

Photosynthesis Objectives

- Following this section, students will:
 - Understand importance of photosynthesis in plant growth
 - Be able to write the balanced equation for photosynthesis
 - Understand key components of light and dark reactions
 - Be able to describe how photosynthesis is measured
 - Understand the influence of environmental factors on photosynthesis



Initial plant weight = 1 lb
Initial soil weight = 100 lbs

After 10 years...

Plant weight = 51 lbs

Soil weight = ?

a. 50 lbs

b. 100 lbs

c. between 75 - 85 lbs

d. slightly less than 100 lbs

A photograph of a dense forest with tall, thin trees. Sunlight filters through the canopy, creating a dappled light effect. The text is centered in the middle of the image.

**>95% of plant dry
weight biomass comes
from photosynthesis**

Why study photosynthesis?

- Ultimate basis of energy in all biological systems
- All food and fiber produced on earth is ultimately due to photosynthesis
- Increasing interest in plants as sinks for carbon

Why study photosynthesis?

- All organic compounds needed for plant growth (proteins, lipids, starches, sugars) are derived from the products of photosynthesis
- Therefore, any abiotic or biotic factor that limits photosynthesis will ultimately limit plant growth and survival

Photosynthesis: balanced reaction



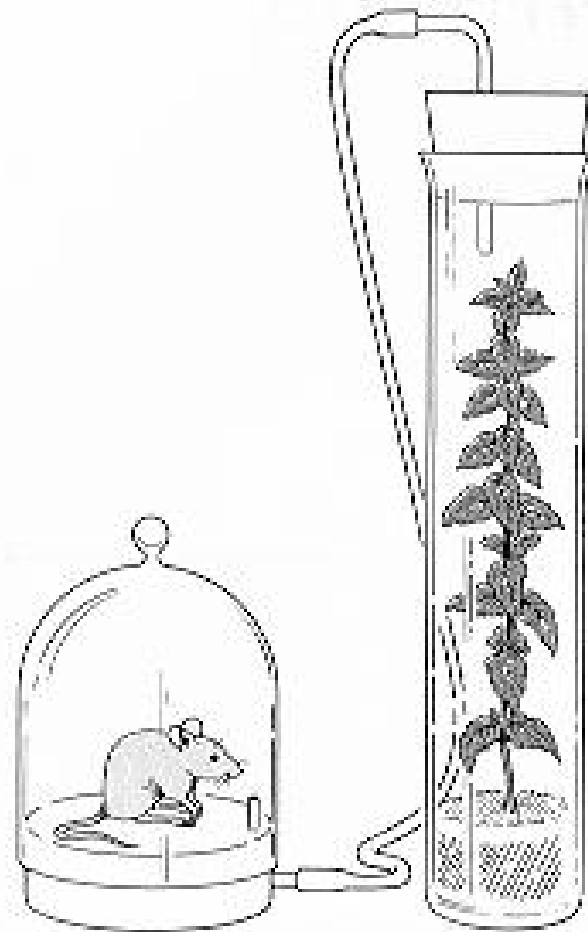
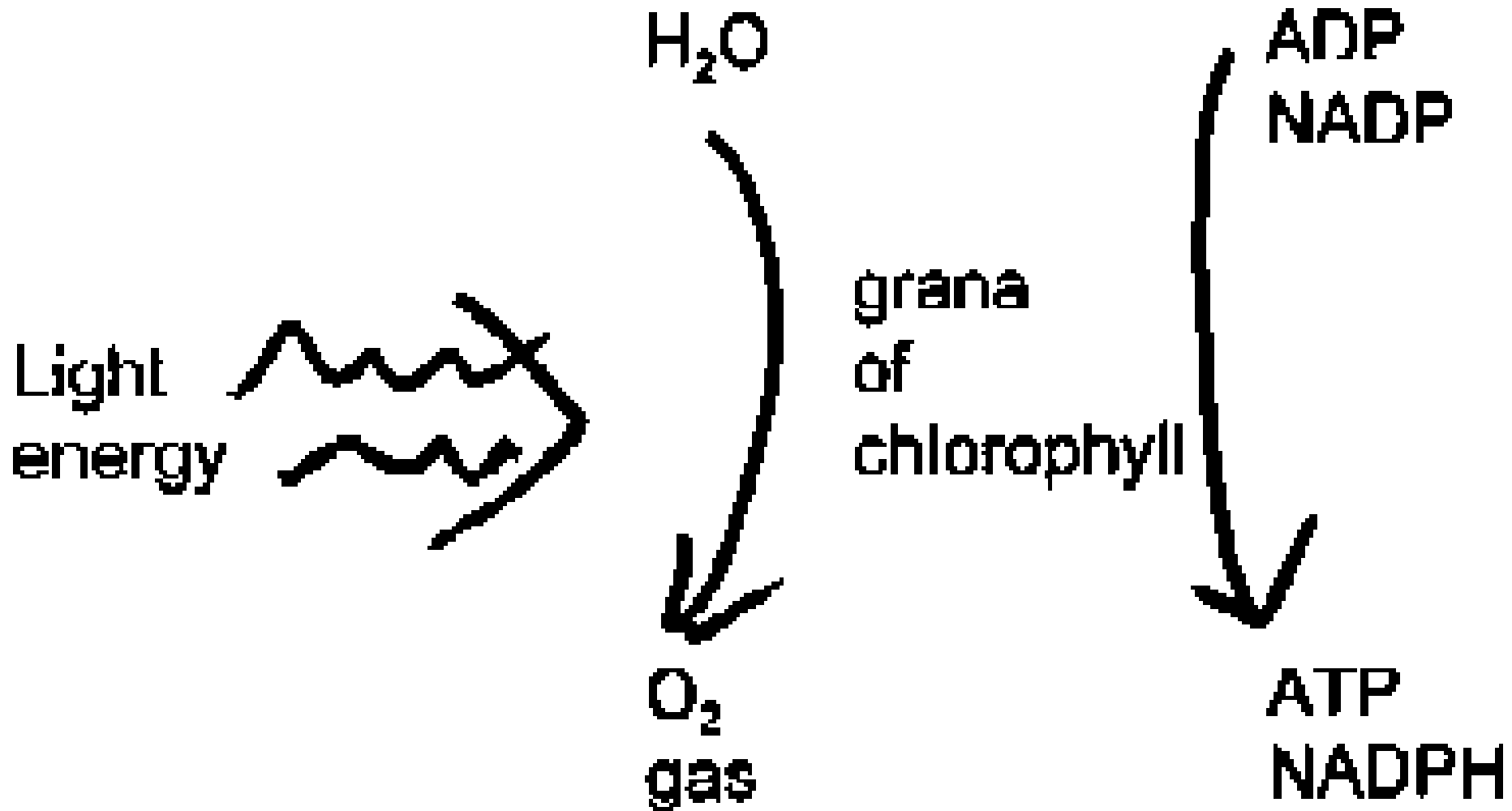


Figure 19-2
Priestley's classic experiment on photosynthesis. [After E.I. Rabinowitch. Photosynthesis. Copyright © 1948 by Scientific American, Inc. All rights reserved.]

Photosynthesis

- Two reactions
- Light
 - Light dependent
- Dark
 - Light independent



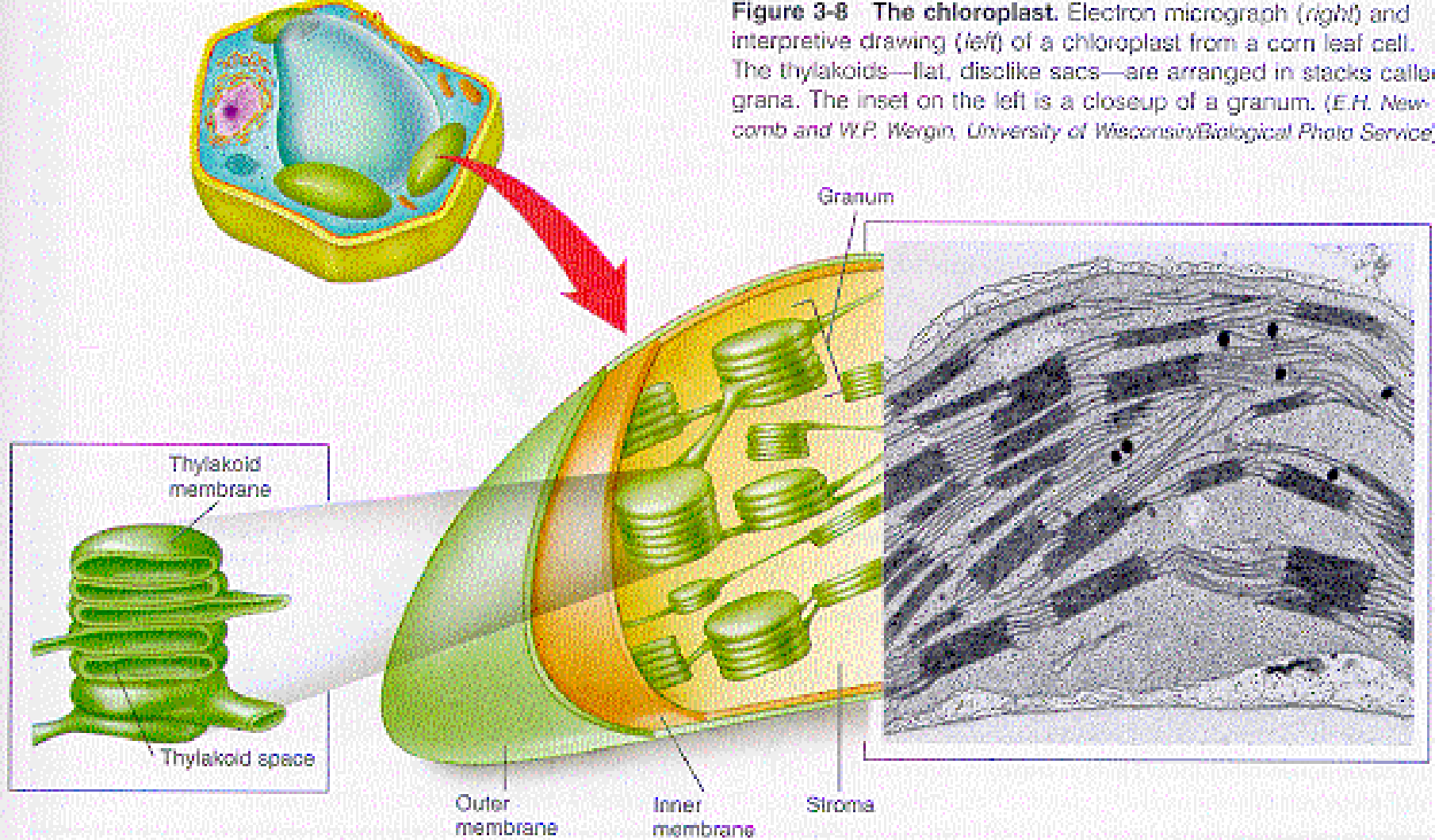
Light reaction

- Light energy absorbed by chlorophyll
- Traps energy in form of ATP
- Splitting of water (releases O_2)
- Additional energy stored in NADPH

Dark reactions (Calvin cycle)

- Cyclic process
- Uses energy stored as ATP and NADPH in light reactions
- CO₂ molecule combines with 5-carbon sugar to form two 3-carbon molecules (C-3 photosynthesis)
- 3-carbon molecules are joined to form 6- carbon sugar (glucose)

Figure 3-8 The chloroplast. Electron micrograph (right) and interpretive drawing (left) of a chloroplast from a corn leaf cell. The thylakoids—flat, disclike sacs—are arranged in stacks called grana. The inset on the left is a closeup of a granum. (E.H. Newcomb and W.P. Wergin, *University of Wisconsin/Biological Photo Service*)



Chloroplasts

- Site of photosynthetic reactions
- Chloroplasts are a membrane system
- Contain chlorophyll
- Made up of:
 - Thylakoid membranes - stacked into grana
 - Stroma

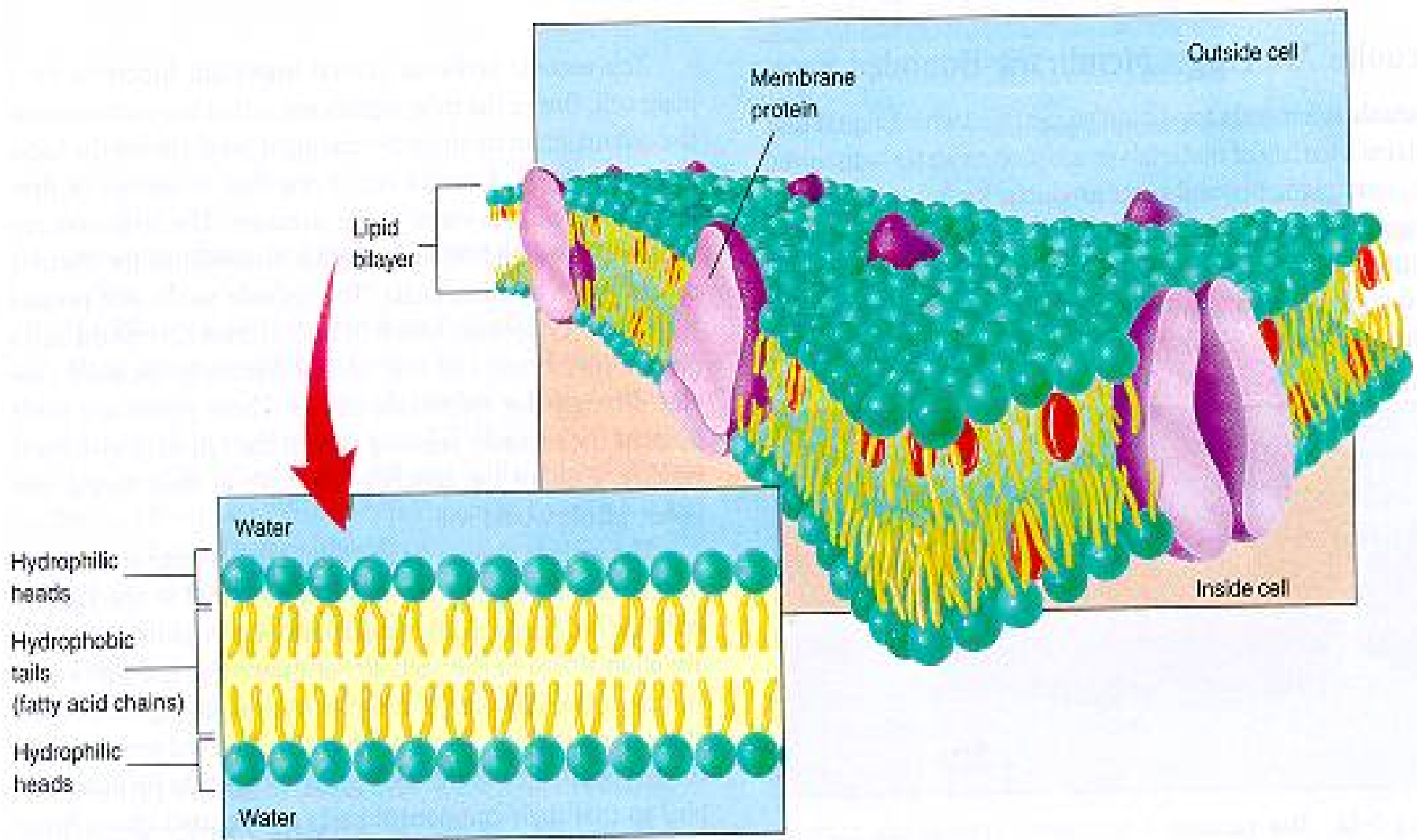


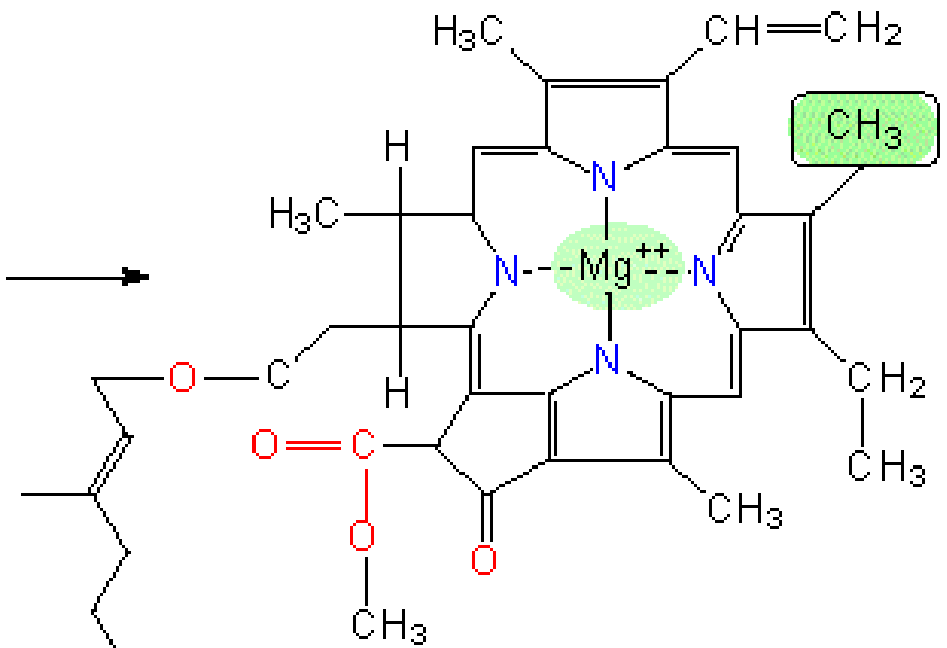
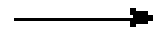
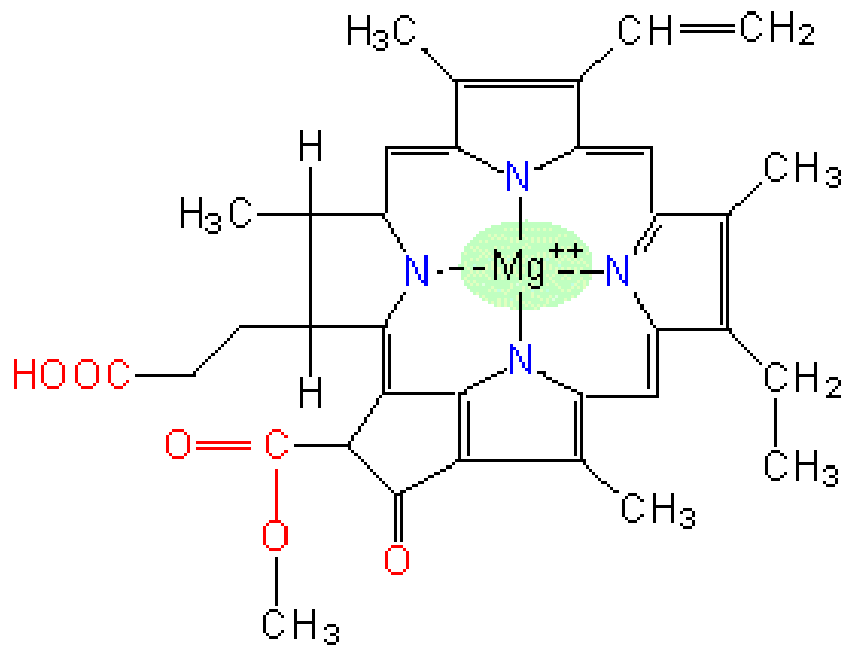
Figure 3-13 Structure of a membrane. The fluid mosaic model describes membranes as consisting of a lipid bilayer in which are embedded a number of proteins. (*Inset*) A phospholipid bilayer forms in watery surroundings. The hydrophilic heads point outward toward the watery surroundings, and the hydrophobic tails point inward so that they are not exposed to the water. In diagrams of phospholipid bilayers, the hydrophilic heads are usually represented by circles and the hydrophobic tails by two lines.

Plant Pigments

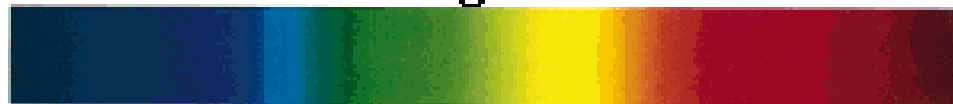
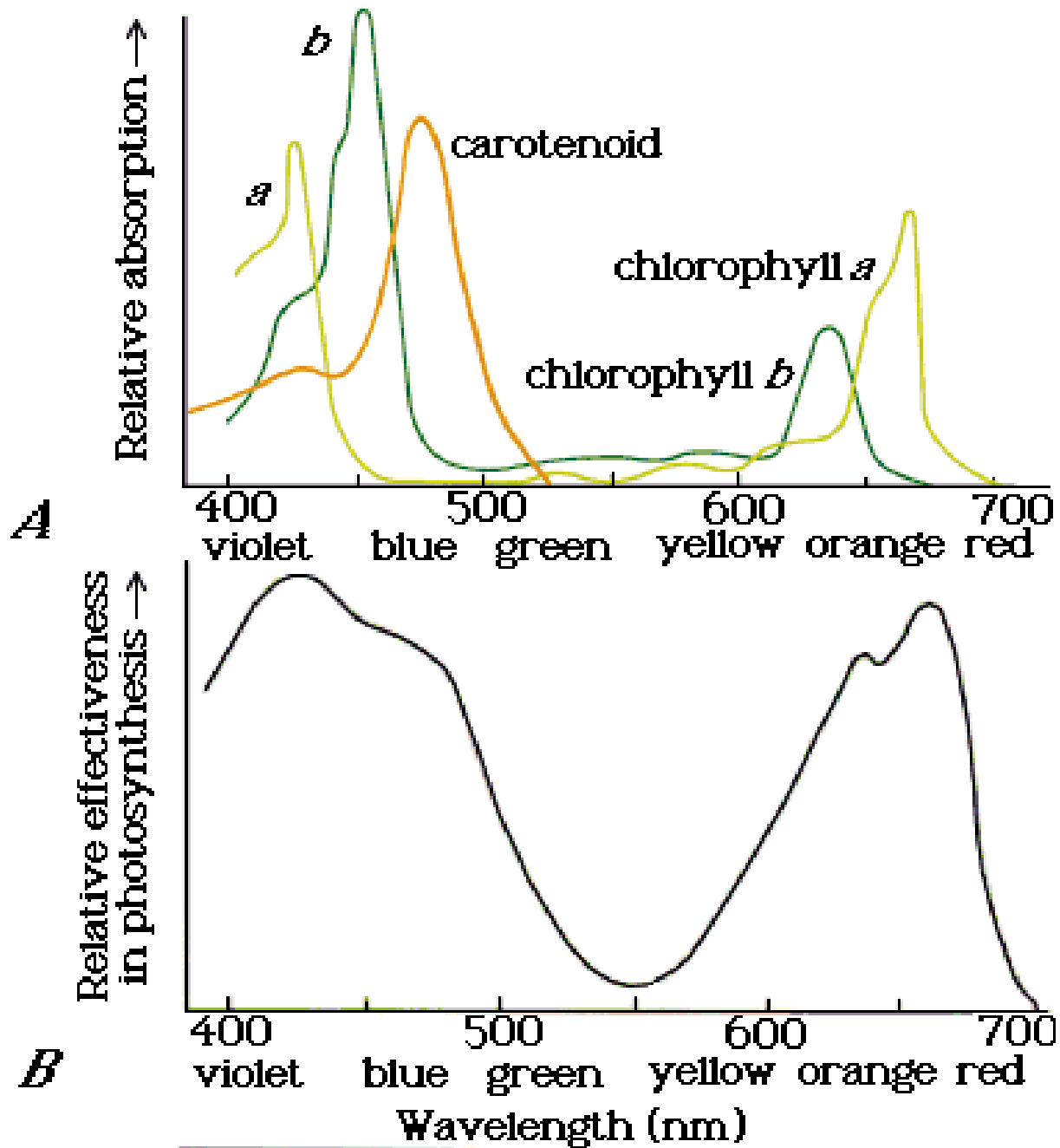
- Chlorophylls
- Carotenoids
 - Carotenes
 - Xanthophylls
- Anthocyanins



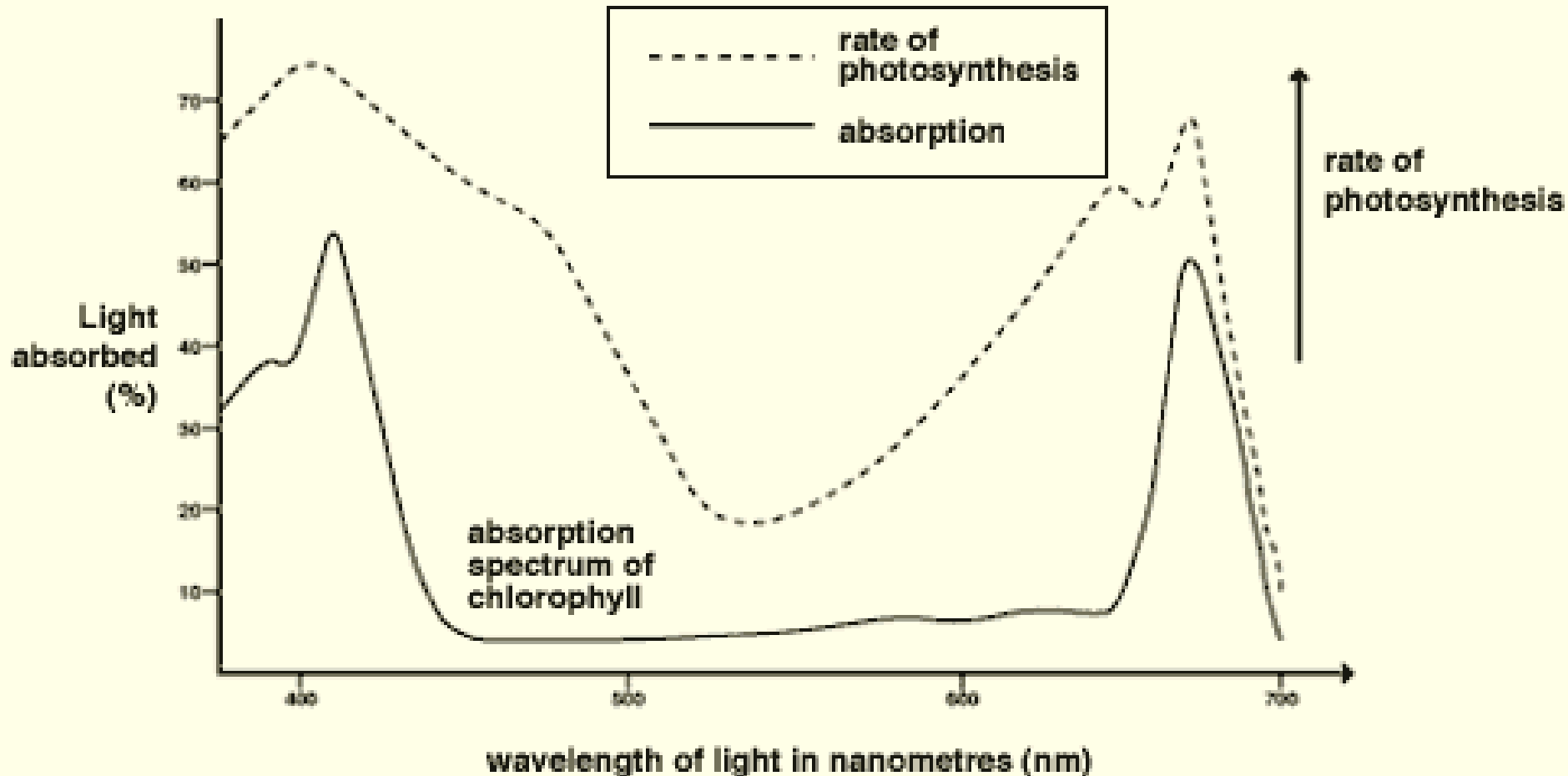
Photosynthetic pigments



chlorophyll b: -CHO



Chlorophyll action spectrum

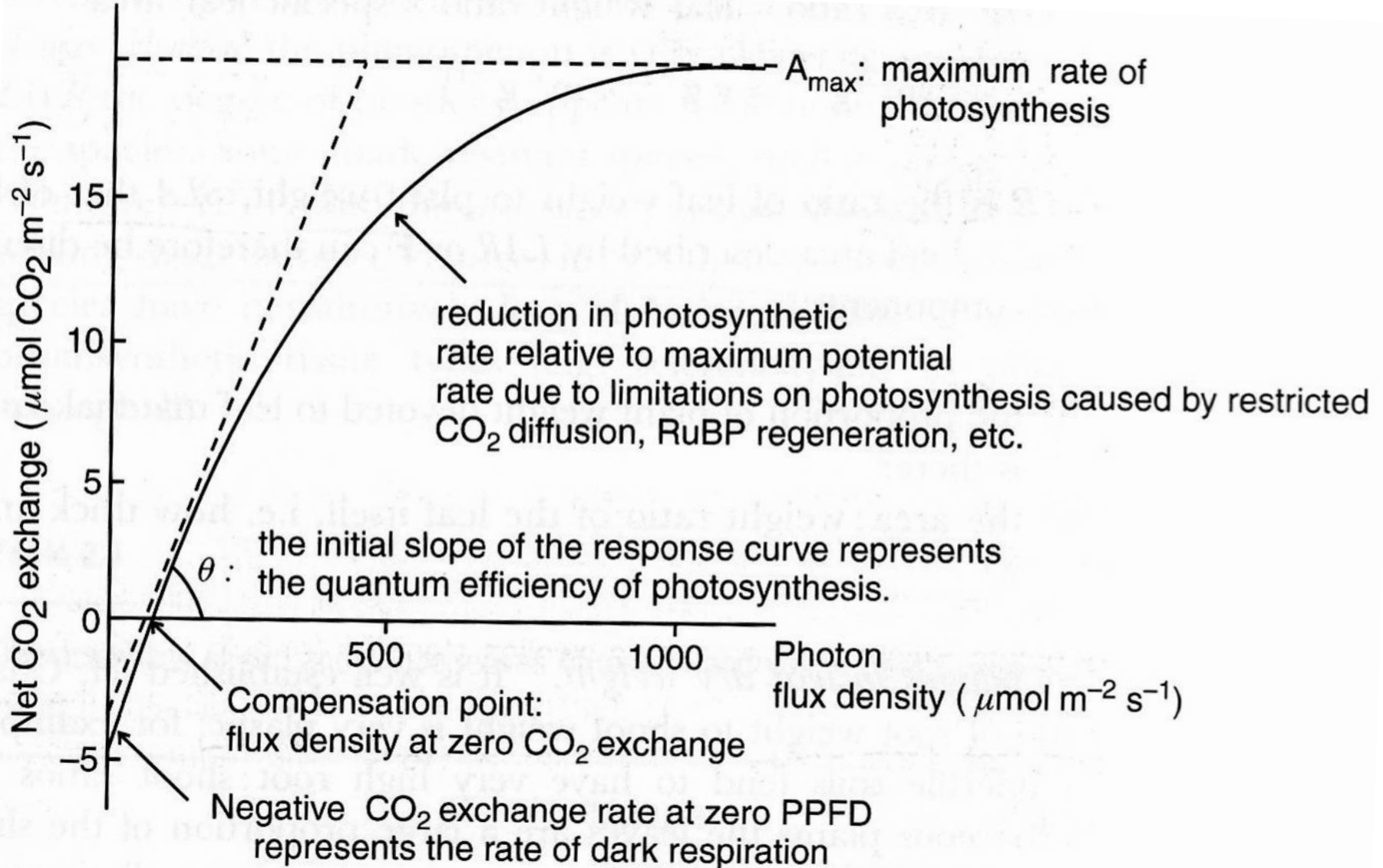


Light Quantity

- Instantaneous
- Cumulative – Daily Light Integral

Effect of light quantity: Photosynthetic light response curve

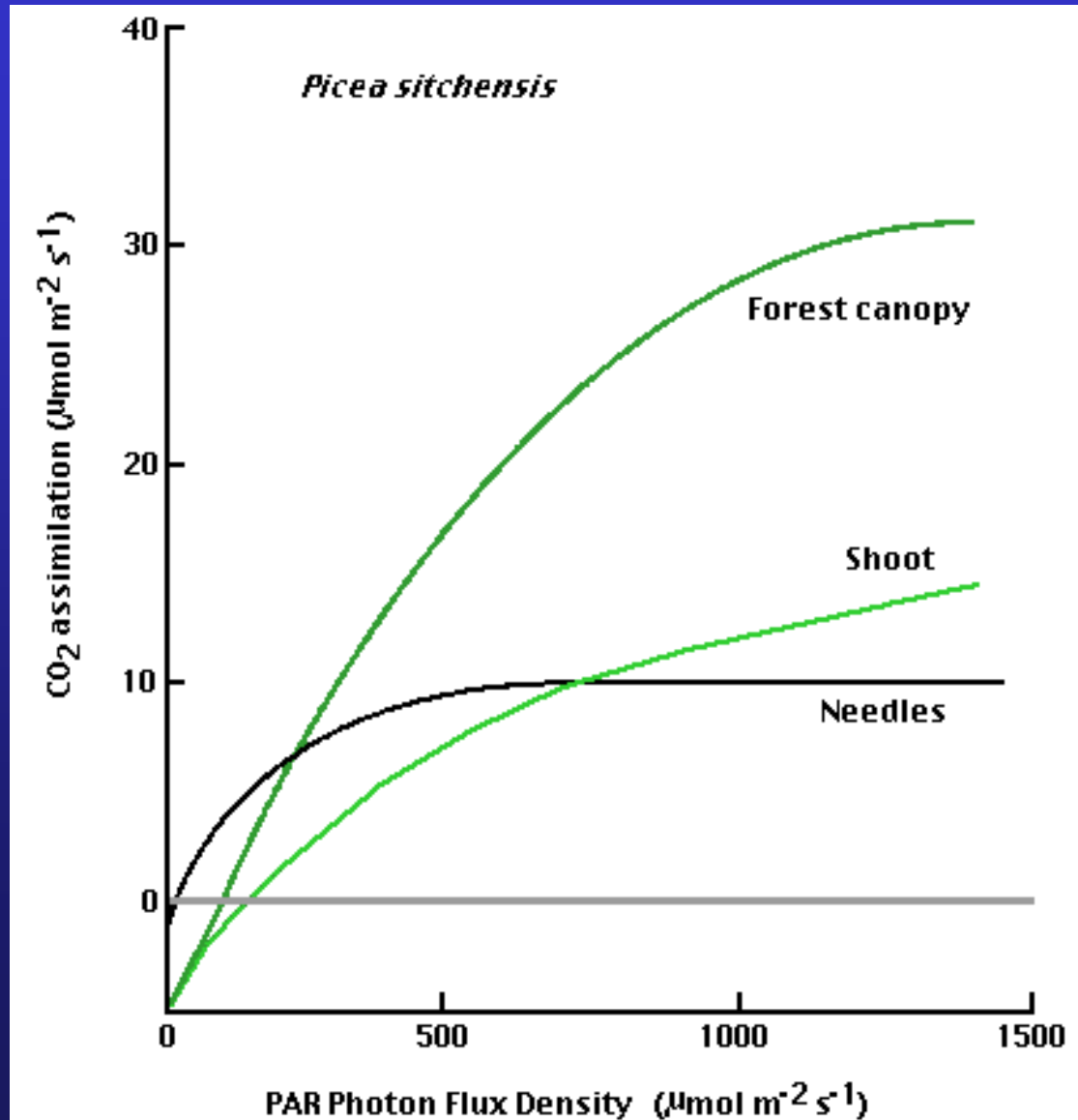
Photosynthetic Light Response Curves



Photosynthetic light response curves

- Dark respiration rate (Daytime respiration rate)
 - Net photosynthetic (P_n) rate when irradiance is 0
- Light compensation point
 - Irradiance level at which $P_n = 0$
- Light saturation point
 - Irradiance level where P_n is maximal
- Quantum yield
 - Slope of the linear phase of the curve
 - moles of CO_2 fixed per mole photons absorbed

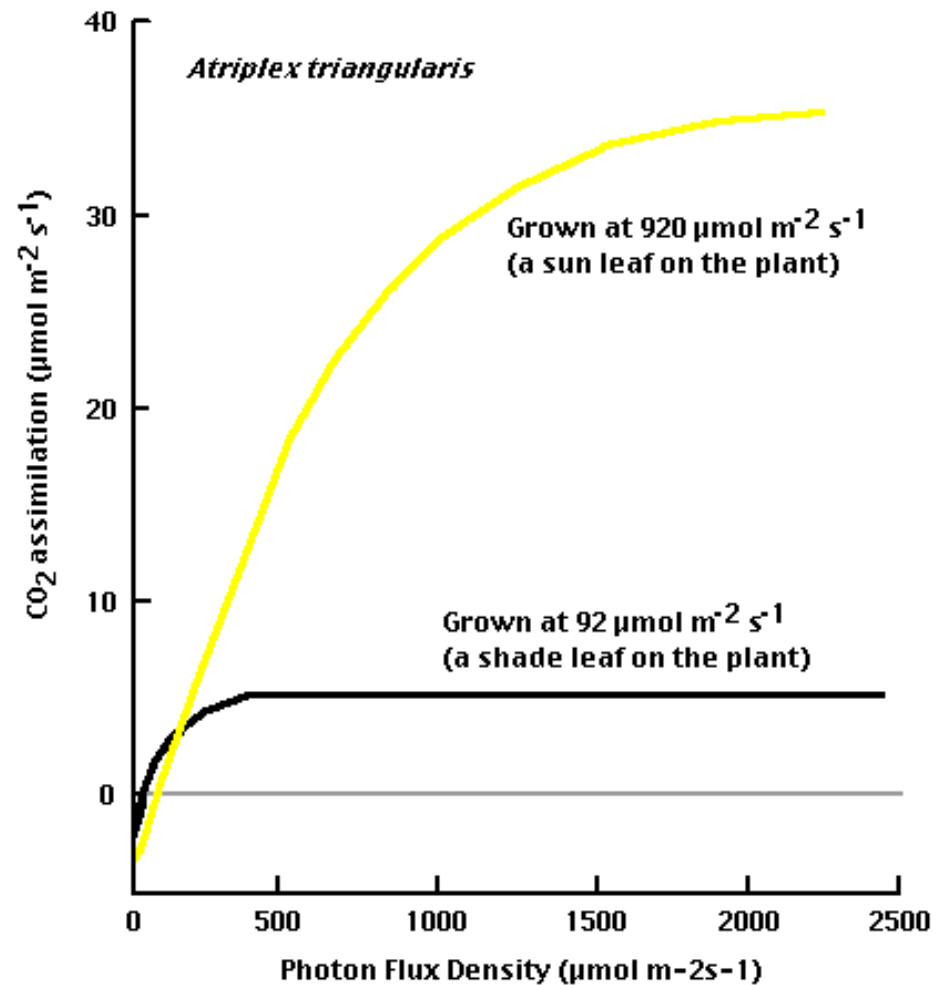
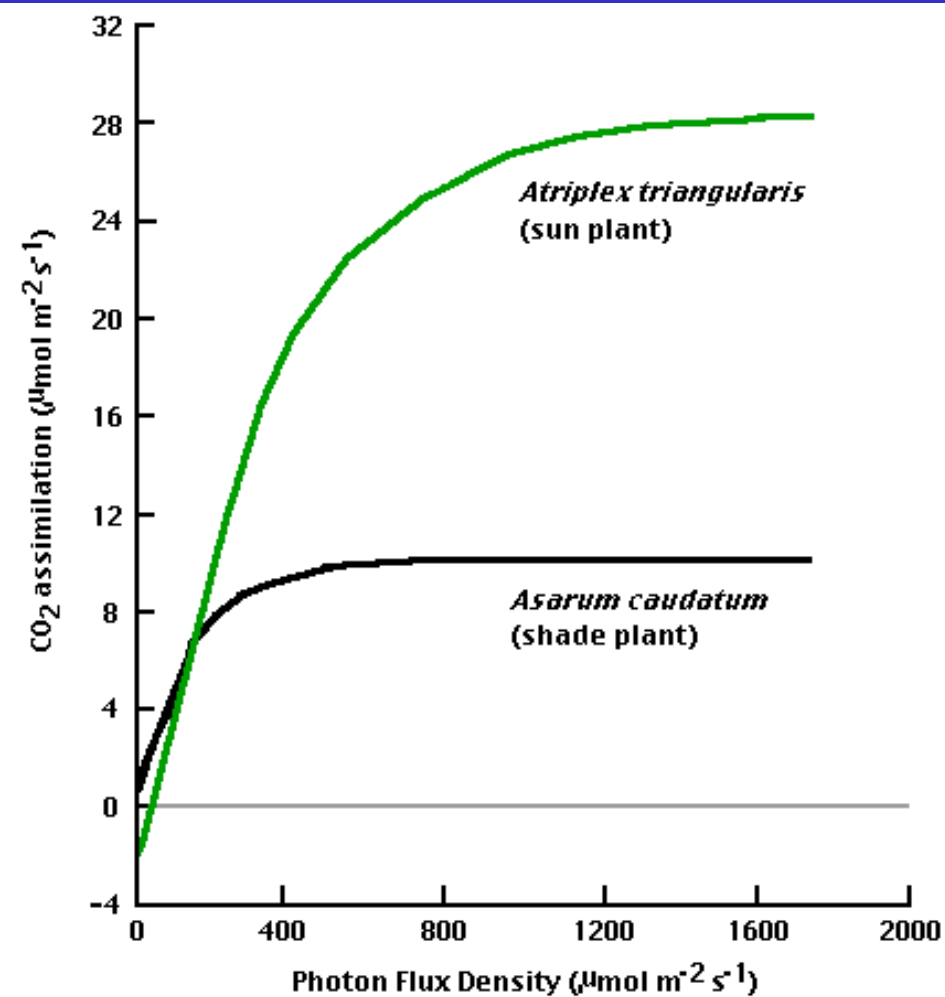
Leaf-level vs. higher level P_n measurements



Photosynthetic Light Response Curves

- Genetic vs. plastic differences.
- The shape of the curve is determined by three variables:
 1. Leaf area per unit mass – an increase provides greater surface area for PAR absorption.
 2. Respiration and photorespiration: a decrease lowers the compensation point.
 3. The capacity of the photosynthetic system
 - Primarily RUBISCO levels

Genetic vs. Plastic Differences



Leaf Area

Table 2.4

Characteristics of sun and shade leaves of mature and young beech trees *Fagus sylvatica* (Skene, 1924)

	Mature		Young	
	Sun leaves	Shade leaves	Sun leaves	Shade leaves
Leaf thickness (μm)	210	108	117	90
Number of palisade layers	2	1–2	1–2	1
Thickness of upper palisade layer (μm)	60	28	39	24

Leaf Morphology

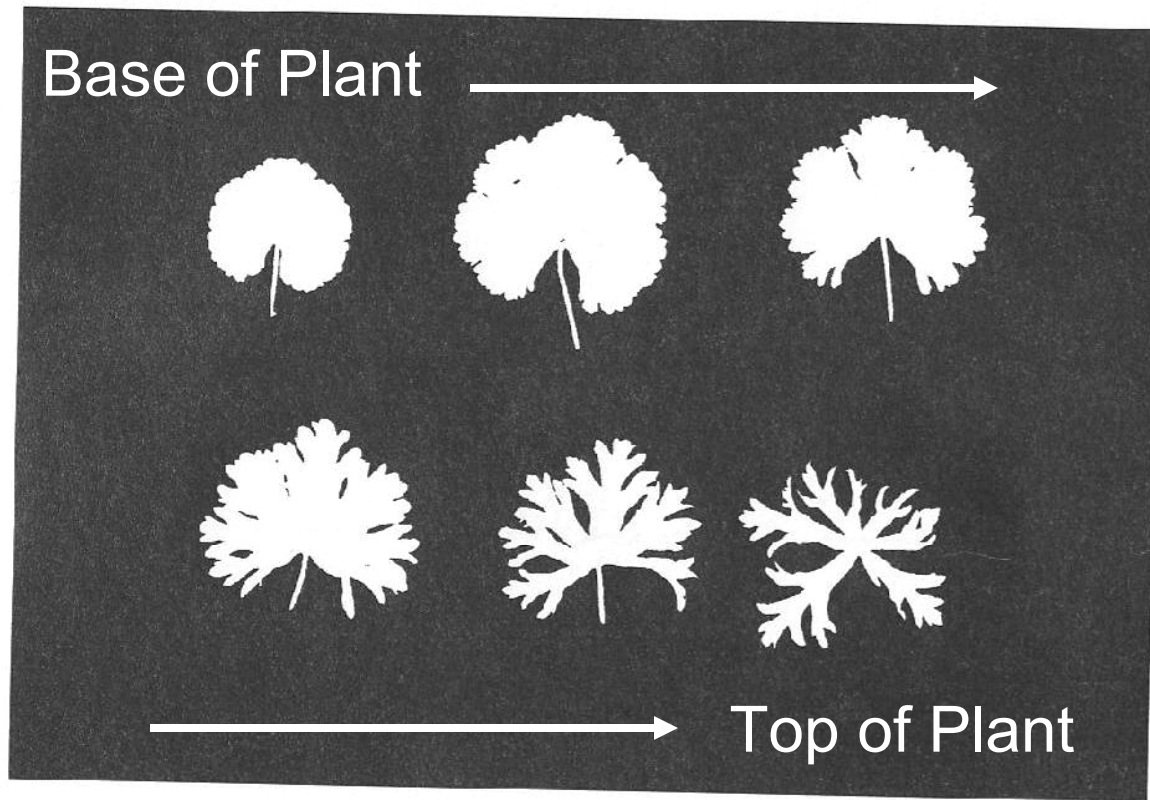


Figure 2.13

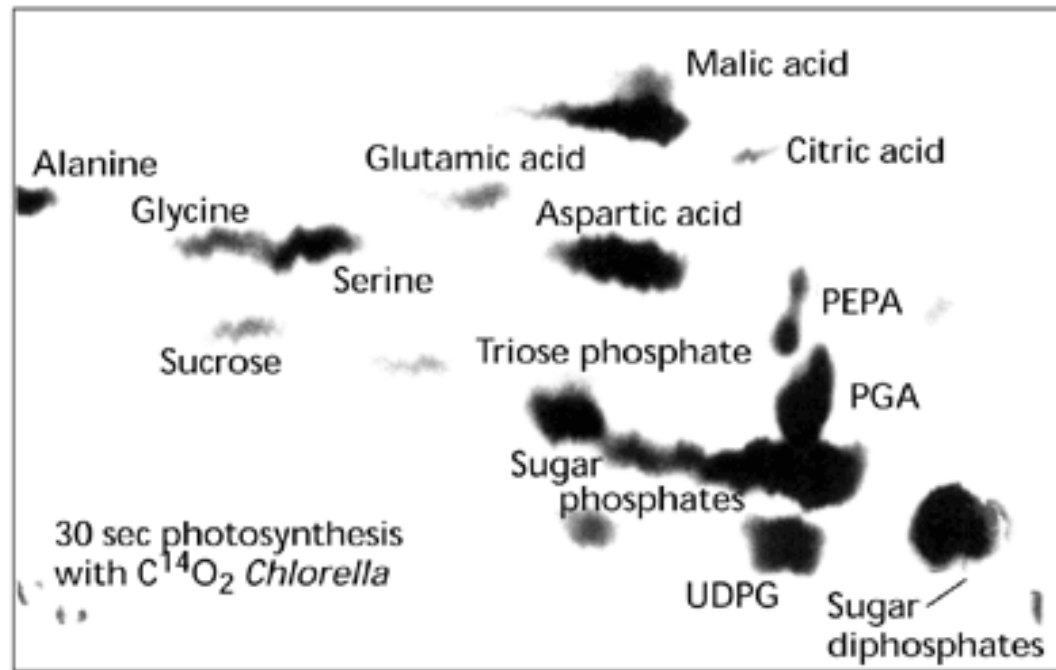
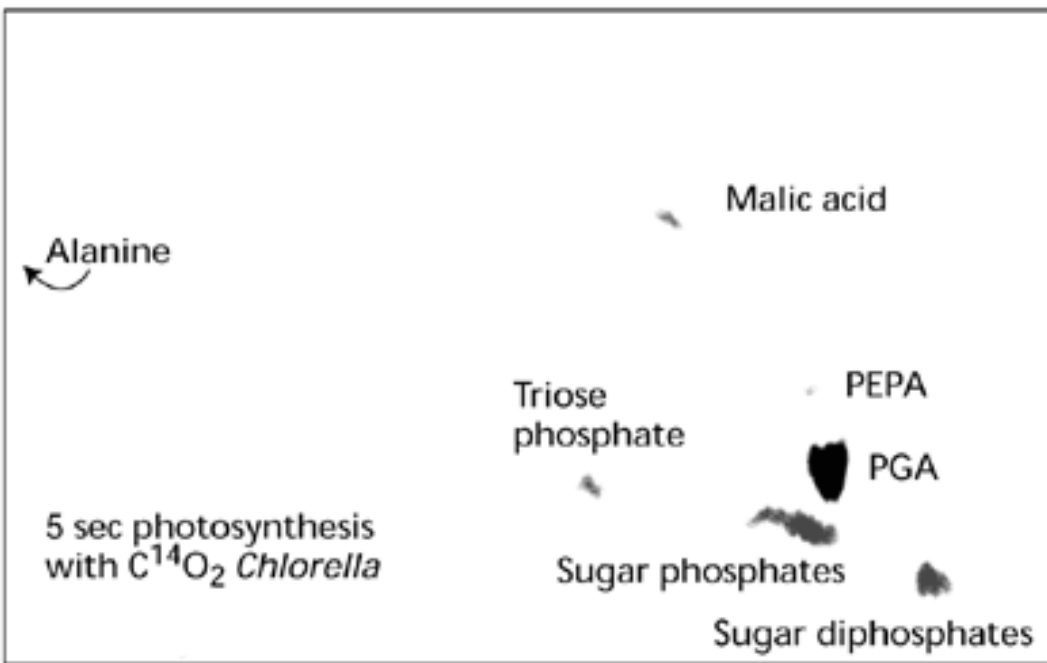
Silhouettes of successive leaves from base to top of a stem of musk mallow *Malva moschata*, showing the progressive increase in leaf dissection

Representative values of A_{\max}

Species	A_{\max} ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
<i>Populus deltoides</i>	8.0-15.9
<i>Populus trichocarpa</i>	10.0-22.0
Hybrid (<i>t x d</i>)	18.0-23.0
<i>Pinus taeda</i>	5.0-6.3
<i>Pinus sylvestris</i>	3.0-6.7
<i>Pinus contorta</i>	2.0-3.2

Dark reactions (Calvin cycle)

- Uses energy stored as ATP and NADPH in light reactions
- CO₂ molecule combines with 5-carbon sugar to form two 3-carbon molecules (C-3 photosynthesis)
- 3-carbon molecules are joined to form 6- carbon sugar (glucose)



RUBP carboxylase (RUBISCO) is a key enzyme in photosynthesis

- Most abundant protein on earth
- Also acts as an oxygenase
- Photorespiration (uses O_2)

Calvin cycle summary

- 5 carbon compound (RUBP) combines with CO_2 to produce 3-C compound (3-PGA)
- Uses energy from light reactions in the form of ATP and NADPH
- Key enzyme is RUBP-carboxylase

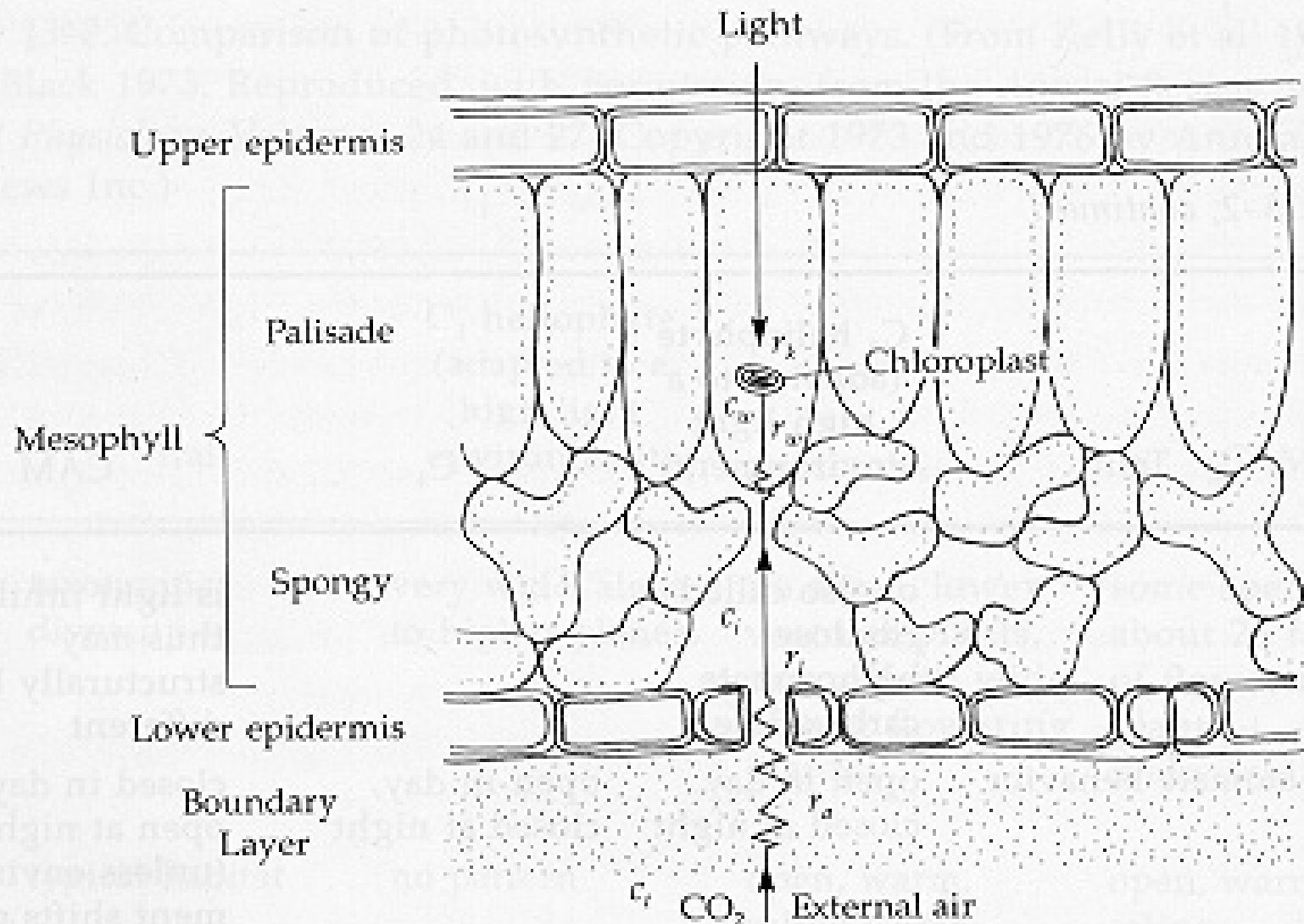


Figure 13-11. Transport pathway, transport resistances, and concentration gradients in a photosynthesizing leaf. See text for definition of terms.

How do we measure photosynthesis?







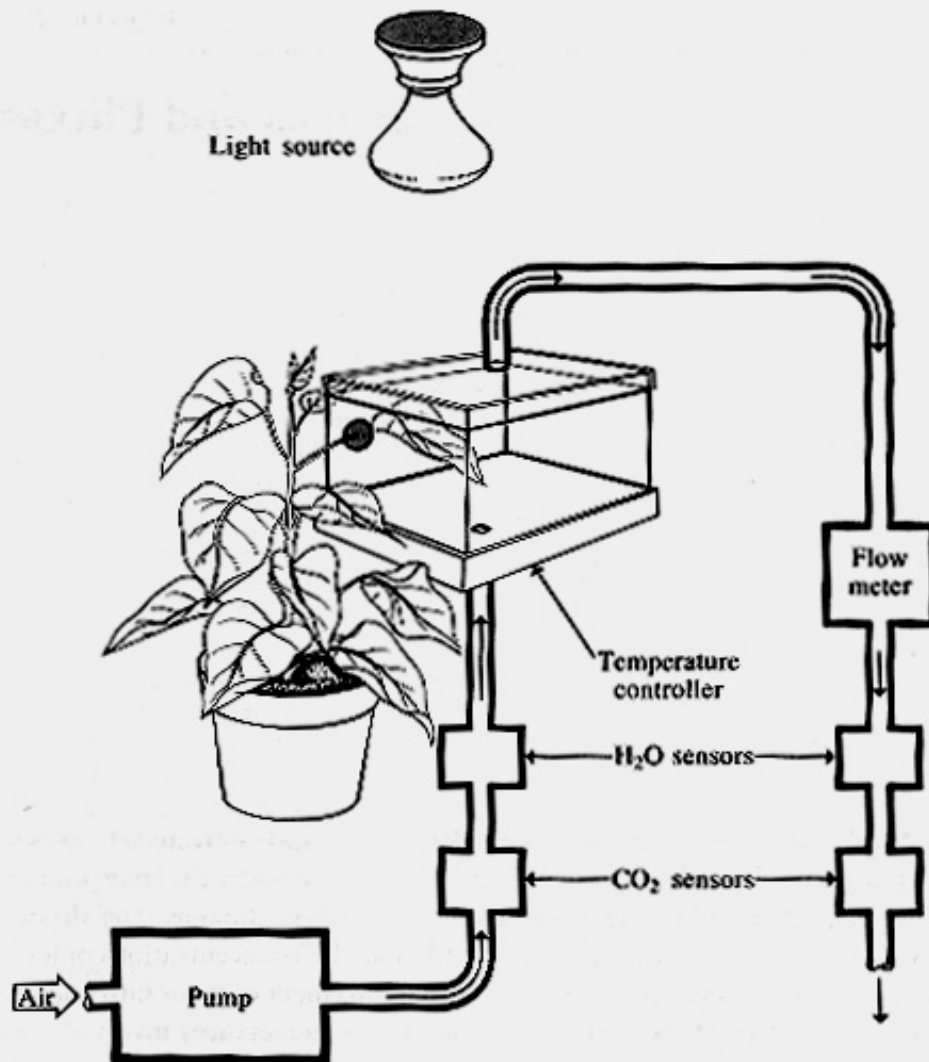


Figure 8.1

Experimental arrangement for the measurement of leaf transpiration and photosynthesis. The water vapor and CO₂ content of the gas entering a transparent chamber enclosing a leaf is compared with that leaving. If the water vapor concentration goes from 0.6 mol m⁻³ entering to 1.0 mol m⁻³ leaving for a gas flow rate of 10⁻⁵ m³ s⁻¹ (10 cm³ s⁻¹), then J_w for a leaf of area 10⁻³ m² (10 cm²) would be $(1.0 \text{ mol m}^{-3} - 0.6 \text{ mol m}^{-3})(10^{-5} \text{ m}^3 \text{ s}^{-1})/(10^{-3} \text{ m}^2)$, or 0.004 mol m⁻² s⁻¹.



What determines photosynthetic productivity?

- **Environmental factors**
- **Internal control**

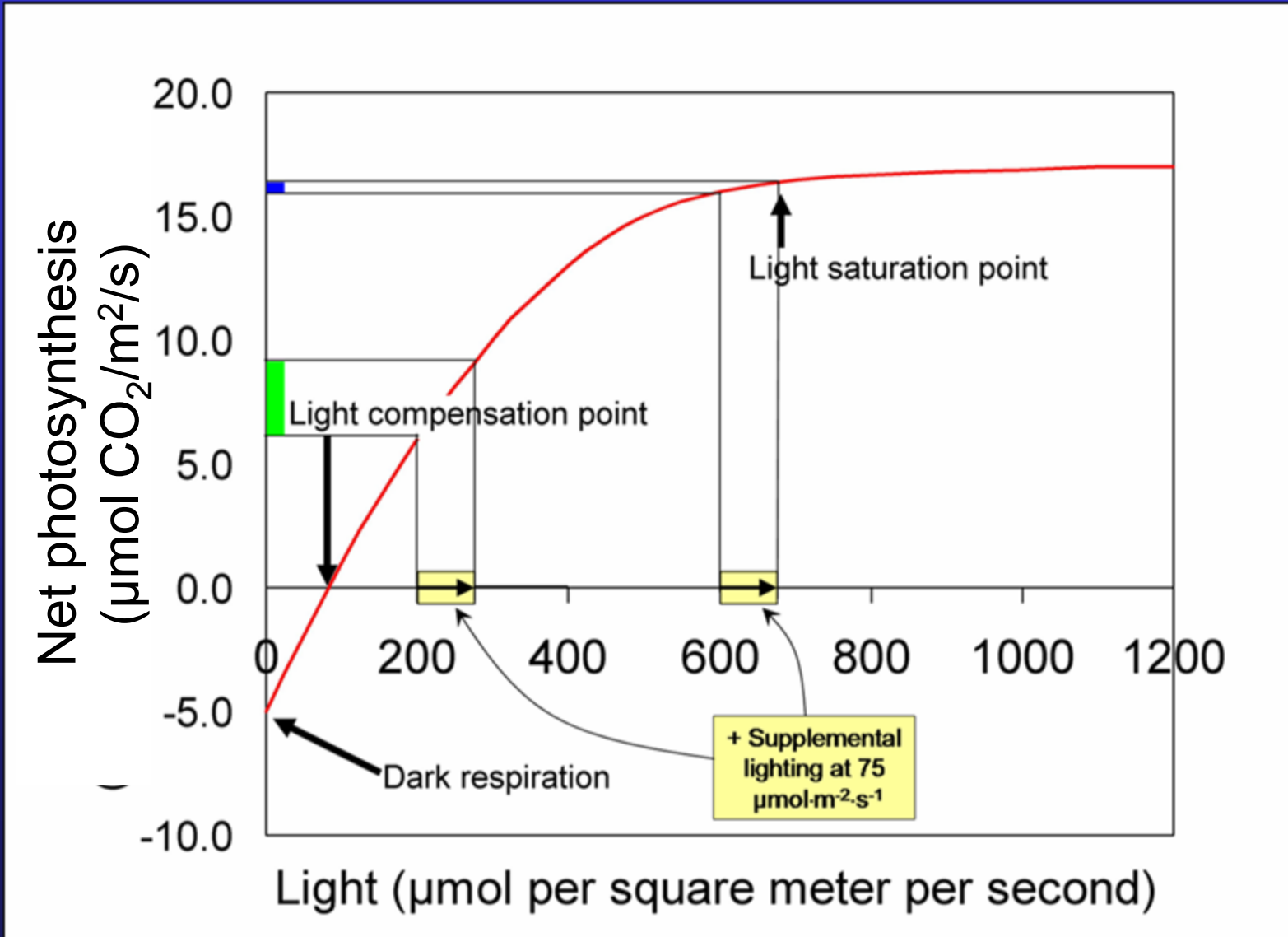
What determines photosynthetic productivity?

- **Environmental factors**
- **Internal control**

Environmental factors that limit photosynthesis

- Light
- Water
- Temperature
- Nutrition
- CO₂

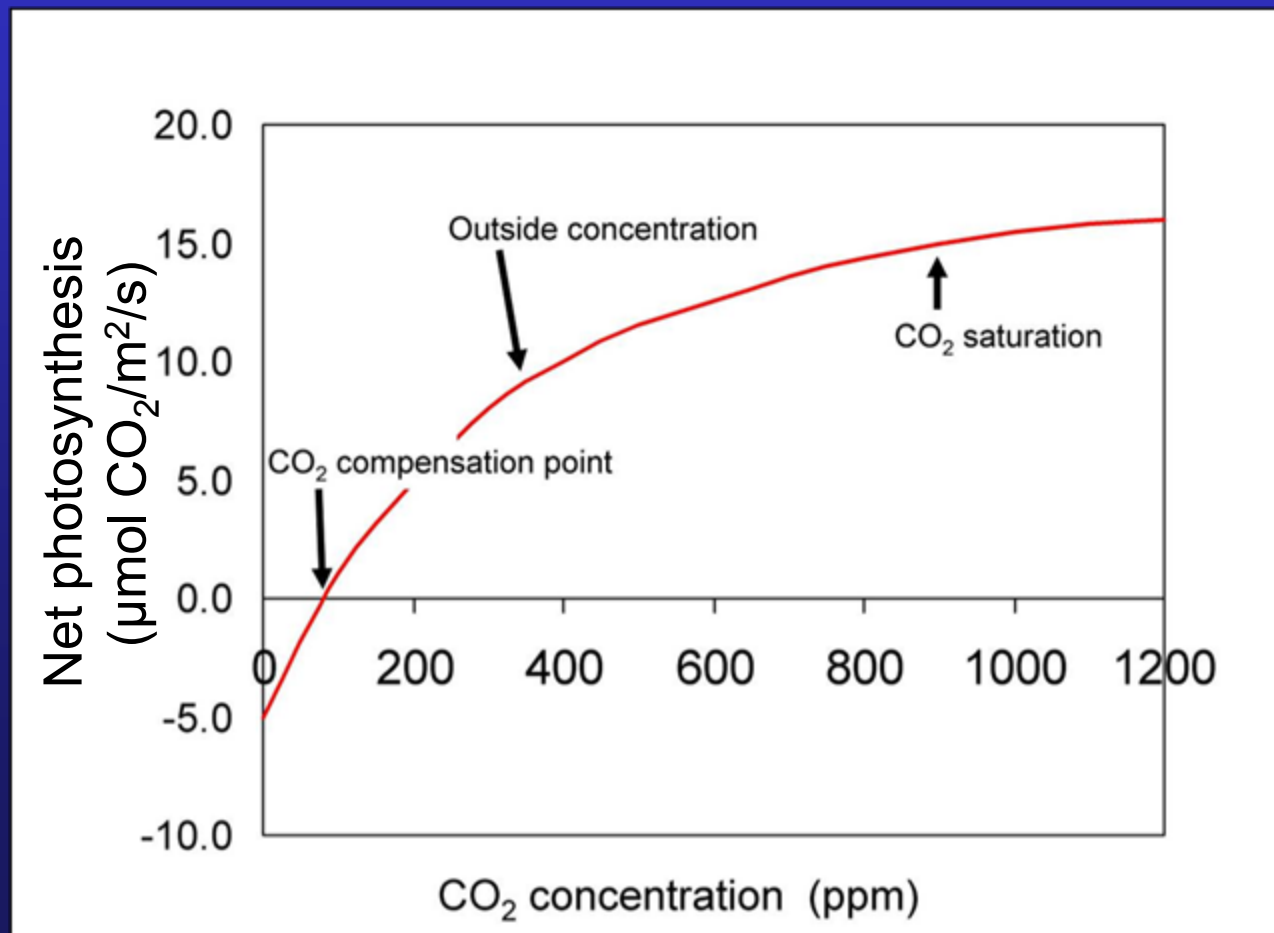
- Supplemental lighting is most effective when the sunlight level is low. This is because of the “diminishing returns” shape of the response curve. (from *Lighting Up Profits*)



2. Photosynthesis

2.2 Environmental factors: Carbon dioxide

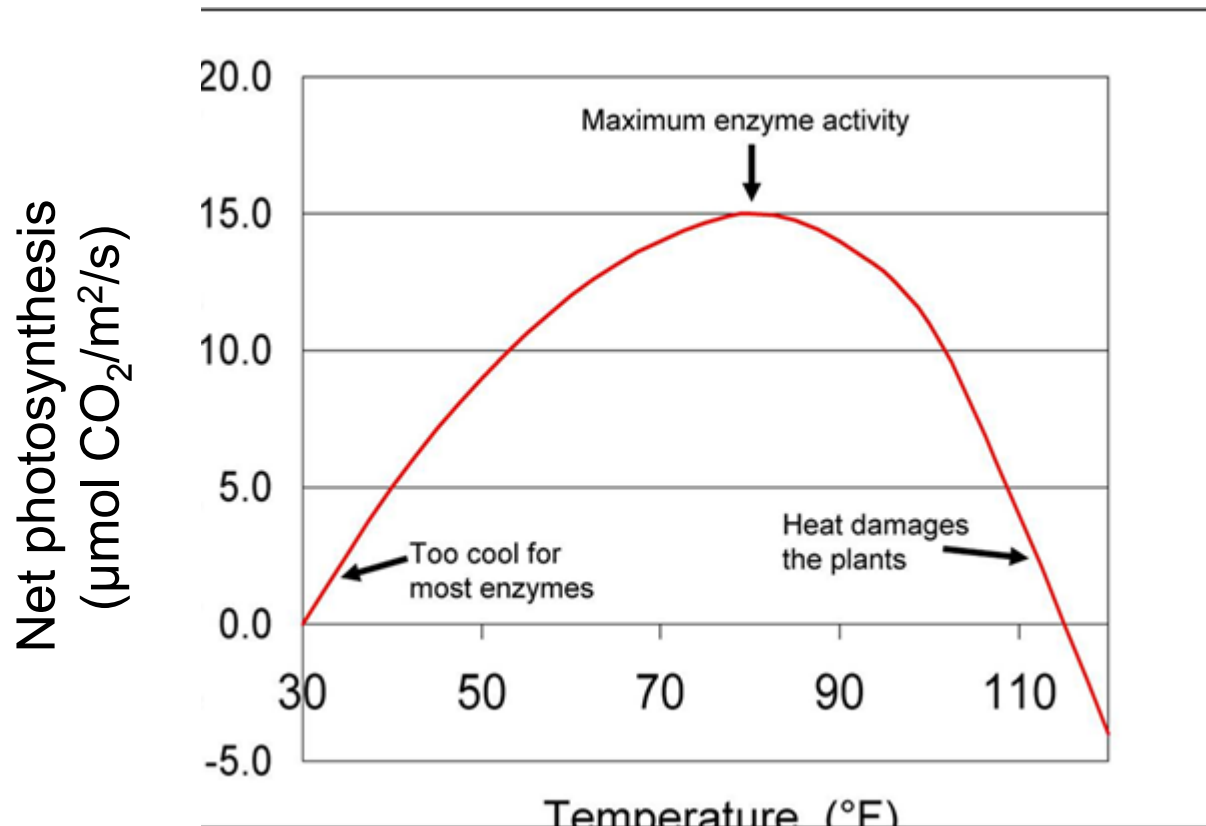
- As CO₂ increases to ≈ 900 ppm, photosynthesis rate increases. (from *Lighting Up Profits*)



2. Photosynthesis

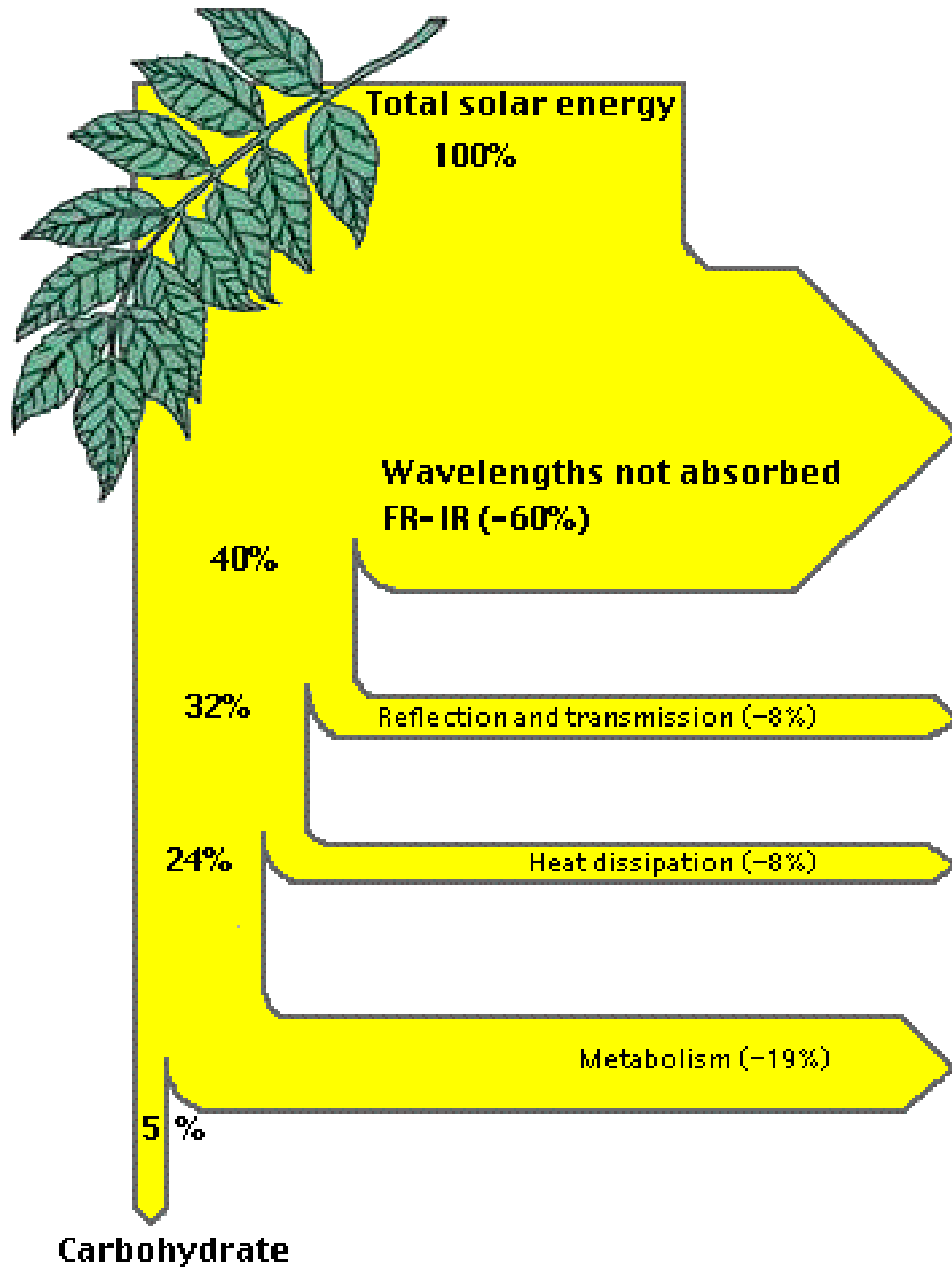
2.2 Environmental factors: Temperature

- Metabolic processes, including photosynthesis, increase to some optimum temperature.
- At low temperature, enzymes are not active.
- At high temperature, plant damage may occur.



How efficient is the conversion of light energy to plant tissue?

- Four major factors:
 - PPF absorption efficiency
 - Photosynthetic efficiency
 - Respiration efficiency
 - Harvest index

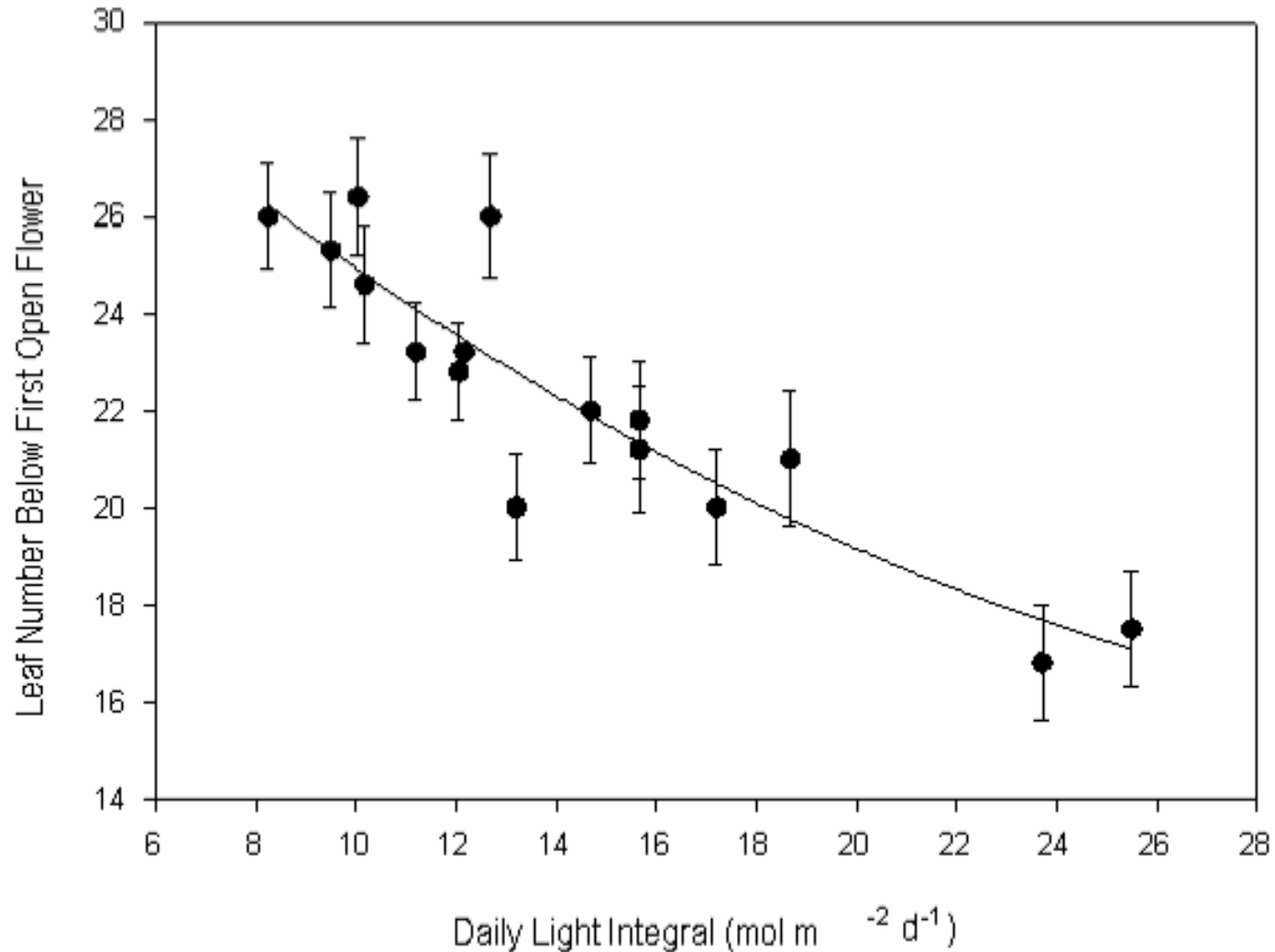


Daily Light Integral and Crop Quality

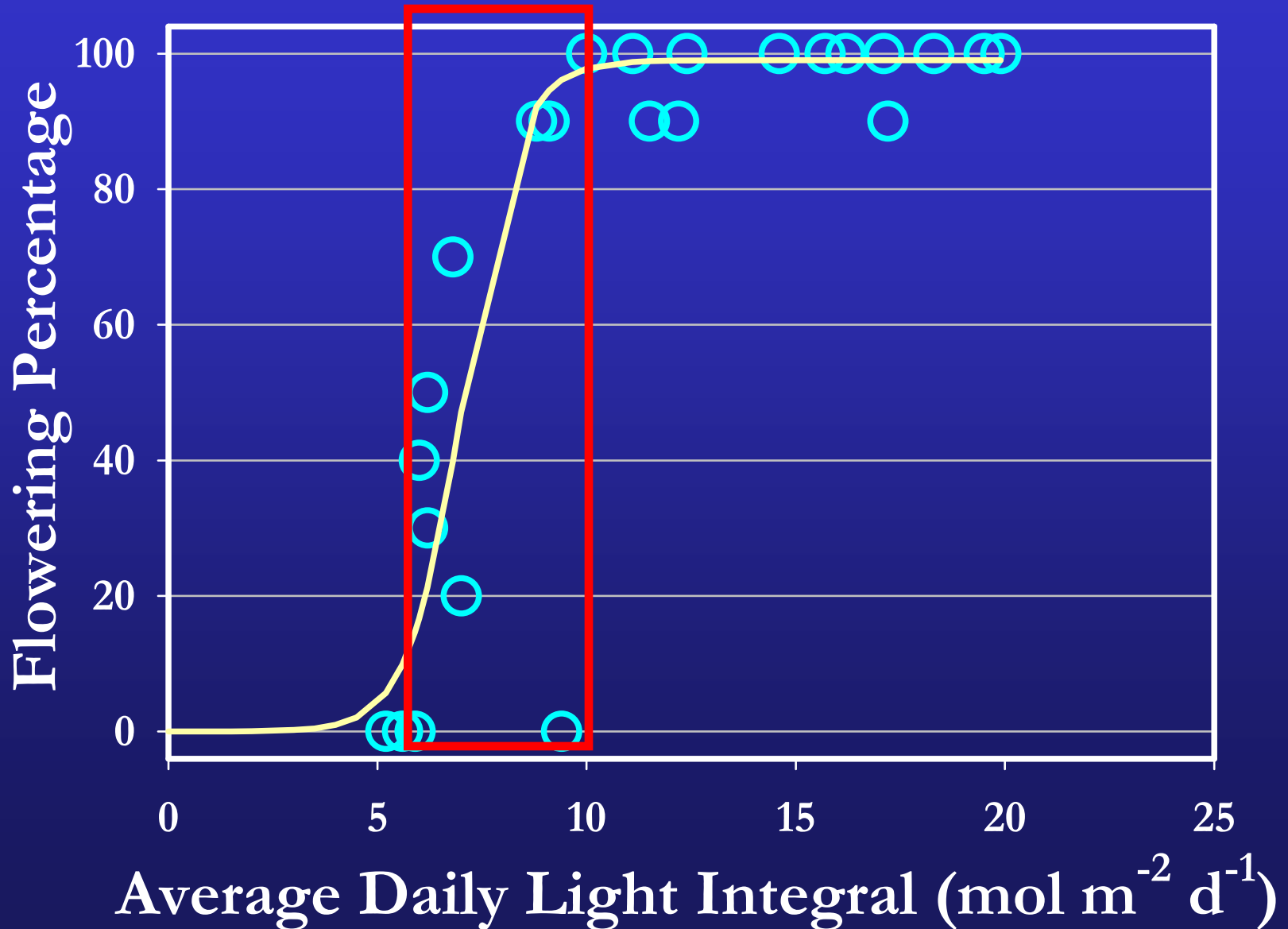
- DLI influences:
 - Flower induction
 - Flowering percentage
 - Flower number
 - Flower size
 - Branching
 - Plant height
 - Growth – shoot and root

DLI and Flower Induction

Hibiscus cisplatinus flowers earlier as total daily light increases



Digitalis purpurea 'Foxy'



Diascia 'Flying Colors Coral'

68 °F



5.3 mol m⁻² d⁻¹



15.5 mol m⁻² d⁻¹

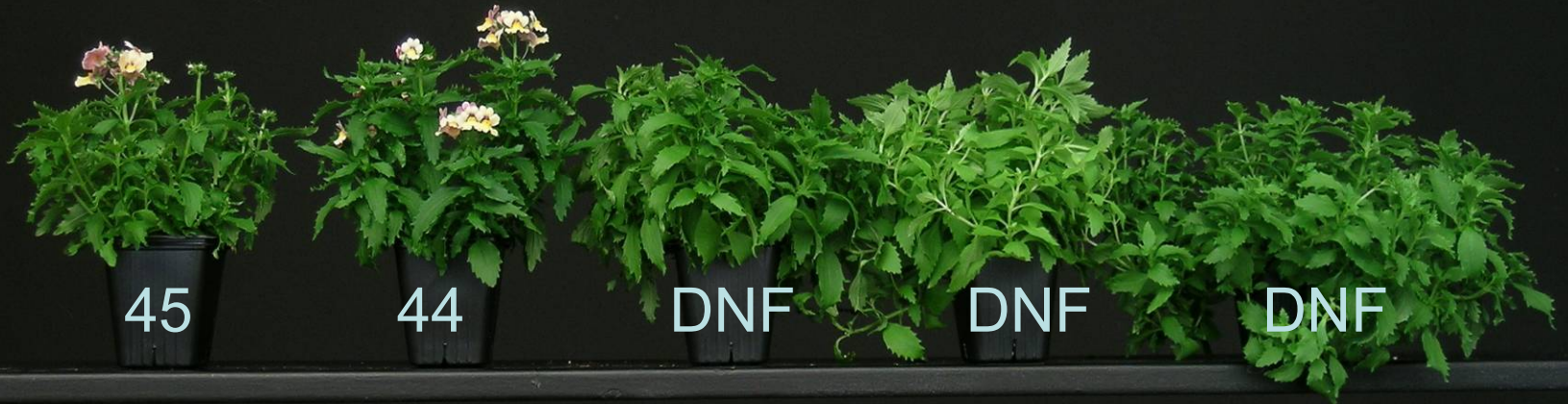
Nemesia 'Sunsatia Peach'

Days to Flower

15.5 mol m⁻² d⁻¹



5.3 mol m⁻² d⁻¹



57

62

68

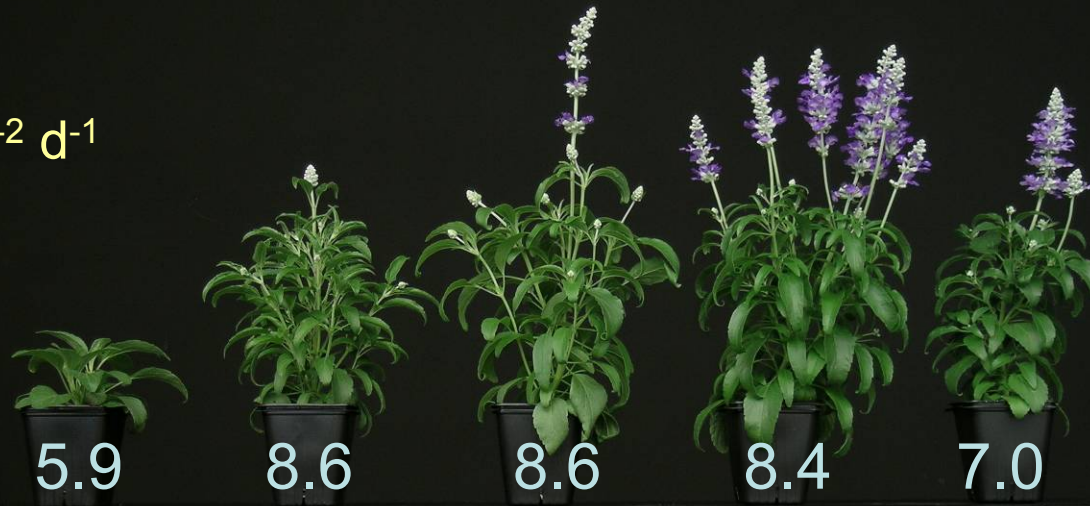
73

79 °F

Salvia farinacea 'Strata'

Lateral Inflorescences

15.5 mol m⁻² d⁻¹



5.3 mol m⁻² d⁻¹



Tagetes patula 'Bonanza Yellow'

Daily Light Integral ($\text{mol} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$):

24

20

10

57 °F



68 °F

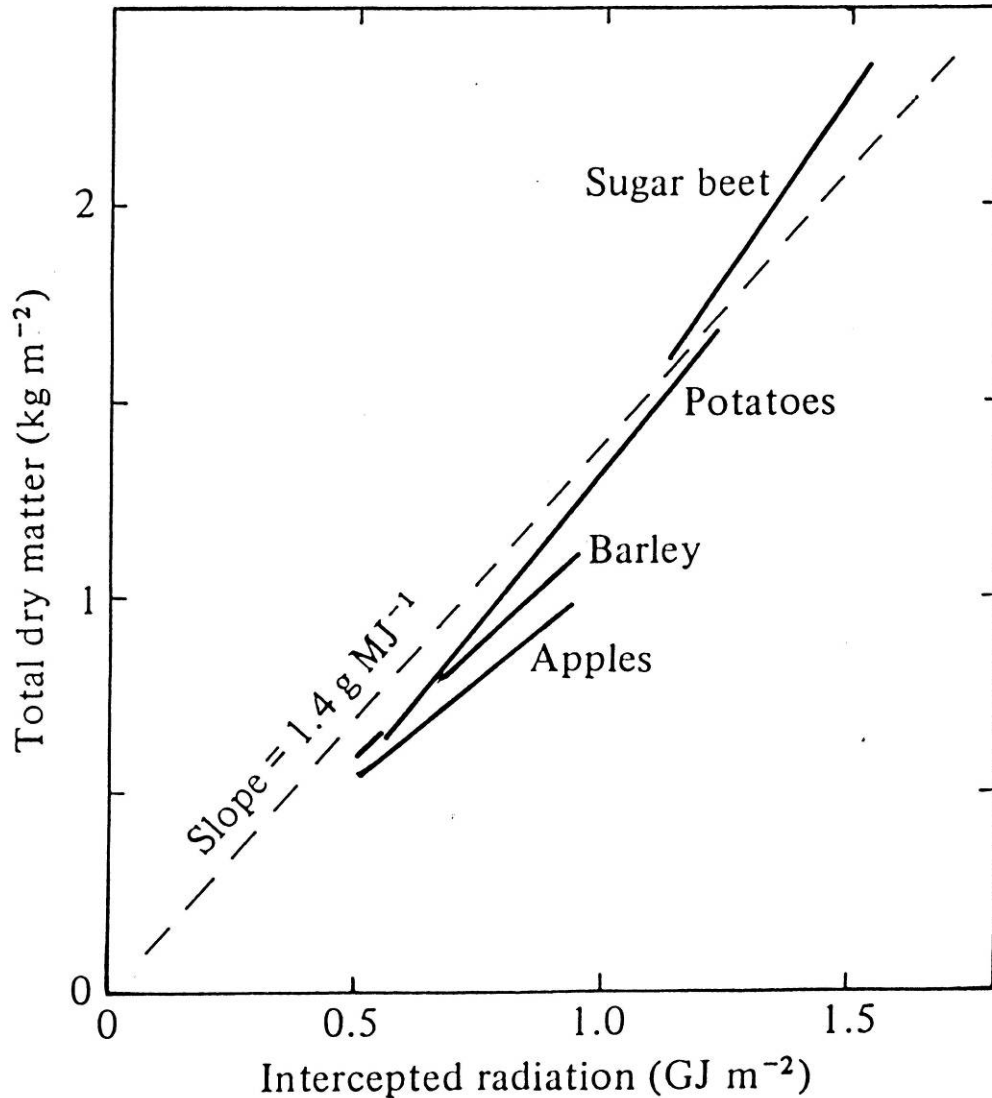


79 °F



— = 1 inch

Daily Light Integral



1 GJ = 1000 MJ

1 MJ = 2 mol

1.4 g MJ⁻¹ = 2.8 g mol⁻¹

DLI ($\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$):

4

7

14

Celosia



Marigold

What determines photosynthetic productivity?

- Environmental factors
- **Internal control**

Source-sink relations

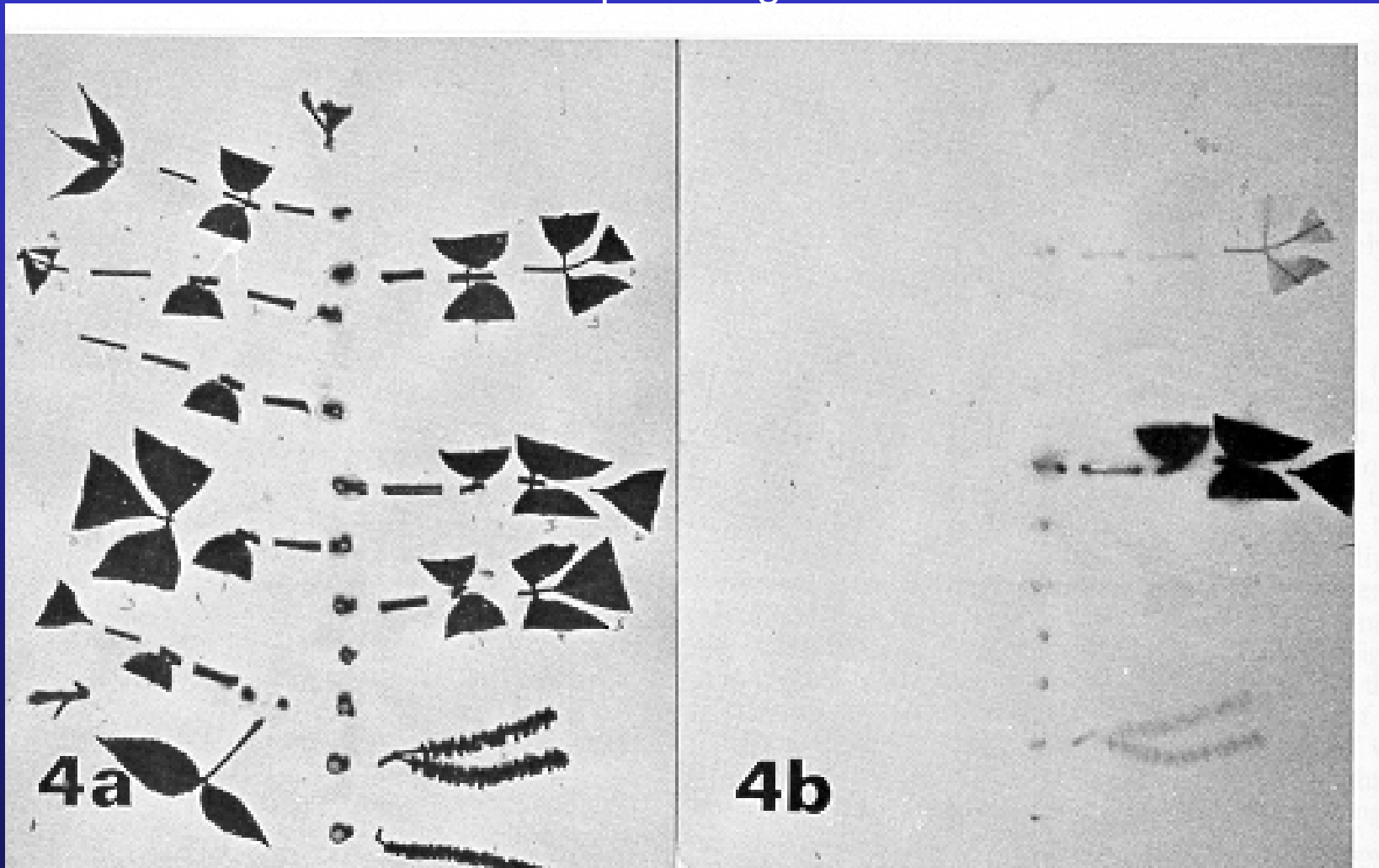
- Source
 - Point where carbohydrates are produced (leaves) or released from storage (roots, stems)
- Sink
 - point on the plant where carbohydrates are used for growth or stored

Source-sink relations

- Some organs may alternate between being a sink or a source
- Examples:
 - newly emerging leaves are a sinks then become sources
 - roots may be sources in early spring then becomes sinks in fall

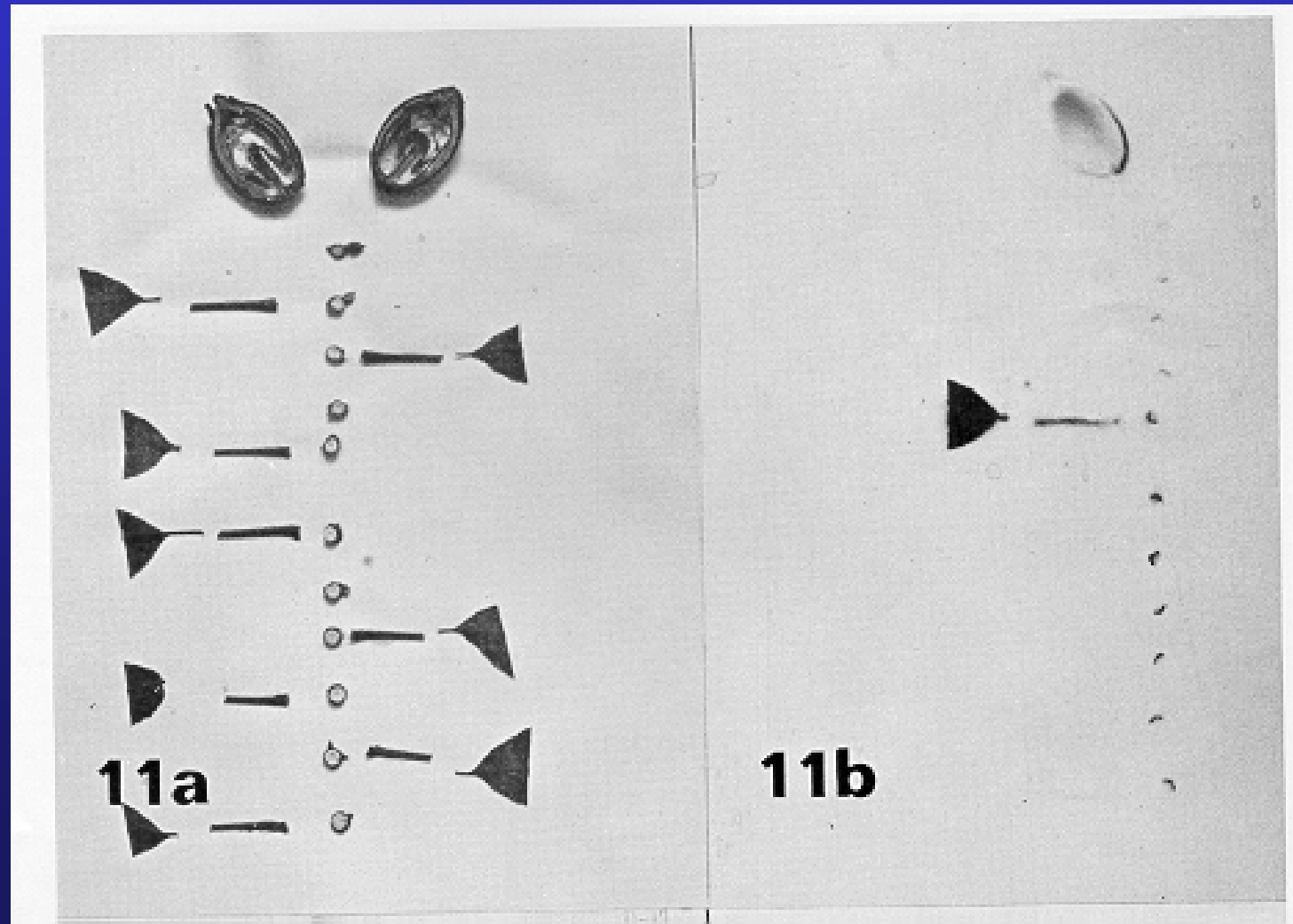
Source-Sink strength

1. Rapid leaf growth



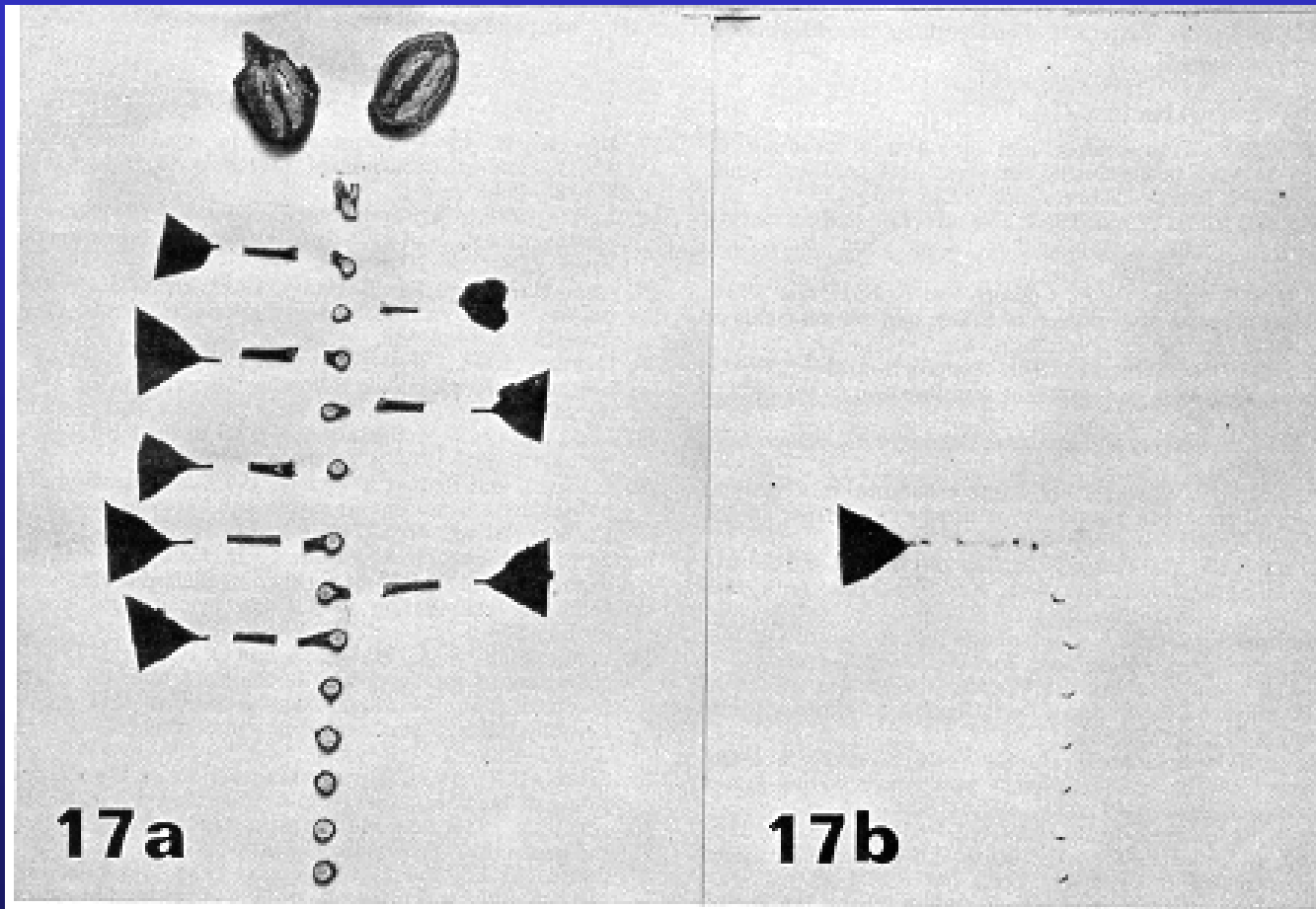
Source-Sink strength

2. Kernal filling



Source-Sink strength

3. Kernals full: basipetal transport only



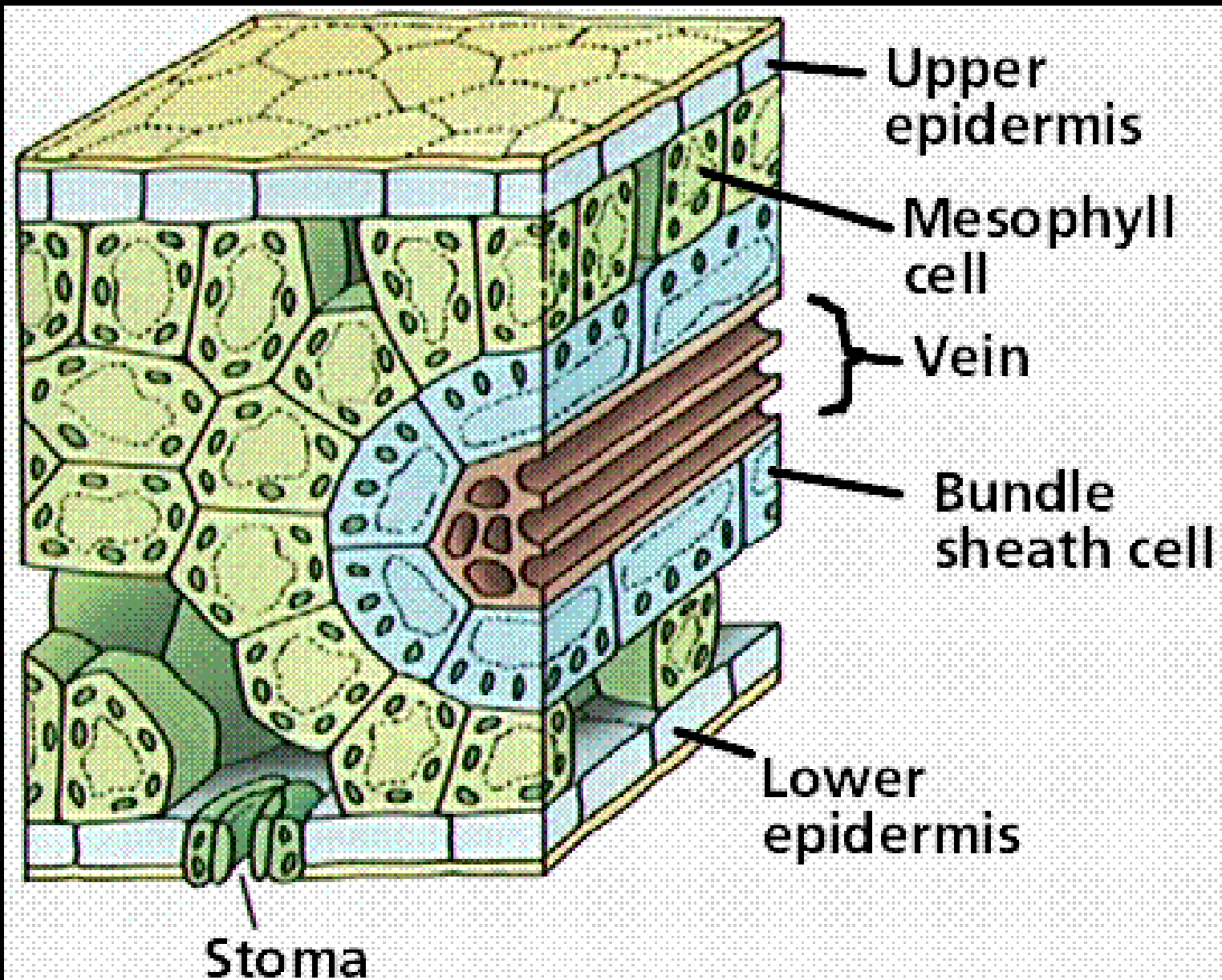
Phloem

- Carbohydrates move throughout the plant via the phloem
- Made up of sieve tube elements and companion cells
- Process by which carbohydrates move into phloem is called 'phloem loading'

Feedback inhibition

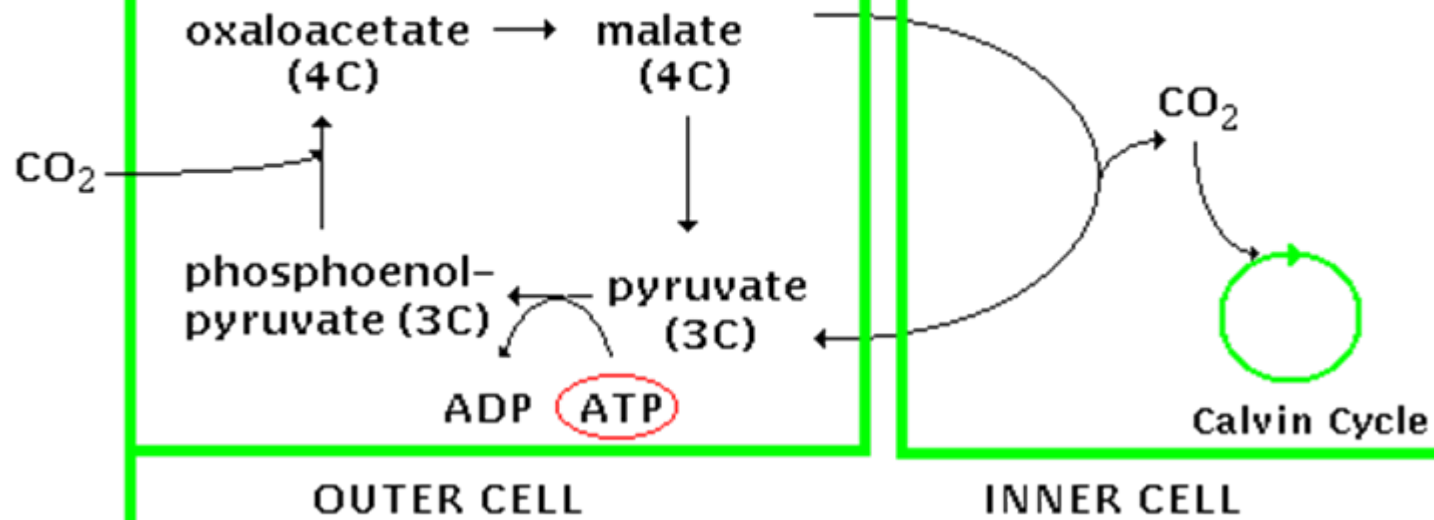
- Regulation of photosynthesis by sink
- Unloading of phloem at sink is can't keep up with assimilation at source
- Pipes “back-up”
 - Evidence:
 - Fruit thinning
 - Girdling

C-4 leaf anatomy

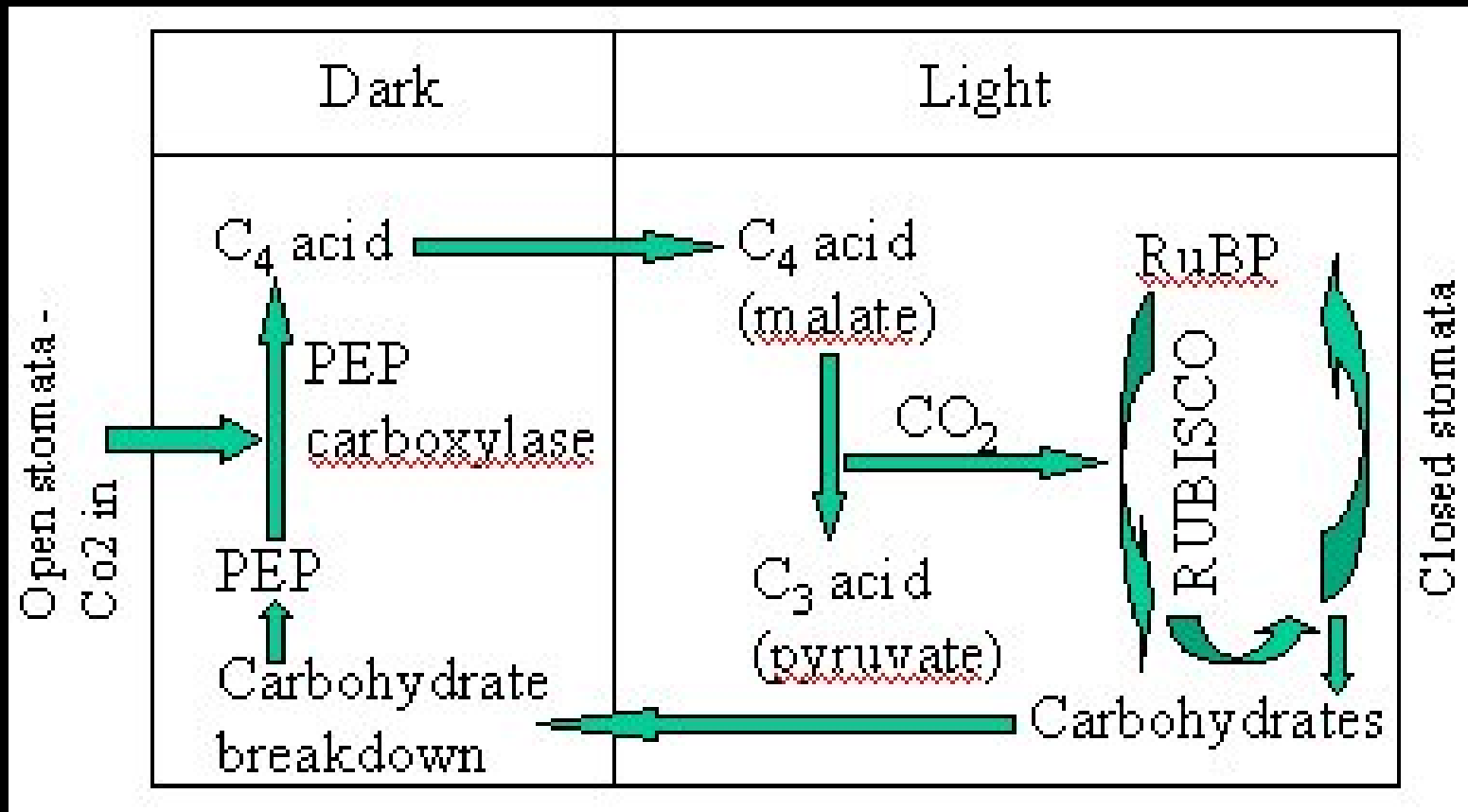


THE C4 PATHWAY

AIR







Summary of C3, C4, & CAM

	C3	C4	CAM
Enzyme	Rubisco	PEPCase	PEPCase
Opt . Temp	15-25oC	30-40oC	35oC
Habit at	Relat ively moist	Arid or t ropical	Arid
Product ivit y (T/ha/y)	22	39	Low & variable

Alternate photosynthetic pathways

- CAM
- C4 photosynthesis