

Plant Function

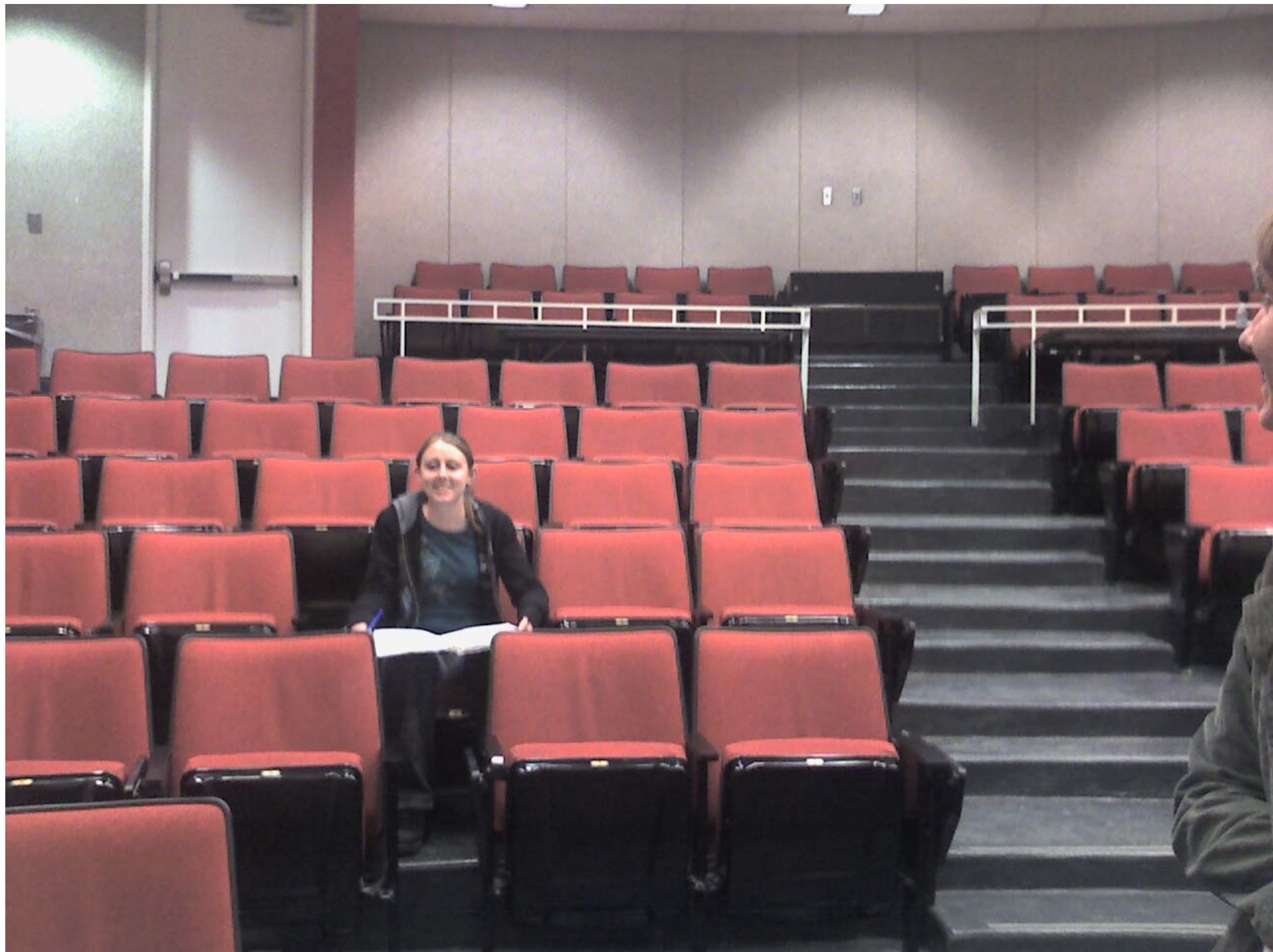
Ecol 182 – 3-22-2007

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Foto: Trond Steen





Summary from last time

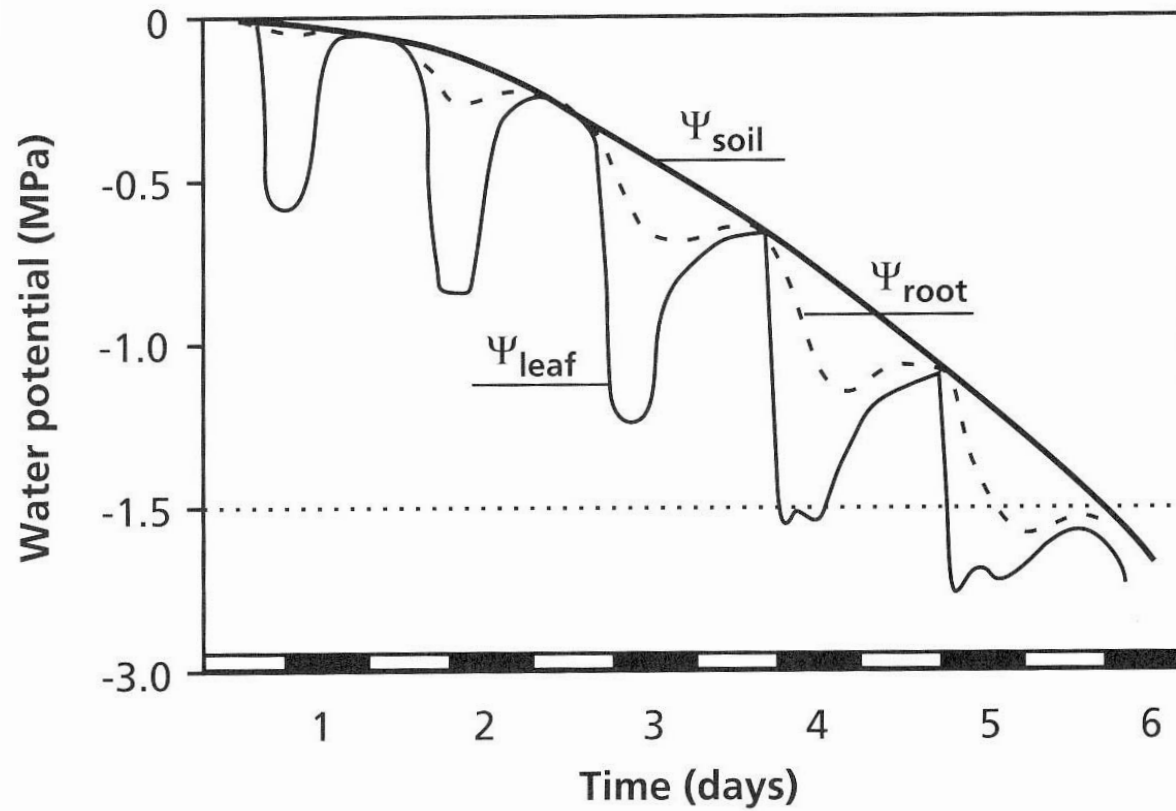
- We talked about?

Uptake & Movement of Water & Solutes in Plants

- **Water potential** is the tendency of a solution to take up water from pure water (Ψ).
- **Water potential** of a system is the sum of the negative solute potential (ψ_s) and the (usually positive) pressure potential (ψ_p).

$$\Psi = \psi_s + \psi_p$$

- Solute potential, pressure potential, and water potential are measured in **megapascals (Mpa)**.

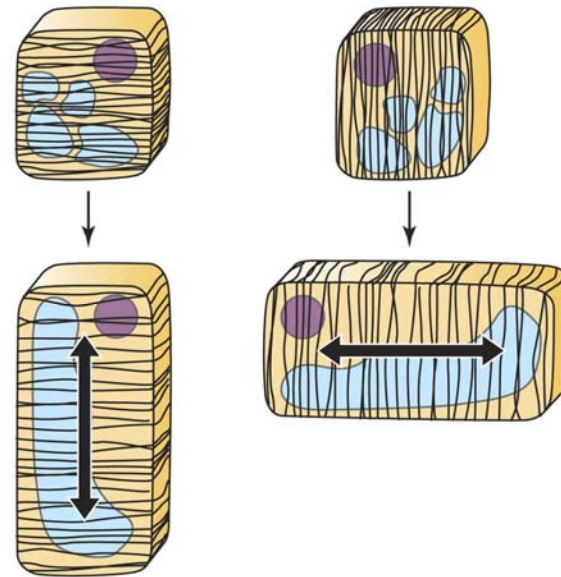


Why is there a disconnect (temporally) between leaf, root and soil?



Figure 1 High and mighty. This composite image of trees in the Humboldt Redwoods State Park includes the 'Stratospheric Giant', the tallest tree on Earth. The image consists of more than 700 photos taken by James Balog—spot the human climbers!

How tall can trees become? – the importance of components of leaf water potential – Coastal Redwoods



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 38.14 Plant Cells Expand
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$$\Psi_{\text{total}} = \Psi_s + \Psi_p$$

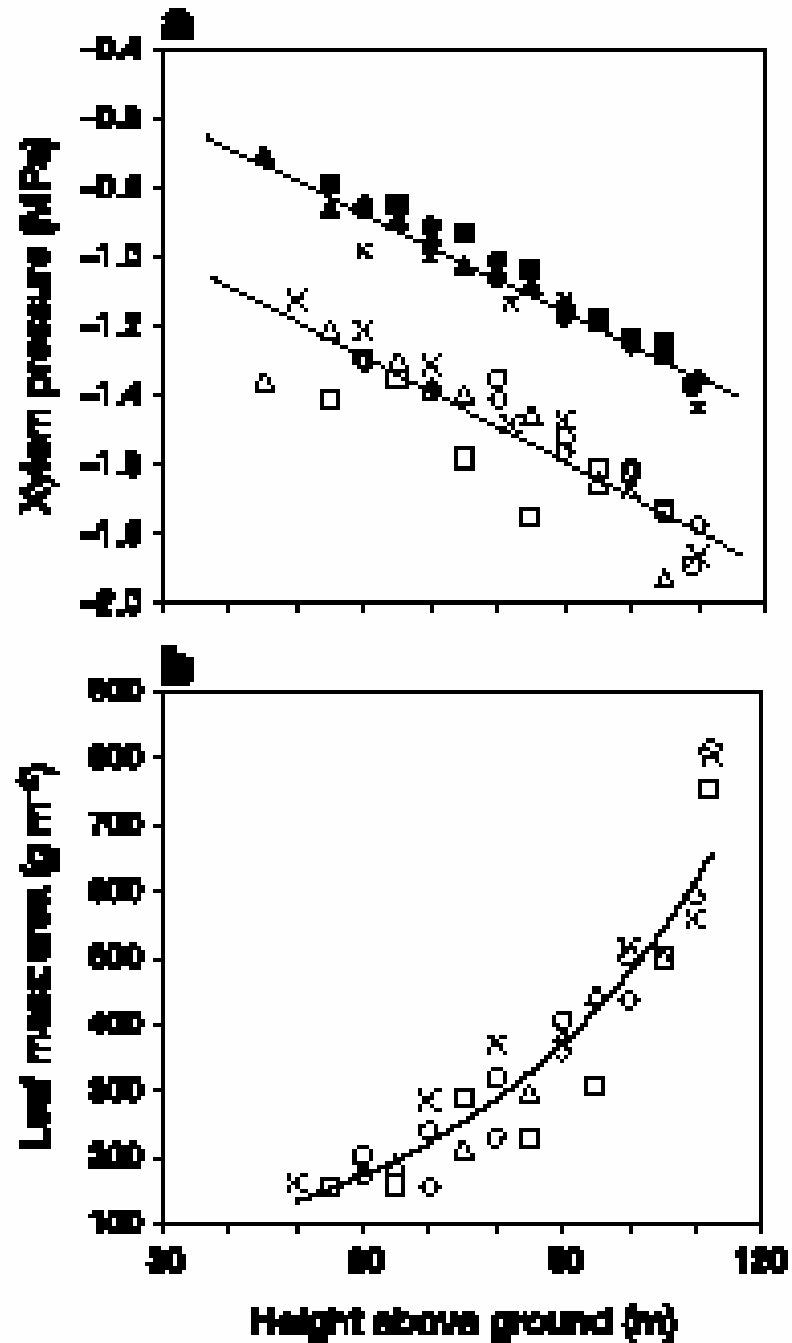
Ψ_s = solute potential

Ψ_p = turgor potential (pressure)

Ψ_p must be positive for growth!

How tall can trees become? – the importance of components of leaf water potential.

Minimum Turgor required for growth is 2 MPa (which is compensated for at about 125 m)



How tall can trees become? – the importance of components of leaf water potential – Coastal Redwoods

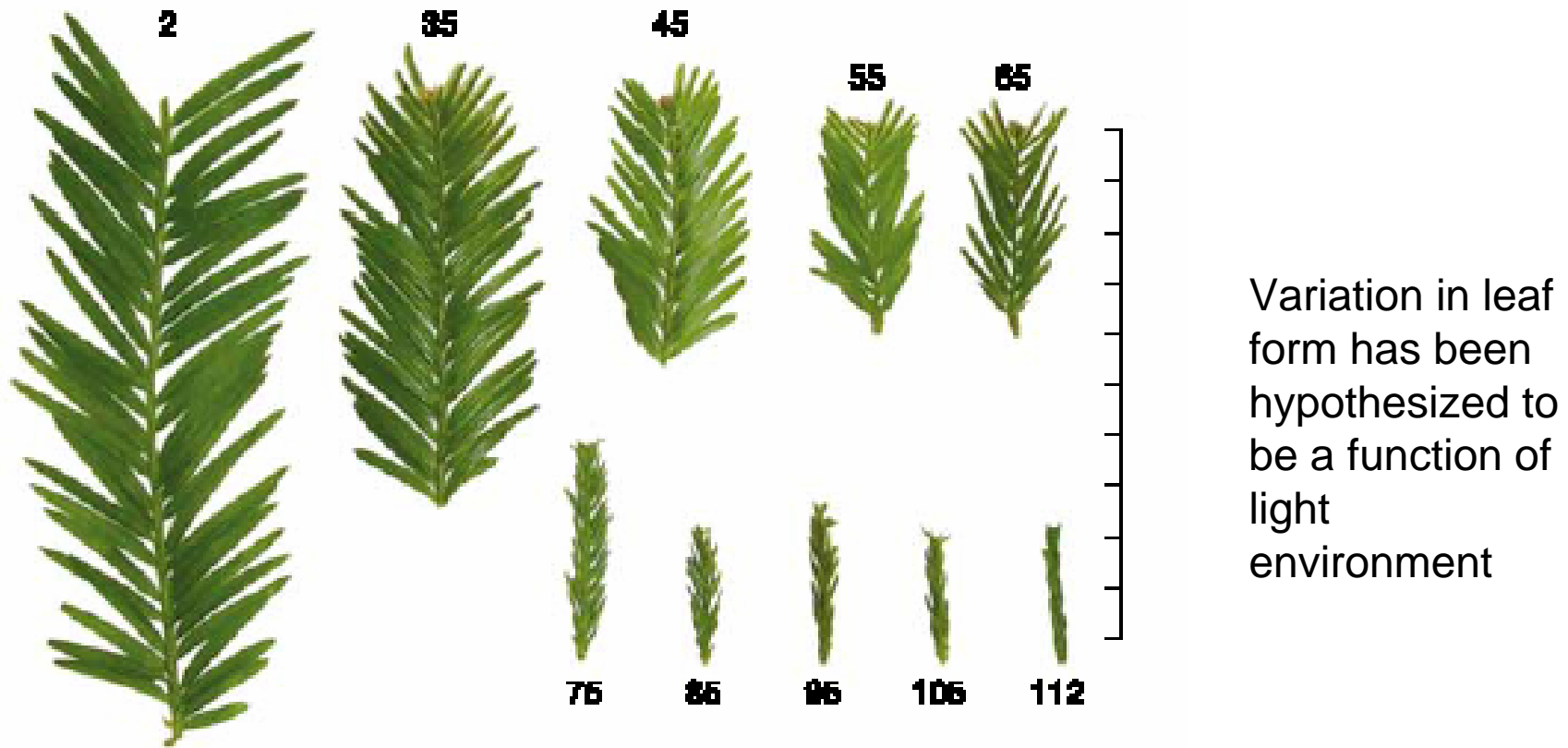


Figure 2 Variation in leaf structure with height in redwood. Leaf length and the angle between the long axis of the leaf and supporting stem segment both decrease with height. Numbers denote the sample height in m. Scale divisions are cm.

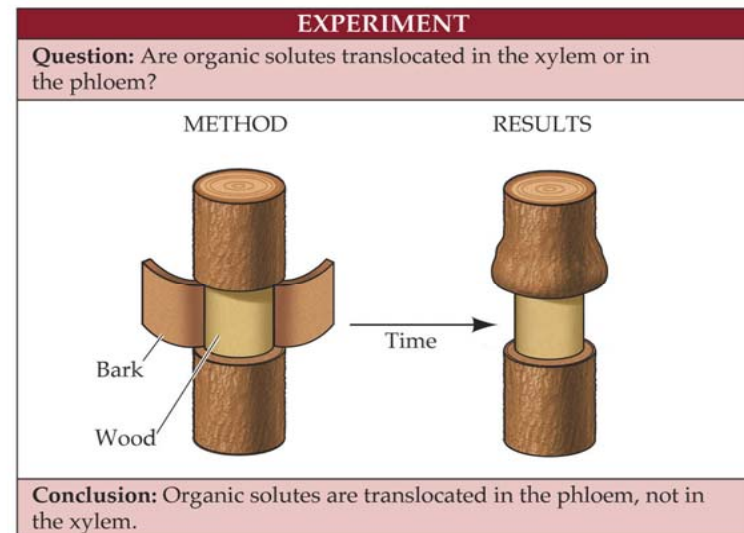


Translocation of Substances in the Phloem

- Sugars, amino acids, some minerals, and other solutes are transported in phloem and move from sources to sinks.
- A **source** is an organ such as a mature leaf or a starch-storing root that produces more sugars than it requires.
- A **sink** is an organ that consumes sugars, such as a root, flower, or developing fruit.
- These solutes are transported in phloem, not xylem, as shown by Malpighi by **girdling** a tree.

Translocation of Substances in the Phloem

- Translocation (movement of organic solutes) stops if the phloem is killed.
- Translocation often proceeds in both directions— both up and down the stem simultaneously.
- Translocation is inhibited by compounds that inhibit respiration and the production of ATP.



Translocation of Substances in the Phloem

- There are two steps in translocation that require energy:
 - **Loading** is the active transport of sucrose and other solutes into the sieve tubes at a source.
 - **Unloading** is the active transport of solutes out of the sieve tubes at a sink.

Translocation of Substances in the Phloem

- **Pressure flow model of transport**
- Source sieve tube cells have a greater sucrose concentration than surrounding cells
 - water enters by osmosis.
 - causes greater pressure potential at the source, so that the sap moves by bulk flow towards the sink.
- Sucrose is unloaded actively at the sink, maintaining the solute and water potential gradients.

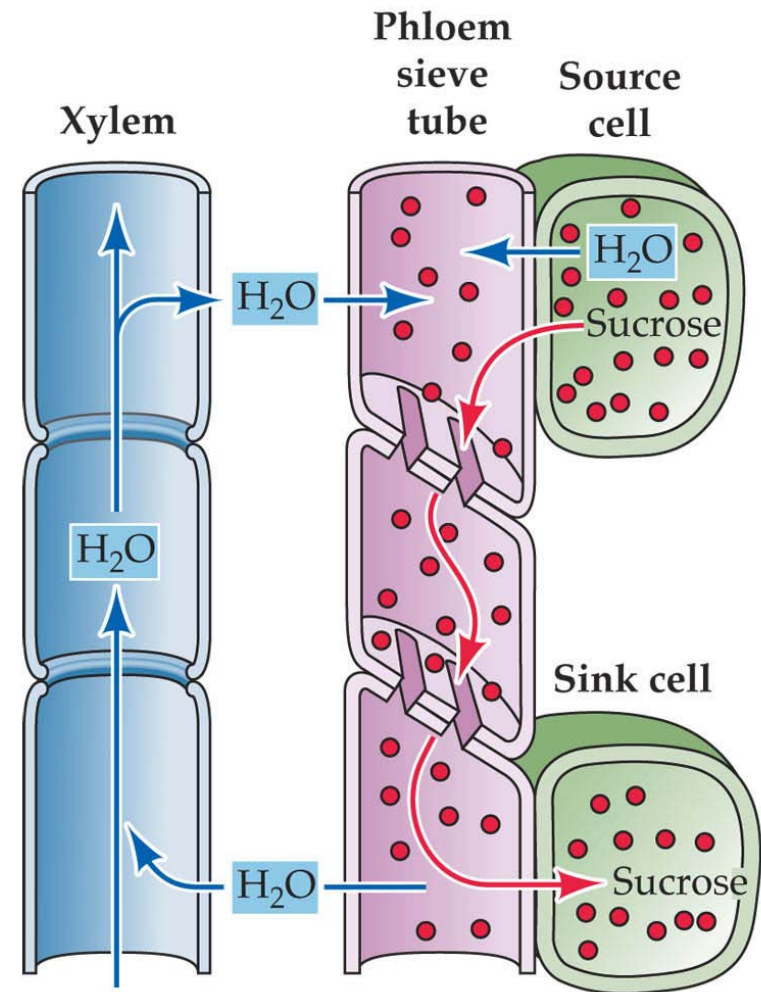


Table 36.1 *Mechanisms of Sap Flow in Plant Vascular Tissues*

36.1 *Mechanisms of Sap Flow in Plant Vascular Tissues*

	XYLEM	PHLOEM
Driving force for bulk flow	Transpiration from leaves	Active transport of sucrose at source
Site of bulk flow	Non-living vessel elements and tracheids (cohesion)	Living sieve tube elements
Pressure potential in sap	Negative (pull from top; tension)	Positive (push from source; pressure)

The Acquisition of Nutrients

- All living things need raw materials from the environment.
- Carbon derives from CO_2 in the air (photosynthesis).
- Hydrogen comes from water.
 - Carbon, oxygen, and hydrogen are fairly plentiful.
- Nitrogen is in relatively short supply for plants.
 - Nitrogen enters living forms first in bacteria, which can convert N_2 in air to forms that are useful to plants.
- Other **mineral nutrients** essential for life include sulfur, phosphorus, potassium, magnesium, and iron.
- Plants take up most nutrients as dissolved solutes in the water of the soil, the **soil solution**.

Nutrient classification – Table 37.1

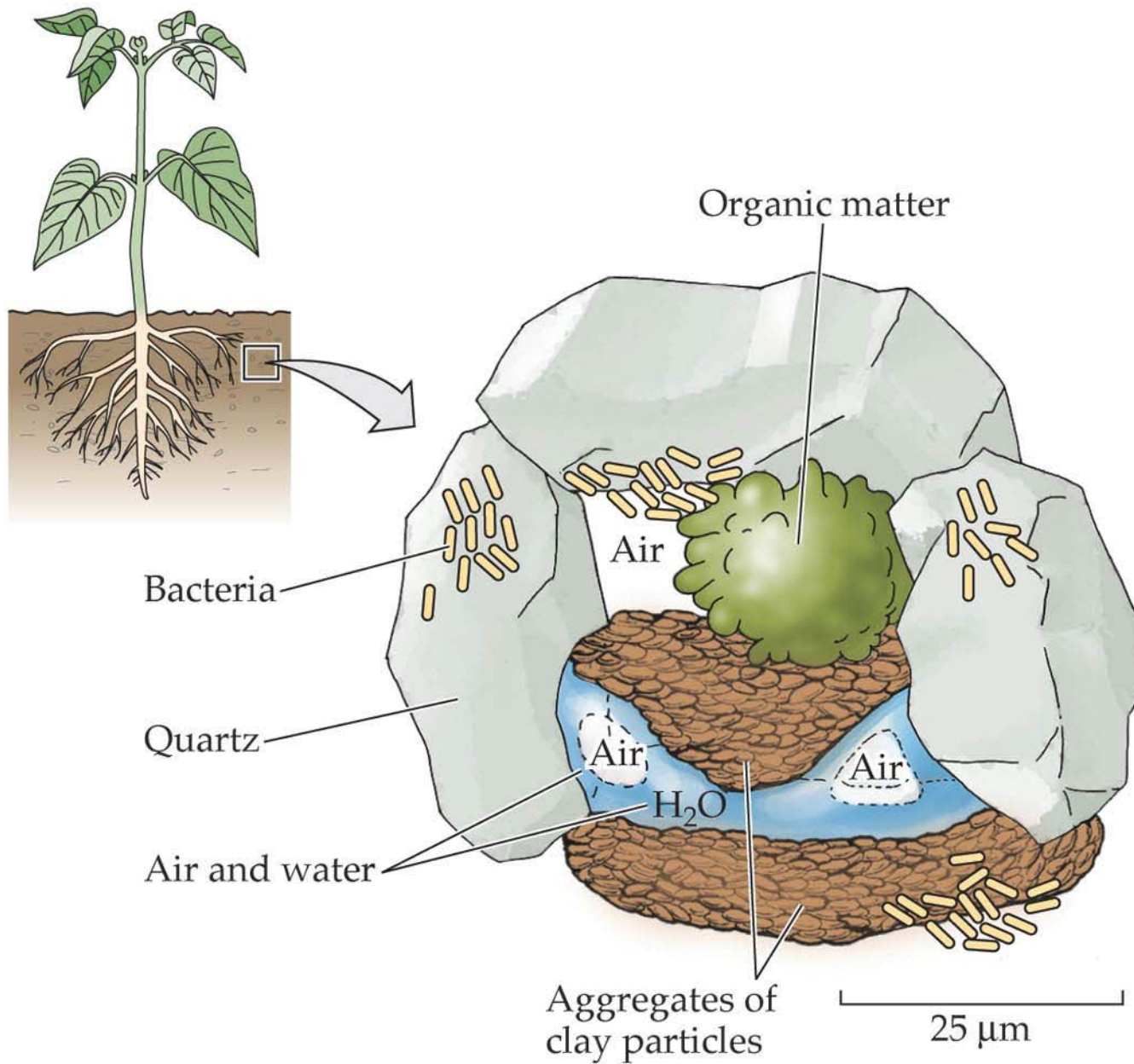
- Amount
 - Macronutrients: (H,C,O,N,K,Ca,Mg,P,S)
 - Micronutrients: (Cl,B,Fe,Mn,Zn,Cu,Mo)
- Function
 - Constituents of organic material: (C,H,O,N,S)
 - Osmotic potential or contribute to enzyme structure/function: (K,Na,Mg,Ca,Mn,Cl)
 - Structural factors in methalloproteins: (Fe,Cu,Mo,Zn)

Nutrient Dynamics (outline)

- **Nutrient availability**
 - Sources of nutrients
 - Direct and indirect controls over sources
- **Nutrient Uptake**
 - Plant and environmental interactions
- **Nutrient Return from the plant to the soil (cycling)**
 - Ecological and environmental processes

Nutrient sources for plants

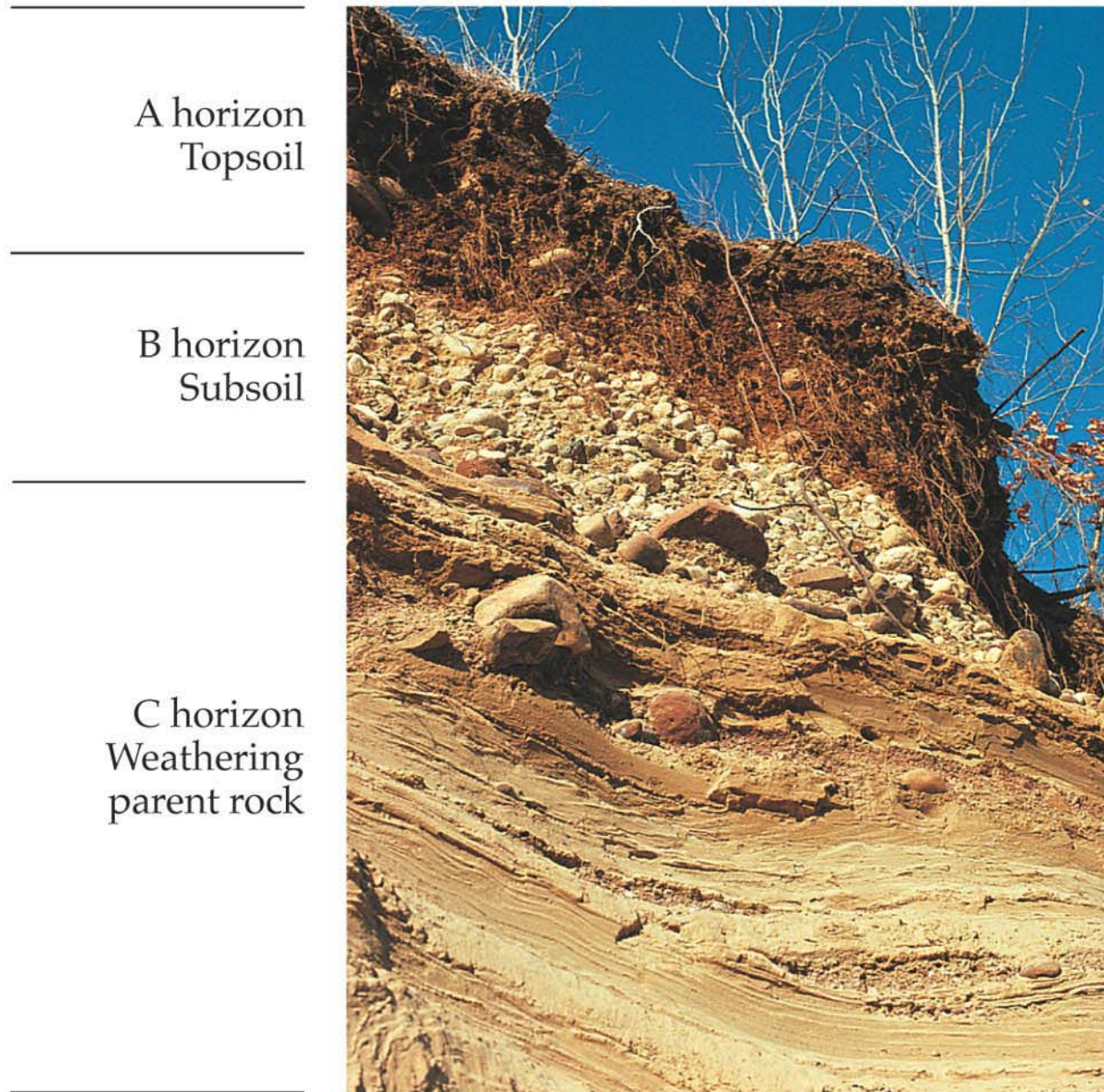
- Mineral nutrients in the soil
 - 98% bound in organic matter (detritus), humus, and insoluble inorganic compounds or incorporated in minerals
 - NOT DIRECTLY AVAILABLE TO PLANTS
 - 2% is adsorbed on soil colloids
 - These are positively charged ions
 - 0.2% is dissolved in the soil water
 - Usually negatively charged, nitrates and phosphates



Soils and Plants

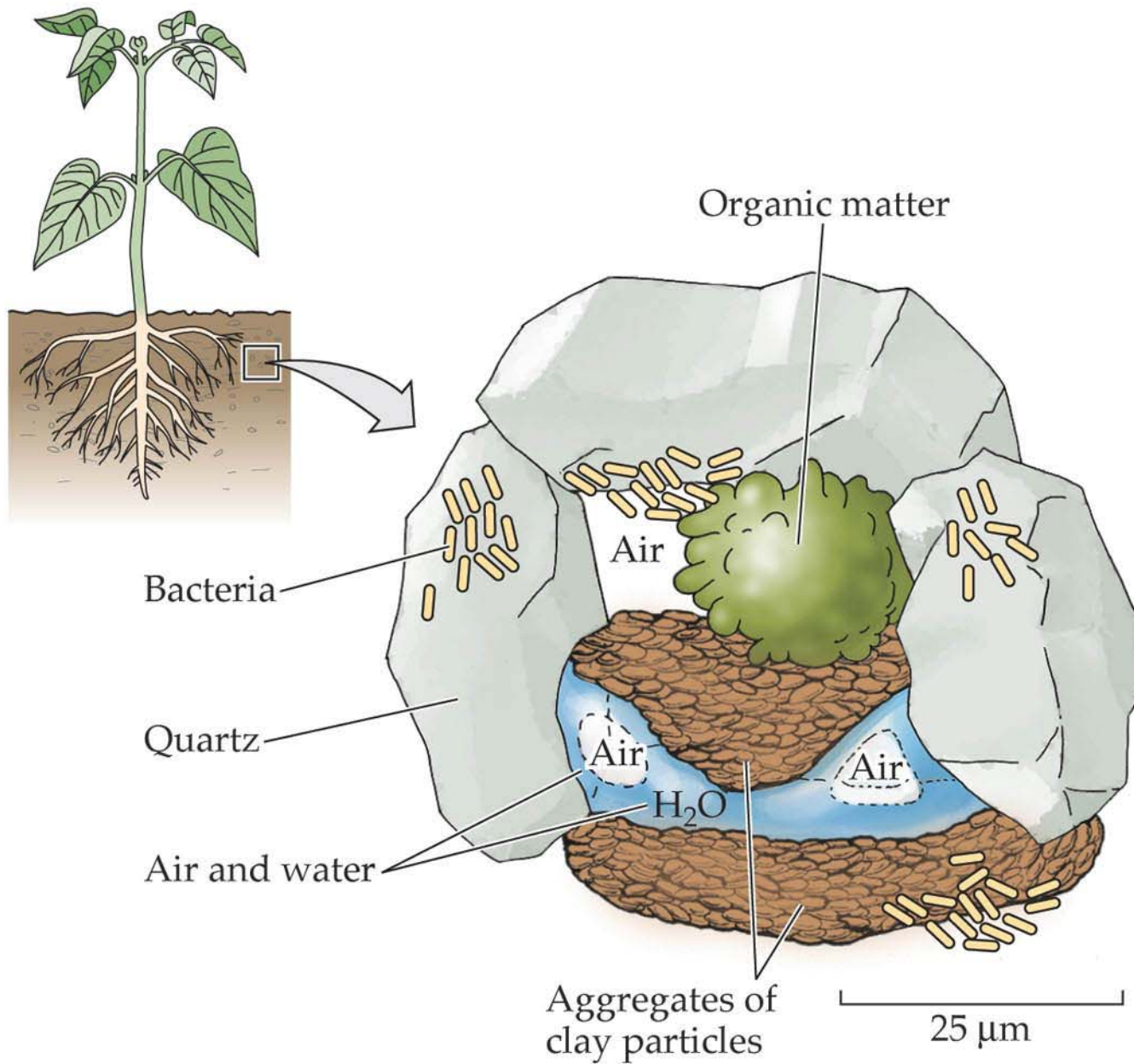
- The structure of many soils changes with depth, revealing a **soil profile**.
- Most soils have two or more horizontal layers, called **horizons**.
- Minerals tend to **leach**, or be carried away by water from the upper horizons, and sink into deeper horizons.
- Soil scientists recognize three major horizons:
 - A, the topsoil
 - B, the subsoil
 - C, the parent rock

Figure 37.3 A Soil Profile



Soil Colloids

- Ion exchangers
 - Exchange capacity depends upon surface area
 - Clay (montmorillonite) ~ 600 – 800 m² g⁻¹
 - Many humic substances ~ 700 m² g⁻¹
 - Retain charged substances (mainly cations, but to a lesser extent, anions)
- Adsorptive binding of nutrient ions result in:
 - Nutrients freed by weathering and decomposition are collected and protected from leaching
 - Concentration in soil solution remains low and constant
 - Removes a potential osmotic effect
 - Adsorbed nutrient ions are readily available to plants



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 37.2 The Complexity of Soil
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Nutrient uptake

- Conditions that affect nutrient content in the soil
 - Soil texture (clay content)
 - Soil organic matter content
 - Soil water content (precipitation)
 - Soil temperature

Environments that tend to result in low nutrient contents

- **Sandy soils** – low clay content and thus inadequate exchange capacity
- **High rainfall** – excessive leaching of nutrients
- **Low rainfall** – inadequate soil moisture for organic matter decomposition
- **Cold soils** – low decomposition; low root respiration and thus low nutrient uptake
- **Waterlogged soils** – inadequate oxygen for root respiration and decomposition

Ion uptake by roots

- The rate at which nutrients are supplied to a plant depends on:
 - The concentration of diffusible minerals in the rooted soil strata
 - Ion-specific rates of diffusion and mass transport
 - Nitrate is fast and phosphate and potassium are slower (diffusivities)
- Ions of nutrient salts are taken up by a purely passive process
 - Following the concentration and charge gradients between the soil solution and the interior of the root

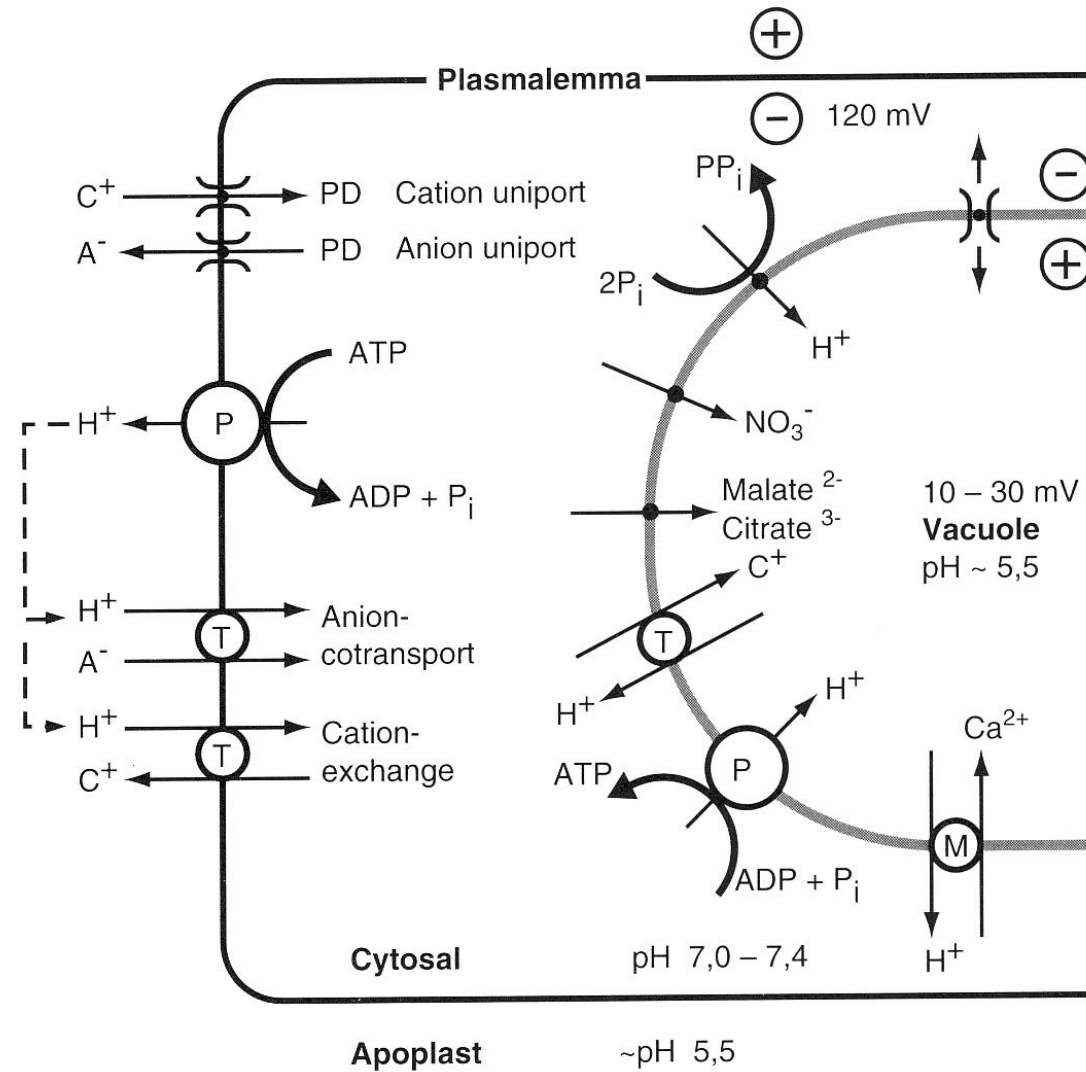
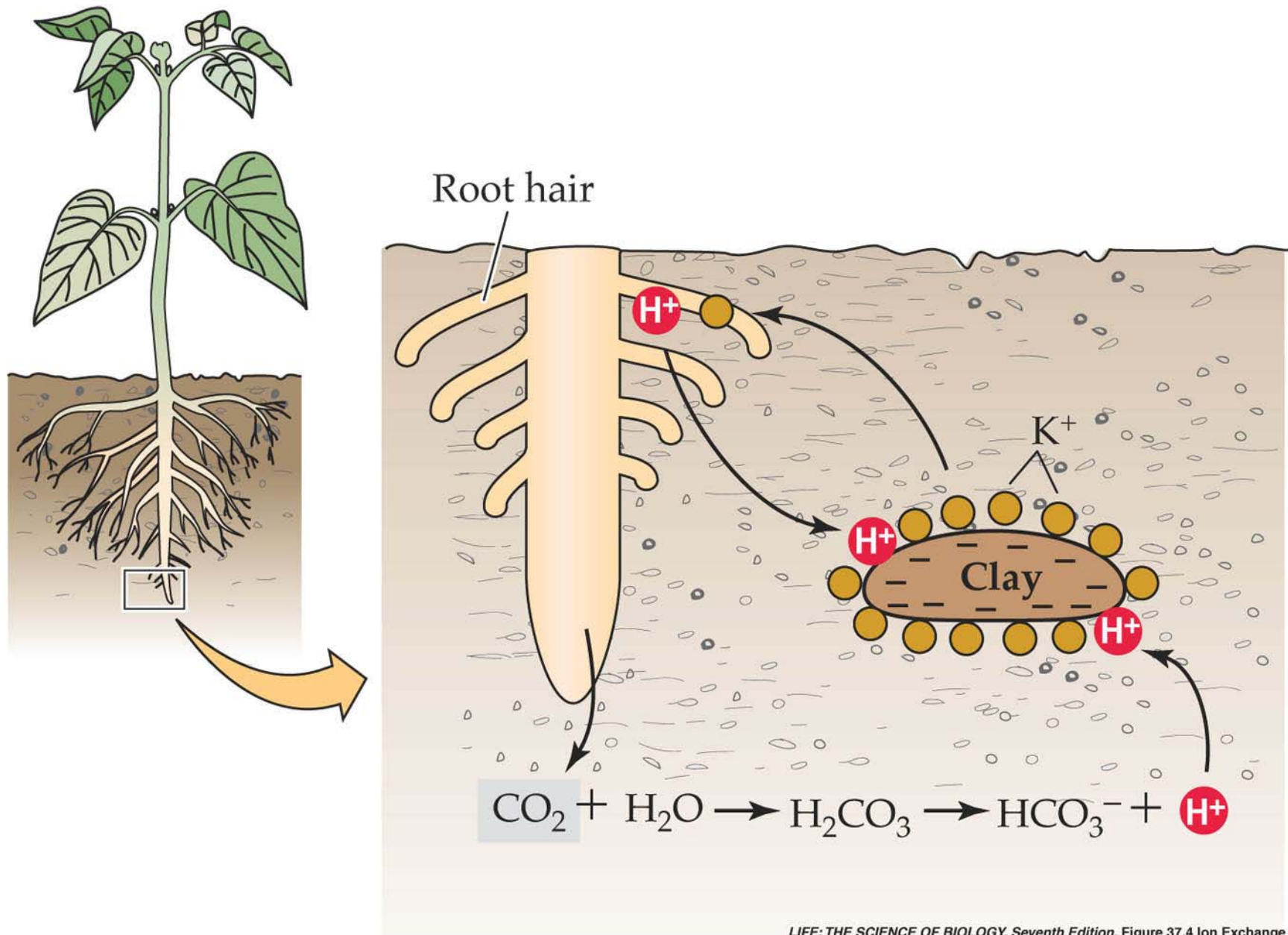


Fig. 3.5. Model of ion transport across plasmalemma and tonoplast.] [= ion channels; *P* proton-transporting membrane-ATPases (“proton pump”); *C* carrier system; *M* calmodulin-dependent transport; *PD* electric potential differences; *A*⁻ anion; *C*⁺ cation; *PP*_i pyrophosphate; *P*_i inorganic phosphate. (After Pitman and Lüttge 1983; Kaiser et al. 1988; Martinoia 1992)

Mass flow vs. diffusion – nutrient delivery

- Nutrient uptake is a function of BOTH plants & soils and includes two processes (1) Mass Flow and (2) Diffusion
 - Mass flow in soils is a rapid process, whereas diffusion is only measured in mm per day in soils
- Where mass flow is insufficient to satisfy plant demand, ion concentrations at the root surface are reduced below that of the surrounding soil volume
 - Zones of depletion create concentration gradients that drives diffusional processes in the soil (as a function of soil water content)

Figure 37.4 Ion Exchange



Nitrogen acquisition

- Nitrogen is the nutrient that plants require in the greatest quantity
 - N frequently limits growth in both agricultural and natural systems
- The carbon expended in acquiring nitrogen can make up a significant fraction of the total energy a plant consumes
- Plants have developed several approaches to nitrogen acquisition, including:
 - Root absorption of inorganic ions ammonium and nitrate
 - Fixation of atmospheric nitrogen
 - Mycorrhizal associations
 - Carnivory

Variation in Acquisition – a cost / benefit function of availability

- Variation in N acquisition – additional carbon costs for ‘other’ absorbing organs
 - NITROGEN FIXERS
 - Some plants have developed associations with bacterial symbionts (*Rhizobium*) that allow for the use of atmospheric nitrogen
 - These plants incur the expense of (1) constructing root nodules (locations of symbiosis) and (2) providing bacterial symbionts with carbon compounds



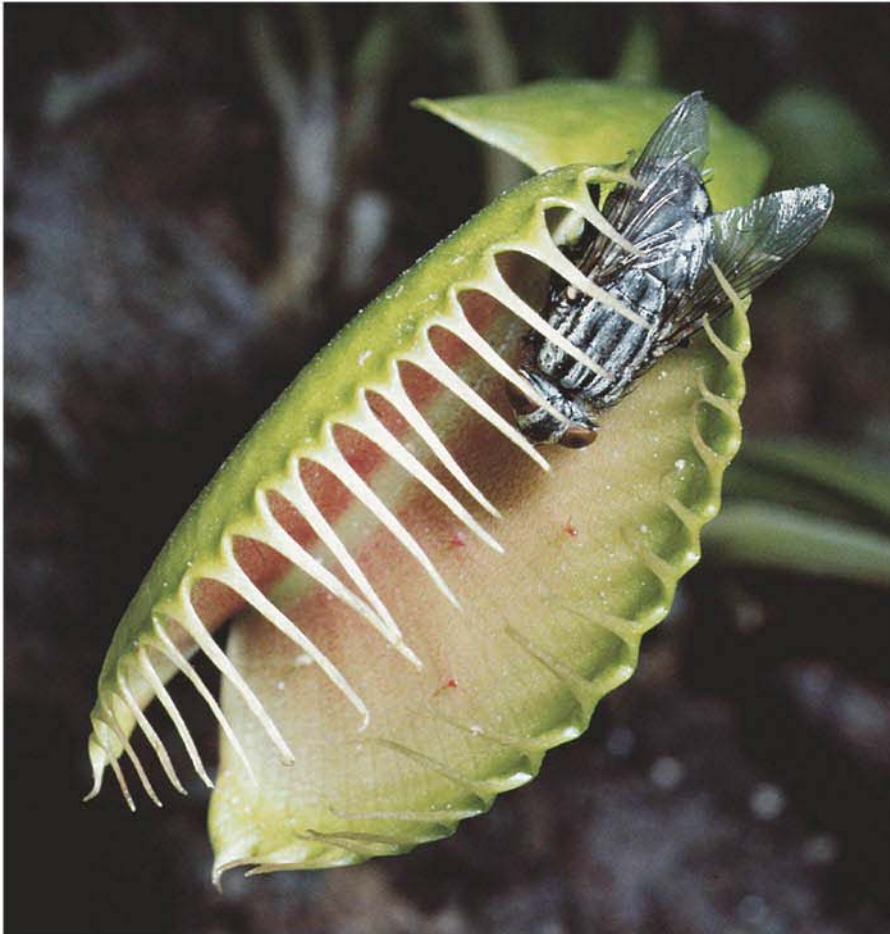
LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 37.5 Root Nodules
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Variation in Acquisition – a cost / benefit function of availability

- Variation in N acquisition – additional carbon costs for ‘other’ absorbing organs
 - MYCORRHIZAL ASSOCIATIONS
 - Associations with fungi that allow greater soil exploration
 - Endomycorrhizae – fungus penetrates root tissue
 - Ectomycorrhizae – fungus forms a sheath over root
 - Effectively increases absorbing surface area
 - Costs (carbon compounds) can be extensive – 15% of total net primary production in a Fir species

Figure 37.9 Carnivorous Plants

(a)



Dionaea muscipula

(b)



Drosera rotundifolia

Integrating nitrogen acquisition into a whole-plant function perspective

- 75% of leaf N is located within chloroplasts (most in PSN function)
- Processes / factors to consider
 - Water-use
 - Photosynthetic gas exchange
 - Root – shoot allocation
 - Reproduction
 - Stress tolerance
 - Competition

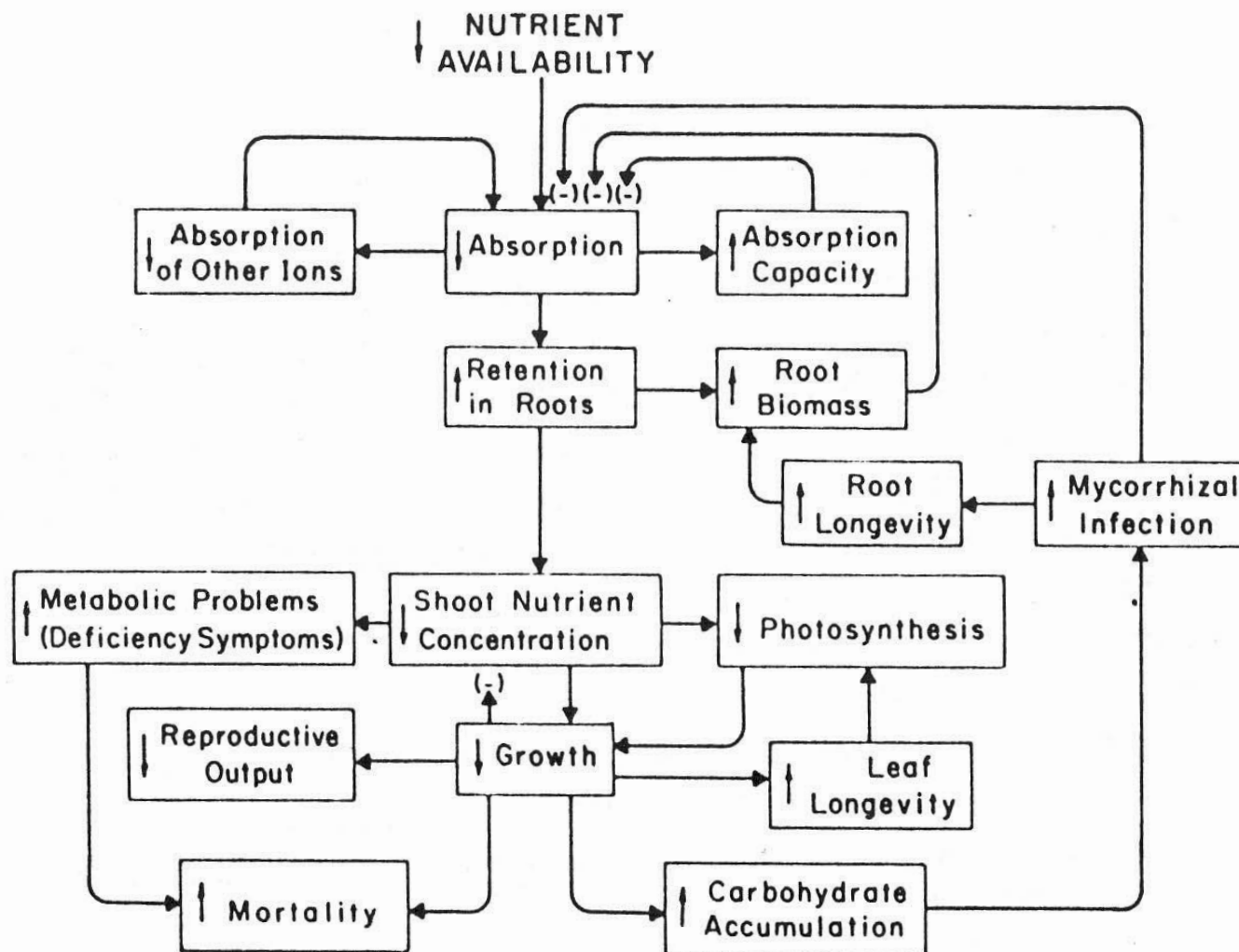
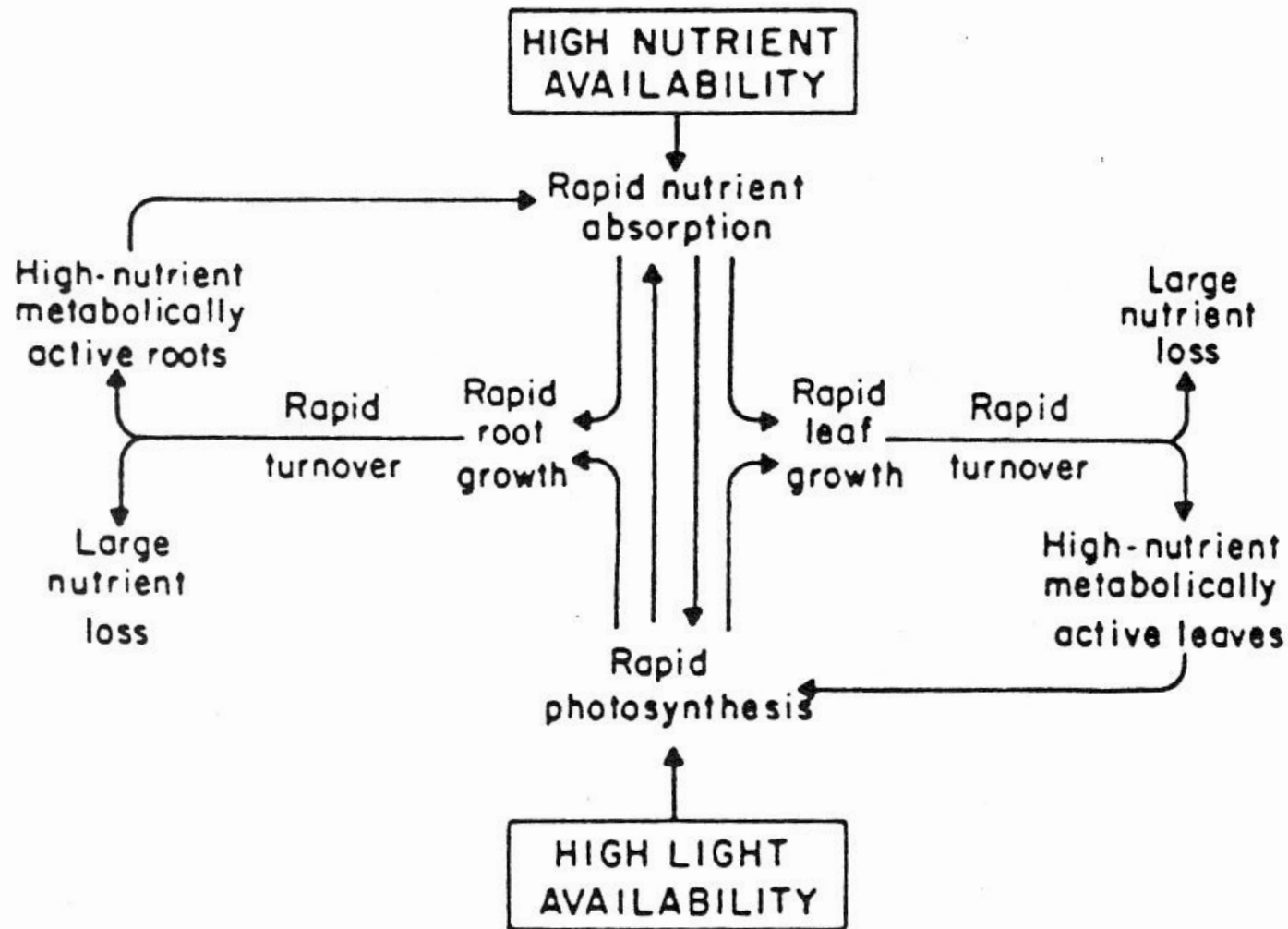
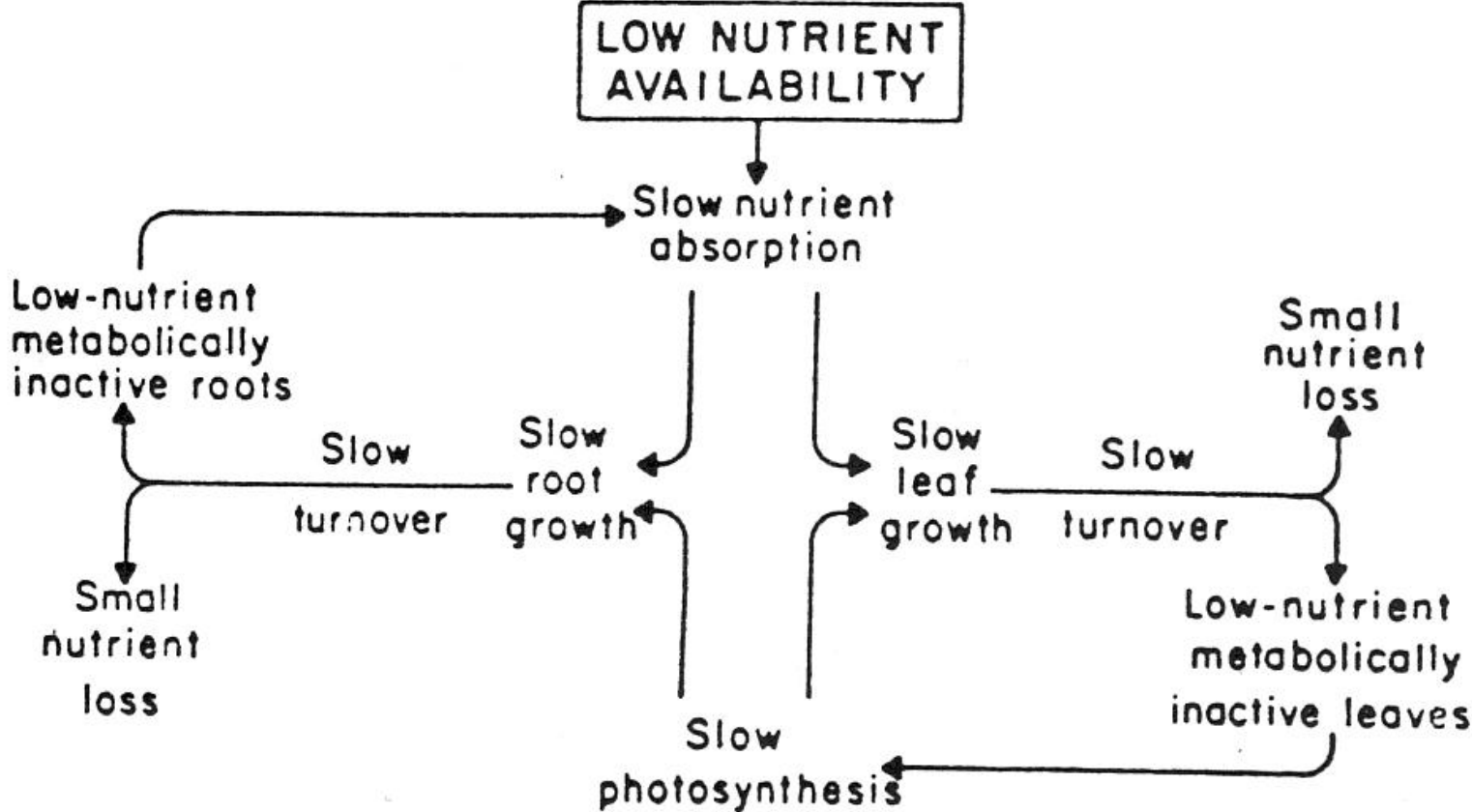


Figure 1 Response of crop plants to decreased availability of a single mobile nutrient. Vertical arrows inside boxes indicate an increase (↑) or decrease (↓) in the parameter. Arrows between boxes indicate a positive effect unless otherwise indicated (-).

COMPETITIVE/RUDERAL STRATEGY



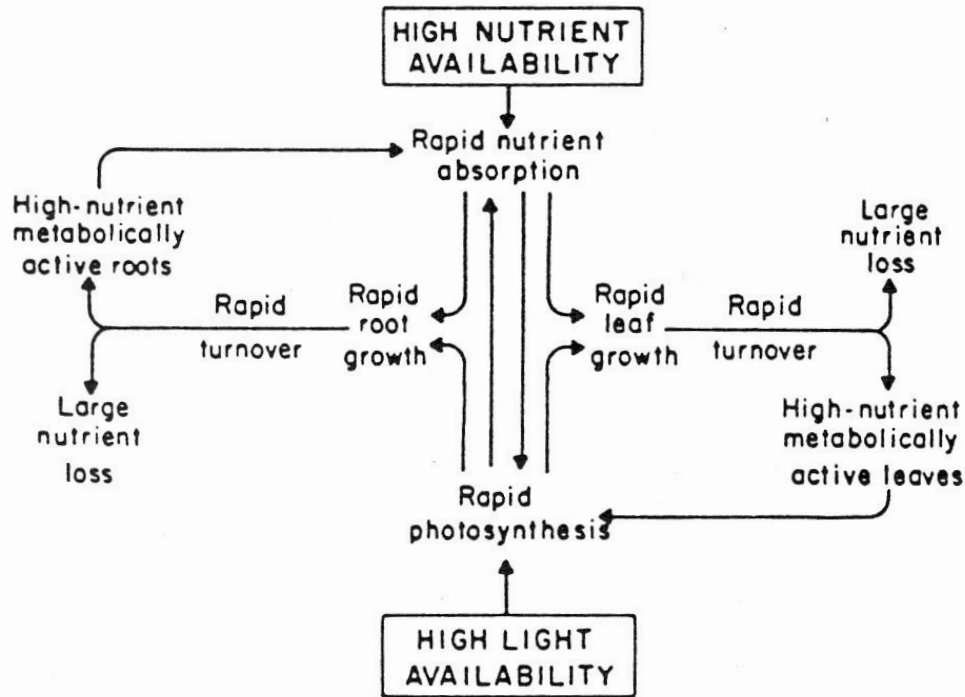
NUTRIENT-STRESS TOLERANT STRATEGY



Nutrient Dynamics (outline – and big deals)

- **Nutrient availability**
 - Sources of nutrients
 - Direct and indirect controls over sources
- **Nutrient Uptake**
 - Plant and environmental interactions
- **Nutrient Return from the plant to the soil (cycling)**
 - Ecological and environmental processes
 - Complexity of cycling

COMPETITIVE/RUDERAL STRATEGY



Big Point –

Tight coupling of nutrient cycling in an ecosystem and the functional diversity of dominant plant species

NUTRIENT-STRESS TOLERANT STRATEGY

