I. Effect of external conditions on photosynthetic rate

(I) Representation of photosynthetic rate

Photosynthetic rate is usually expressed in CO_2 uptake or O_2 evolution per unit leaf area within unit time (μmol $CO_2/m^2/s$), or the amount of dry matter accumulated ($DW/m^2/h$).

True Photosynthesis = Apparent Photosynthesis + Respiration + Light Respiration

Chapter VII Photosynthesis-Factors Affecting Photosynthesis

(II) Light

1. Relationship between light intensity and photosynthetic rate

①Light compensation point: means the light intensity when CO_2 uptake by a leaf in the photosynthetic process equals the amount of CO_2 evolved by the same leaf in the light respiration process and the respiration process at the same time.

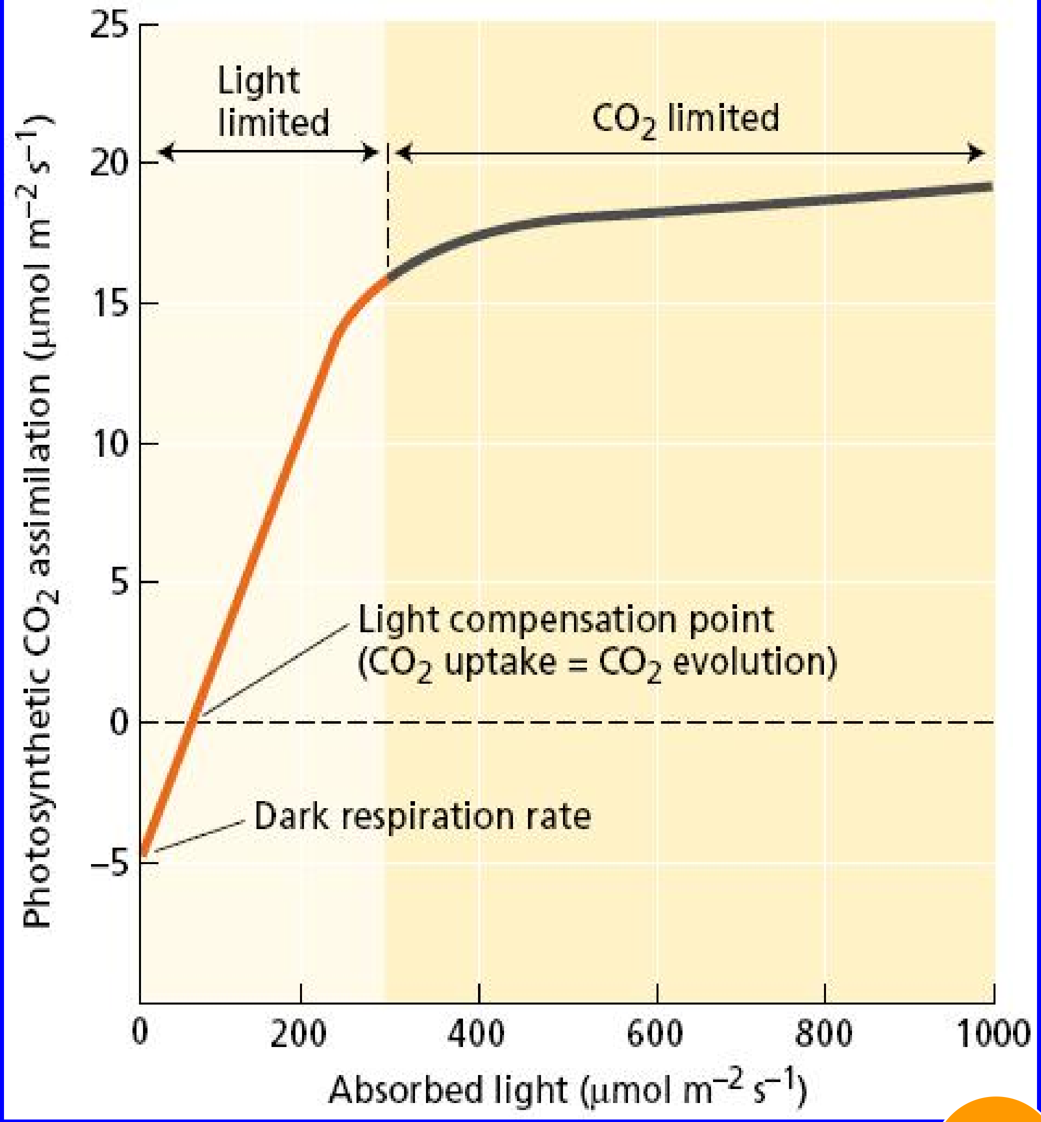
② The straight-line portion shows that the photosynthetic rate and light intensity are linear, and the light is a limited factor of the photosynthesis.

③ Light saturation: as light intensity is increased beyond a certain value, the photosynthetic rate increase becomes slower gradually. Eventually an intensity is reached above which light no longer is the factor limiting the overall rate of photosynthesis, and this light intensity is referred to as Light Saturation Point. Electron transport response, Rubisco activity or phosphotriose metabolism become the limited factors. CO_2 assimilation can’t be conducted together with absorption of light energy.

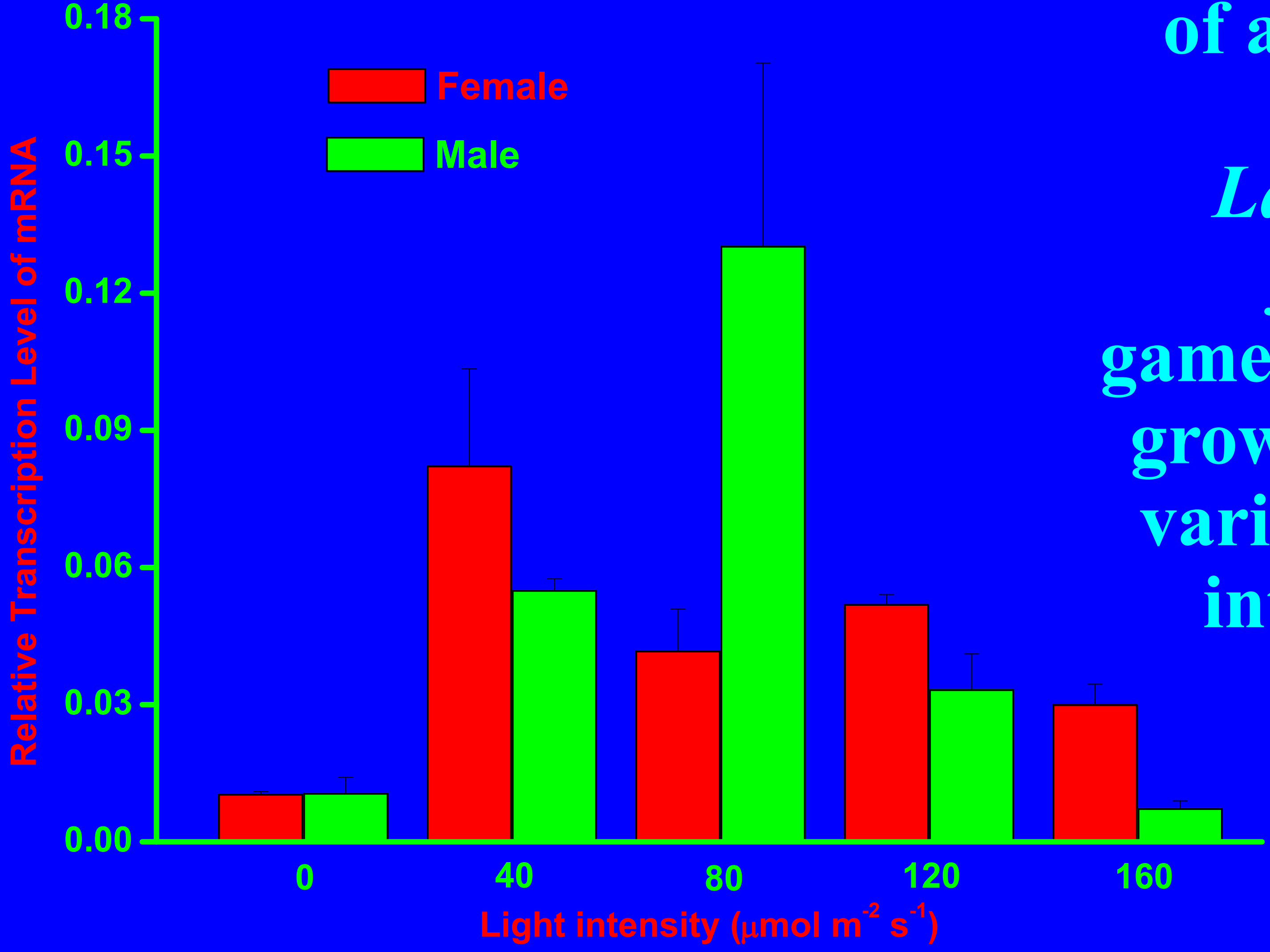
④Photoinhibition of photosynthesis: means that when the light energy exceeds the amount available for photosynthetic system, the overall capacity of photosynthesis will decrease. It occurs in PSII system mainly.

Chapter VII Photosynthesis-Factors Affecting Photosynthesis

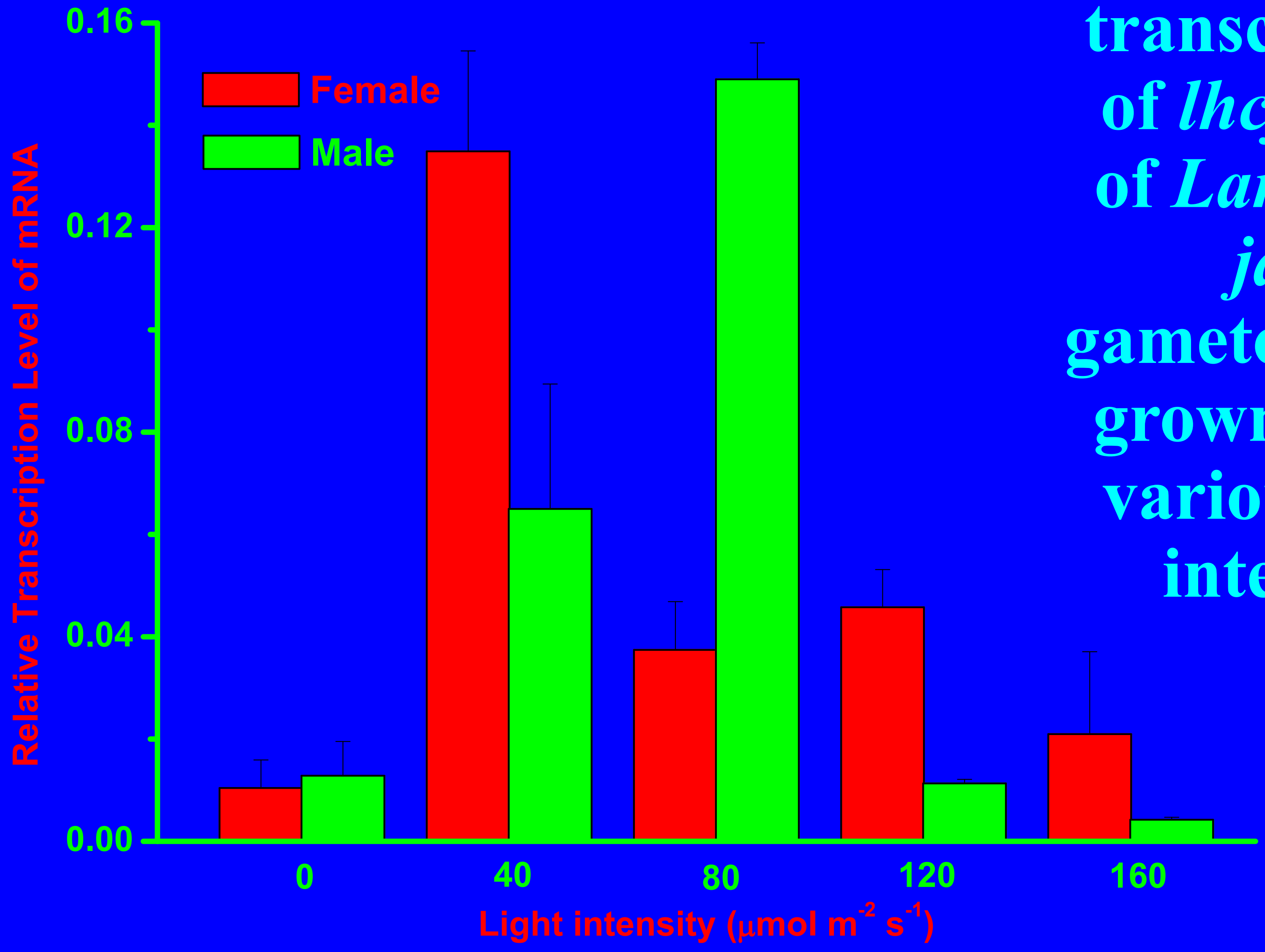
Response of photosynthesis to light in a C_3 plant. In darkness, respiration causes a net efflux of CO_2 from the plant. The light compensation point is reached when photosynthetic CO_2 assimilation equals the amount of CO_2 evolved by respiration. Increasing light above the light compensation point proportionally increases photosynthesis indicating that photosynthesis is limited by the rate of electron transport, which in turn is limited by the amount of available light. This portion of the curve is referred to as light-limited. Further increases in photosynthesis are eventually limited by the carboxylation capacity of rubisco or the metabolism of triose phosphates.



The relative transcription of and *lhcf6* gene of *Laminaria japonica* gametophytes grown under various light intensities.



The relative transcription of *lhcf5* gene of *Laminaria japonica* gametophytes grown under various light intensities.



Chapter VII Photosynthesis-Factors Affecting Photosynthesis

I. Effect of light quality on photosynthetic rate

① The light intensity is weak on a cloudy day, and blue and green lights are in the majority;

②The light under forest canopy is rich in green light;

③The light in deep water is relatively rich in short- wavelength light.

3. Practical significance in production

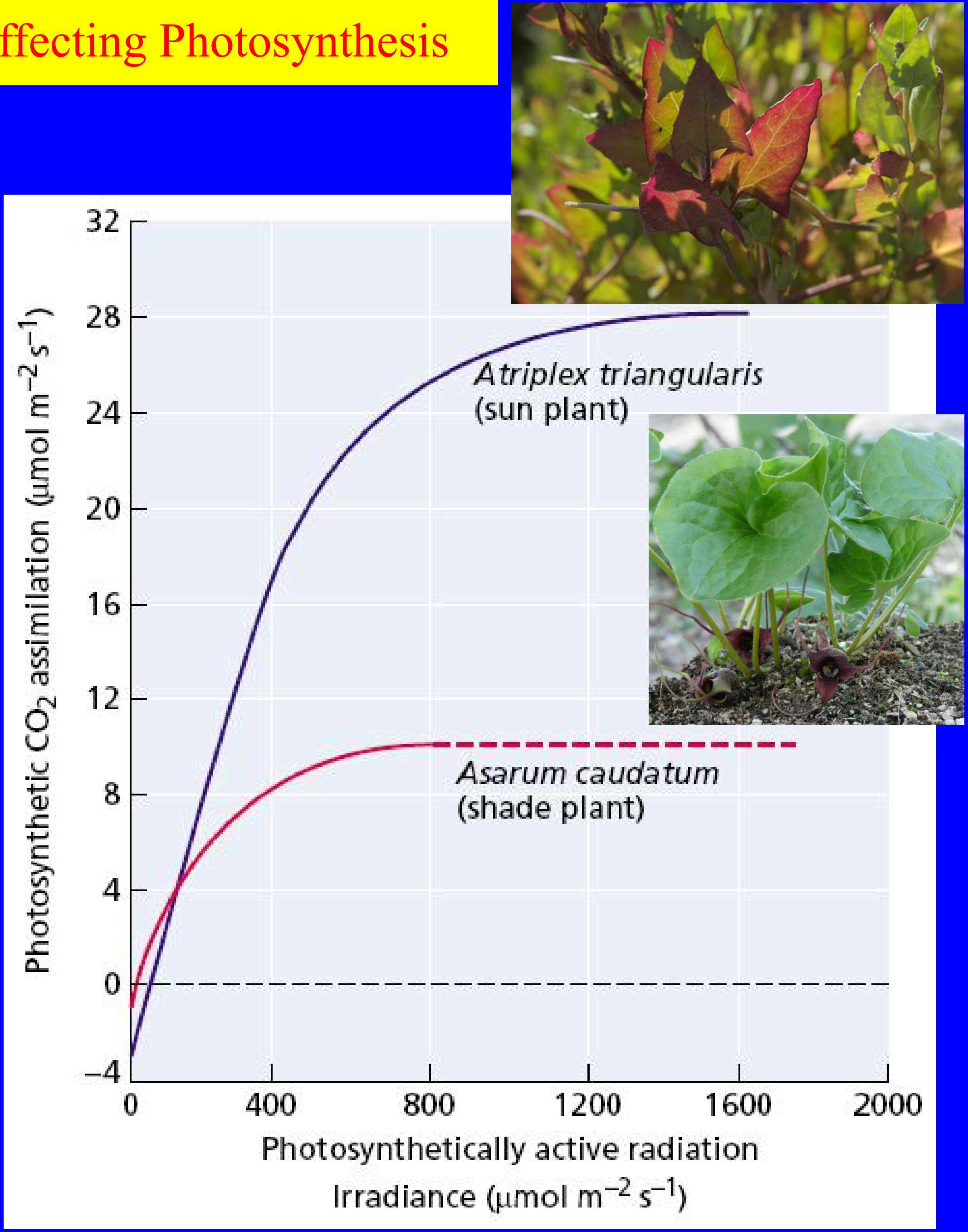
Intercropping and relay intercropping, thinning, pruning and harvesting, reasonable compact planting, fertile water are managed appropriately to ensure good light permeability.

4. Sun and shade plants

The shade plants have a low light compensation point and light saturation intensity; the conducting tissue of shade plants is thin; the shade plants have large granum and many lamellas, and its chlorophyll content is high; in order to adopt to the short-wavelength light under the shade, the ratio of chlorophyll *a* to chlorophyll *b* in the shade plants is low, but chlorophyll b content is higher relatively.

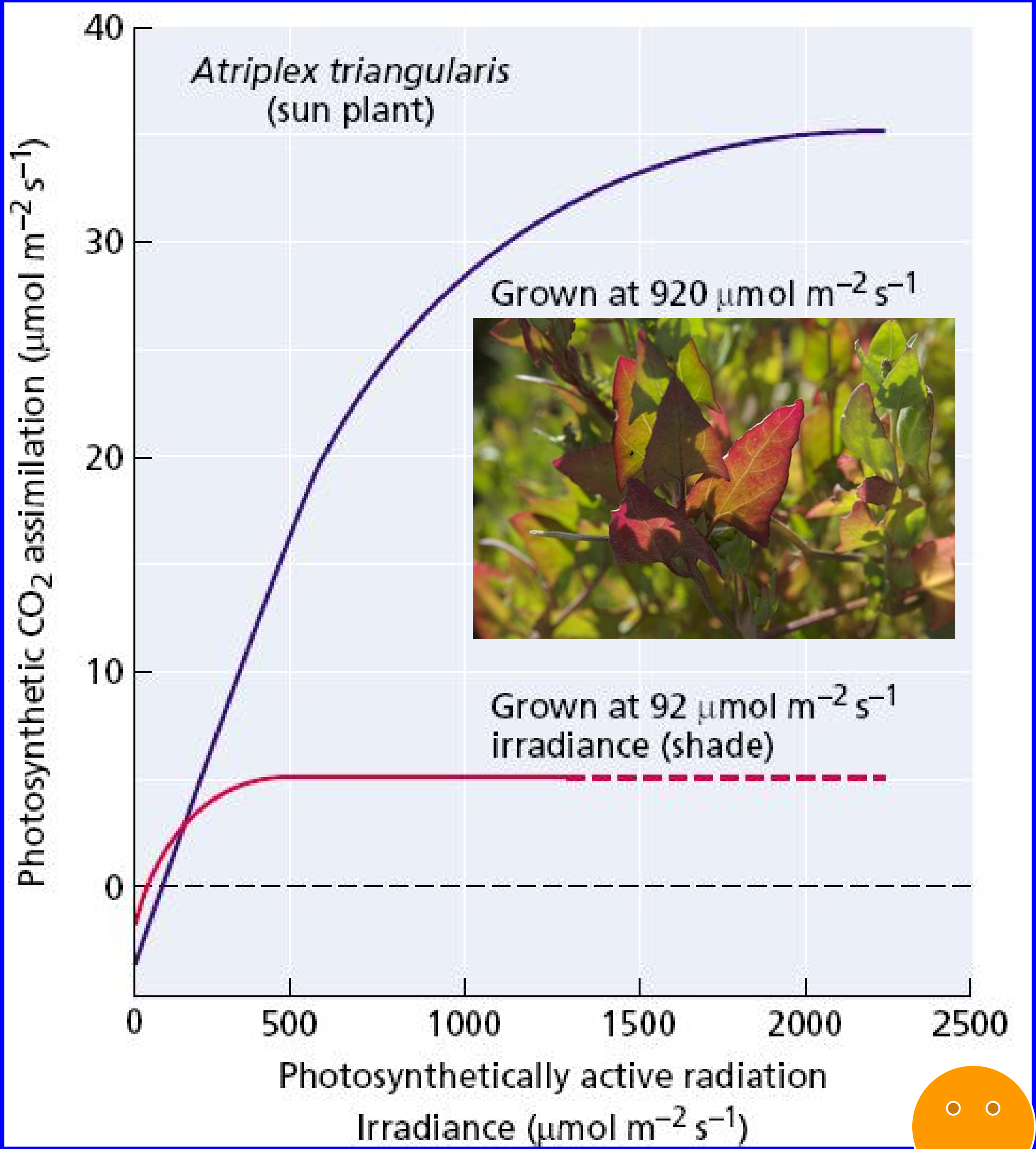
Chapter VII Photosynthesis-Factors Affecting Photosynthesis

Light-response curves of photosynthetic carbon fixation in sun and shade plants. *Atriplex triangularis* (triangle orache) is a sun plant, and *Asarum caudatum* (a wild ginger) is a shade plant. Typically, shade plants have a low light compensation point and have lower maximal photosynthetic rates than sun plants. The dashed line has been extrapolated from the measured part of the curve. (Harvey 1979)



Chapter VII Photosynthesis-Factors Affecting Photosynthesis

Light-response of photosynthesis of a sun plant gown under sun or shade conditions. The upper curve represents an *Atriplex triangularis* leaf grown at an irradiance ten times higher than that of the lower curve. In the leaf grown at the lower light levels, photosynthesis saturates at a substantially lower irradiance, indicating that the photosynthetic properties of a leaf depend on its growing conditions. The dashed line has been extrapolated from the measured part of the curve. (Bj鰎kman 1981)



Chapter VII Photosynthesis-Factors Affecting Photosynthesis

(III) Carbon dioxide (CO2)

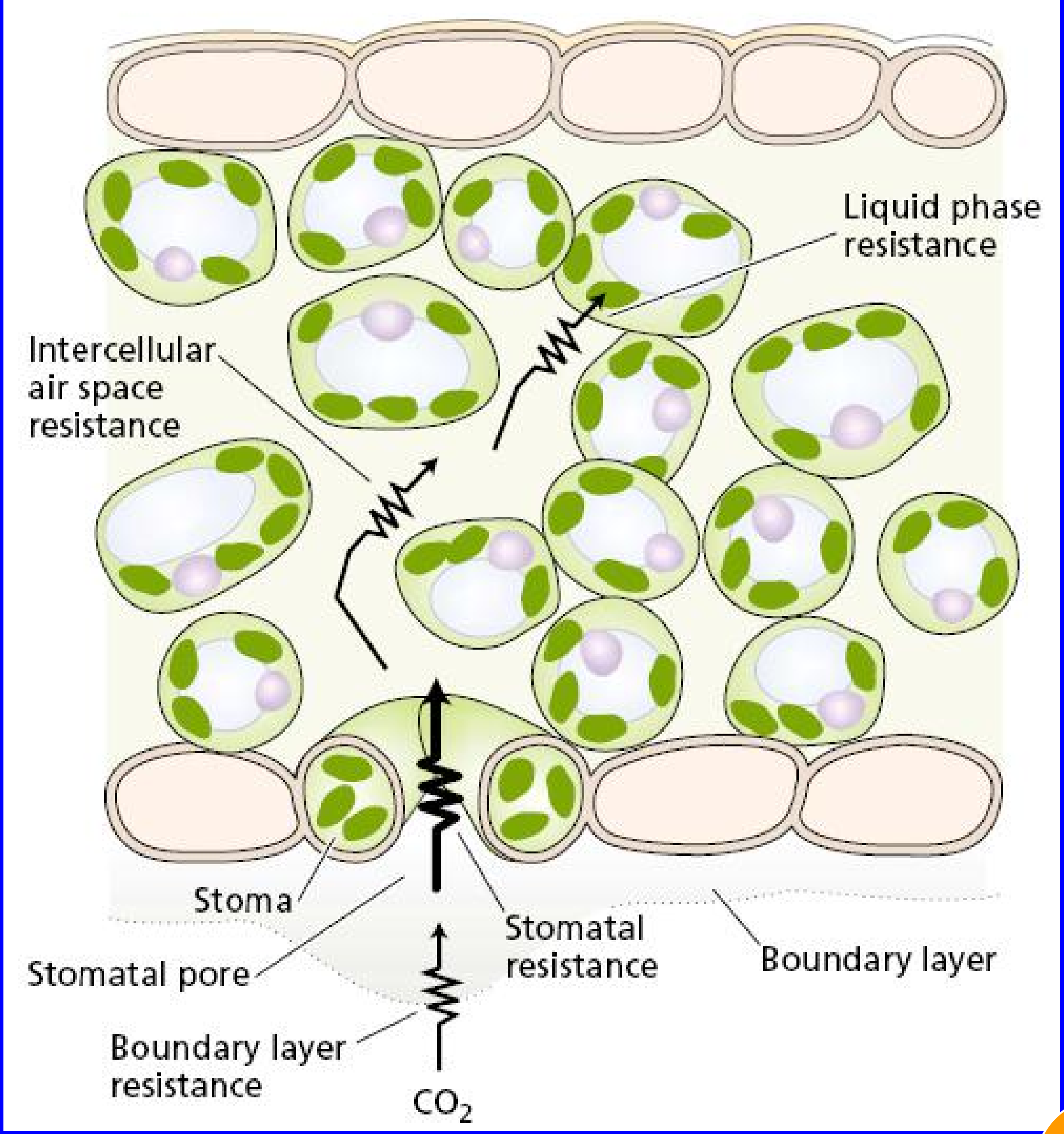
1. Pathway of CO_2 into cell:

CO_2 in the air enters the gap between mesophyllic cells via stomatal pore, and quickly diffuses in a gaseous manner; CO_2 enters the chloroplast via cell wall slowly. Root may absorb CO_2 and carbonate from the soil for photosynthesis.

2. CO_2compensation point:

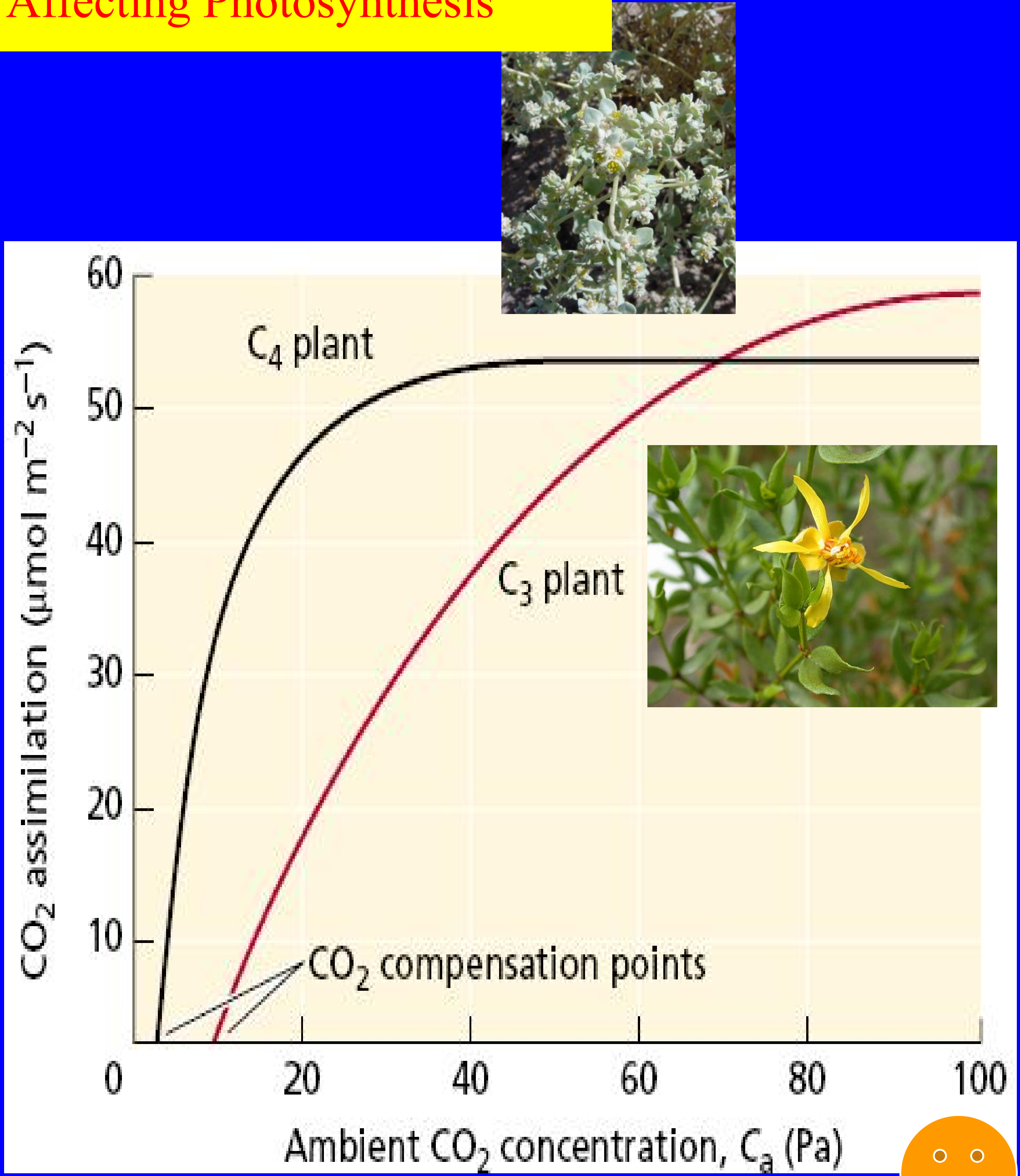
When CO_2 uptake in photosynthesis process equals the amount of CO_2 evolved by respiration, the outside CO_2 content is referred to as the compensation point. The compensation point is high at weak light intensity, and low at strong light intensity.

Points of resistance to the diffusion of CO_2 from outside the leaf to the chloroplasts. The stomatal pore is the major point of resistance to CO_2 diffusion.



Chapter VII Photosynthesis-Factors Affecting Photosynthesis

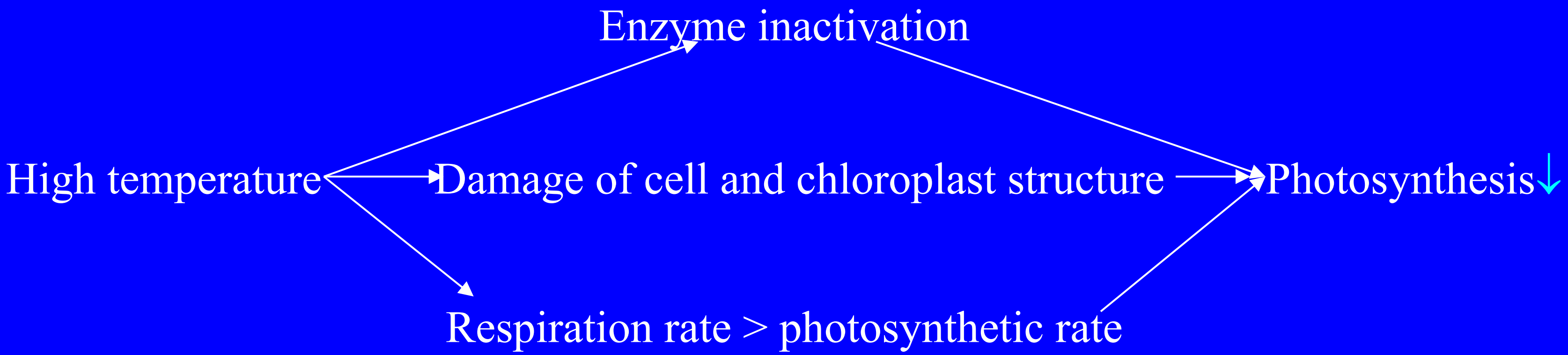
Changes in photosynthesis as a function of ambient intercellular CO_2 concentrations in *Tidestromia oblongifolia* (Arizona honeysweet), a C4 plant, and *Larrea divaricata* (creosote bush), a C3 plant. Photosynthetic rate is plotted against partial pressure of CO_2 in ambient air. The partial pressure at which CO_2 assimilation is zero defines the CO_2 compensation point. (Berry & Downton 1982)



Chapter VII Photosynthesis-Factors Affecting Photosynthesis

(IV) Temperature

The plants may be photosynthetic under 10-35 ° C generally. Optimum temperature: 25-30 ° C; decreased above 35 ° C; completely stopped at 40-50 ° C.

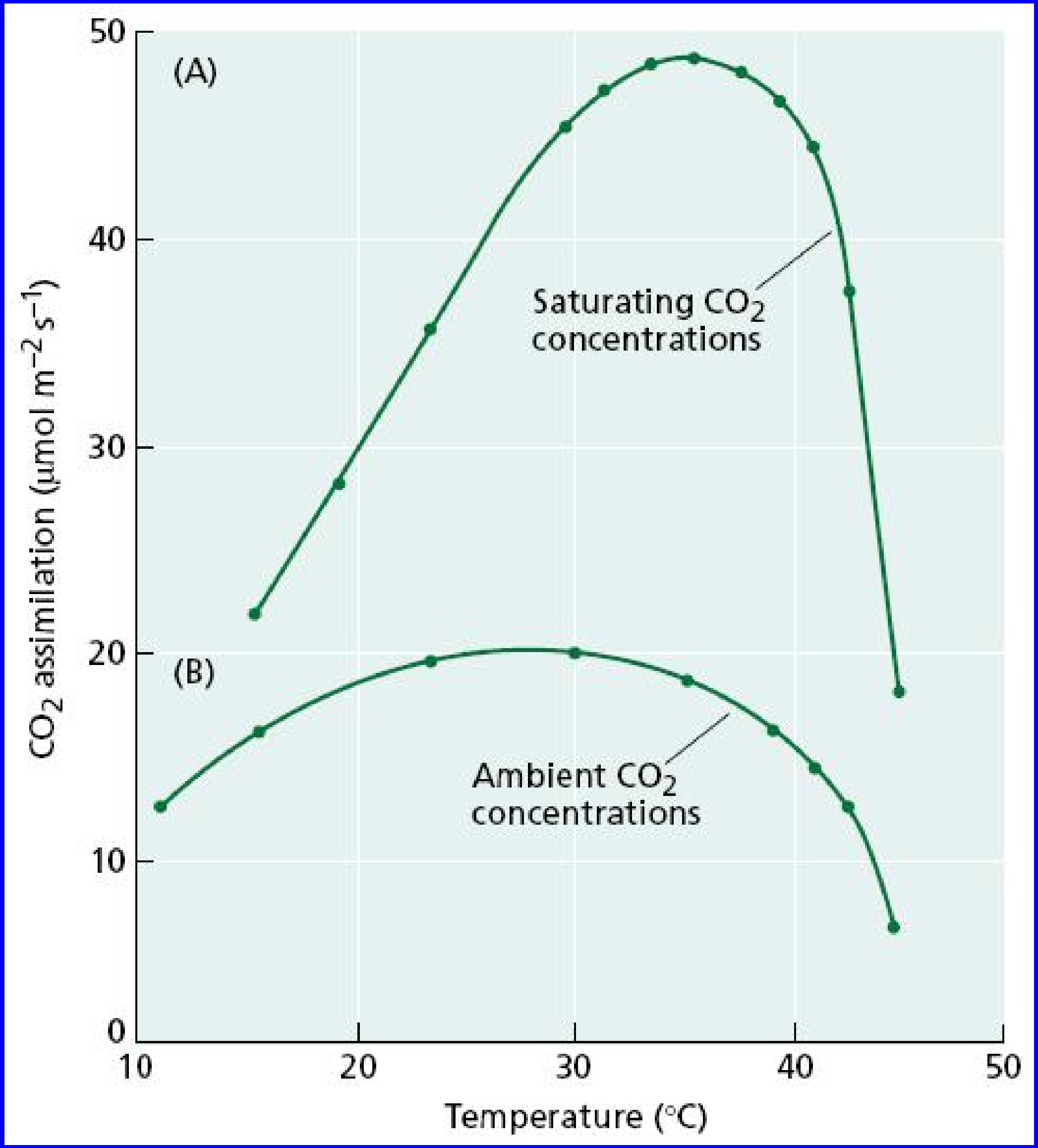


Enzyme inactivation

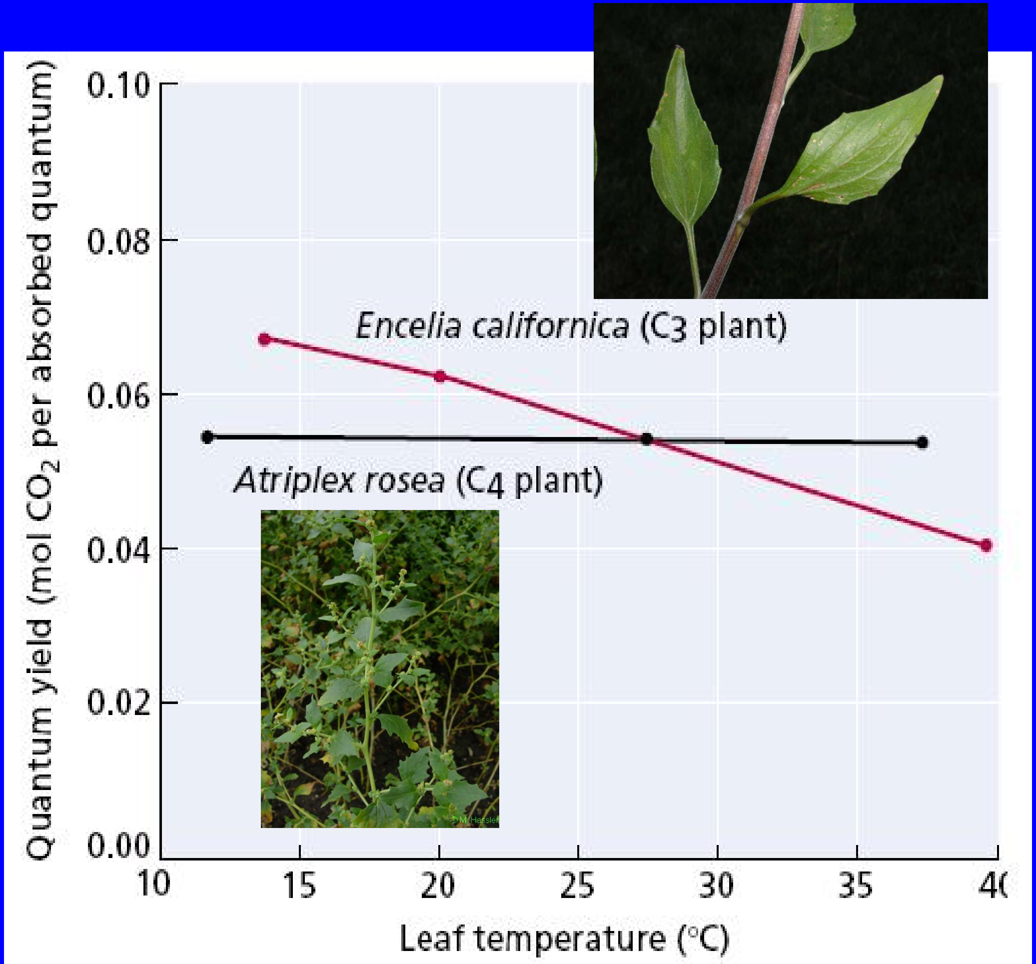
High temperature → Damage of cell and chloroplast structure → Photosynthesis↓

Respiration rate > photosynthetic rate

Changes in photosynthesis as a function of temperature at CO_2 concentrations that saturate photosynthetic CO_2 assimilation (A) and at normal atmospheric CO_2 concentrations (B). Photosynthesis depends strongly on temperature at saturating CO_2 concentrations. Note the significantly higher photosynthetic rates at saturating CO_2 concentrations. (Berry & Bj鍵kman 1980)



Chapter VII Photosynthesis-Factors Affecting Photosynthesis



The quantum yield of photosynthetic carbon fixation in a C3 plant and in a C4 plant as a function of leaf temperature. In normal air, photorespiration increases with temperature in C3 plants, and the energy cost of net CO_2 fixation increases accordingly. This higher energy cost is expressed in lower quantum yields at higher temperatures. Because of the CO_2 concentrating mechanisms of C4 plants, photorespiration is low in these plants, and the quantum yield does not show a temperature dependence. Note that at lower temperatures the quantum yield of C3 plants is higher than that of C4 plants, indicating that photosynthesis in C3 plants is more efficient at lower temperatures. (Ehleringer & Bj鍵kman 1977)

Chapter VII Photosynthesis-Factors Affecting Photosynthesis

(V) Mineral elements

1. N, Mg, Fe, Mn - biological synthesis of chlorophyll
2. Cu, Fe, S, Cl - photosynthetic electron transport and water-splitting process
3. K, P - carbohydrate metabolism
4. P - conversion and energy transfer of in-process product of photosynthesis

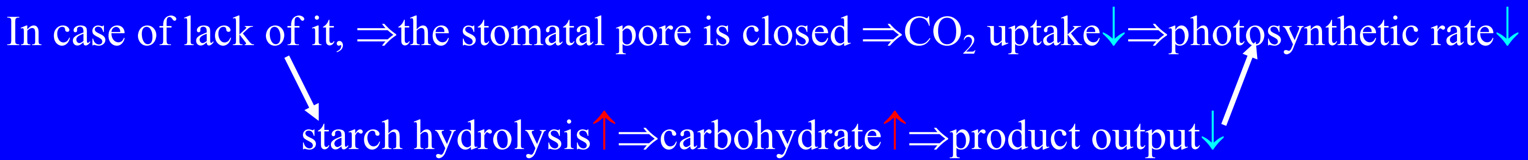
Chapter VII Photosynthesis-Factors Affecting Photosynthesis

(VI) Water

1. Direct effect

It is the raw material of photosynthesis, and the photosynthetic rate decreases in case of lack of it.

2. Indirect effect



In case of lack of it, ⇒the stomatal pore is closed ⇒CO_2 uptake↓⇒photosynthetic rate↓

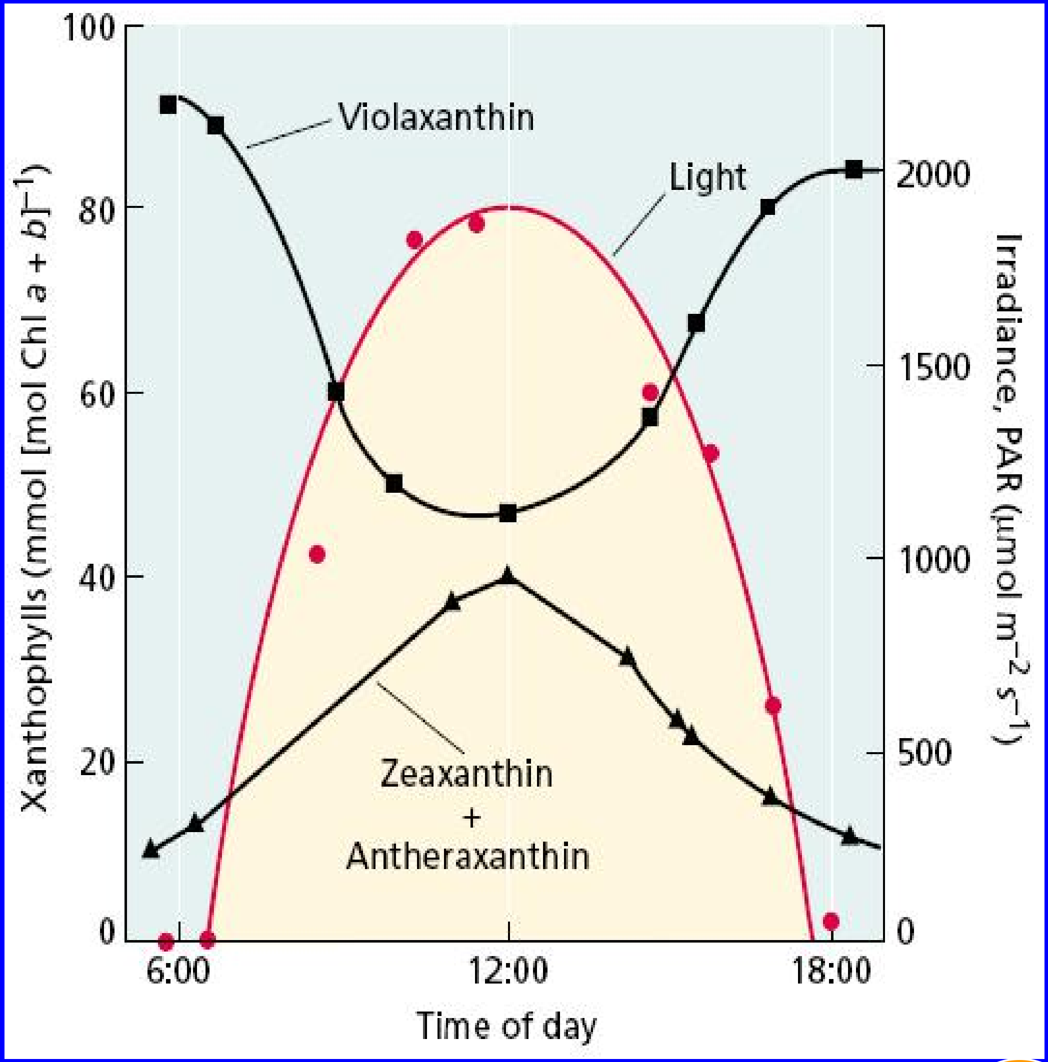
starch hydrolysis↑⇒carbohydrate↑⇒product output↓

Chapter VII Photosynthesis-Factors Affecting Photosynthesis

(VII) Daily variation of photosynthetic rate

1. The photosynthetic process is in line with the solar radiation process: the photosynthesis is a unimodal curve;
2. When the weather changes from time to time, the photosynthesis is a irregular curve;
3. When the solar intensity is extremely high, the photosynthesis is a bimodal curve.

Diurnal changes in xanthophyll content as a function of irradiance in sunflower (*Helianthus annuus*). As the amount of light incident to a leaf increases, a greater proportion of violaxanthin is converted to antheraxanthin and zeaxanthin, thereby dissipating excess excitation energy and protecting the photosynthetic apparatus. (Demmig-Adams & Adams 1996)



Chapter VII Photosynthesis-Factors Affecting Photosynthesis

I. Effect of internal factors on photosynthetic rate

(I) Different parts

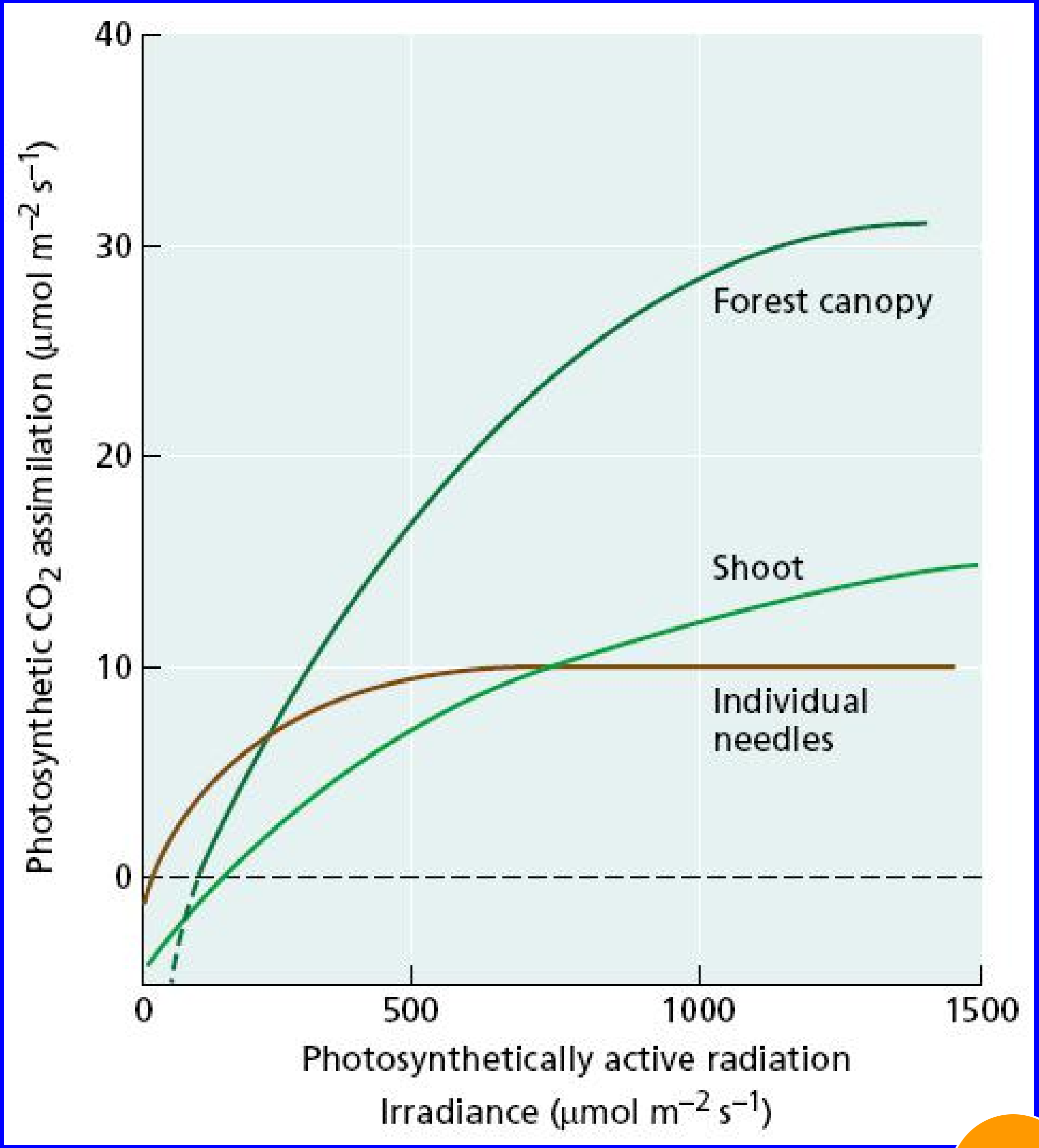
The higher the chlorophyll content is, the stronger the photosynthesis is (the mature part is strong, but the immature and aging parts are weak in photosynthesis).

(II) Different growth periods

1. Single plant - the photosynthesis in vegetative growth period is strongest, and decreases at the end of growth period.
2. Plant population - the photosynthetic rate is mainly subject to total leaf area and population structure.

Chapter VII Photosynthesis-Factors Affecting Photosynthesis

Changes in photosynthesis (expressed on a per-square-meter basis) in individual needles, a complex shoot, and a forest canopy of Sitka spruce (*Picea sitchensis*) as a function of irradiance. Complex shoots consist of groupings of needles that often shade each other, similar to the situation in a canopy where branches often shade other branches. As a result of shading, much higher irradiance levels are needed to saturate photosynthesis. The dashed line has been extrapolated from the measured part of the curve. (Jarvis & Leverenz 1983)



Chapter VII Photosynthesis - Solar Energy Utilization of Plant

I. Efficiency for solar energy utilization of plant

Efficiency for solar energy utilization

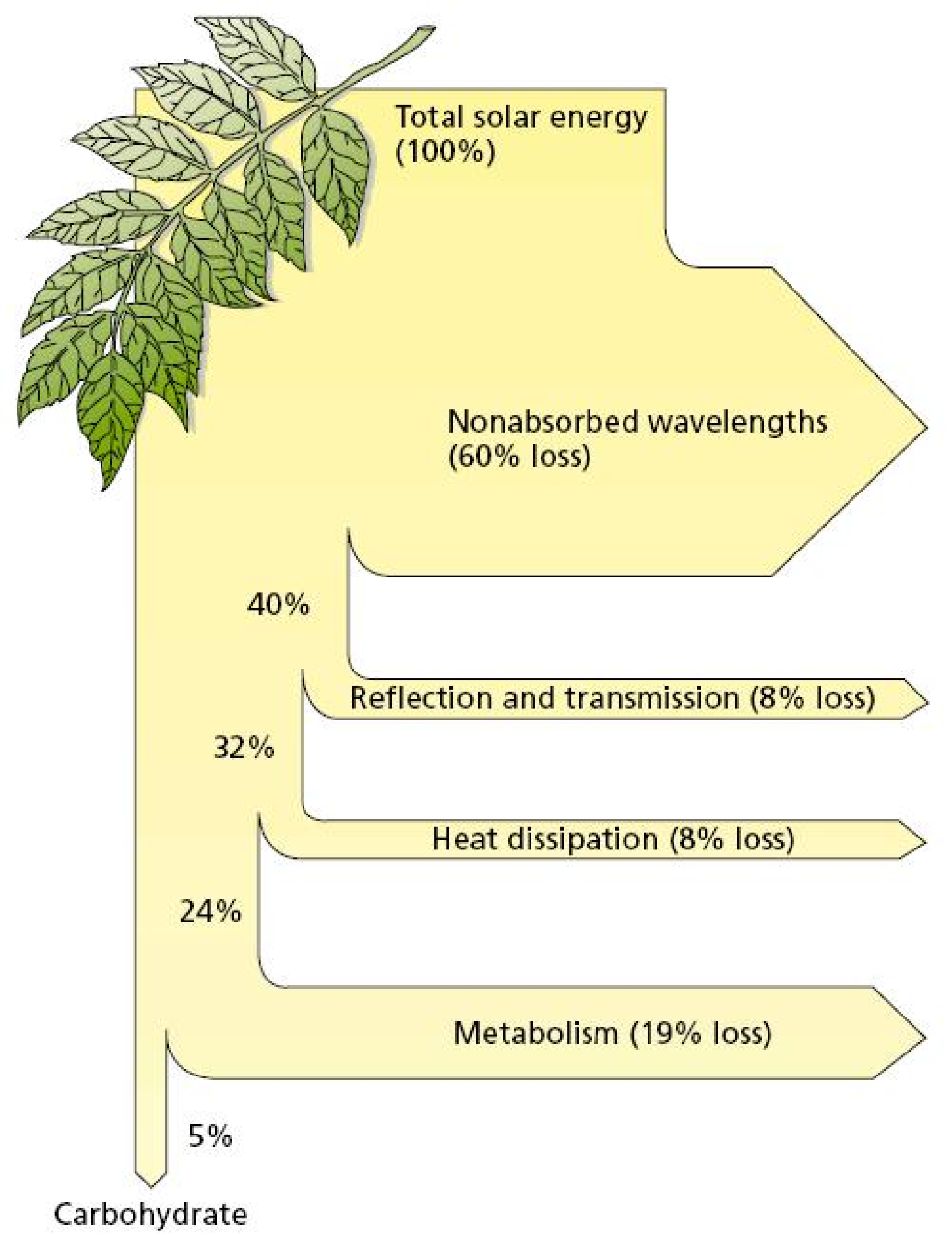
Efficiency for Solar Energy Utilization refers to the percentage of the energy contained in the organism accumulated through plant photosynthesis in the solar energy absorbed by the unit ground. Efficiency for solar energy utilization of plant is about 5%.

Solar energy absorbed by a leaf 100%

- Wavelength light which can not be absorbed, energy loss 60%
- Reflection and light transmission, energy loss 8%
- Heat dissipation, energy loss 8%
- Metabolism, energy loss 19%
- Conversion, energy converted into carbohydrate 5%

Chapter VII Photosynthesis - Solar Energy Utilization of Plant

Conversion of solar energy into carbohydrates by a leaf. Of the total incident energy, only 5% is converted into carbohydrates.



Chapter VII Photosynthesis - Solar Energy Utilization of Plant

II. Pathway to improve the efficiency for solar energy utilization

(I) Extend the photosynthetic duration

1. Improve the multiple crop index

Multiple crop index refers to the ratio of harvested land area of crops to the cultivated area in a year. The multiple crop index may be improved through crop rotation, intercropping and relay intercropping.

2. Supplement the artificial light

Fluorescent light is an ideal artificial light source.

(II) Increase the photosynthetic area

1. Reasonable compact planting

2. Changing the plant type

(III) Improve the photosynthetic efficiency

1. Increase CO_2 concentration

① Control the planting specification and fertile water, and select correct row direction based on local conditions, to ensure well ventilation in late stage.

② Apply organic fertilizer, to increase the number of soil microorganisms, so as to enhance the active energy, decompose organic matters and evolve CO_2

③Deeply apply ammonium bicarbonate as fertilizer.

2. Decrease the light respiration

① Utilize the light respiratory inhibitor (α-hydroxy sulfonic acid compound) to inhibit the light respiration, so as to improve the photosynthetic efficiency.

② Change the environmental components, especially increase CO_2 concentration.