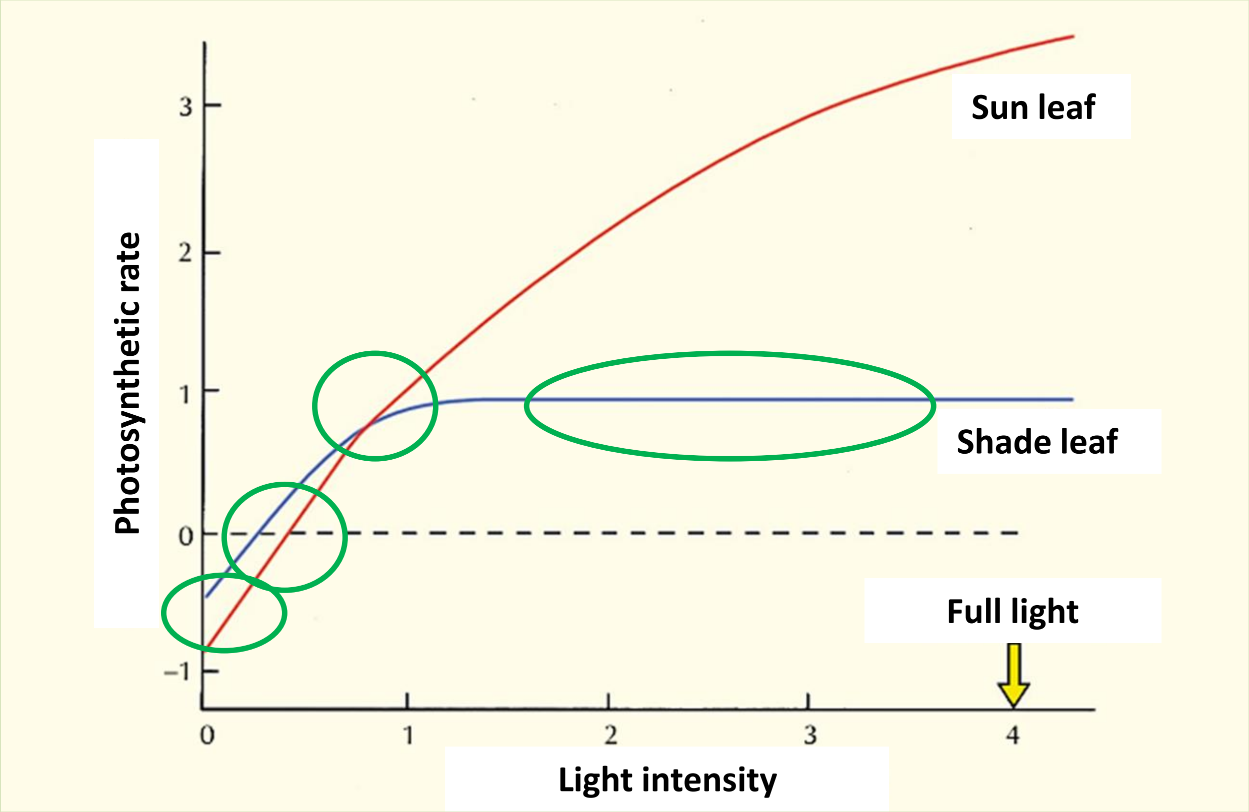
3 days after exposing plant to high light 30% reduction of antenna size

Transition from shade to high light (e.g. lightflecks)

↓

Mobile molecules of PSII antenna size migrate to PSI

Photosynthesis responses to light quantity (intensity)



- Higher respiration rates in sun leaf
- Earlier light compensation point in shade leaf
- Earlier light saturation point in shade leaf
- Lower photosynthetic rates at light saturation in shade leaf

Photosynthesis responses to light quantity (intensity): genetic traits or acclimation

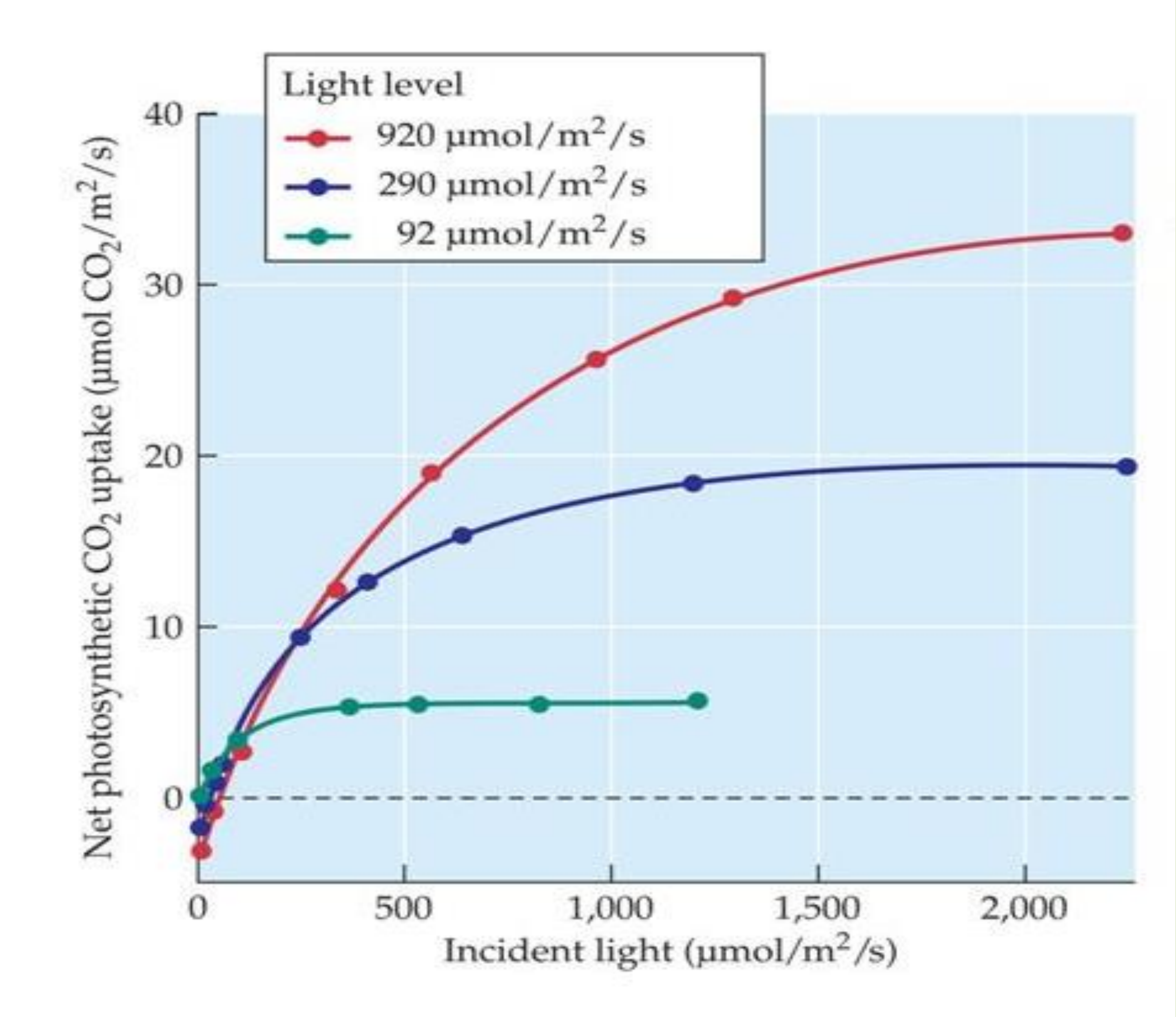
Light intensity inside the greenhouse: more than 10-20 times lower than full light

Anthurium

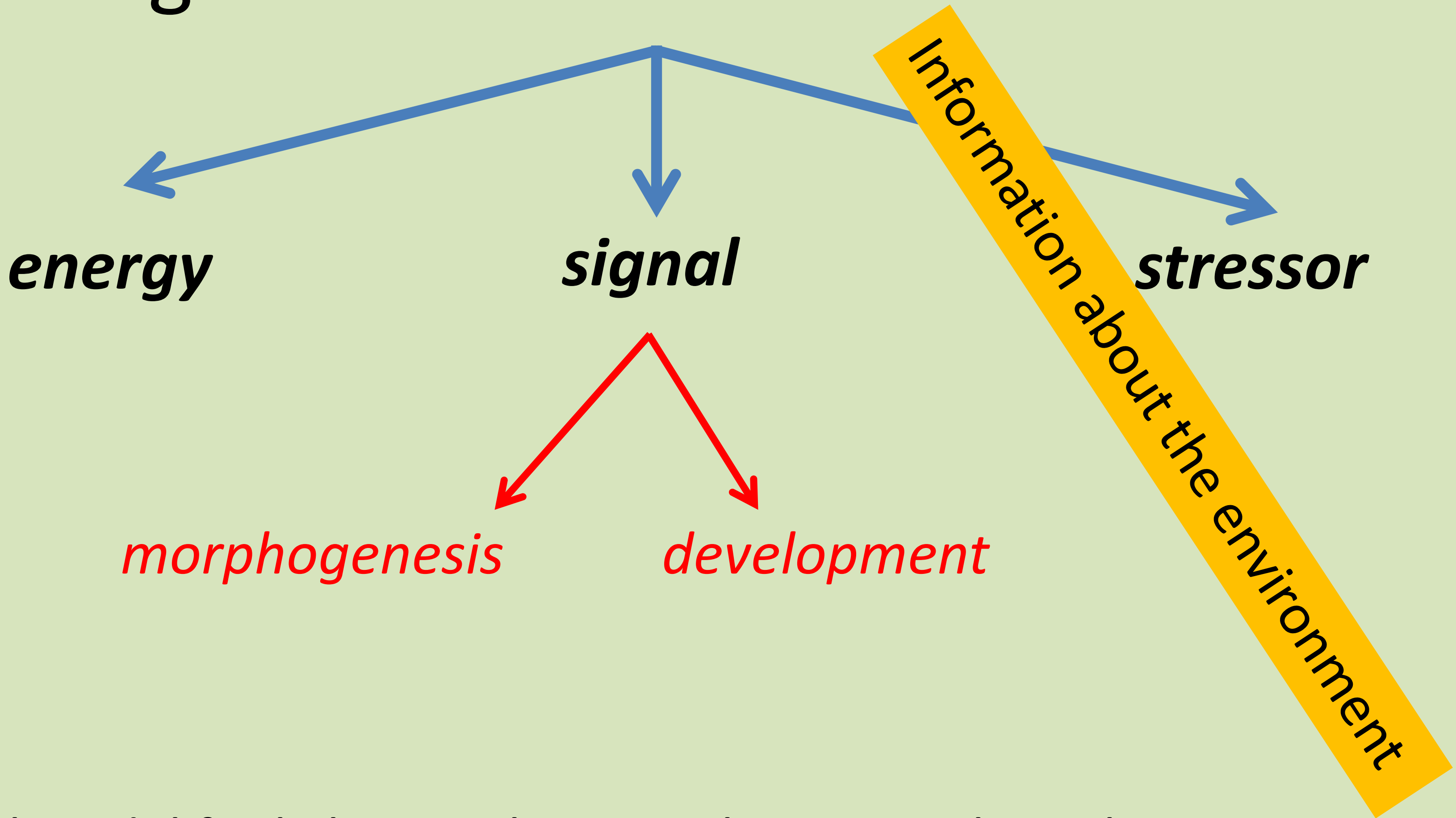
Shade plants or shade-tolerant plants

Bromeliads

Photosynthesis responses to light quantity acclimation of photosynthesis



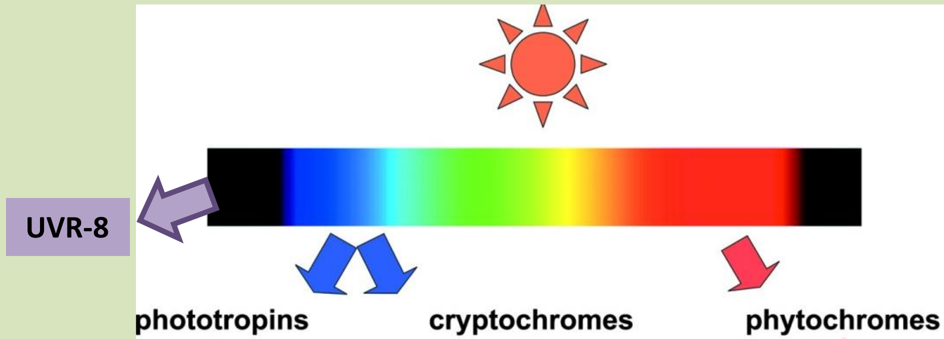
Light as environmental factor



A general model for light signaling entails extranuclear photoreceptors initiating a signaling cascade whose end result is either the **modulation of gene expression** or a **change in cellular physiological parameters**, such as membrane potential or local pH, in order to modify morphology and trigger developmental processes

Light as ***signal***

Plants contain at least three different photoreceptor systems that are involved in modulating development



1. phytochromes, which primarily absorb red and far-red light

2. blue-light/UV-A receptors → cryptochromes
→ phototropins
→ ZTL family

3. UV-B receptors → UVR-8

The photosynthetic pigments comprise an additional group of photoreceptors

Light as ***signal***

- seed germination
- stem elongation
- dormancy
- blooming in day length sensitive plants

1. phytochromes, which primarily absorb red and far-red light

620-700nm

710-850nm

Light as ***signal***

- chlorophylls+carotenoids+anthocyanins biosynthesis induction
- inhibition of hypocotyl elongation
- cotyledon expansion
- stomatal opening

- phototropism
- chloroplast movement
- stomatal opening

2. blue-light/UV-A receptors → cryptochromes

2. blue-light/UV-A receptors → phototropins

2. blue-light/UV-A receptors → ZTL family

- photoperiod reading and circadian clock regulation

Light as ***signal***

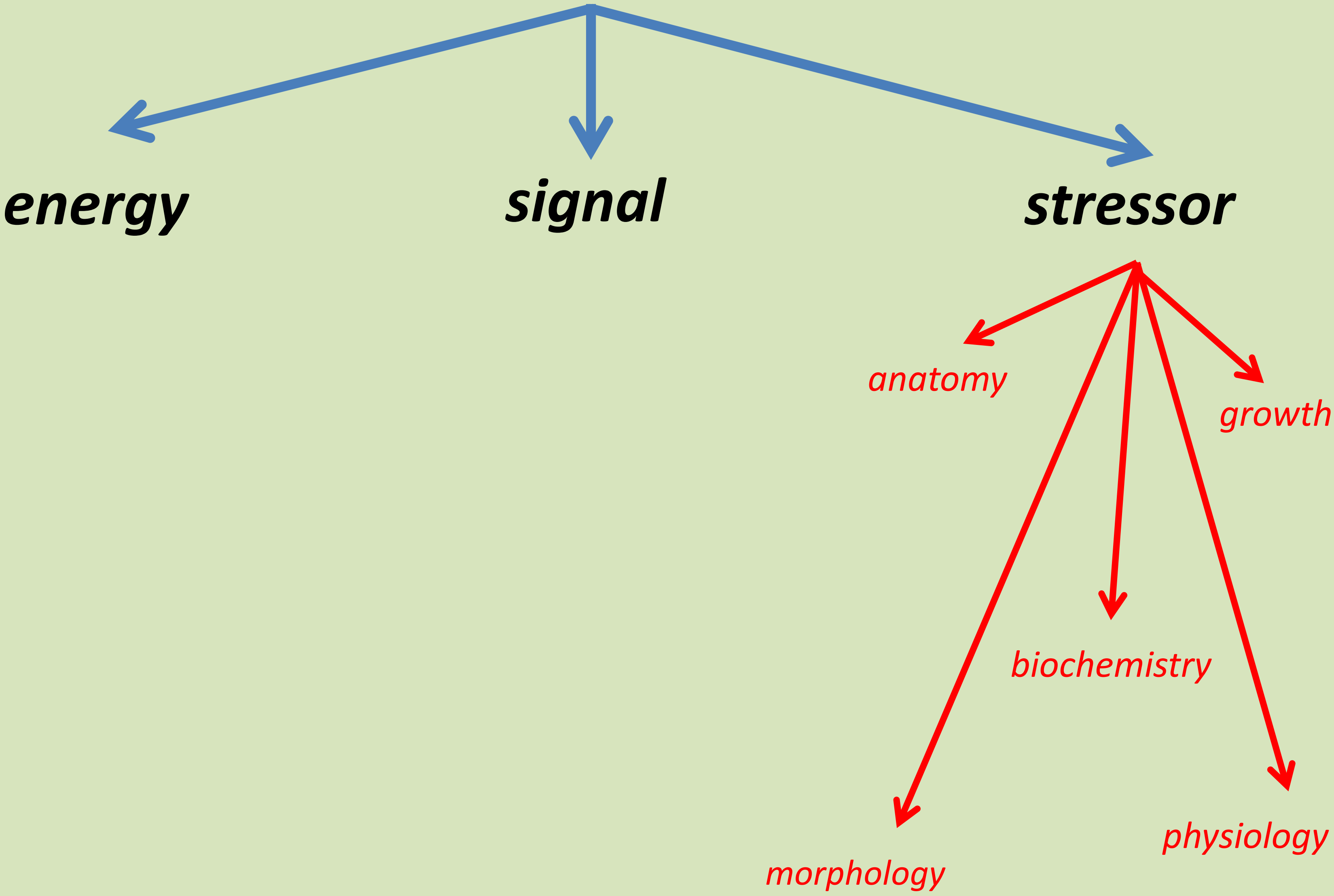
low doses of UV-B initiate photomorphogenic responses

- suppression of both hypocotyl extension and root growth
- promotion of cotyledon opening
- biosynthesis of flavonoid compounds, which are constituents of the UV-absorbing sun screen

Health promoting phytochemicals

3. UV-B receptors → UVR-8

Light as environmental factor



Light as environmental factor

energy | ***signal*** | ***stressor***

stressor → High light → excess energy

stressor → Low light → inadequate energy

	High light	Low light
the problem	photoinhibition chlorophyll degradation ROS leaf burning	stunted growth death
the adaptation	avoidance energy dissipation	maximization of energy capture

Light as stress factor

Adaptations on different levels of organization:
- whole plant
- organ
- cellular
- molecular

the adaptation — avoidance, energy dissipation — maximization of energy capture

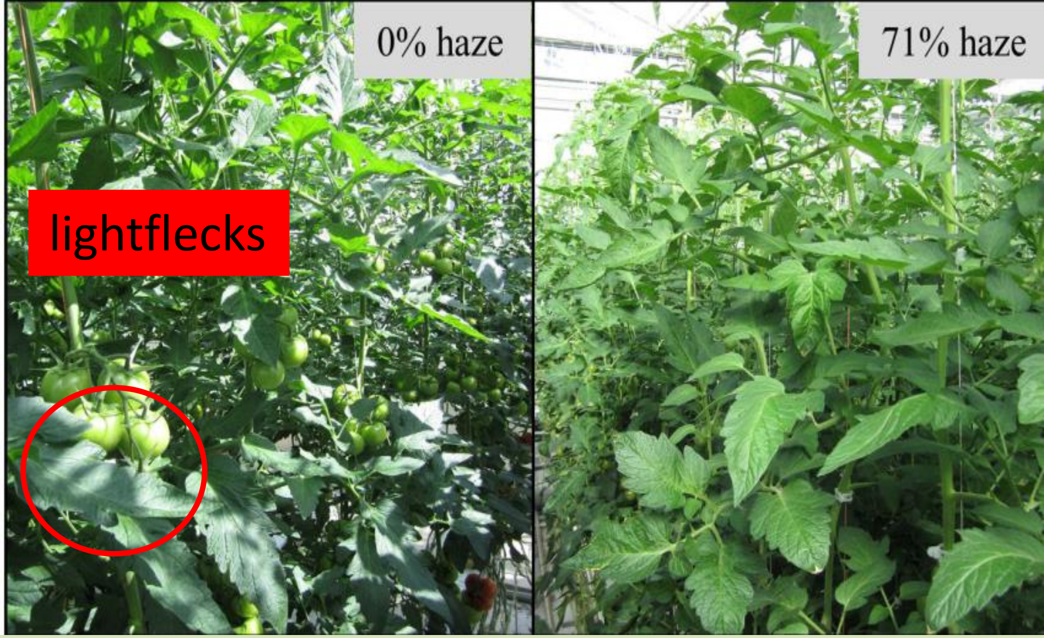
Snapshot: why better growth under diffuse light

- Use natural light efficiently
- High light transmission greenhouse
- Make the light diffuse (5-10% higher production)

Fig. 1. Light distribution in tomato canopy in the conventional clear (0% haze) and diffuse (71% haze) glasshouse on a clear day. Light is more homogeneously distributed in 71 % haze compared with 0 % haze treatment where many light and shaded spots in the middle and lower of the canopy.

haze: the percentage of transmitted light that is scattered unequal distribution of light – horizontal

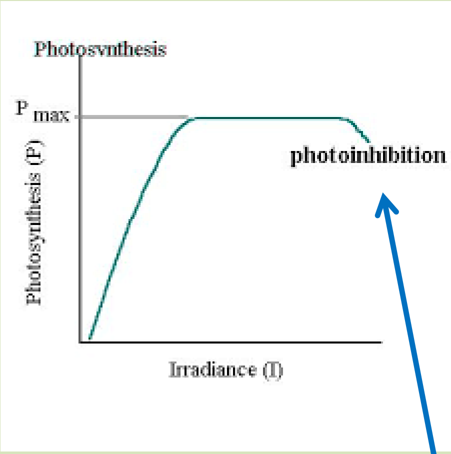
leaves at the middle of the canopy receive transiently too much light while adapted and function to lower light level

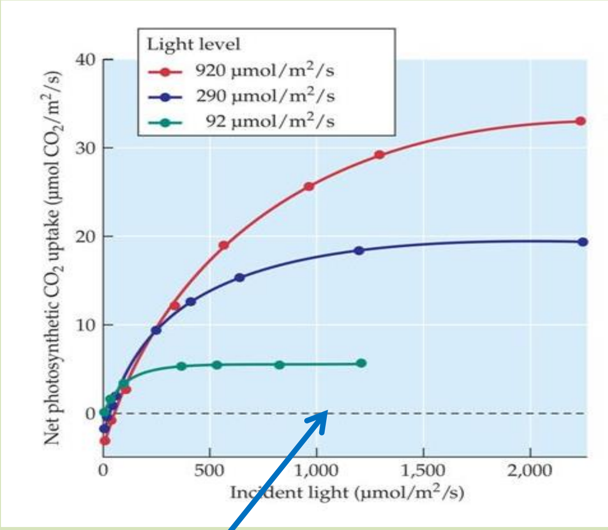


unequal distribution of light – vertical

leaves at the top of the canopy receive too much light while leaves deeper in the canopy receive too little light

unequal distribution of light – vertical

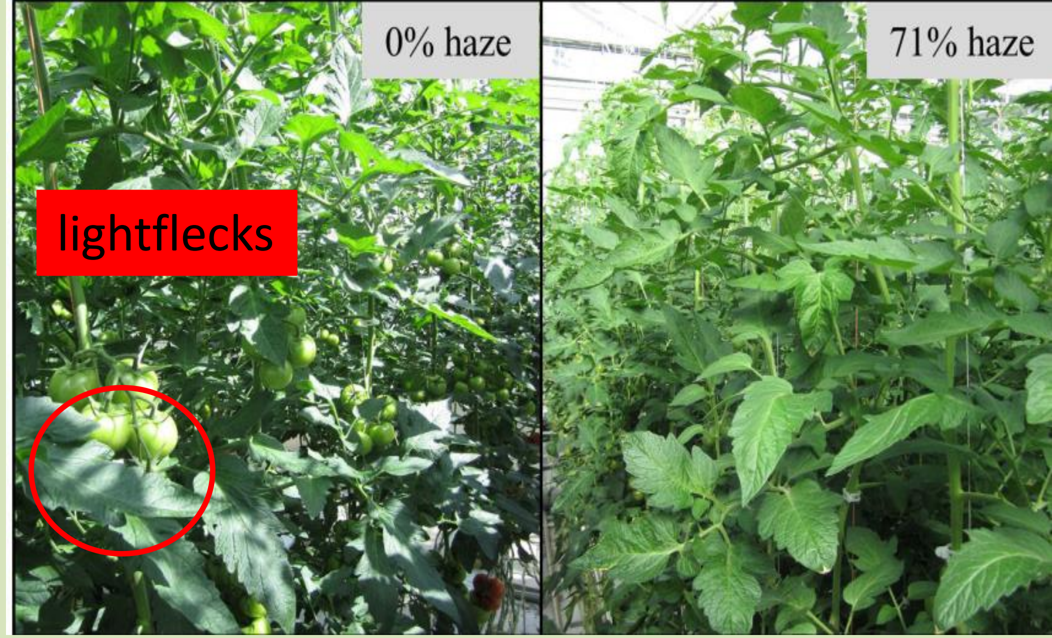


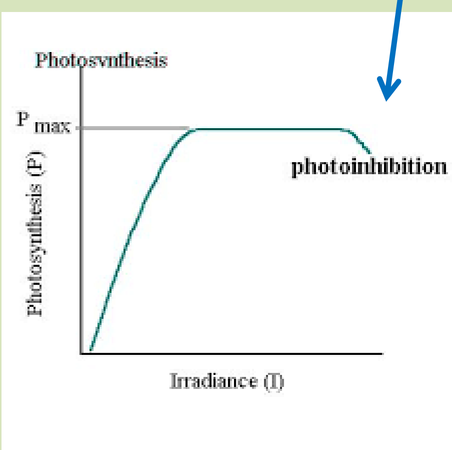


leaves at the top of the canopy receive too much light while leaves deeper in the canopy receive too little light

unequal distribution of light – horizontal

leaves at the middle of the canopy receive transiently too much light while adapted and function to lower light level

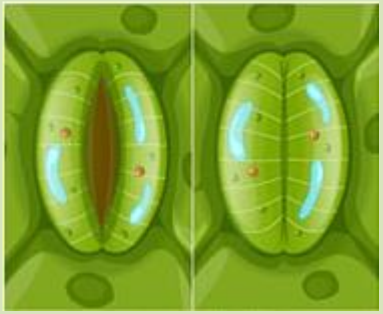




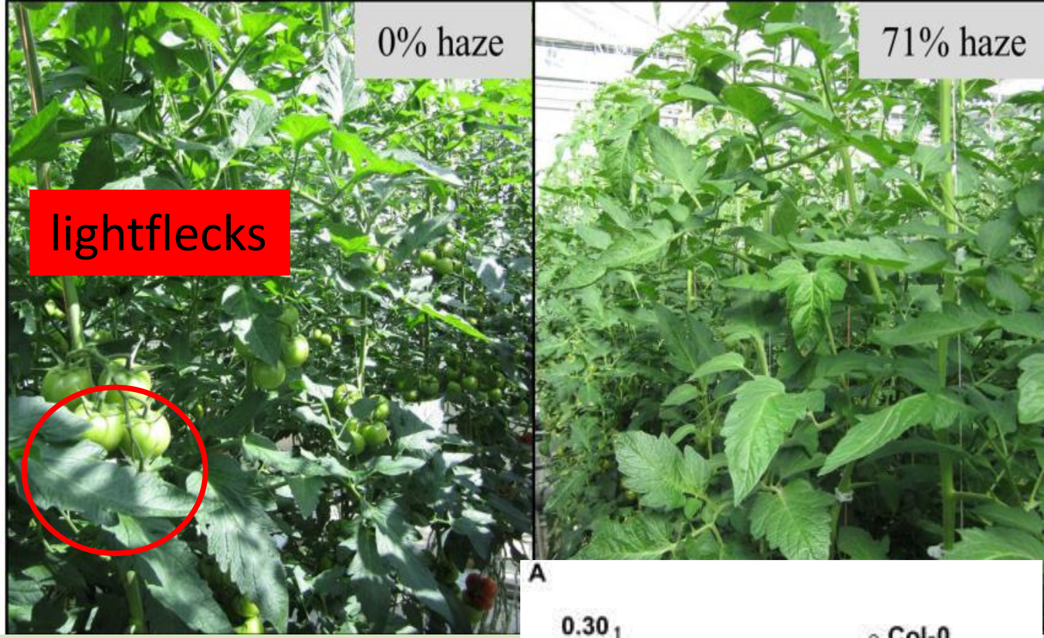
Or

Acclimation to the new light environment through biochemical and physiological modifications

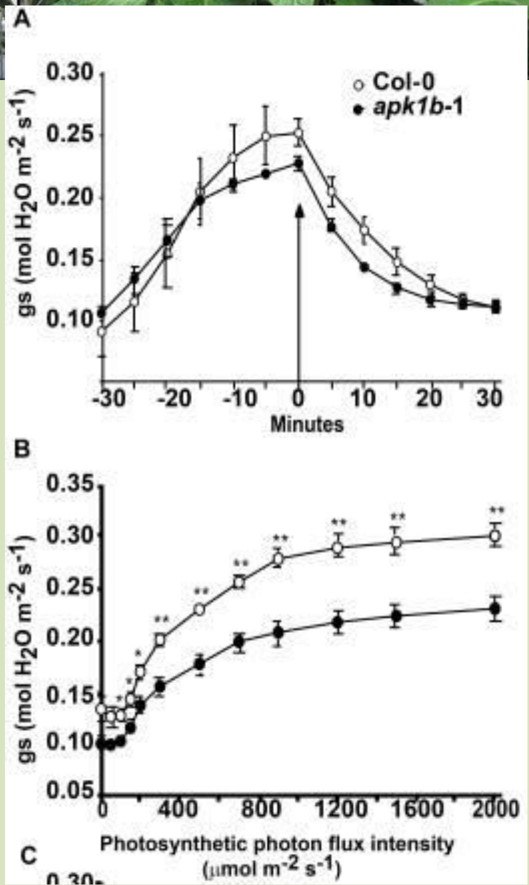
takes time



Stomatal aperture regulate carbon uptake of a leaf



In saturating light for 30 min, then (arrow) darkness



In response to **fluctuating** light, stomata exhibit a dynamic response that is slower than the response of fluctuating light itself, which may limit the CO_2 assimilation under fluctuating light conditions

How diffuse light address these issues

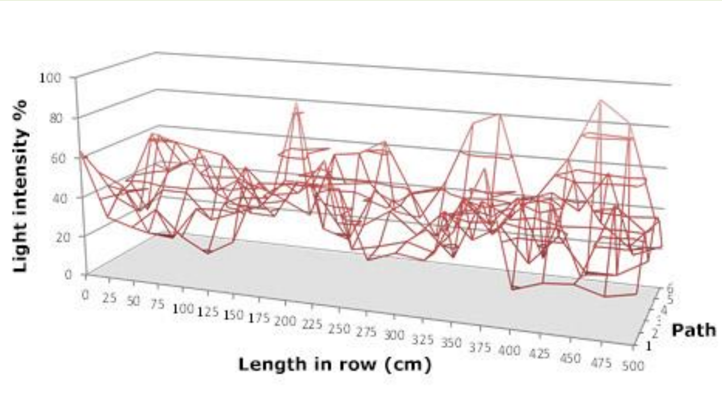
Scattered light:

★ arrives at an object from many directions simultaneously

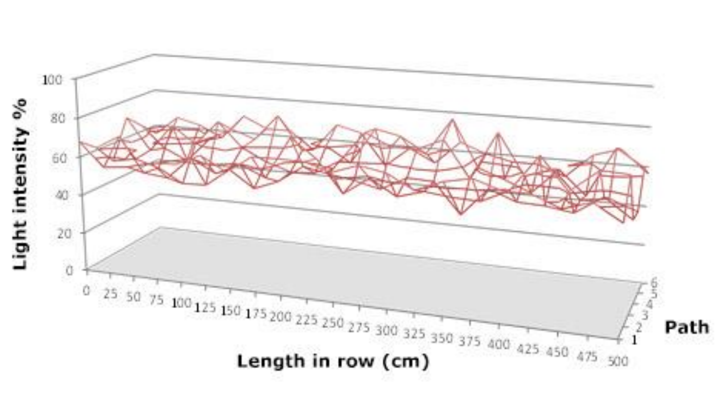
★ penetrates deeper into the crop canopy

less shading and less variation of light intensity within a canopy

unequal distribution of light – horizontal	diffuse light ensures that changes in light intensity are minimized in all areas of the crop
unequal distribution of light – vertical	lower positioned leaves in the canopy may receive a higher average light intensity in diffuse compared to direct light conditions



Light peaks in a greenhouse under clear glass



More uniform light distribution under a diffuse glass

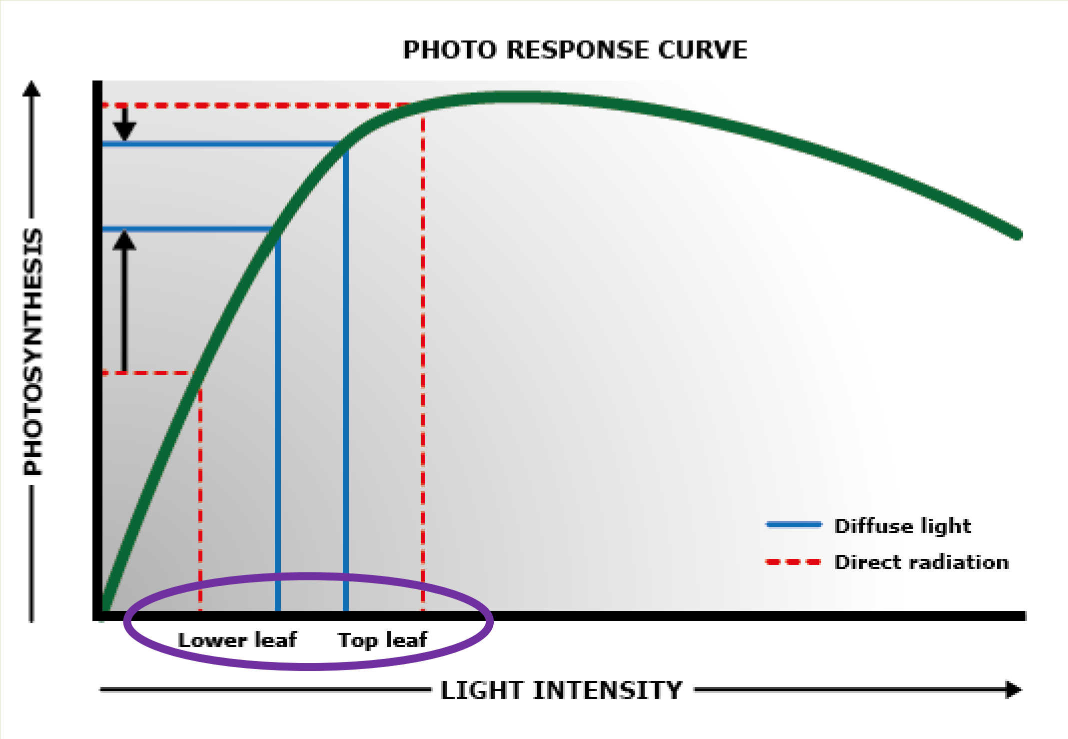
Improving light distribution in both horizontal and vertical direction

homogeneous light distribution within the crop canopy

improves crop photosynthesis

Is it merely a result of light intensity or does plant physiological and morphological acclimation also occur?

the lower leaves move further up the steep part of the curve and the leaves at the top move towards the left, also towards the steeper part



less light falls onto the leaves at the top of the canopy but more falls onto the lower leaves

Physiological acclimation

higher leaf photosynthetic capacity in the middle and lower part of the canopy

less stomatal limitation on leaf photosynthesis

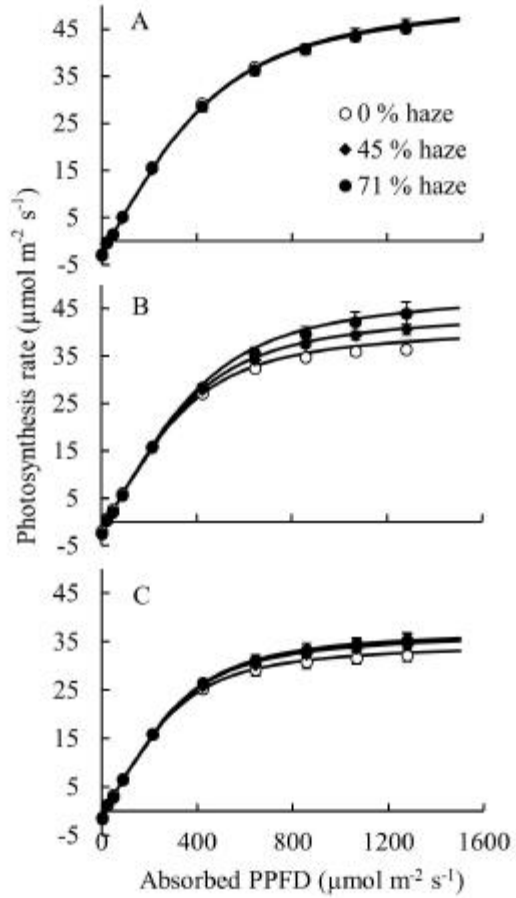


Fig. 8. Photosynthetic light response curves of leaves at top (A), middle (B) and bottom (C) of the canopy. These measurements were taken in June. During the measurements, leaf temperature and CO_2 concentration in the measurement chamber were maintained at 25 °C, and 700 μmol mol^{-1}, respectively. Error bars show ± SE (n = 6).

better growth under diffuse light

no lightflecks,
no saturating – photoinhibitory--inadequate light

physiological acclimation of the photosynthetic machinery
less stomatal limitation to photosynthesis induction

optimized photosynthetic use of light by plant canopies

Tomato, 8% more photosynthesis
10% more production

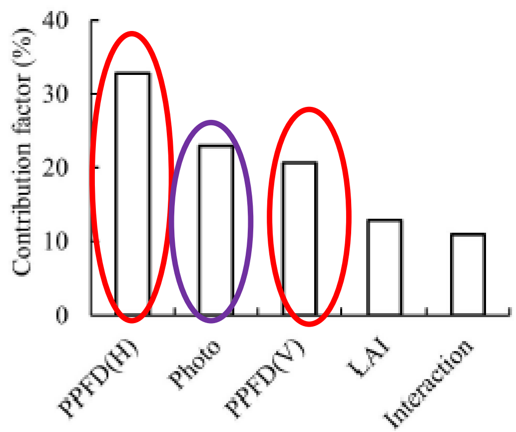


Fig. 9. Quantification of the contributing factors to crop photosynthesis enhancement over a designated growing period (1 Apr to 1 Oct. 2011) in the 71 % haze treatment. The X-axis represents the influence factors: PPFD(H): horizontal PPFD distribution; Photo: leaf photosynthesis light response curve; PPFD(V): vertical PPFD distribution; LAI: leaf area index; Interaction: interaction effect of the four factors.

T. Li et al. *Annals of Botany 114, 2014*