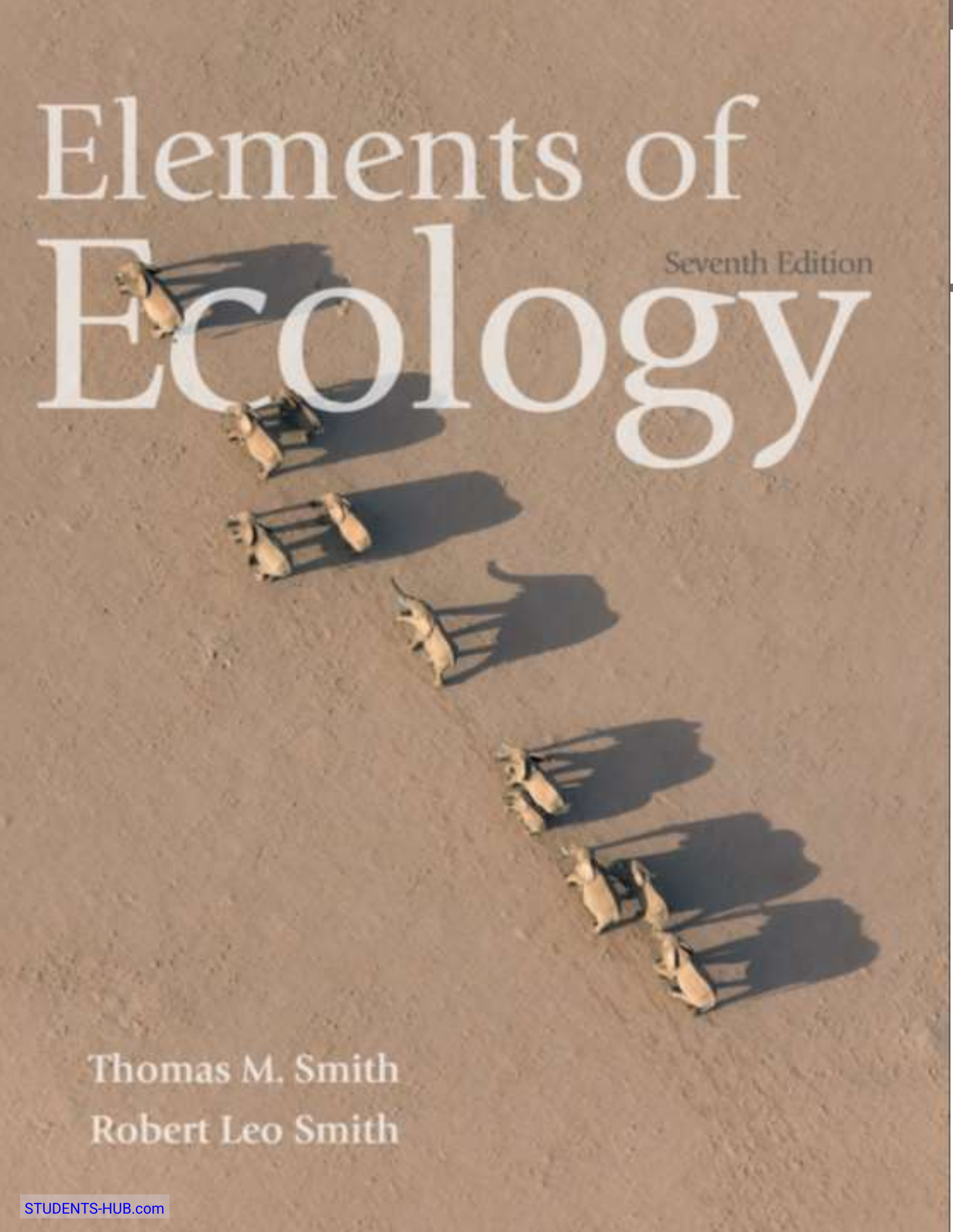
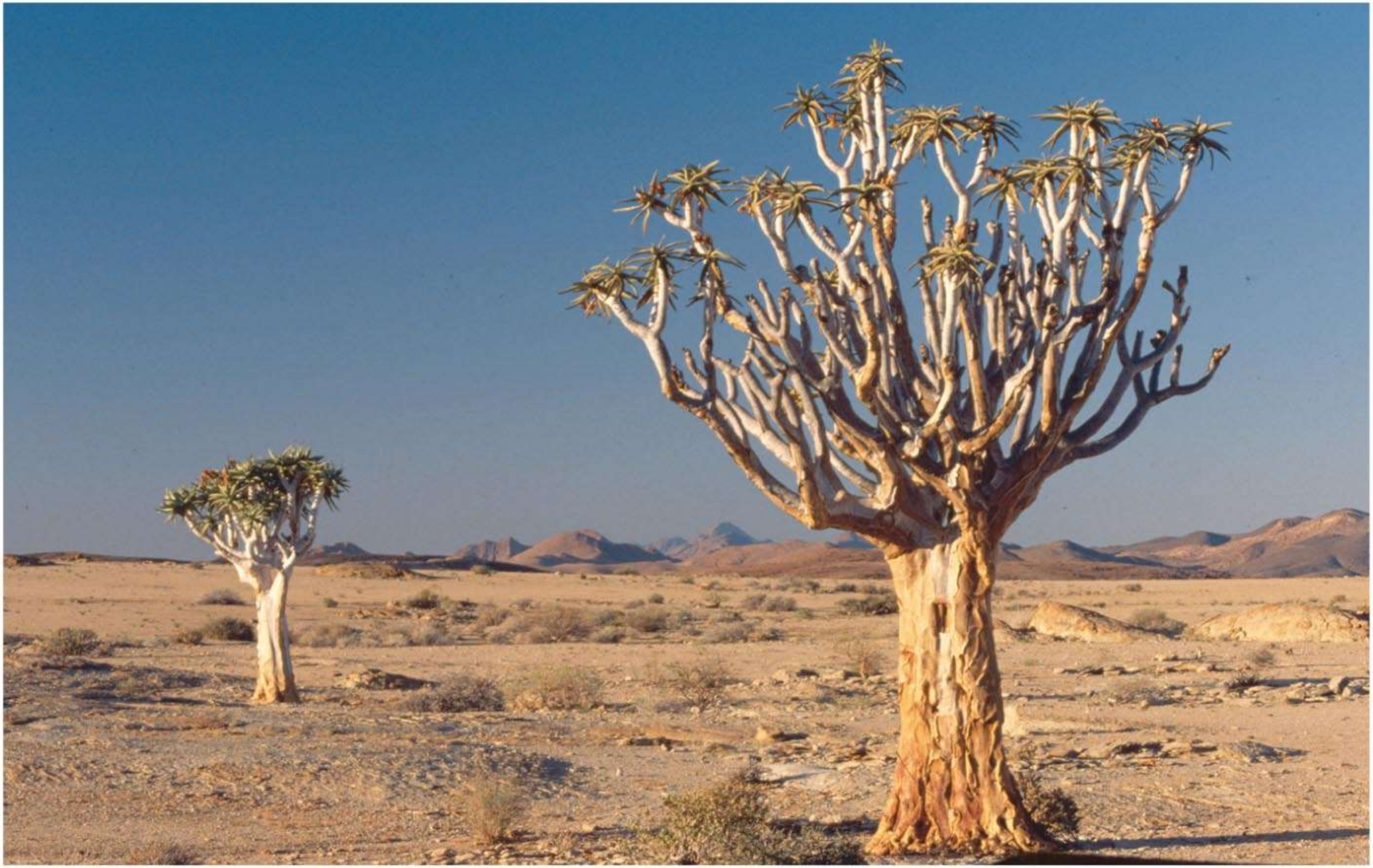


Chapter 6

Plant Adaptations to the Environment

Lecture prepared by
Aimee C. Wyrick

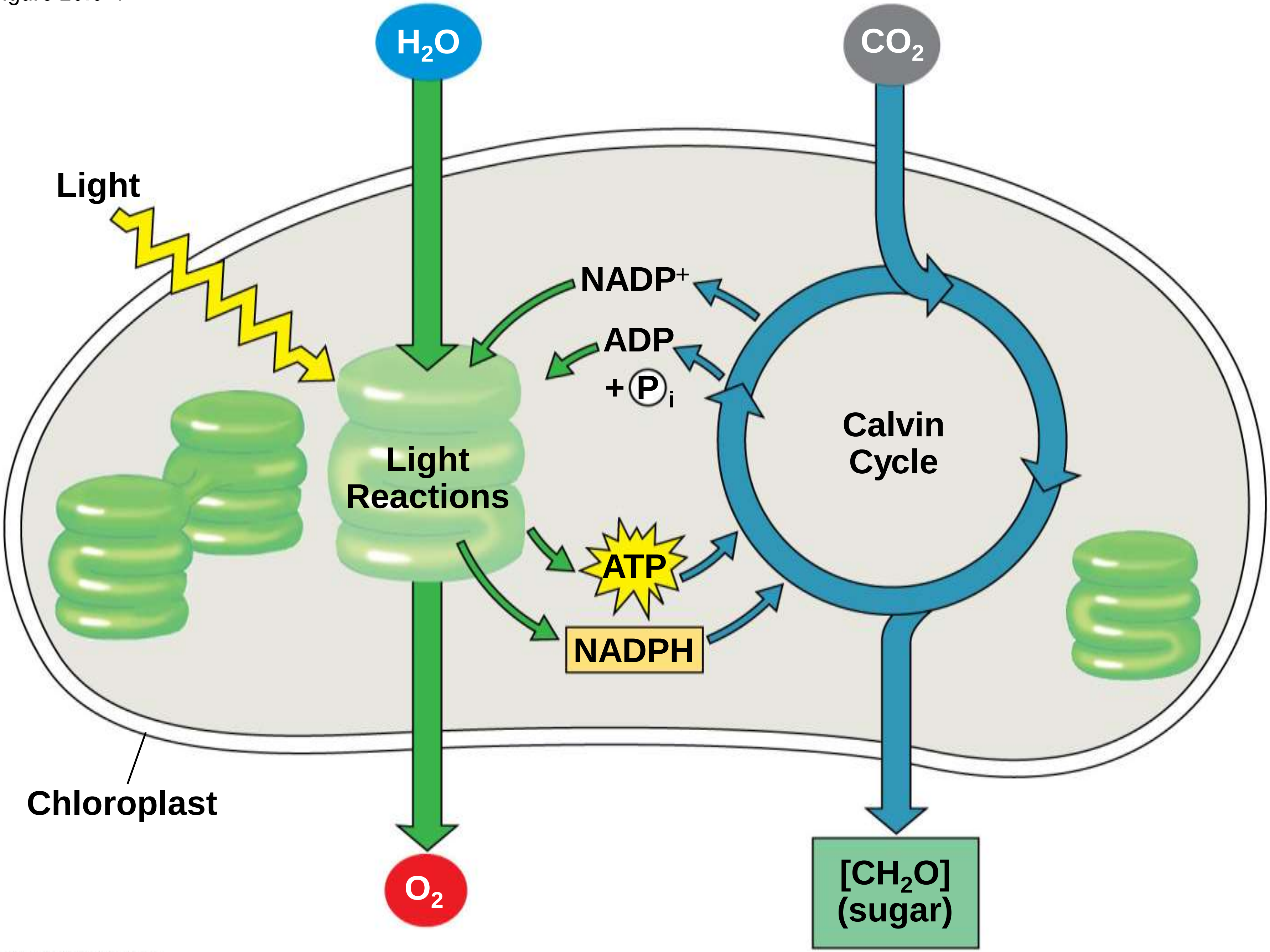


The Kokerboom tree is a desert tree in Namibian desert that uses CAM photosynthetic pathway to conserve water.

6.1 Photosynthesis Is the Conversion of Carbon Dioxide into Simple Sugars

- Photosynthesis begins with **light reactions:**
  - Absorption of light energy by **chlorophyll** (a pigment molecule)
  - Conversion of the light energy into ATP and NADPH
- Photosynthesis continues with the **dark reactions:**
  - Incorporation of **CO_2 into simple (organic) sugars** using the energy provided by ATP and NADPH.
  - Carboxylation is catalyzed by the enzyme **rubisco** (ribulose biphosphate carboxylase-oxygenase or **RuBP**)

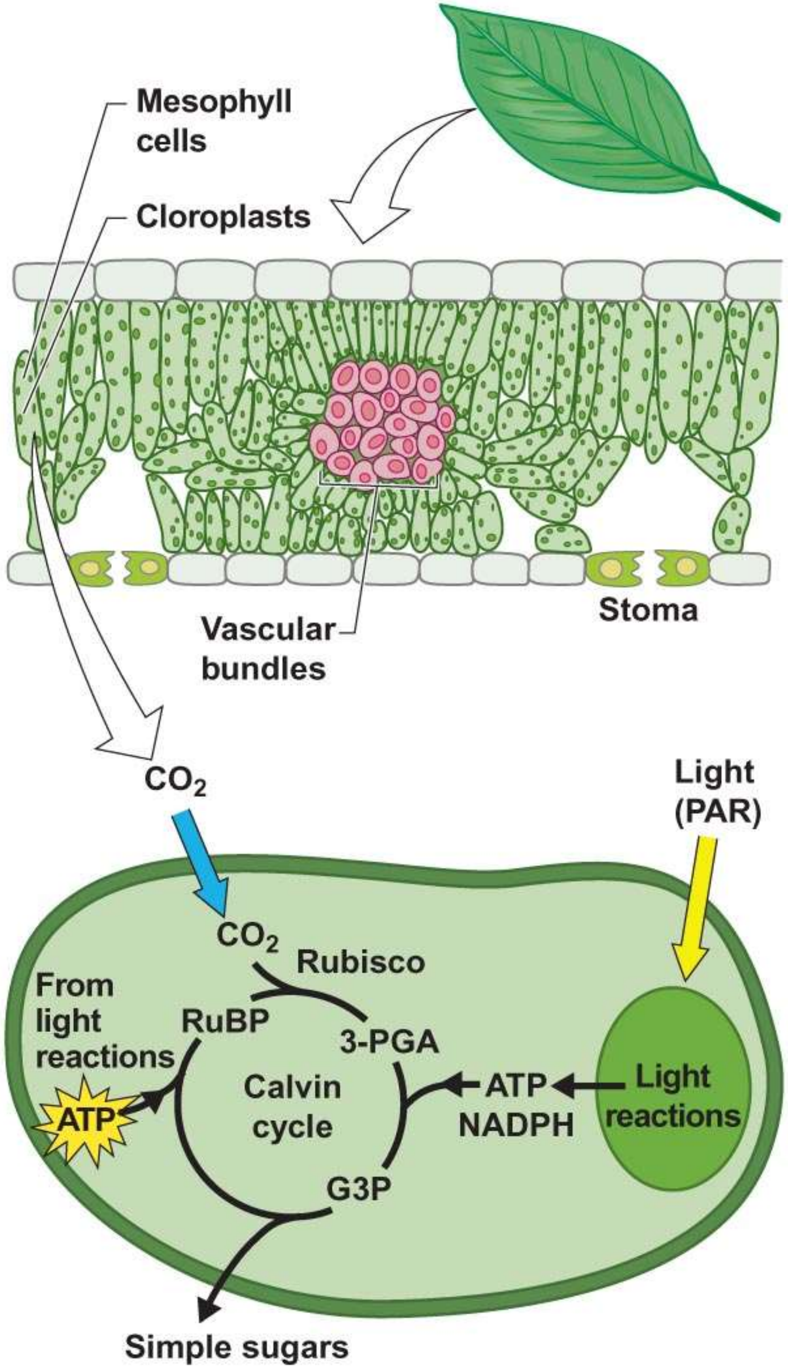
Figure 10.6-4



H_2O
CO_2
Light
$NADP^+$
ADP
+ Ⓟi
Light Reactions
Calvin Cycle
ATP
NADPH
Chloroplast
O_2
[CH_2O]
(sugar)

C_3 Pathway

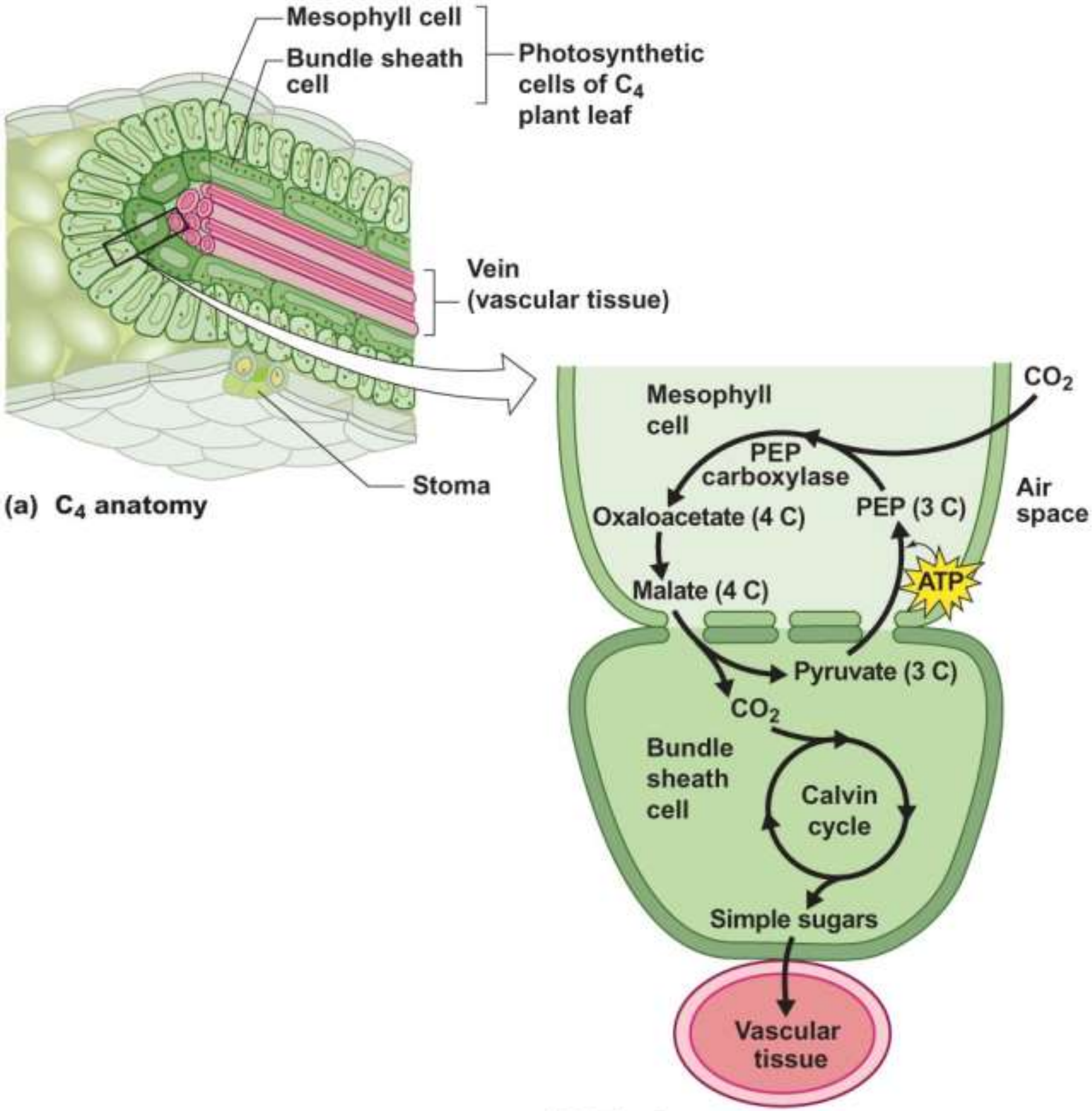
- The **Calvin–Benson cycle** (**C_3 cycle**) initially **fixes** CO_2 into 3-PGA (phosphoglycerate) which is a 3-carbon sugar.
  - The series of dark reactions of **C_3 plants.**


Mesophyll
cells
Cloroplasts
Vascular
bundles
Stoma
CO_2
Light
(PAR)
CO_2
Rubisco
From
light
reactions
RuBP
3-PGA
Calvin
cycle
ATP
ATP
NADPH
Light
reactions
G3P
Simple sugars

C_4 & CAM Pathways

- Plants adapted to **warmer and drier environments** have developed **alternative photosynthetic pathways that increase water-use efficiency:**
  - **Examples: the C_4 & CAM photosynthetic pathways**

- The **C_4 photosynthetic pathway** spatially *separates CO_2 fixation* and *assimilation of CO_2 into the Calvin Cycle* (dark reactions).
- **Carbon fixation:**
  - CO_2 is initially fixed into the **organic acid oxaloacetate (OAA)** in the **mesophyll cell**.
  - CO_2 fixation is catalyzed by the enzyme **PEP carboxylase.**
- **Carbon assimilation:**
  - **Oxaloacetate** is broken down and **releases CO_2** into the **bundle sheath** where it is incorporated into the Calvin Cycle.

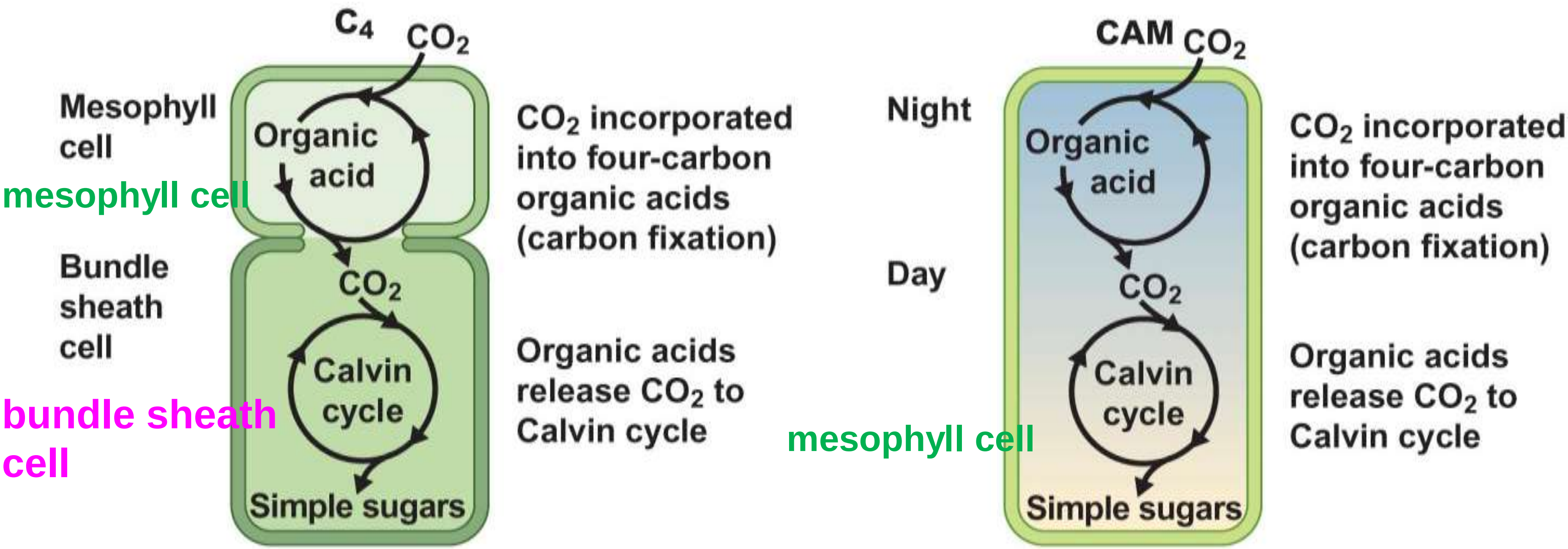


(b) The C_4 pathway

- An increase in photosynthetic efficiency of the **C_4 photosynthetic pathway** :
  - PEP carboxylase does not interact with oxygen (as does RuBP)
  - The conversion of organic acids back into CO_2 acts to concentrate CO_2 (This increases the rate of reaction).
- For a given degree of stomatal opening and water loss, **C_4 plants** typically fix more carbon → greater water-use efficiency.
  - Most commonly found in grasses native to tropical and subtropical regions.

- Plants adapted to **warmer and drier environments** have developed alternative photosynthetic pathways that increase water-use efficiency:
  - **C_4 photosynthetic pathway**
  - **CAM** (crassulacean acid metabolism) **pathway**

- The **CAM pathway** temporally separates CO_2 fixation and assimilation of CO_2 into the Calvin Cycle (dark reactions).
- **Carbon fixation:**
  - Stomata are **open at night.**
  - CO_2 is initially fixed by PEP carboxylase into malic acid at night.
- **Carbon assimilation:**
  - Stomata are **closed during the day.**
  - Malic acid reconverts to CO_2 and is assimilated into the Calvin Cycle.

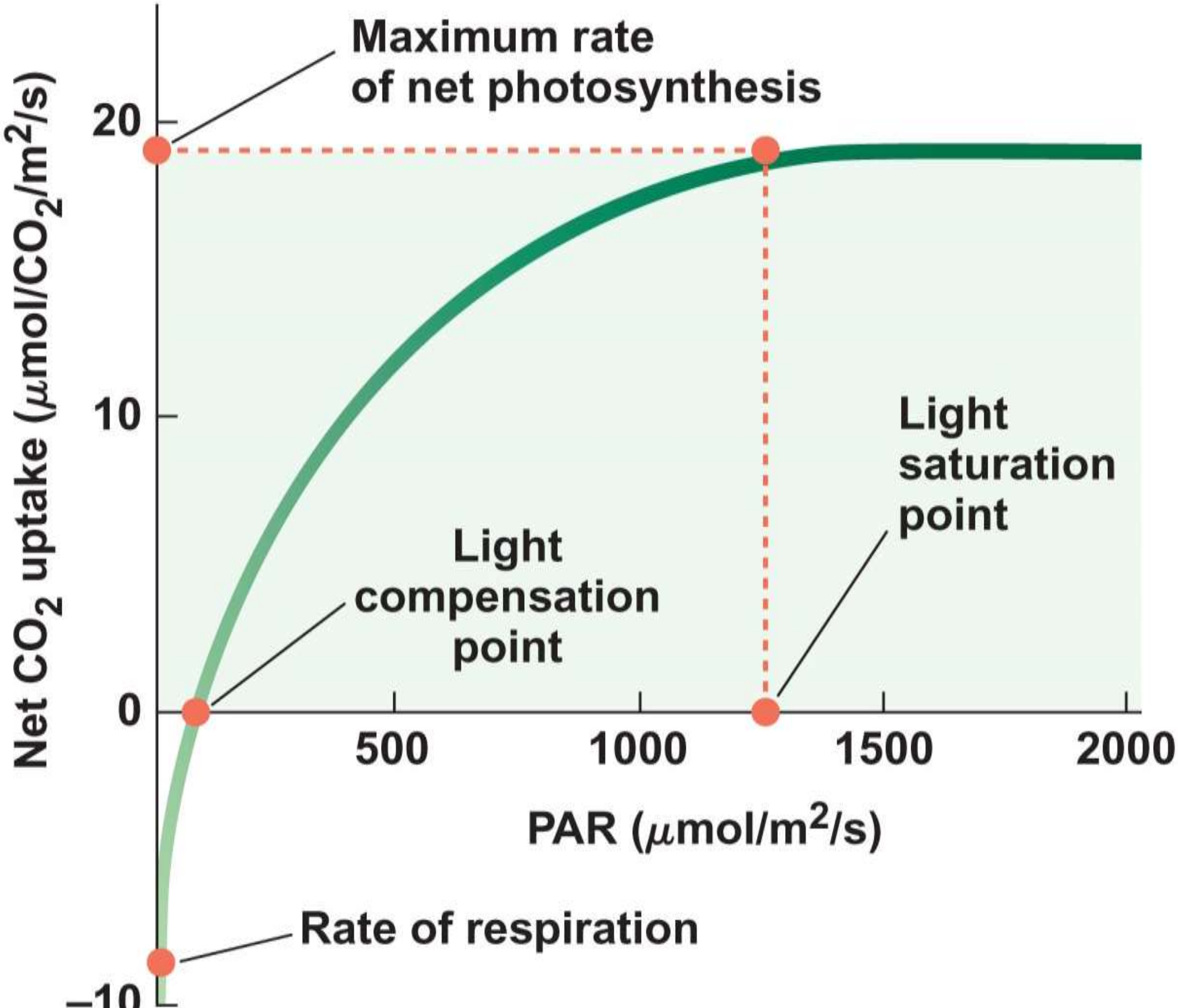


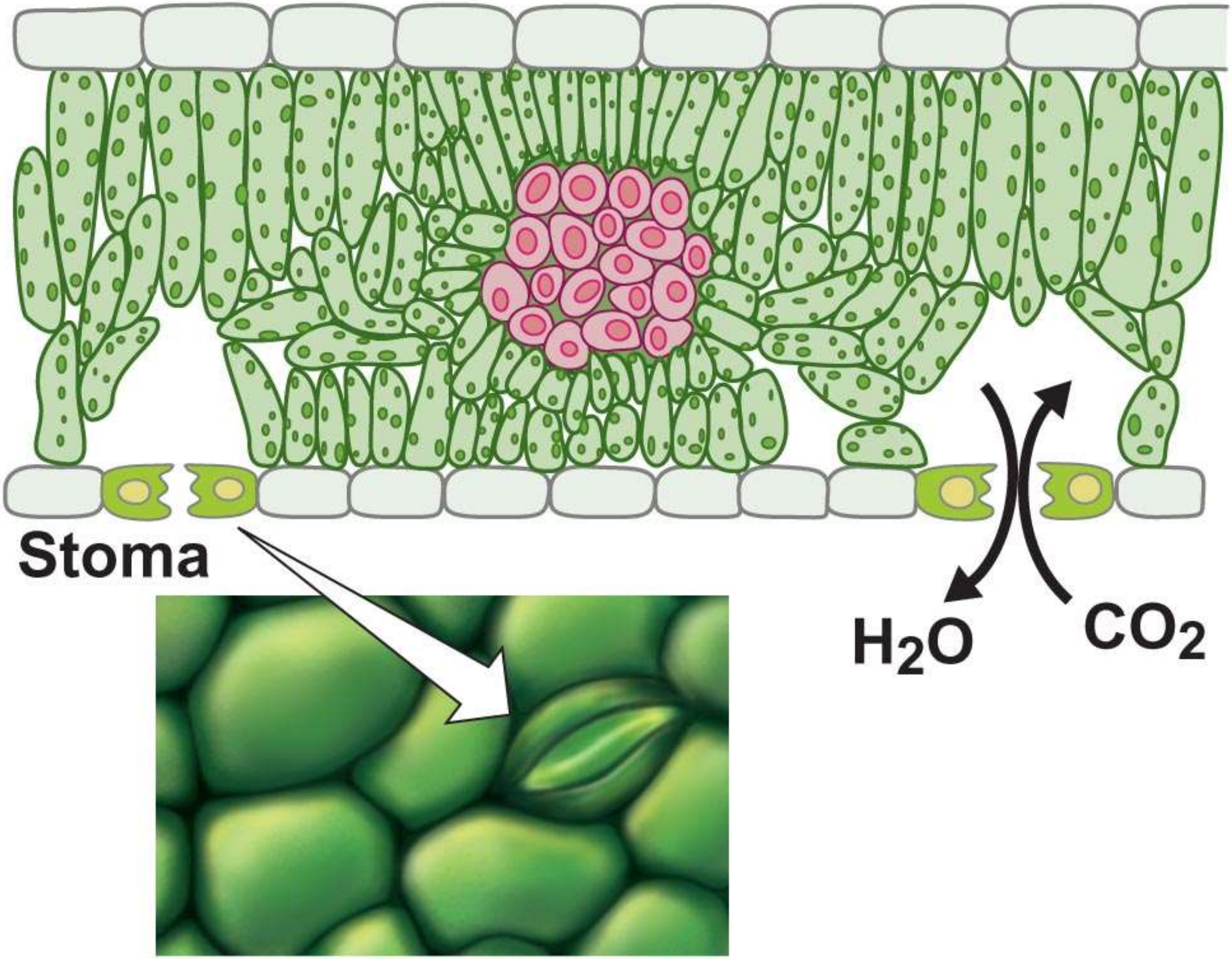
(a) Spatial separation of steps. In C_4 plants, carbon fixation and the Calvin cycle occur in different types of cells.

(b) Temporal separation of steps. In CAM plants, carbon fixation and the Calvin cycle occur in the same cells at different times.

6.2 The Light a Plant Receives Affects Its Photosynthetic Activity

- **The availability of light**, photosynthetically active radiation (PAR), to the leaf directly ***influences the rate of photosynthesis.***
- The **light compensation point (LCP)** *is the point at which the rate of net photosynthesis is zero.*
- The **light saturation point** *is the point above which no further increase in photosynthesis occurs*
- **Photoinhibition** *is the negative effect of high light levels.*

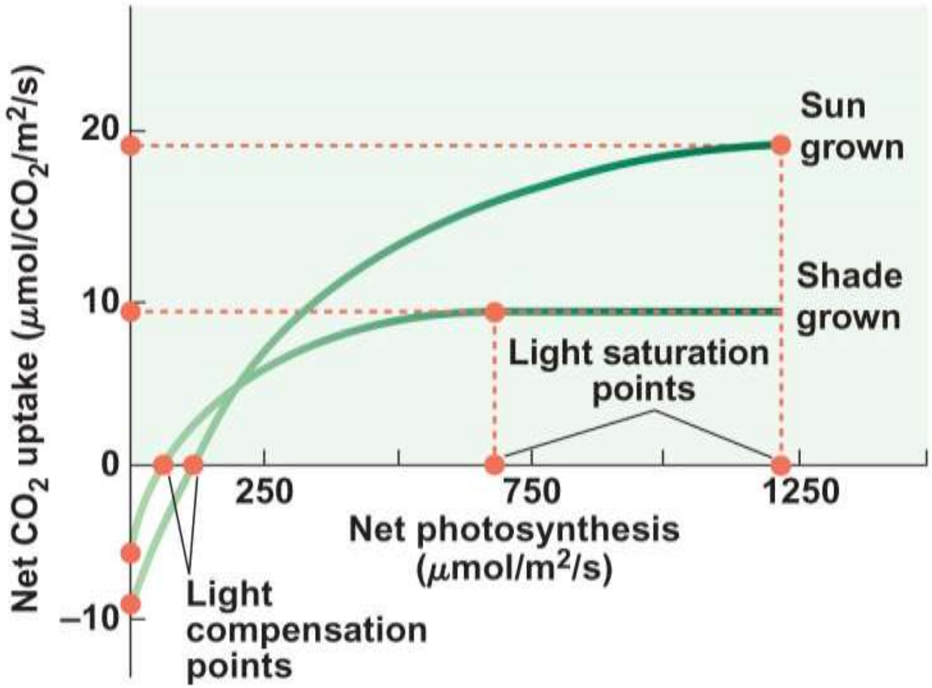

Maximum rate
of net photosynthesis
Light
saturation
point
Light
compensation
point
Rate of respiration
Net CO_2 uptake (μmol/CO_2/m^2/s)
20
10
0
–10
500
1000
1500
2000
PAR (μmol/m^2/s)


Stoma
H_2O
CO_2

- The rate of water loss from plants varies daily depending on:
  - **Humidity**
  - **Temperature**
  - **Plant characteristics** (stomata opening and closing)
- The **water-use efficiency** *is the ratio of carbon fixed (photosynthesis) per unit of water lost (transpiration).*
  - Terrestrial plants must balance intake of CO_2 with the loss of water.

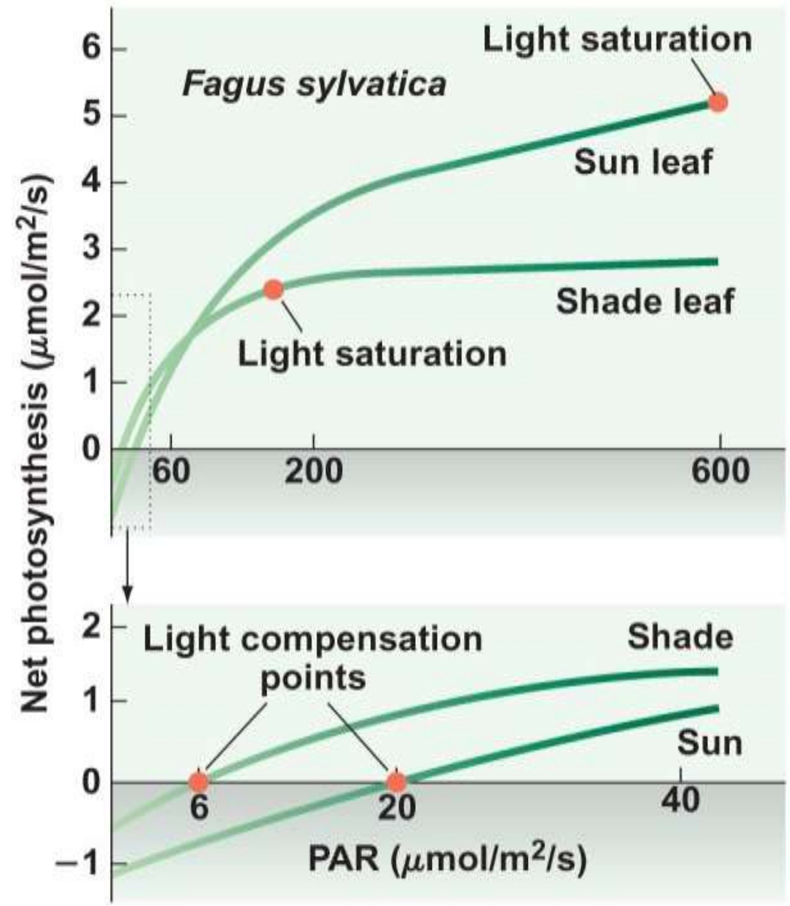
6.9 Species of Plants Are Adapted to Different Light Environments

- The presence of other plants greatly influences (by shading) the amount of PAR that each receives.
- Sun versus shade plants:
  - **Shade (low-light) plants** tend to have a lower light saturation point and a lower maximum rate of photosynthesis.



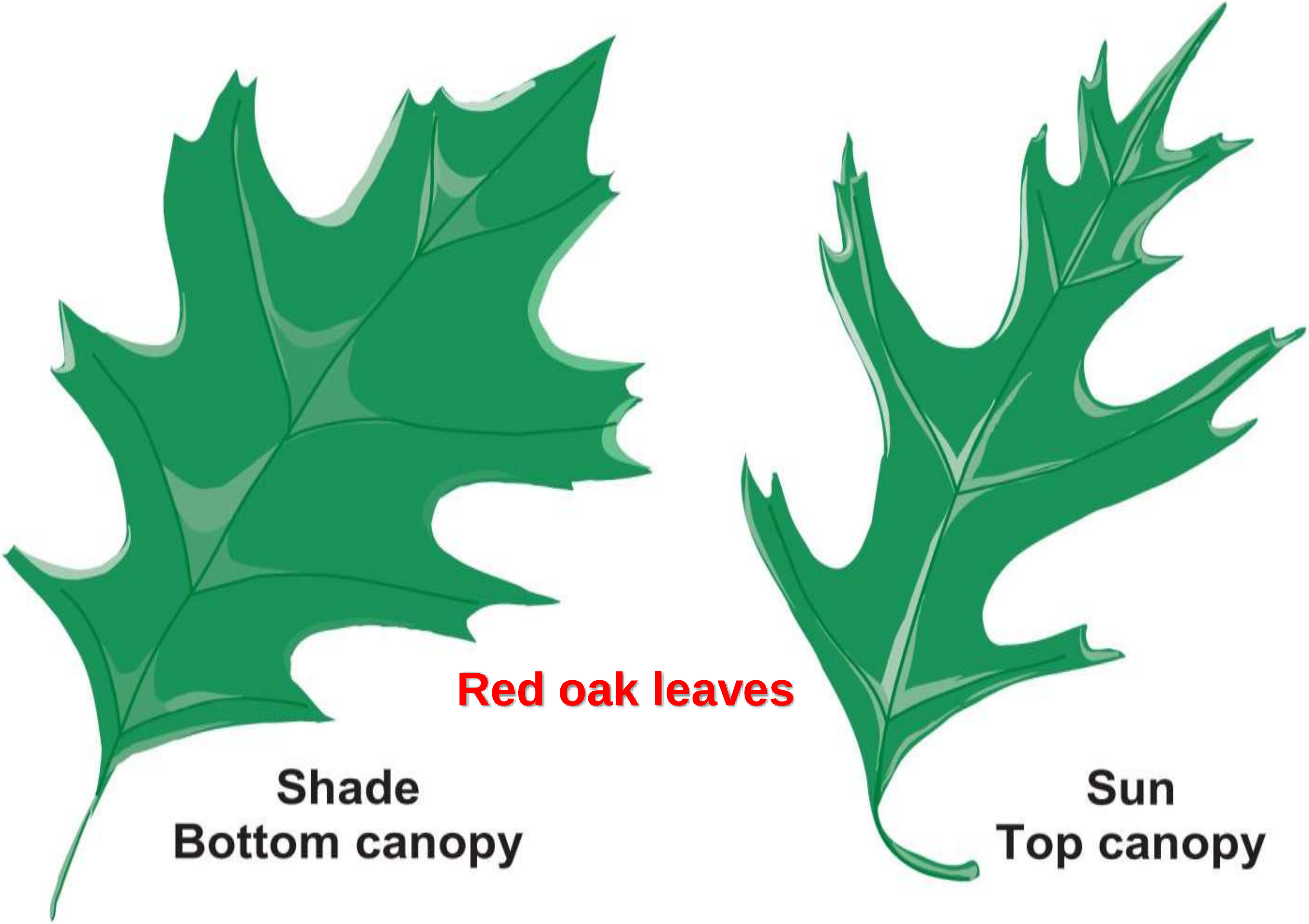
Net CO_2 uptake (μmol/CO_2/m^2/s)
20
10
0
−10
250
750
1250
Net photosynthesis
(μmol/m^2/s)
Sun
grown
Shade
grown
Light saturation
points
Light
compensation
points

(a)



Net photosynthesis (μmol/m^2/s)
Fagus sylvatica
Light saturation
Sun leaf
Shade leaf
Light saturation
6
5
4
3
2
1
0
60
200
600
Light compensation
points
Shade
Sun
2
1
0
−1
6
20
40
PAR (μmol/m^2/s)

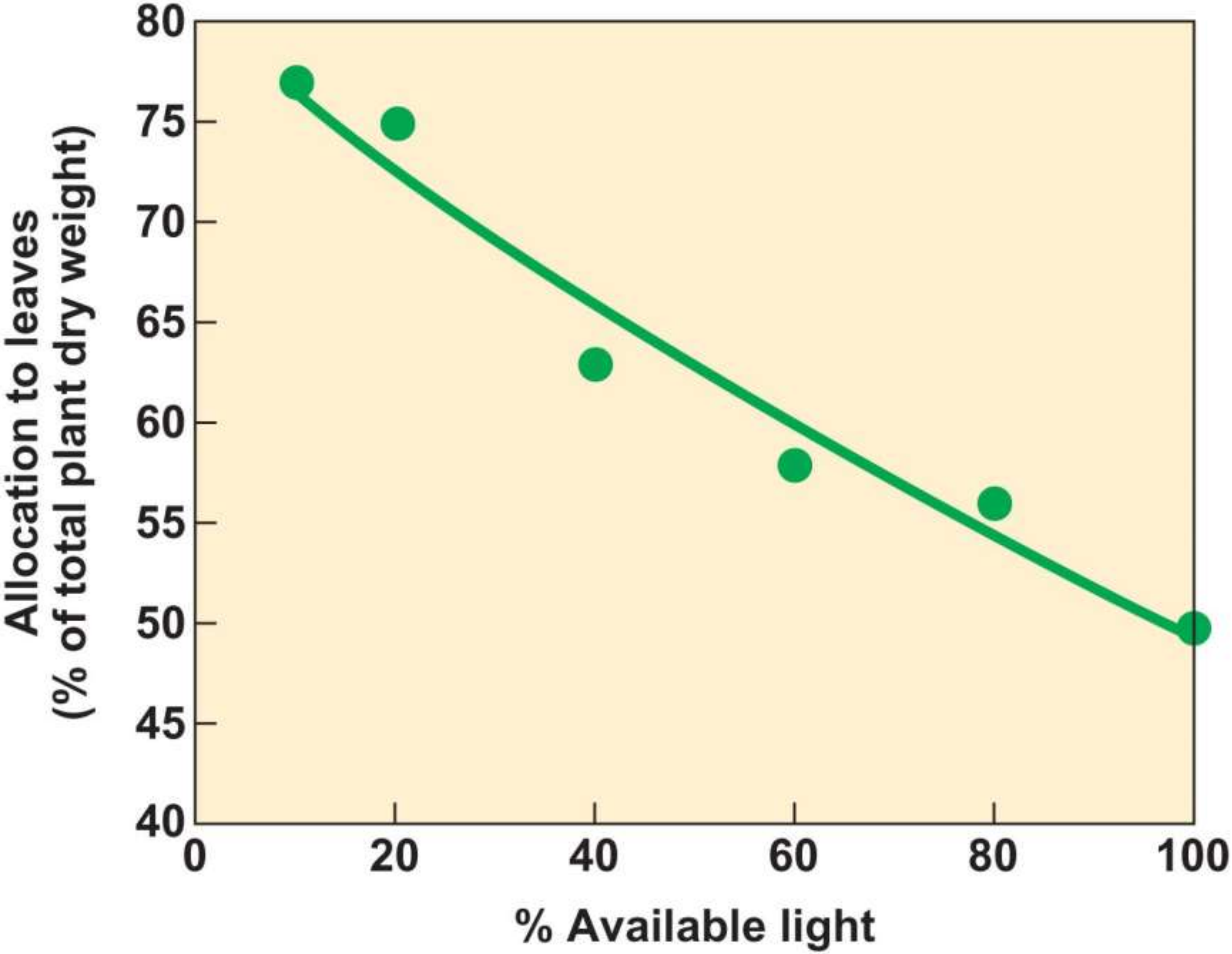
(b)


Red oak leaves
Shade
Bottom canopy
Sun
Top canopy

- **Differences in the performance** of sun versus shade plants are **related to rubisco**:
  - *Rubisco is a costly molecule for a plant to manufacture*
- **Shade plants produce less rubisco** which reduces energy cost and leaf respiration rate and **produces more chlorophyll**:
  - **Lowers photosynthesis rate** → **Lower light compensation point.**
  - **Restricts maximum photosynthetic rate** because there is only so much rubisco available to fix CO_2

- **Phenotypic plasticity** *is the ability of a plant to change its form under different environmental conditions.*
- **It can be observed:**
  - ***Among individuals of the <u>same species</u> grown in different light conditions.***
  - ***Among <u>leaves on the same plant</u> with different light exposures.***

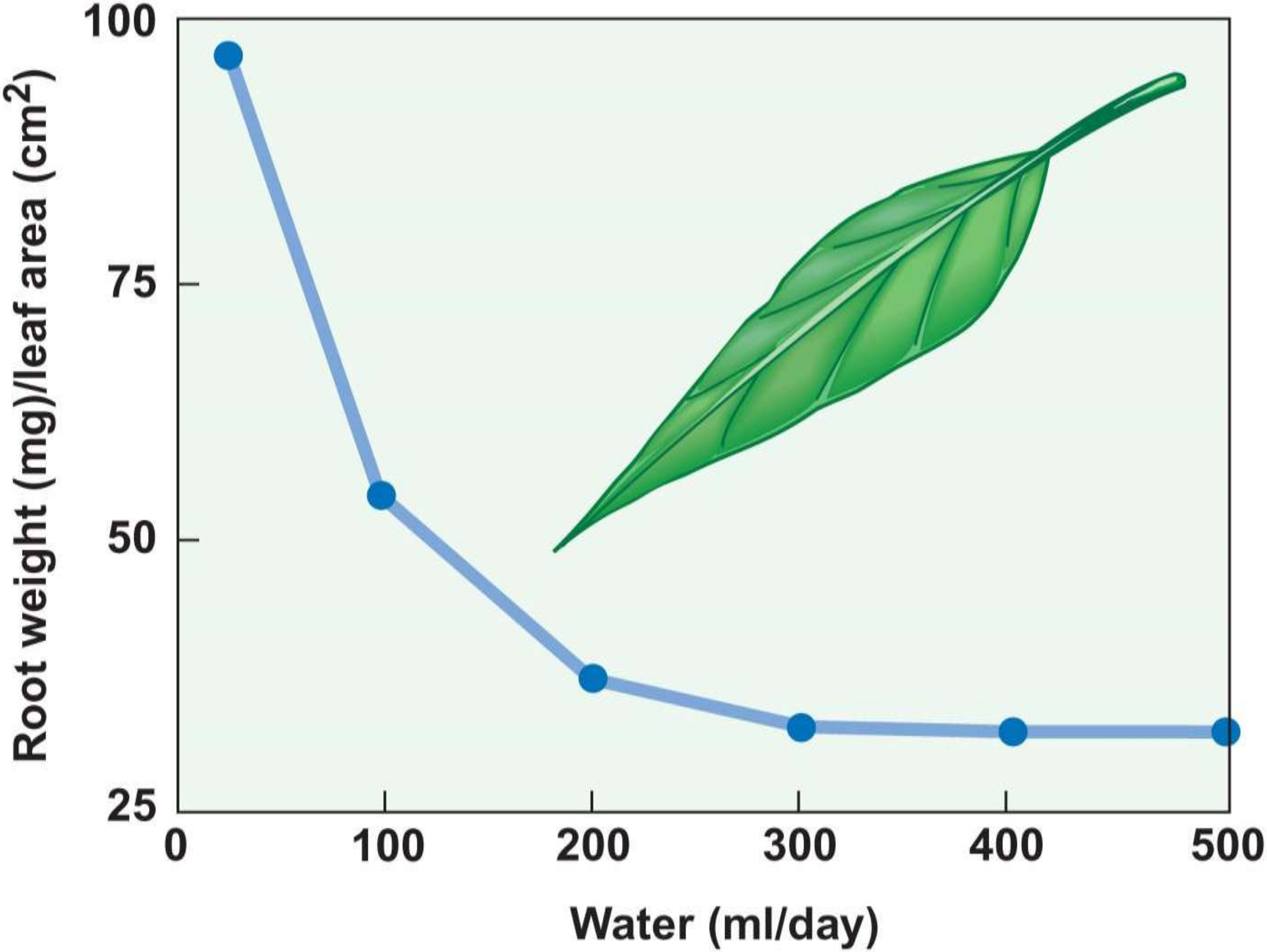
- Genetic differentiation between plant species in response to light:
  - **Shade-intolerant** (**sun-adapted**) species are those that are adapted to **high-light environments.**
  - **Shade-tolerant** (**shade-adapted**) species are those adapted to **low-light environments.**


Allocation to leaves
(% of total plant dry weight)
80
75
70
65
60
55
50
45
40
0
20
40
60
80
100
% Available light

- Plants **respond to moisture stress** differently:
  - **Leaf curling and wilting.**
  - **Inhibition of chlorophyll production → loss of leaves.**
  - **Drought deciduous.**
  - **Modified photosynthetic pathway.**

- In response to **lower soil water**, a plant can **increase carbon allocation to roots**:
  - *Explore a larger volume and depth of soil*
  - *Reduce leaf area exposed to solar radiation and transpiration*
- **Leaf area reduction** is a result of reduced allocation of carbon to leaf production and changes in leaf morphology (both size and shape):
  - Smaller and thicker

- **Additional leaf modifications** to minimize water loss:
  - **Cell wall thickness**
  - **Stomatal size (tiny)**
  - **Dense vascular system**
  - **Leaves covered with hairs, wax, resins: reduce light absorption.**

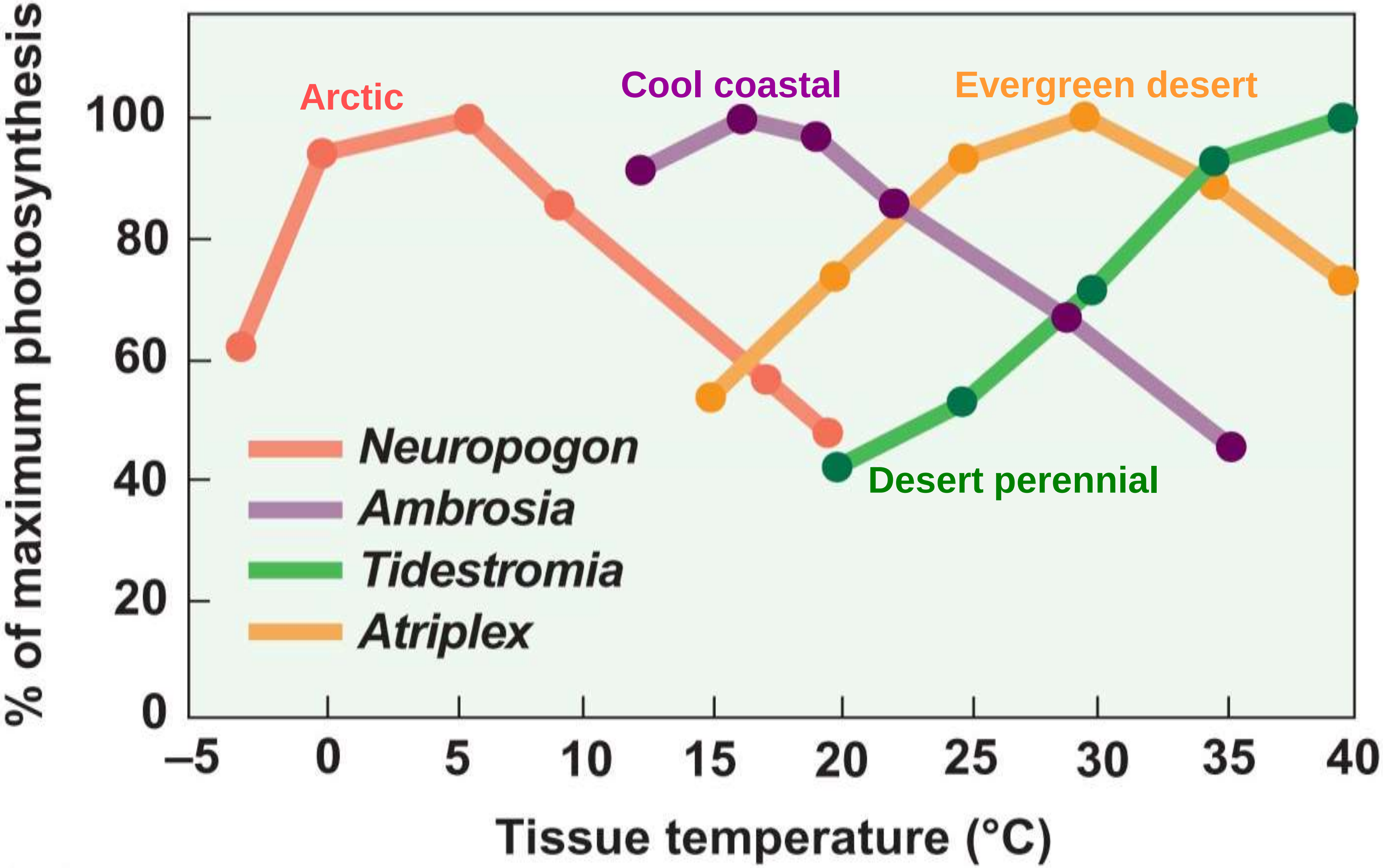


100
75
50
25
Root weight (mg)/leaf area (cm²)
0
100
200
300
400
500
Water (ml/day)

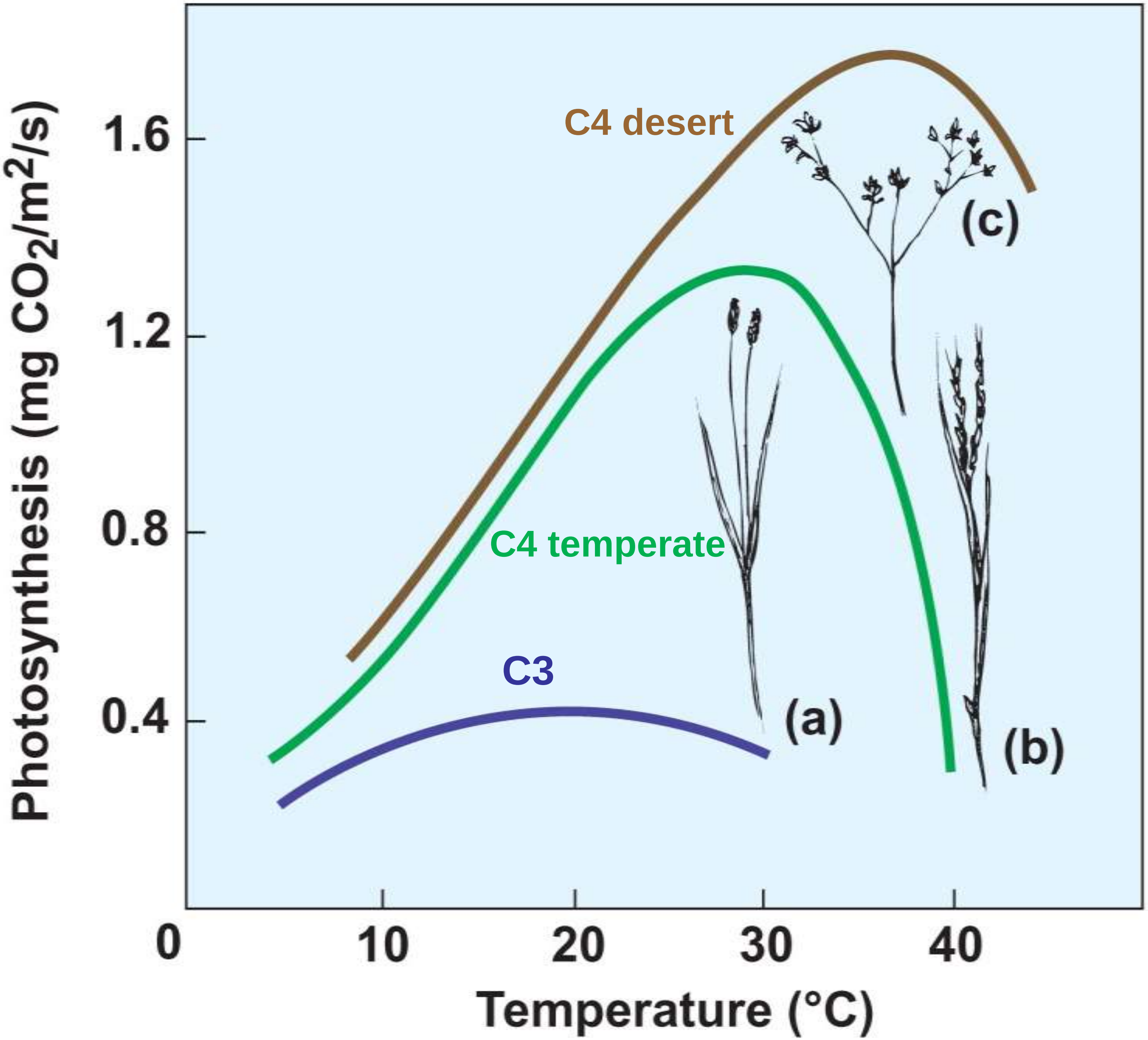
- Differences in plant morphology are most pronounced between species of plants adapted to **wet (mesic)** and **dry (xeric)** environments.

6.11 Plants Vary in Their Response to Environmental Temperatures

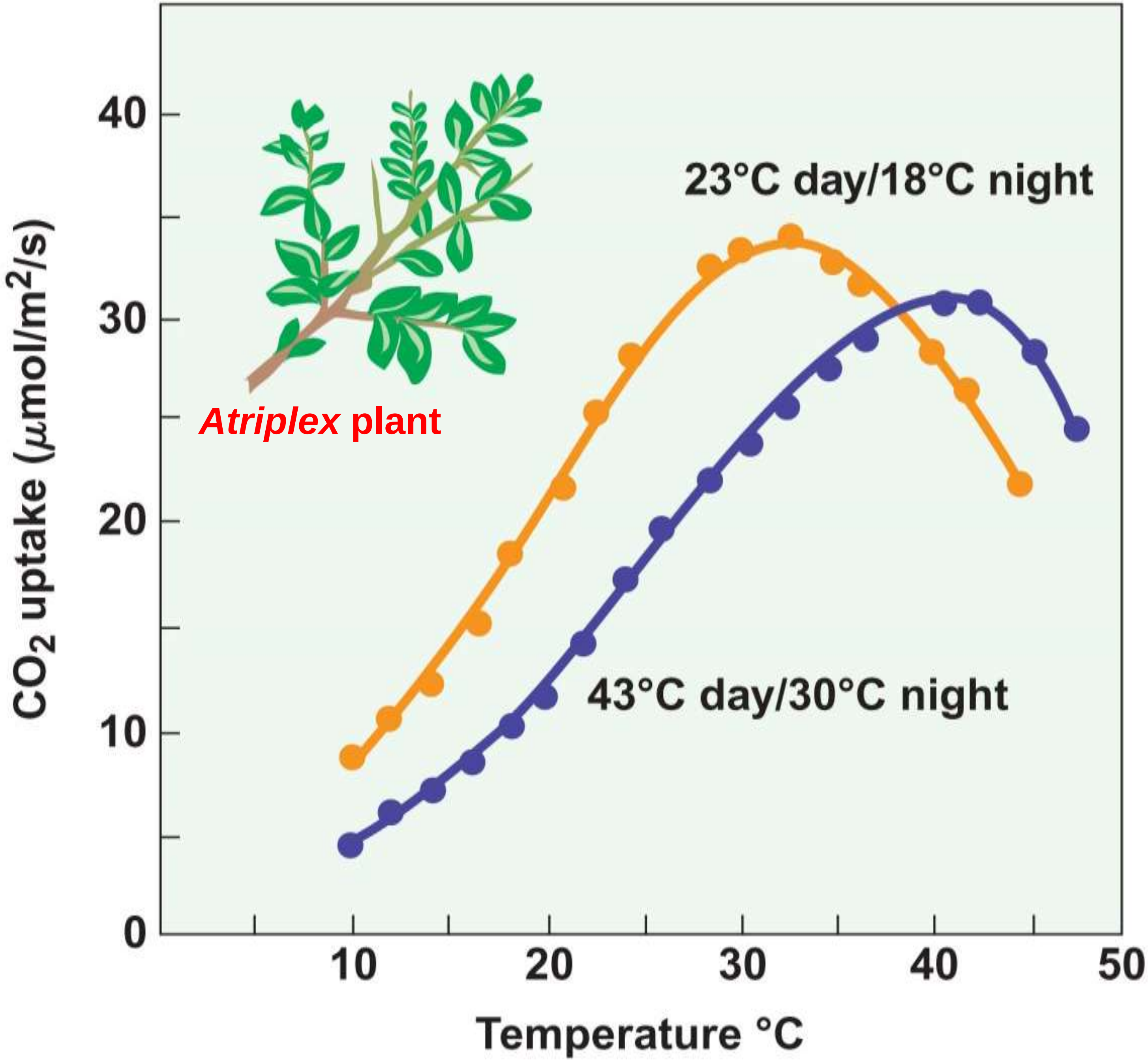
- Species found in **cooler environments** typically have a lower T_{min}, T_{opt}, and T_{max} than species in warmer climates.
  - Related to the biochemical and physiological adaptations.
- The differences in environmental temperature adaptations are **most pronounced between C_3 and C_4 plants.**



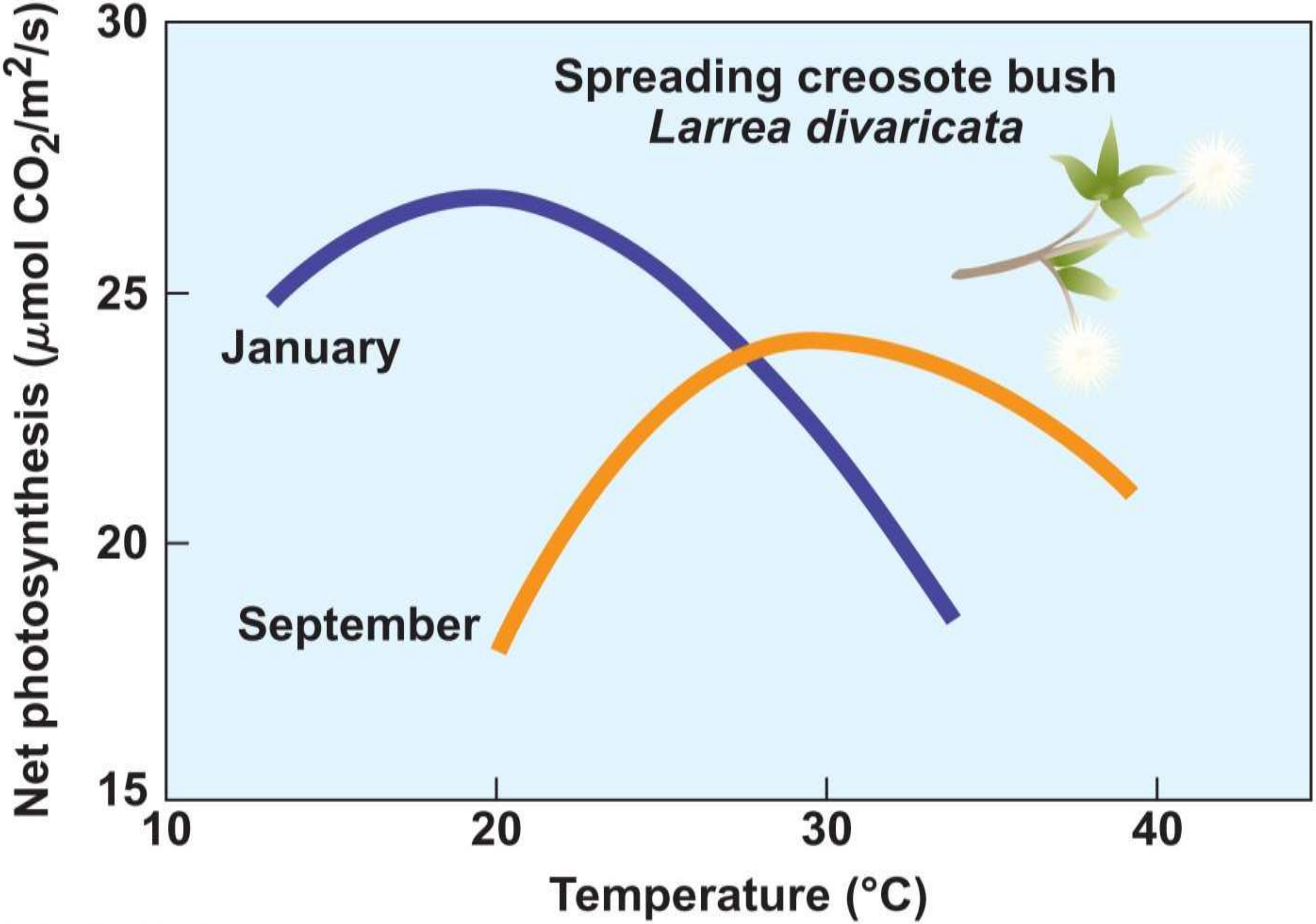
% of maximum photosynthesis
100
80
60
40
20
0
Arctic
Cool coastal
Evergreen desert
Desert perennial
Neuropogon
Ambrosia
Tidestromia
Atriplex
–5
0
5
10
15
20
25
30
35
40
Tissue temperature (°C)


C4 desert
C4 temperate
C3
(a)
(b)
(c)
1.6
1.2
0.8
0.4
0
10
20
30
40
Photosynthesis (mg CO_2/m^2/s)
Temperature (°C)

- Temperature responses are not fixed.
- When individuals of the **same species are grown under different thermal conditions**, a divergence in temperature response of net photosynthesis is often observed:
  - The T_{opt} shifts in the direction of the thermal conditions under which the plant is grown.
- A similar pattern is seen in individual plants in response to seasonal shifts in temperature (acclimation) [this is reversible].



40
30
20
10
0
CO2 uptake (μmol/m2/s)
23°C day/18°C night
43°C day/30°C night
Atriplex plant
10
20
30
40
50
Temperature °C

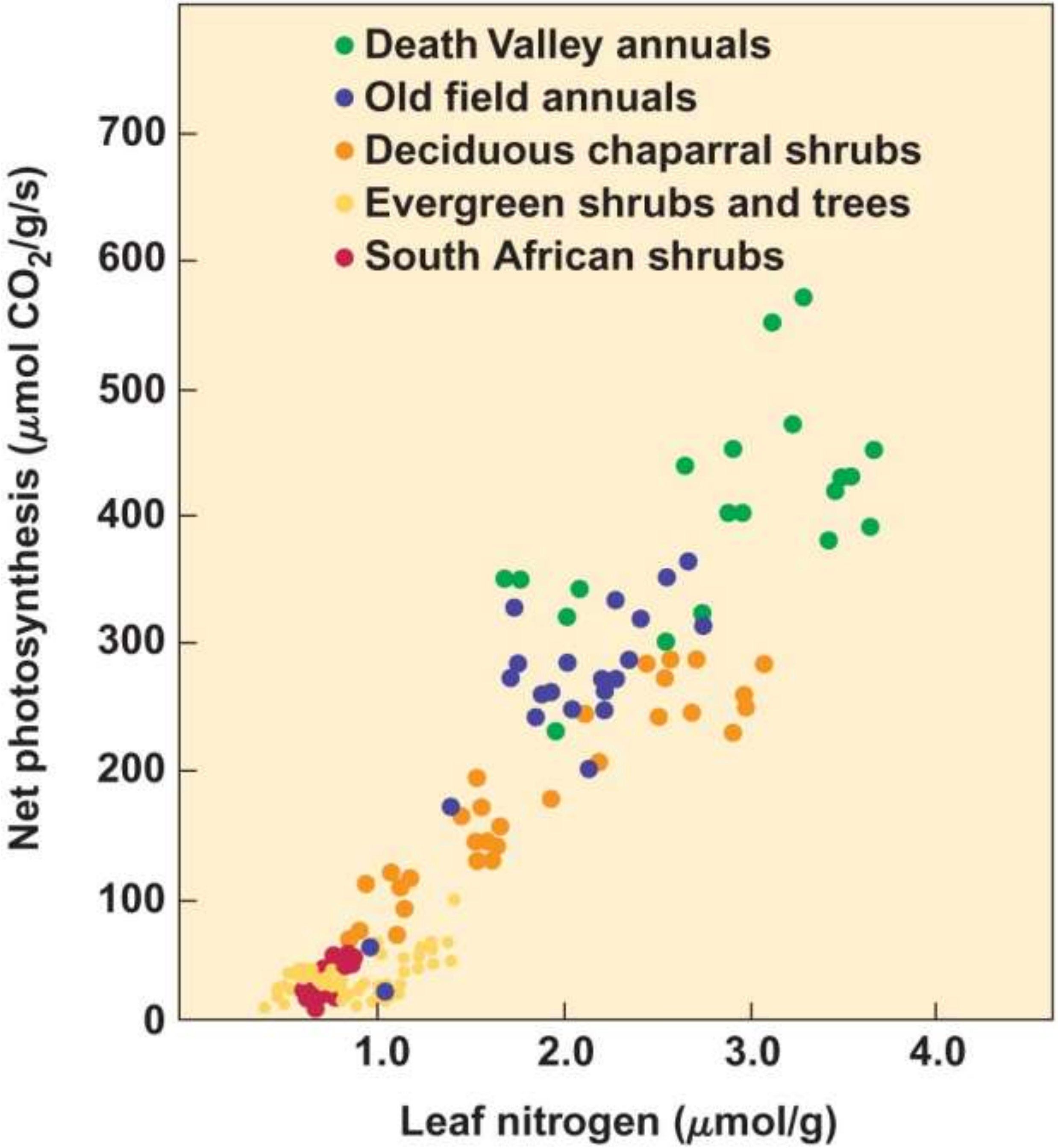

Spreading creosote bush
Larrea divaricata
Net photosynthesis (μmol CO_2/m^2/s)
30
25
20
15
January
September
10
20
30
40
Temperature (°C)

- Plants **native to seasonally cold environments** have evolved several adaptations for survival:
  - **Frost hardening**—the conversion of cold-sensitive cells into hardy ones.
  - Formation/addition of protective compounds—**antifreeze**
  - **Winter deciduous.**

6.12 Plants Exhibit Adaptations to Variations in Nutrient Availability

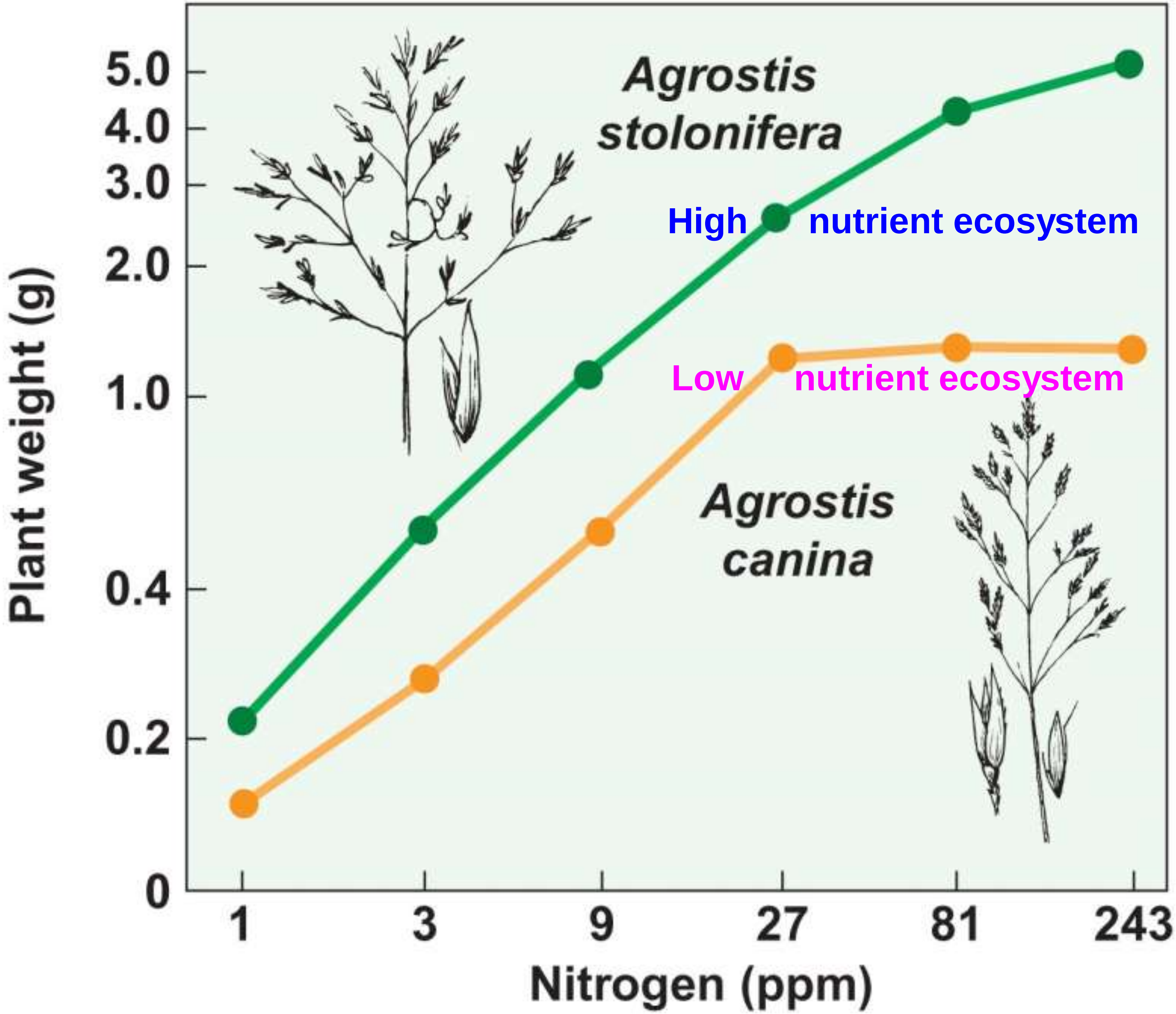
- Plants require a variety of chemical elements (nutrients) to carry out metabolic processes.
- The availability of nutrients has direct effects on plant survival, growth, and reproduction.
- **Macronutrients** are those that are needed in large amounts. (**C, H, O, N, Ca, P, Mg, S, K**).
- **Micronutrients** (trace elements) are needed in lesser, often minute quantities. (**Cl, Fe, Mn, B, Cu, Mo, Zn, Ni).**

- **Nitrogen** plays a major role in photosynthesis as it is the major element found in both rubisco and chlorophyll.
- The maximum (light saturated) rate of photosynthesis is **correlated with the leaf nitrogen content.**

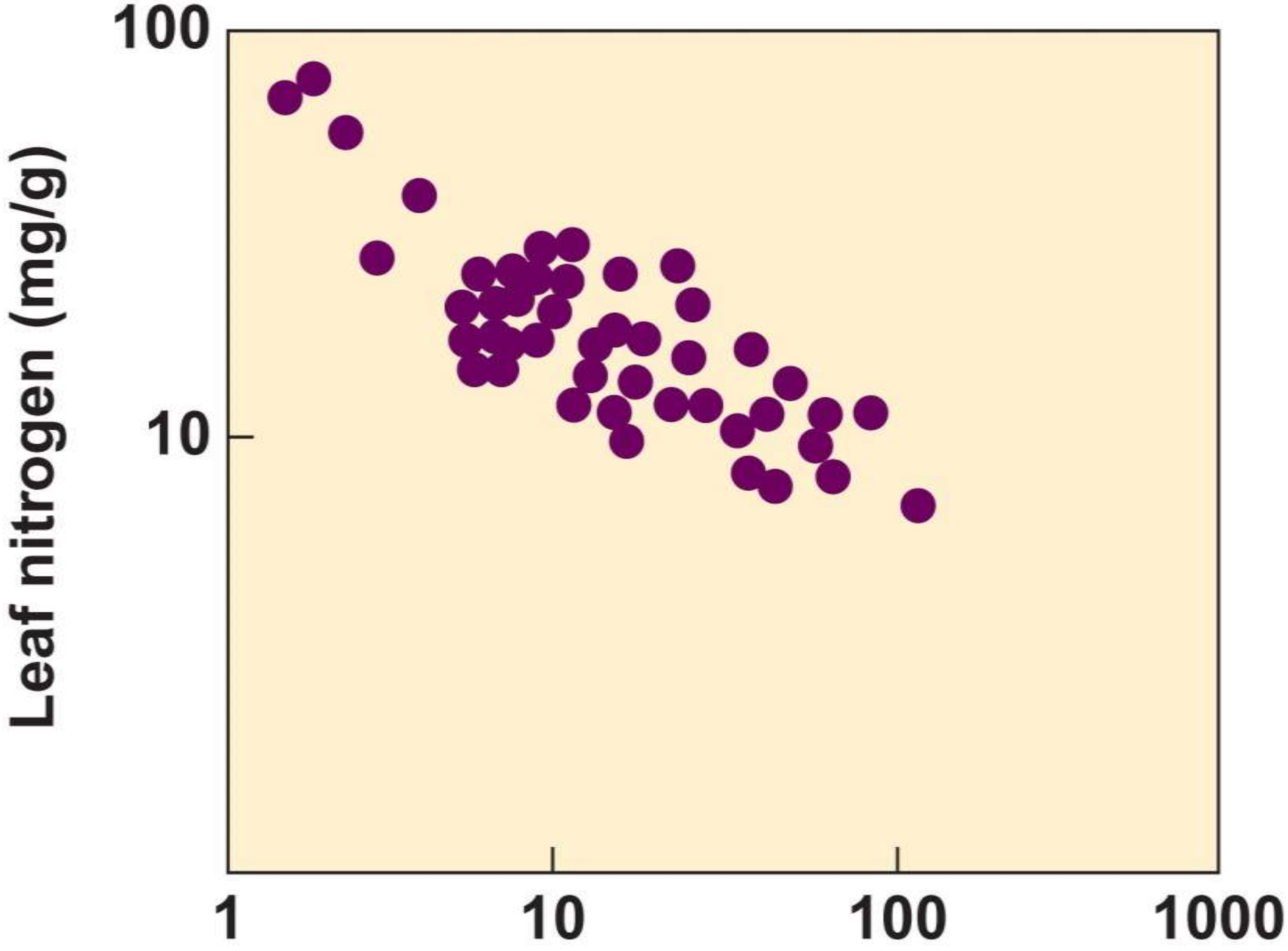


Death Valley annuals
Old field annuals
Deciduous chaparral shrubs
Evergreen shrubs and trees
South African shrubs
Net photosynthesis (μmol CO_2/g/s)
700
600
500
400
300
200
100
0
1.0
2.0
3.0
4.0
Leaf nitrogen (μmol/g)

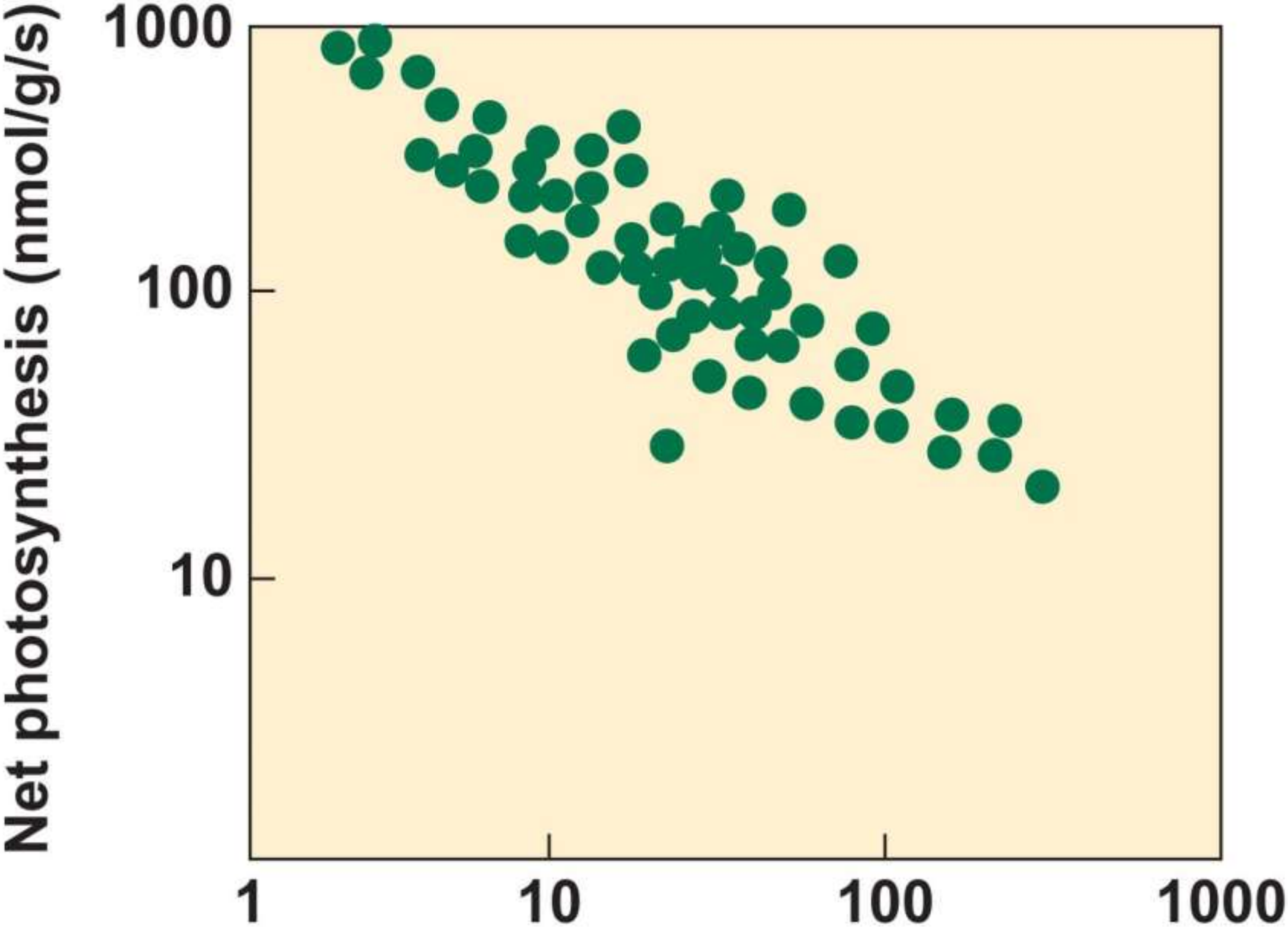
- **Nutrient availability** is directly related to geology, climate, and biological activity.
- **A plant's growth rate influences its demand for a nutrient**, and the plant's uptake rate of the nutrient also influences growth.
  - *Not all plants have the same maximum potential rate of growth.*
- Generally, *there is a reduction in photosynthesis in plants characteristic of low-nutrient environments.*


Agrostis stolonifera
High nutrient ecosystem
Low nutrient ecosystem
Agrostis canina
Plant weight (g)
5.0
4.0
3.0
2.0
1.0
0.4
0.2
0
1
3
9
27
81
243
Nitrogen (ppm)

- Hypothesized **adaptations to low-nutrient environments:**
  - **Low maximum growth rate.**
  - **Leaf longevity.**
  - **Increased root production.**
  - **Become carnivorous.**



(a)


Net photosynthesis (nmol/g/s)
1000
100
10
1
10
100
1000
Leaf life span (months)

(b)

- **Halophytes** *are plants that take in water containing high levels of solutes.*
- For a halophyte to maintain a water potential gradient, they:
  - Accumulate high levels of ions within their cells (especially leaves).
  - Dilute solutes with stored water.
  - Secrete salt onto the leaf surface to be washed away by rainwater.
- The degree of salt tolerance varies greatly in different halophytes.

End of chapter