

Chapter 37

Soil and Plant Nutrition

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Overview: “The Nation that Destroys Its Soil Destroys Itself”

- Farmland productivity often suffers from chemical contamination, mineral deficiencies, acidity, salinity, and poor drainage
- Healthy soils improve plant growth by enhancing plant **nutrition**
- Typically, plants obtain carbon dioxide from the air, and water and minerals from the soil

Fig. 37-1



Concept 37.1: Soil is a living, finite resource

- Plants obtain most of their water and minerals from the upper layers of soil
- Living organisms play an important role in these soil layers
- This complex ecosystem is fragile

Soil Texture

- Soil particles are classified by size; from largest to smallest they are called sand, silt, and clay
- Soil is stratified into layers called **soil horizons**
- **Topsoil** consists of mineral particles, living organisms, and **humus**, the decaying organic material

Fig. 37-2



A horizon

B horizon

C horizon

-
- After a heavy rainfall, water drains from the larger spaces in the soil, but smaller spaces retain water because of its attraction to clay and other particles
 - The film of loosely bound water is usually available to plants
 - **Loams** are the most fertile topsoils and contain equal amounts of sand, silt, and clay

Topsoil Composition

- A soil's composition refers to its inorganic (mineral) and organic chemical components

Inorganic Components

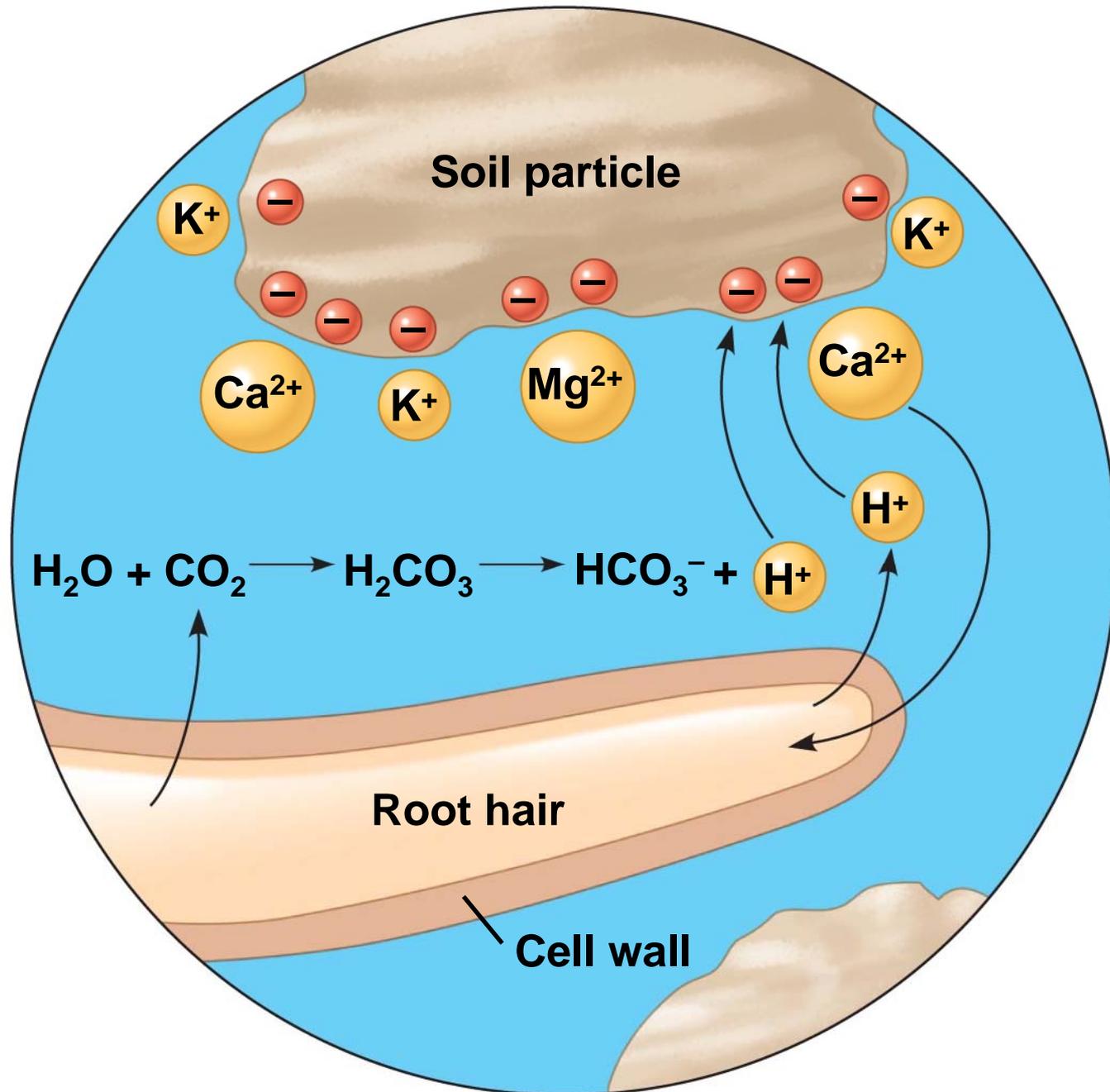
- Cations (for example K^+ , Ca^{2+} , Mg^{2+}) adhere to negatively charged soil particles; this prevents them from leaching out of the soil through percolating groundwater

-
- During **cation exchange**, cations are displaced from soil particles by other cations
 - Displaced cations enter the soil solution and can be taken up by plant roots
 - Negatively charged ions do not bind with soil particles and can be lost from the soil by leaching

PLAY

Animation: How Plants Obtain Minerals from Soil

Fig. 37-3



Organic Components

- Humus builds a crumbly soil that retains water but is still porous
- It also increases the soil's capacity to exchange cations and serves as a reservoir of mineral nutrients
- Topsoil contains bacteria, fungi, algae, other protists, insects, earthworms, nematodes, and plant roots
- These organisms help to decompose organic material and mix the soil

Soil Conservation and Sustainable Agriculture

- In contrast with natural ecosystems, agriculture depletes the mineral content of soil, taxes water reserves, and encourages erosion
- The goal of **sustainable agriculture** is to use farming methods that are conservation-minded, environmentally safe, and profitable

Irrigation

- Irrigation is a huge drain on water resources when used for farming in arid regions
- The primary source of irrigation water is underground water reserves called *aquifers*
- The depleting of aquifers can result in *subsidence*, the settling or sinking of land

Fig. 37-4



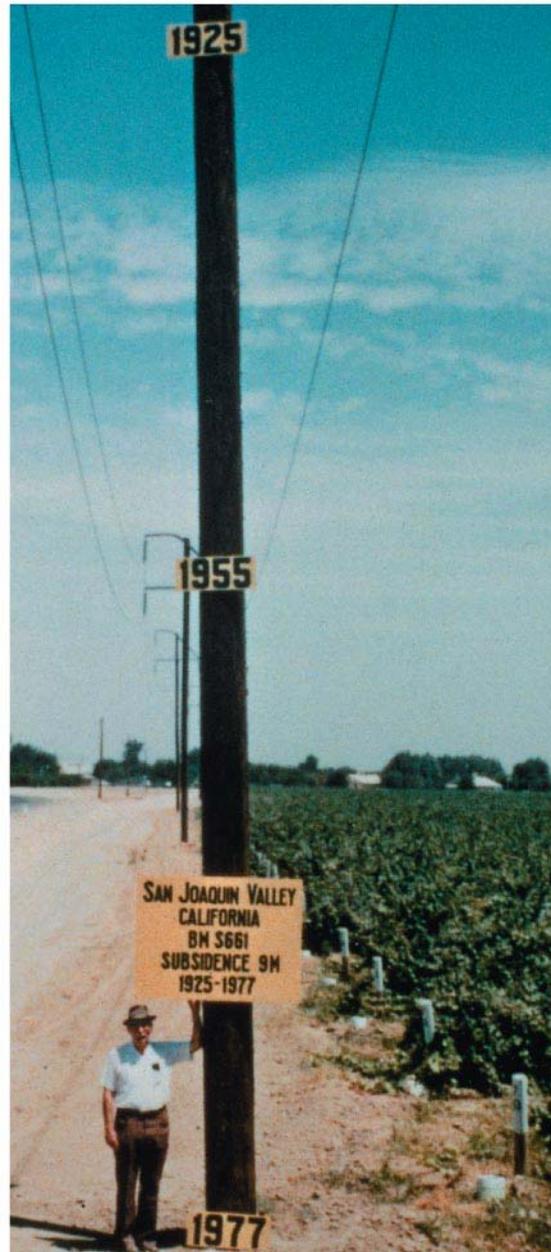
Land subsidence in California

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Sinkhole in Florida

Fig. 37-4a



Land subsidence in California



Sinkhole in Florida

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- Irrigation can lead to *salinization*, the concentration of salts in soil as water evaporates
 - Drip irrigation requires less water and reduces salinization

Fertilization

- Soils can become depleted of nutrients as plants and the nutrients they contain are harvested
- **Fertilization** replaces mineral nutrients that have been lost from the soil
- Commercial fertilizers are enriched in nitrogen, phosphorus, and potassium
- Organic fertilizers are composed of manure, fishmeal, or compost

Adjusting Soil pH

- Soil pH affects cation exchange and the chemical form of minerals
- Cations are more available in slightly acidic soil, as H^+ ions displace mineral cations from clay particles

Controlling Erosion

- Topsoil from thousands of acres of farmland is lost to water and wind erosion each year in the United States
- Erosion of soil causes loss of nutrients

Fig. 37-5



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- Erosion can be reduced by
 - Planting trees as windbreaks
 - Terracing hillside crops
 - Cultivating in a contour pattern
 - Practicing **no-till agriculture**

Preventing Soil Compaction

- Soil compaction from heavy equipment reduces pore space between soil particles
- Soil compaction slows gas exchange and reduces root growth

Phytoremediation

- Some areas are unfit for agriculture because of contamination of soil or groundwater with toxic pollutants
- **Phytoremediation** is a biological, nondestructive technology that reclaims contaminated areas
- Plants capable of extracting soil pollutants are grown and are then disposed of safely

Concept 37.2: Plants require essential elements to complete their life cycle

- Plants derive most of their organic mass from the CO₂ of air, but they also depend on soil nutrients such as water and minerals

Macronutrients and Micronutrients

- More than 50 chemical elements have been identified among the inorganic substances in plants, but not all of these are essential to plants
- A chemical element is considered an **essential element** if it is required for a plant to complete its life cycle
- Researchers use **hydroponic culture** to determine which chemical elements are essential

TECHNIQUE



Control: Solution containing all minerals

Experimental: Solution without potassium

Table 37.1 Essential Elements in Plants

Element	Form Available to Plants	% Mass in Dry Tissue	Major Functions
Macronutrients			
Carbon	CO ₂	45%	Major component of plant's organic compounds
Oxygen	CO ₂	45%	Major component of plant's organic compounds
Hydrogen	H ₂ O	6%	Major component of plant's organic compounds
Nitrogen	NO ₃ ⁻ , NH ₄ ⁺	1.5%	Component of nucleic acids, proteins, hormones, chlorophyll, coenzymes
Potassium	K ⁺	1.0%	Cofactor that functions in protein synthesis; major solute functioning in water balance; operation of stomata
Calcium	Ca ²⁺	0.5%	Important in formation and stability of cell walls and in maintenance of membrane structure and permeability; activates some enzymes; regulates many responses of cells to stimuli
Magnesium	Mg ²⁺	0.2%	Component of chlorophyll; activates many enzymes
Phosphorus	H ₂ PO ₄ ⁻ , HPO ₄ ²⁻	0.2%	Component of nucleic acids, phospholipids, ATP, several coenzymes
Sulfur	SO ₄ ²⁻	0.1%	Component of proteins, coenzymes
Micronutrients			
Chlorine	Cl ⁻	0.01%	Required for water-splitting step of photosynthesis; functions in water balance
Iron	Fe ³⁺ , Fe ²⁺	0.01%	Component of cytochromes; activates some enzymes
Manganese	Mn ²⁺	0.005%	Active in formation of amino acids; activates some enzymes; required for water-splitting step of photosynthesis
Boron	H ₂ BO ₃ ⁻	0.002%	Cofactor in chlorophyll synthesis; may be involved in carbohydrate transport and nucleic acid synthesis; role in cell wall function
Zinc	Zn ²⁺	0.002%	Active in formation of chlorophyll; activates some enzymes
Copper	Cu ⁺ , Cu ²⁺	0.001%	Component of many redox and lignin-biosynthetic enzymes
Nickel	Ni ²⁺	0.001%	Cofactor for an enzyme functioning in nitrogen metabolism
Molybdenum	MoO ₄ ²⁻	0.0001%	Essential for symbiotic relationship with nitrogen-fixing bacteria; cofactor in nitrate reduction

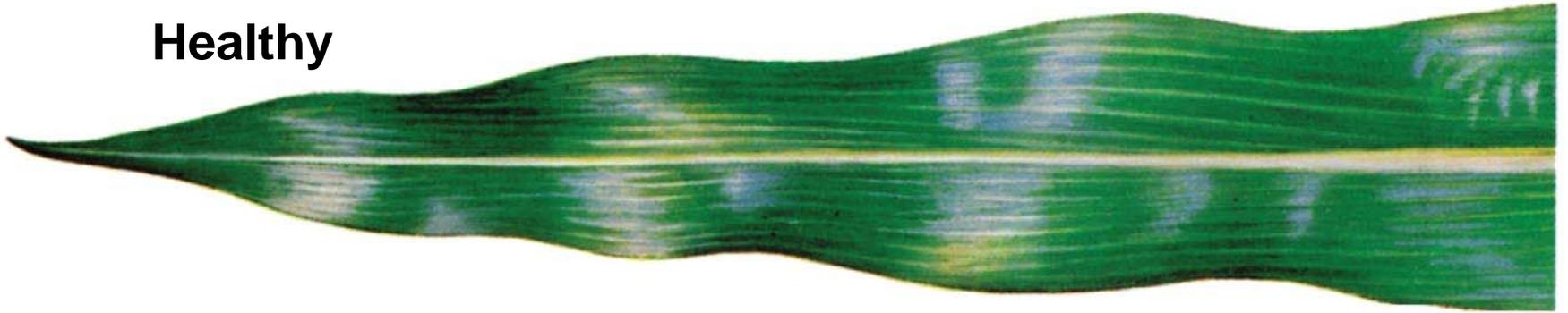
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- Nine of the essential elements are called **macronutrients** because plants require them in relatively large amounts
 - The macronutrients are carbon, oxygen, hydrogen, nitrogen, phosphorus, sulfur, potassium, calcium, and magnesium

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- The remaining eight are called **micronutrients** because plants need them in very small amounts
 - The micronutrients are chlorine, iron, manganese, boron, zinc, copper, nickel, and molybdenum

Symptoms of Mineral Deficiency

- Symptoms of mineral deficiency depend on the nutrient's function and mobility within the plant
- Deficiency of a mobile nutrient usually affects older organs more than young ones
- Deficiency of a less mobile nutrient usually affects younger organs more than older ones
- The most common deficiencies are those of nitrogen, potassium, and phosphorus

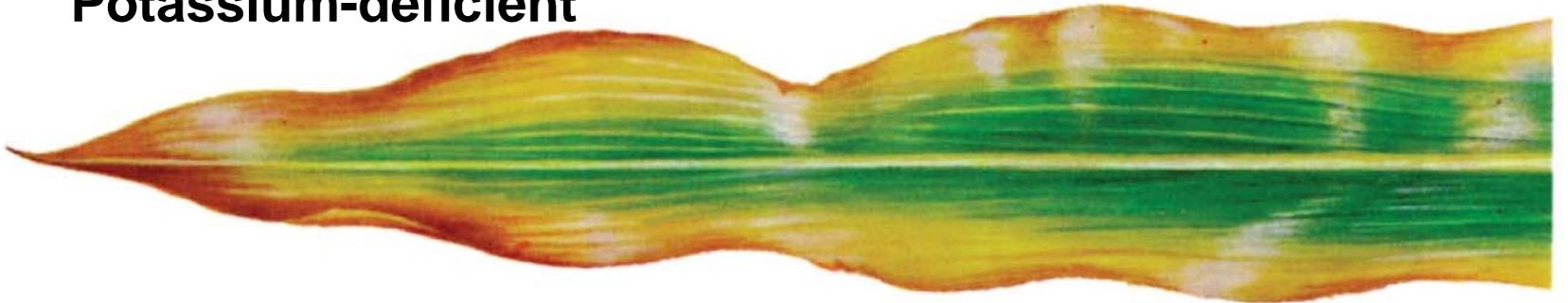
Healthy



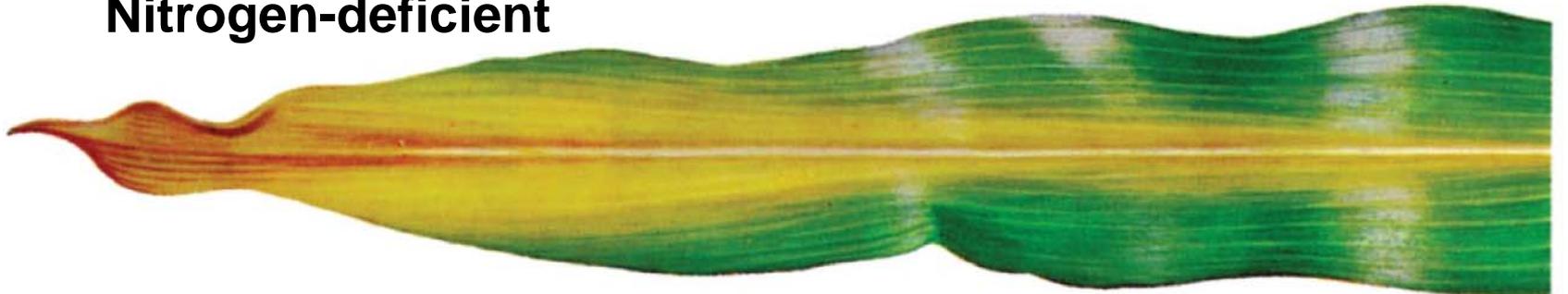
Phosphate-deficient



Potassium-deficient



Nitrogen-deficient



Improving Plant Nutrition by Genetic Modification: Some Examples

- Genetic engineering can improve plant nutrition and fertilizer usage

Resistance to Aluminum Toxicity

- Aluminum in acidic soils damages roots and greatly reduces crop yields
- The introduction of bacterial genes into plant genomes can cause plants to secrete acids that bind to and tie up aluminum

Flood Tolerance

- Waterlogged soils deprive roots of oxygen and cause buildup of ethanol and toxins
- The gene *Submergence 1A-1* is responsible for submergence tolerance in flood-resistant rice

Smart Plants

- “Smart” plants inform the grower of a nutrient deficiency before damage has occurred
- A blue tinge indicates when these plants need phosphate-containing fertilizer

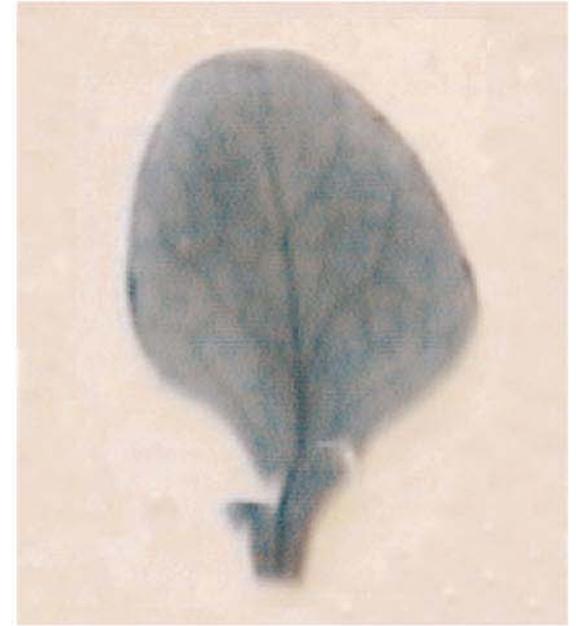
Fig. 37-8



No phosphorus deficiency



Beginning phosphorus deficiency



Well-developed phosphorus deficiency

Concept 37.3: Plant nutrition often involves relationships with other organisms

- Plants and soil microbes have a mutualistic relationship
 - Dead plants provide energy needed by soil-dwelling microorganisms
 - Secretions from living roots support a wide variety of microbes in the near-root environment

Soil Bacteria and Plant Nutrition

- The layer of soil bound to the plant's roots is the **rhizosphere**
- The rhizosphere has high microbial activity because of sugars, amino acids, and organic acids secreted by roots

Rhizobacteria

- Free-living **rhizobacteria** thrive in the rhizosphere, and some can enter roots
- Rhizobacteria can play several roles
 - Produce hormones that stimulate plant growth
 - Produce antibiotics that protect roots from disease
 - Absorb toxic metals or make nutrients more available to roots

-
- Inoculation of seeds with rhizobacteria can increase crop yields

Bacteria in the Nitrogen Cycle

- Nitrogen can be an important limiting nutrient for plant growth
- The **nitrogen cycle** transforms nitrogen and nitrogen-containing compounds
- Most soil nitrogen comes from actions of soil bacteria

Fig. 37-9

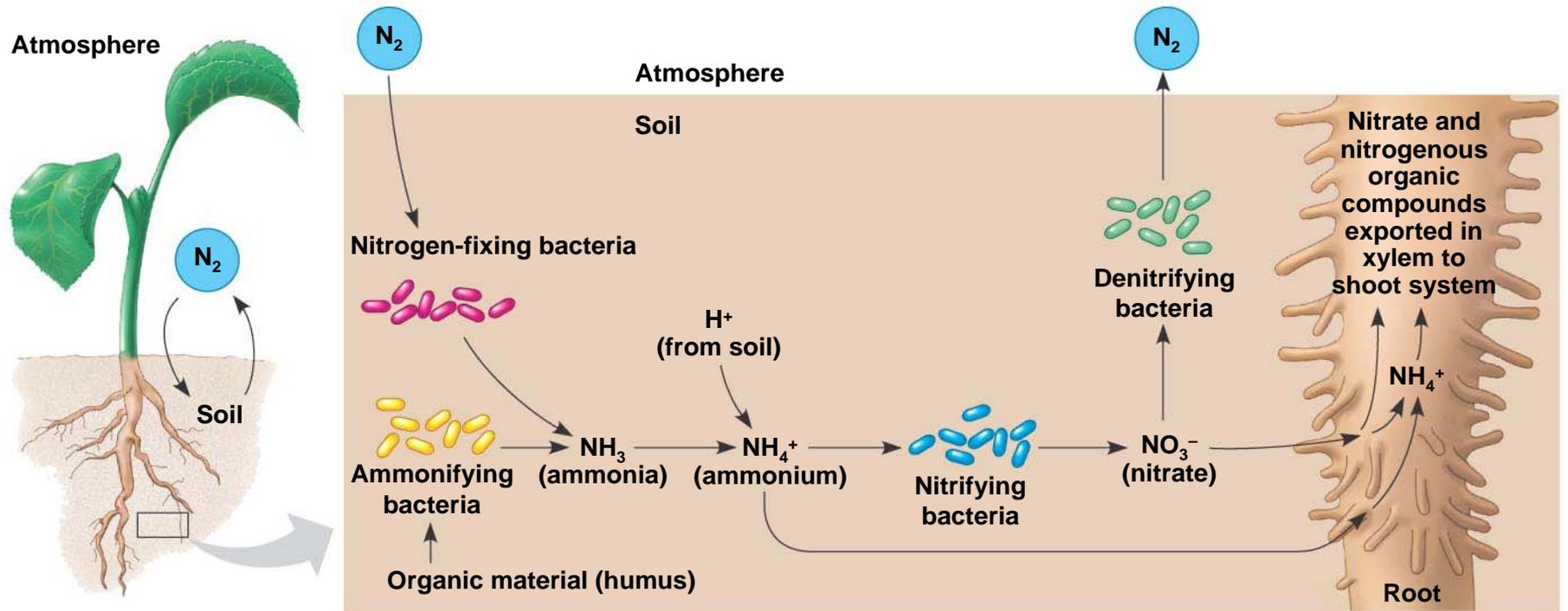
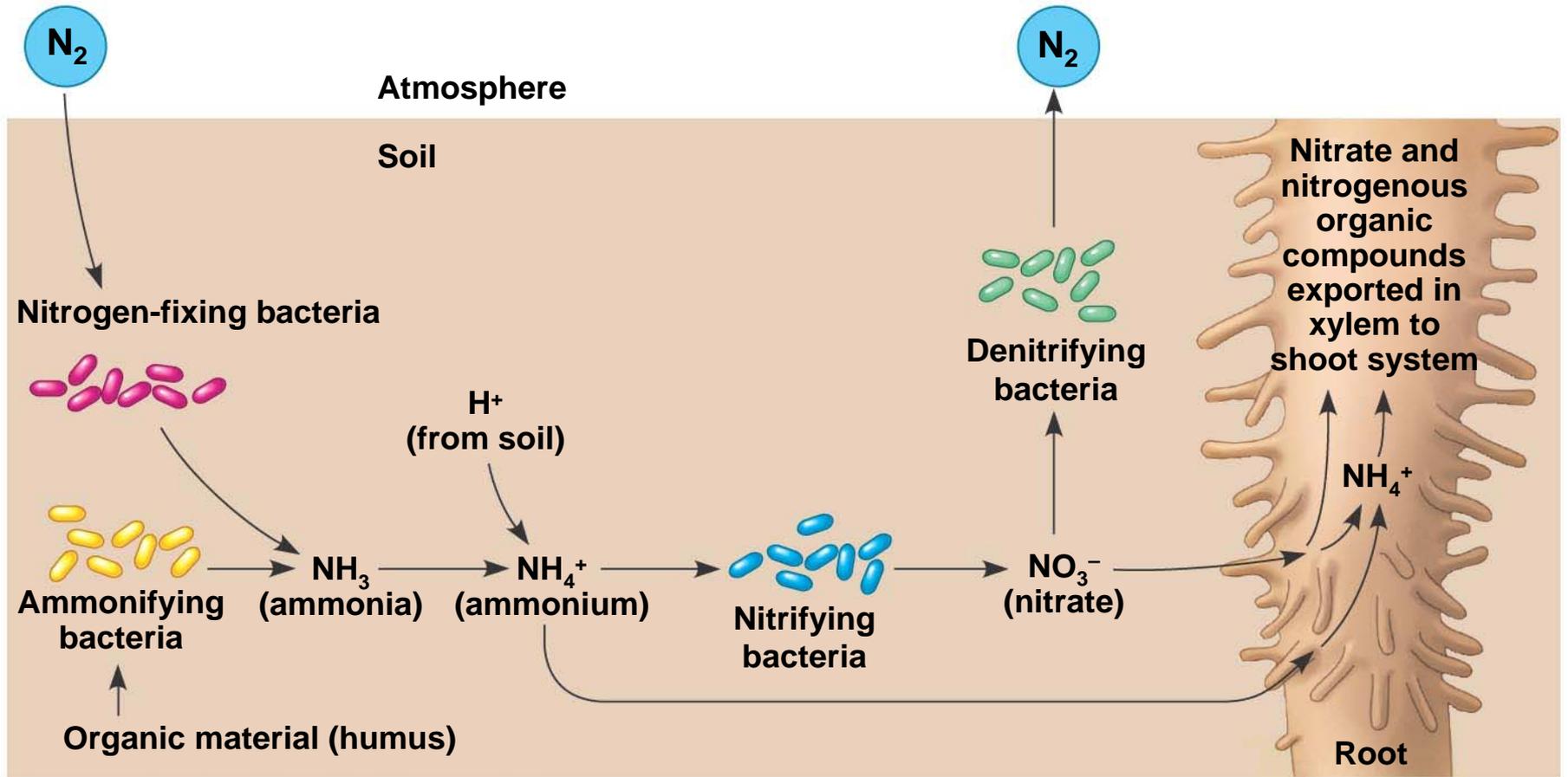


Fig. 37-9-1



Fig. 37-9-2

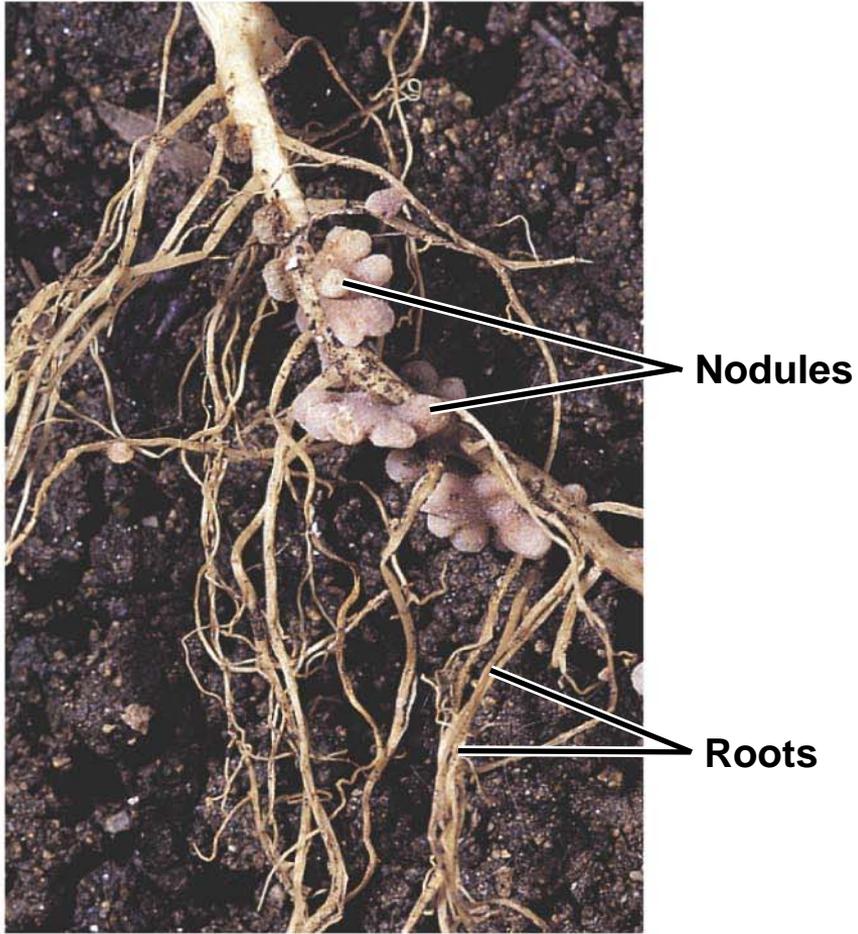


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- Plants absorb nitrogen as either NO_3^- or NH_4^+
 - Bacteria break down organic compounds or use N_2 to produce NH_3 , which is converted to NH_4^+
 - *Nitrification* is carried out by bacteria that convert NH_3 into NO_3^-

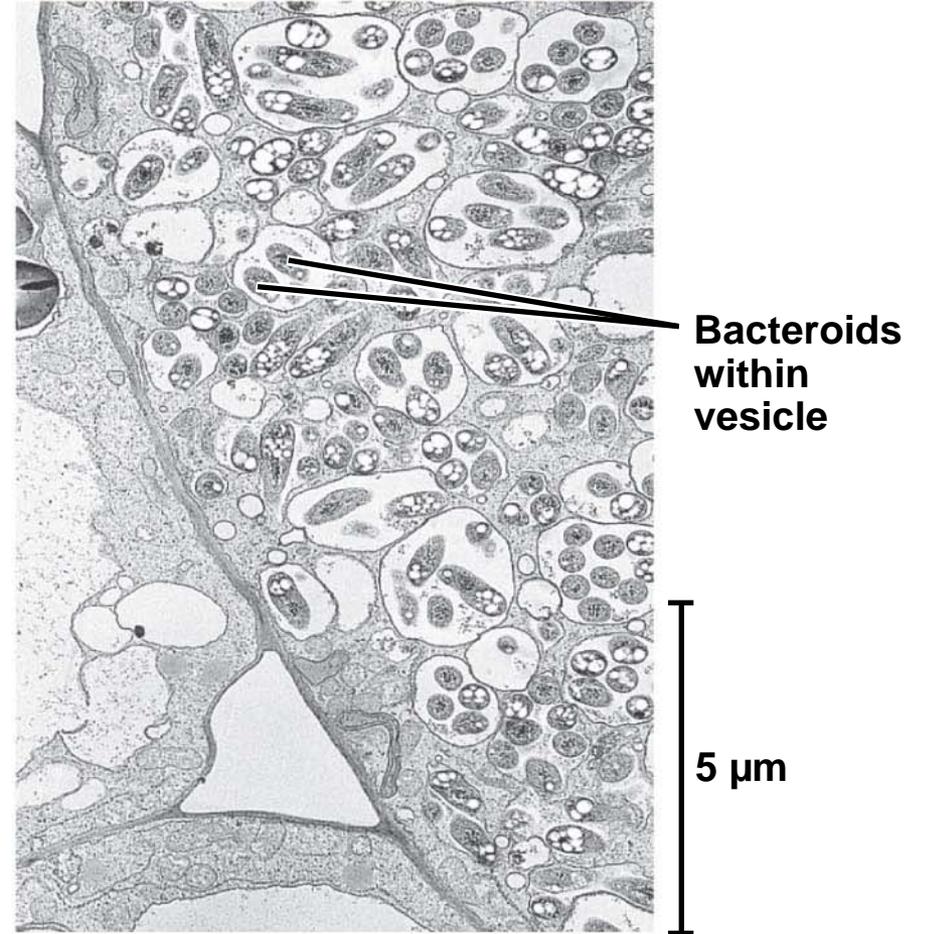
Nitrogen-Fixing Bacteria: A Closer Look

- N_2 is abundant in the atmosphere, but unavailable to plants
- **Nitrogen fixation** is the conversion of nitrogen from N_2 to NH_3
- Symbiotic relationships with nitrogen-fixing bacteria provide some plant species with a built-in source of fixed nitrogen
- Key symbioses occur between nitrogen-fixing bacteria and plants, including those in the legume family (peas, beans, and other similar plants)

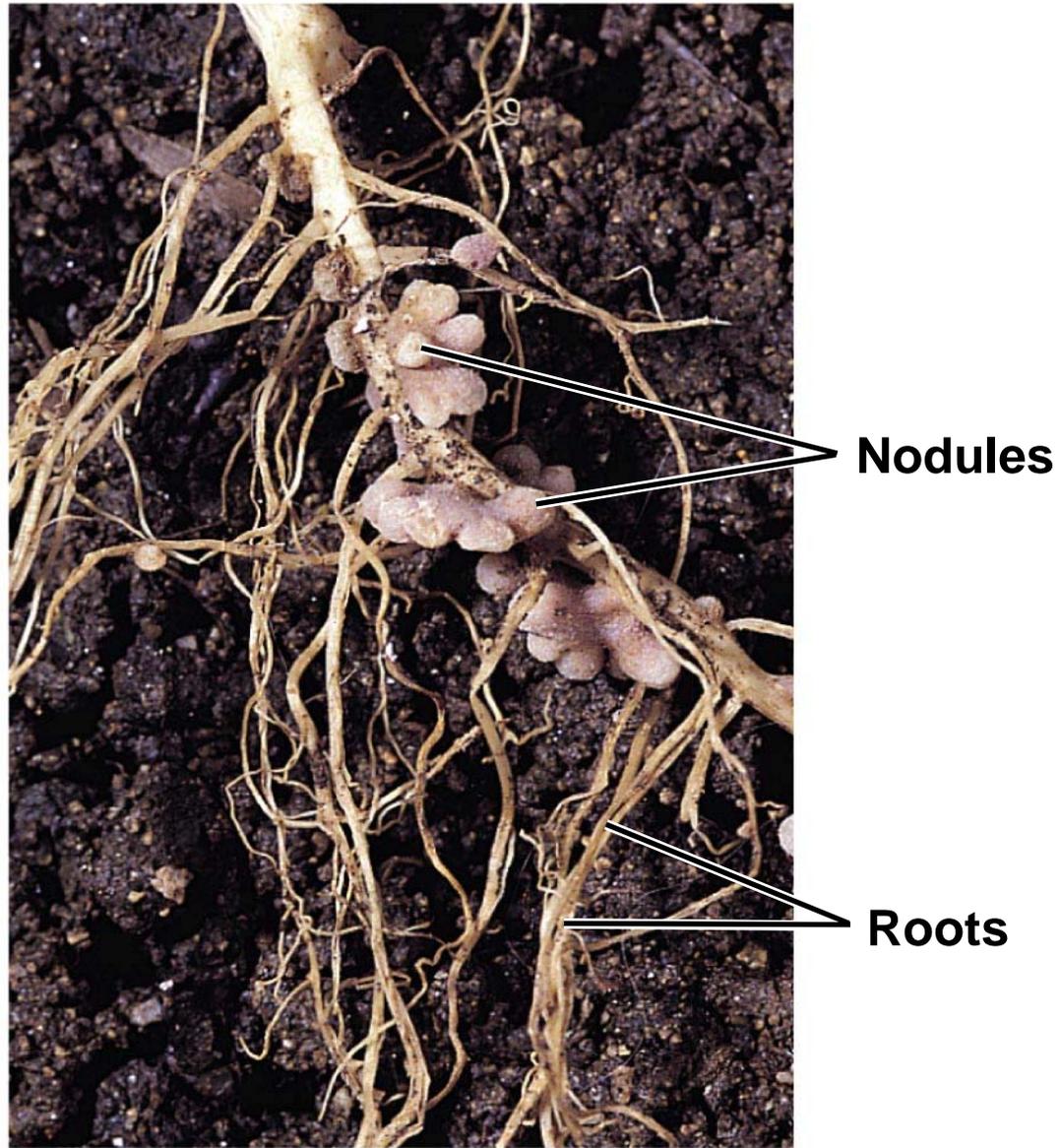
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- Along a legume's roots are swellings called **nodules**, composed of plant cells “infected” by nitrogen-fixing *Rhizobium* bacteria
 - Inside the root nodule, *Rhizobium* bacteria assume a form called **bacteroids**, which are contained within vesicles formed by the root cell
 - The bacteria of a root nodule obtain sugar from the plant and supply the plant with fixed nitrogen



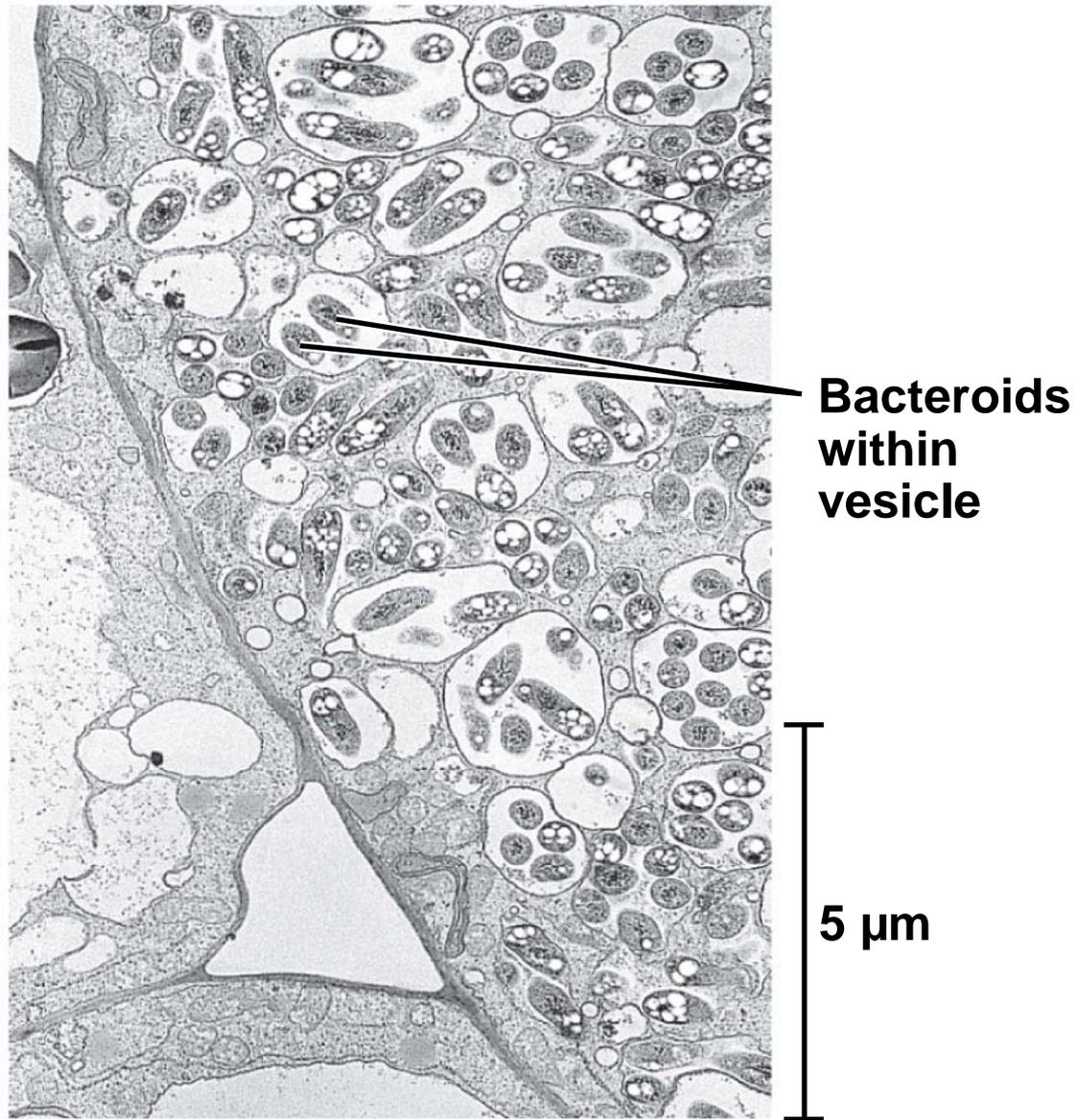
(a) Pea plant root



(b) Bacteroids in a soybean root nodule



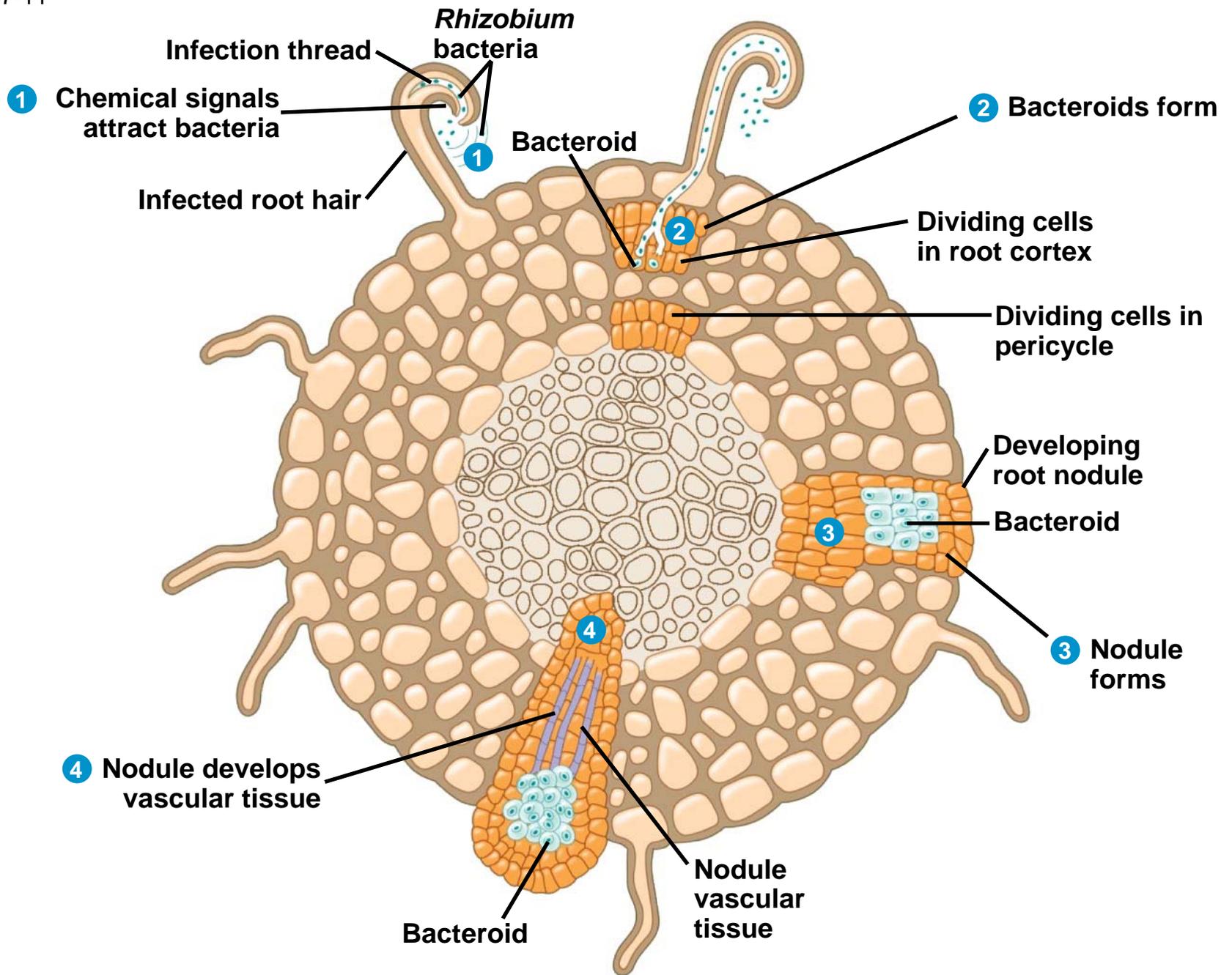
(a) Pea plant root



(b) Bacteroids in a soybean root nodule

-
- Each legume species is associated with a particular strain of *Rhizobium*
 - The development of a nitrogen-fixing root nodule depends on chemical dialogue between *Rhizobium* bacteria and root cells of their specific plant hosts

Fig. 37-11



Nitrogen Fixation and Agriculture

- **Crop rotation** takes advantage of the agricultural benefits of symbiotic nitrogen fixation
- A non-legume such as maize is planted one year, and the next year a legume is planted to restore the concentration of fixed nitrogen in the soil

-
- Instead of being harvested, the legume crop is often plowed under to decompose as “green manure” and reduce the need for manufactured fertilizer
 - Non-legumes such as alder trees, certain tropical grasses, and rice benefit either directly or indirectly from nitrogen-fixing bacteria

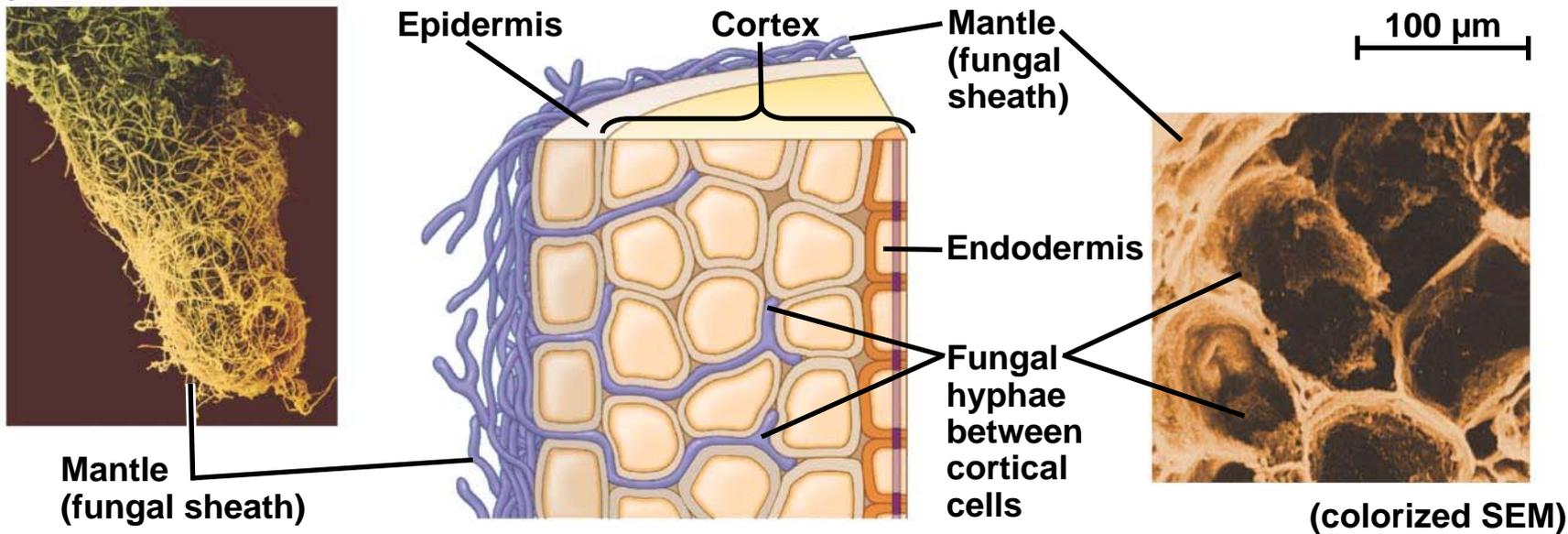
Fungi and Plant Nutrition

- **Mycorrhizae** are mutualistic associations of fungi and roots
- The fungus benefits from a steady supply of sugar from the host plant
- The host plant benefits because the fungus increases the surface area for water uptake and mineral absorption
- Mycorrhizal relationships are common and might have helped plants to first colonize land

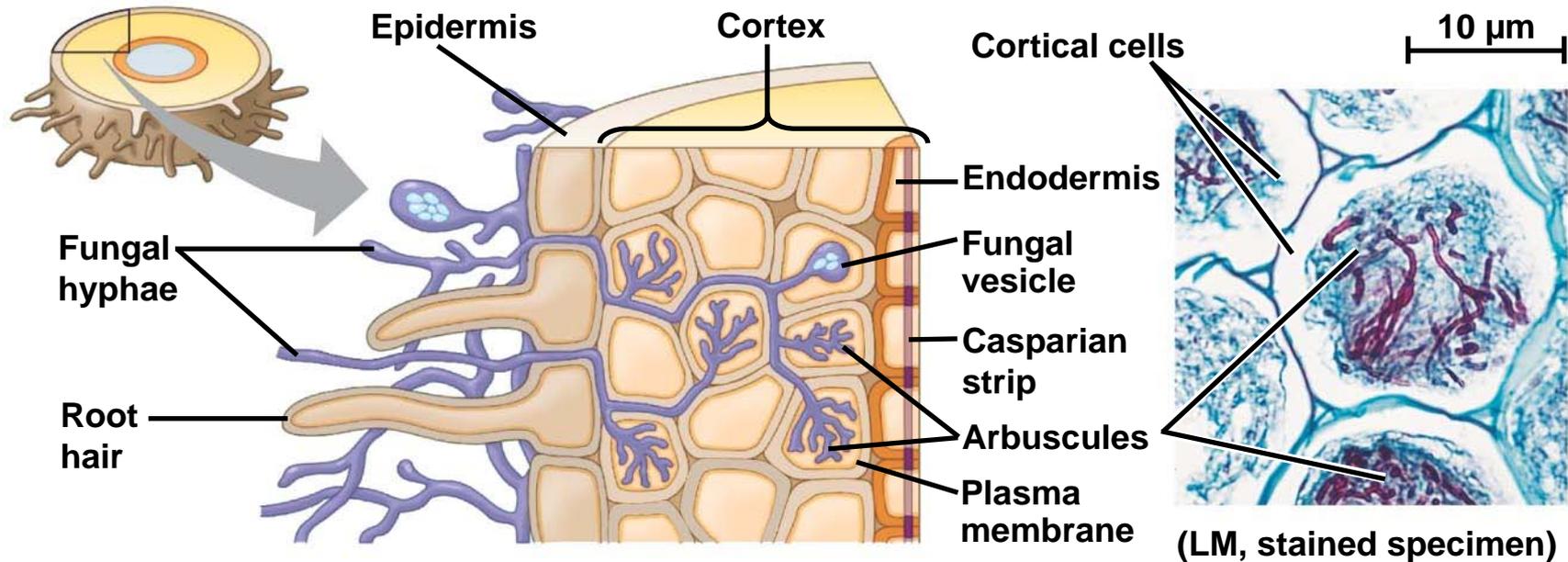
The Two Main Types of Mycorrhizae

- In **ectomycorrhizae**, the mycelium of the fungus forms a dense sheath over the surface of the root
- These hyphae form a network in the apoplast, but do not penetrate the root cells

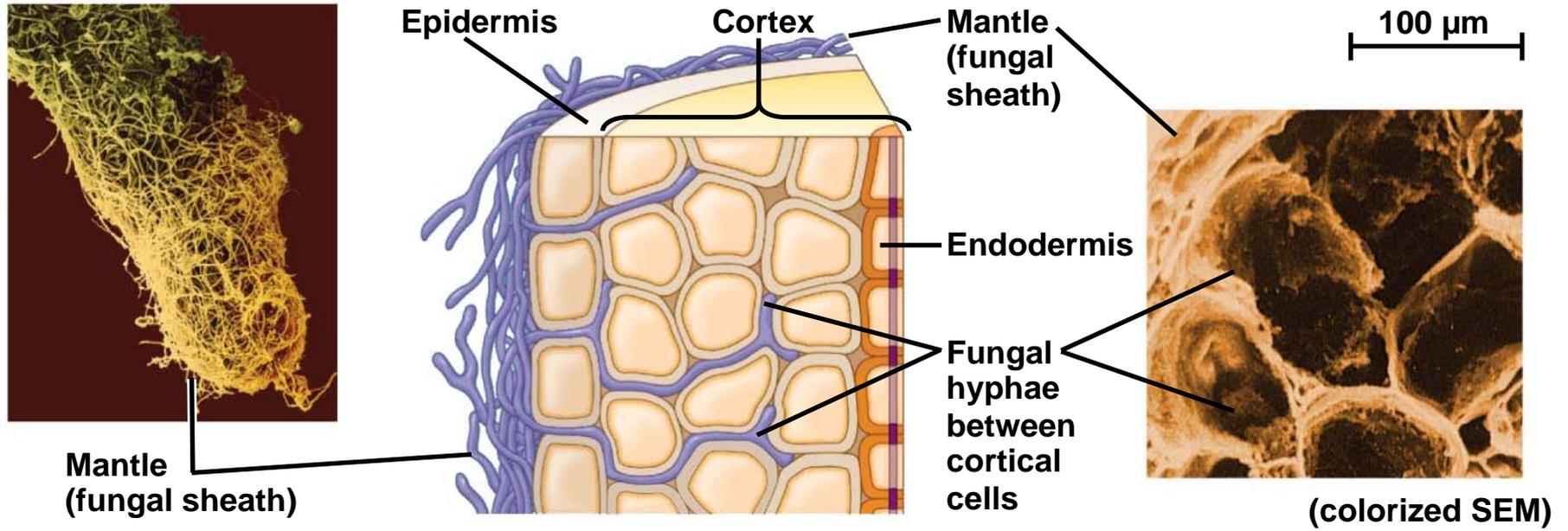
Fig. 37-12



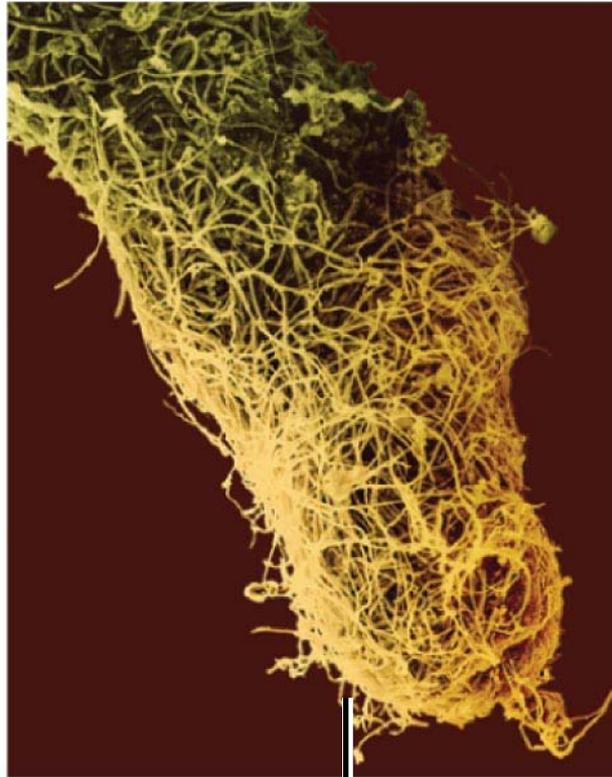
(a) Ectomycorrhizae



(b) Arbuscular mycorrhizae (endomycorrhizae)



(a) Ectomycorrhizae



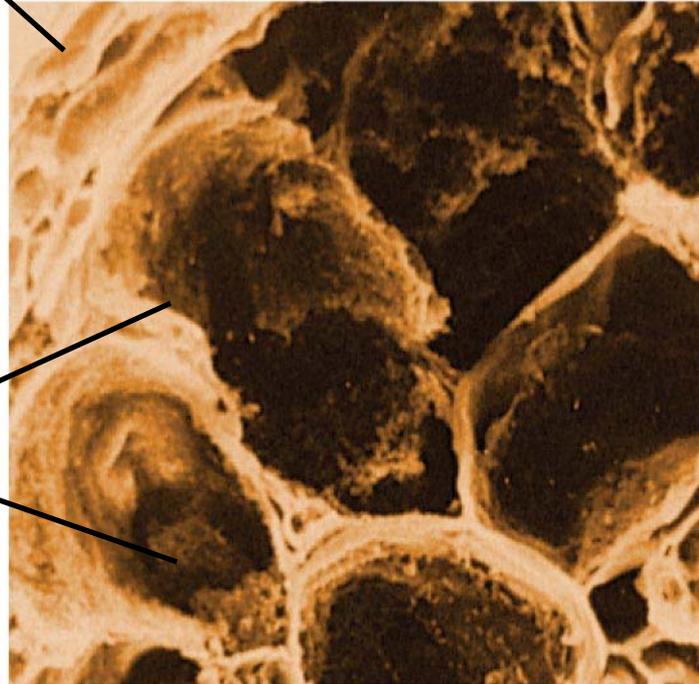
Mantle
(fungal sheath)

(a) Ectomycorrhizae

**Mantle
(fungal
sheath)**

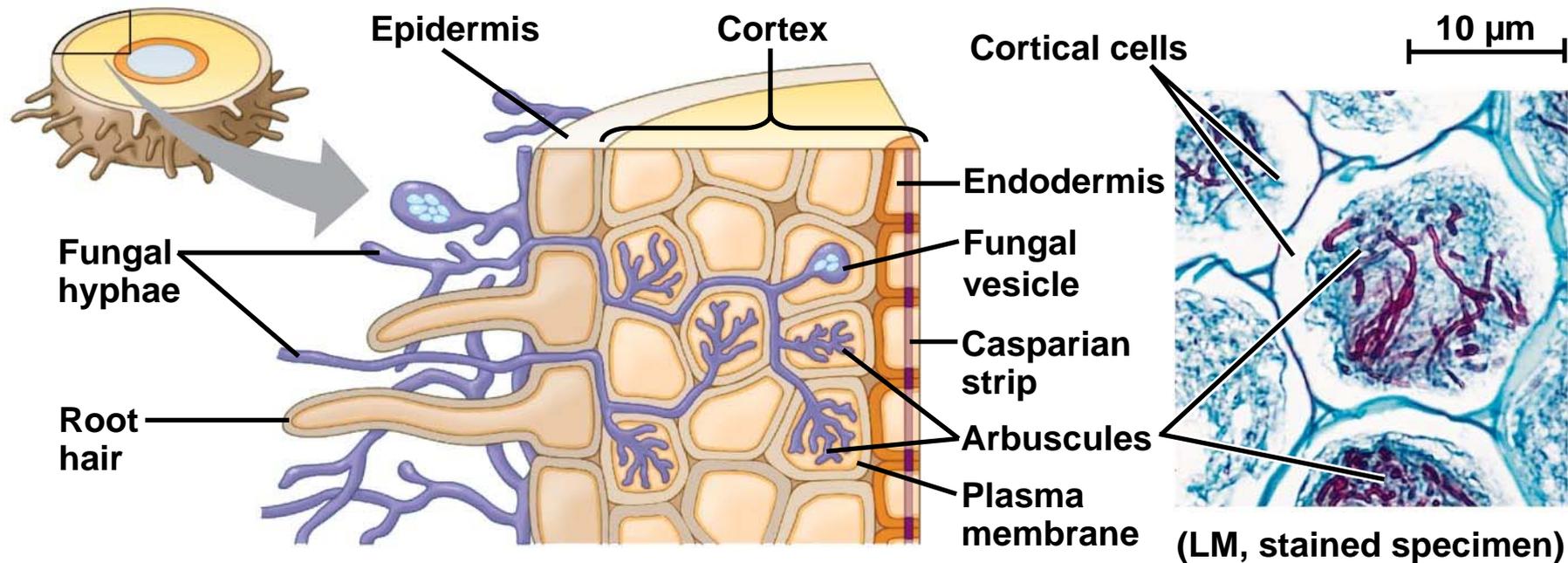
100 μm

**Fungal
hyphae
between
cortical
cells**

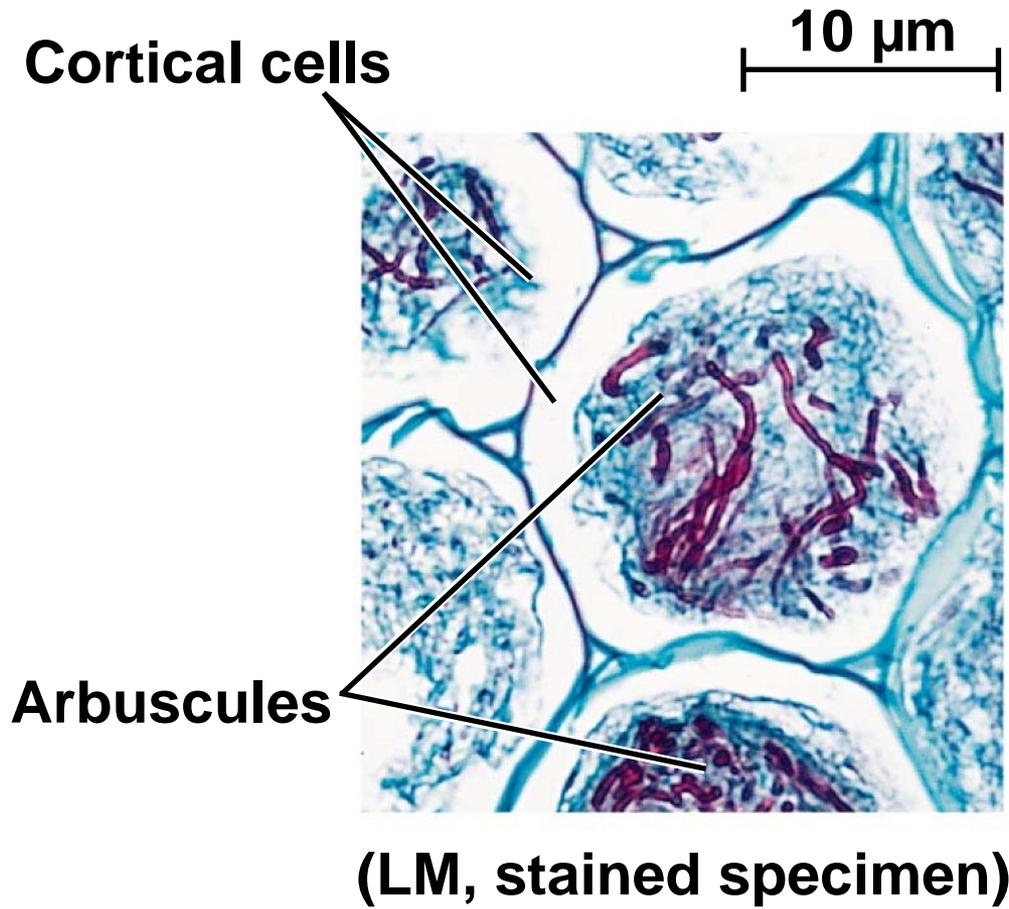


(colorized SEM)

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- In **arbuscular mycorrhizae**, microscopic fungal hyphae extend into the root
 - These mycorrhizae penetrate the cell wall but not the plasma membrane to form branched arbuscules within root cells



(b) Arbuscular mycorrhizae (endomycorrhizae)



Agricultural and Ecological Importance of Mycorrhizae

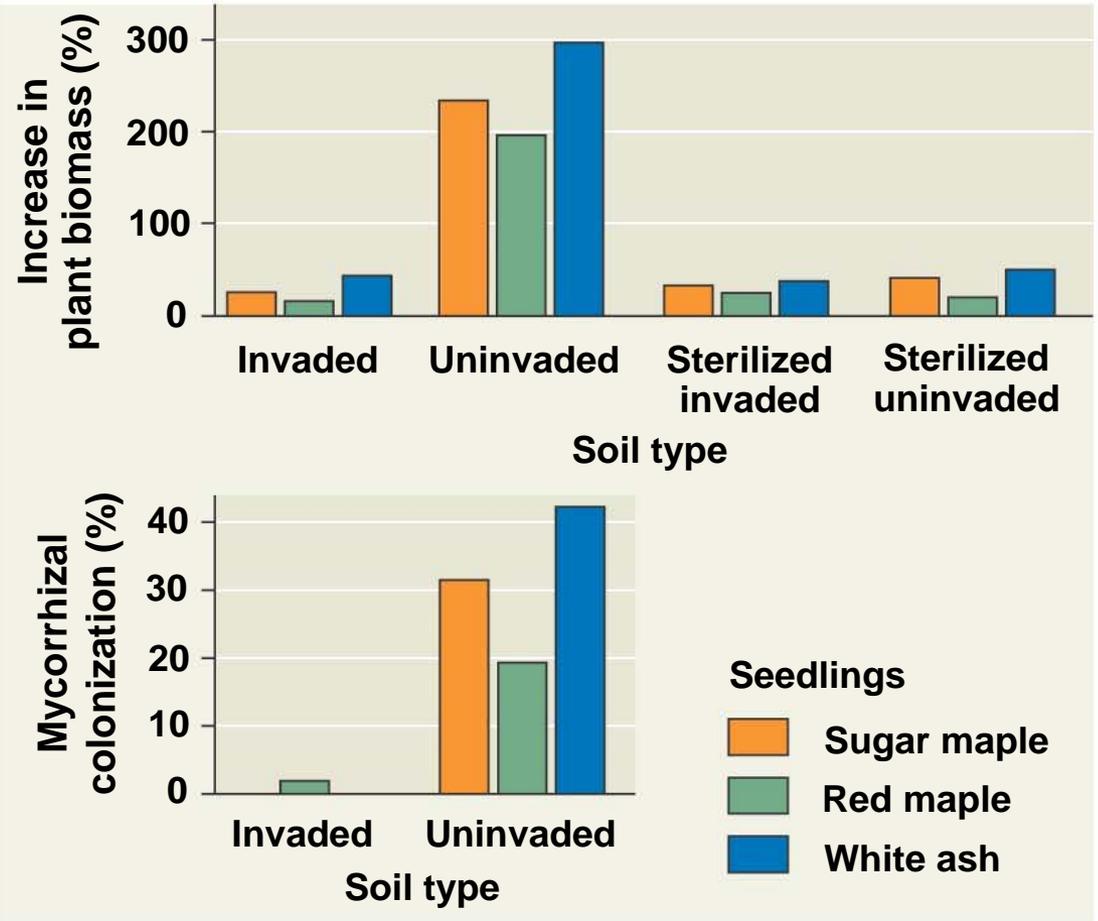
- Farmers and foresters often inoculate seeds with fungal spores to promote formation of mycorrhizae
- Some invasive exotic plants disrupt interactions between native plants and their mycorrhizal fungi

Fig. 37-13

EXPERIMENT



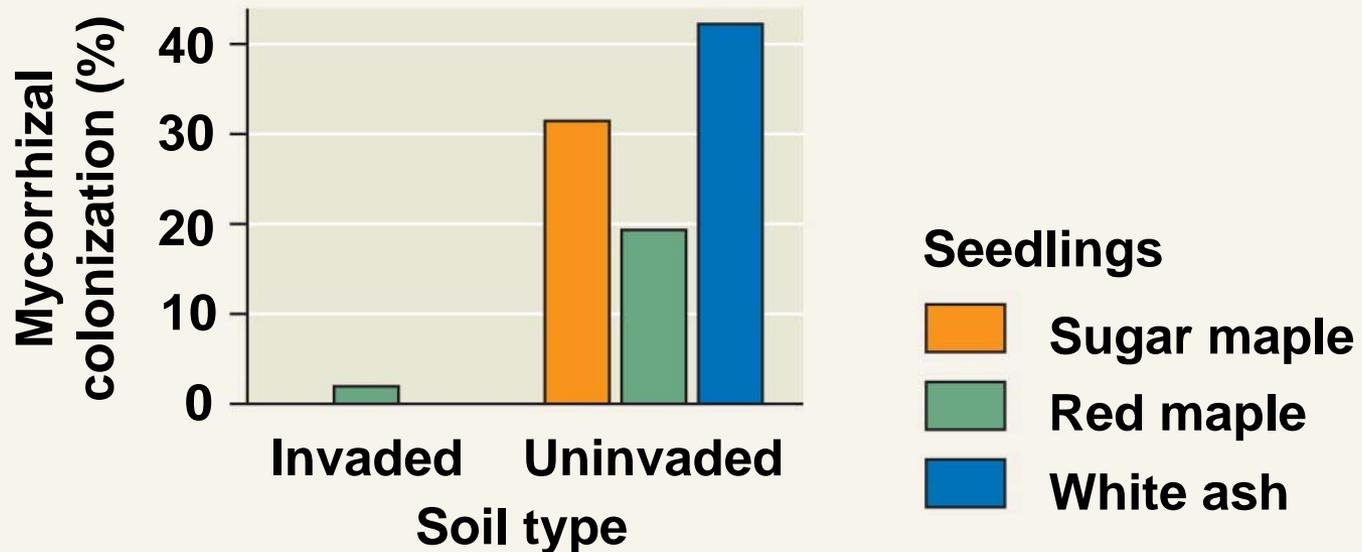
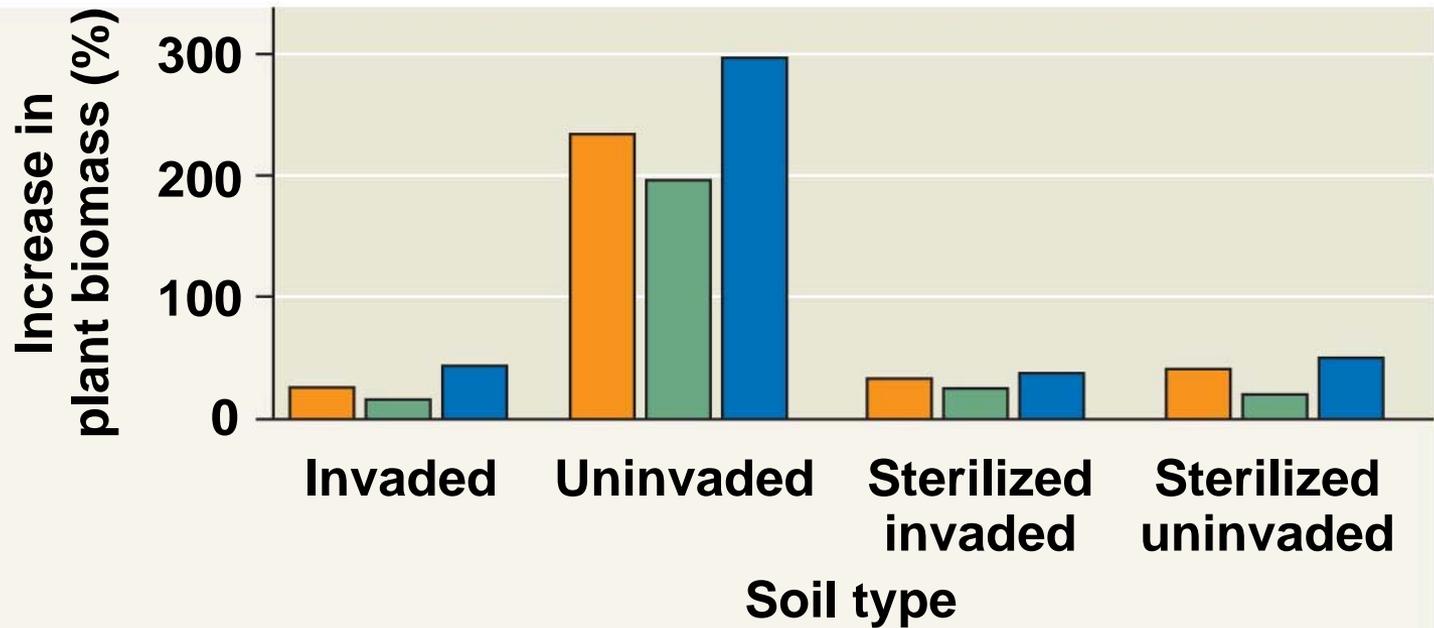
RESULTS



EXPERIMENT



RESULTS



Epiphytes, Parasitic Plants, and Carnivorous Plants

- Some plants have nutritional adaptations that use other organisms in nonmutualistic ways
- An **epiphyte** grows on another plant and obtains water and minerals from rain



Staghorn fern, an epiphyte

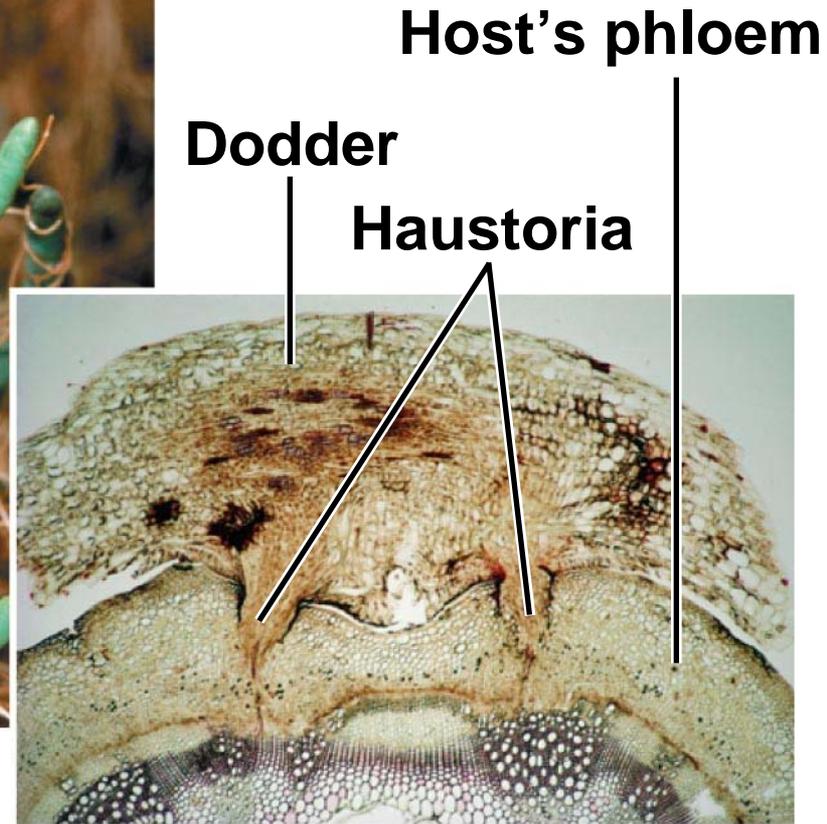
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- Parasitic plants absorb sugars and minerals from their living host plant



Mistletoe, a photosynthetic parasite

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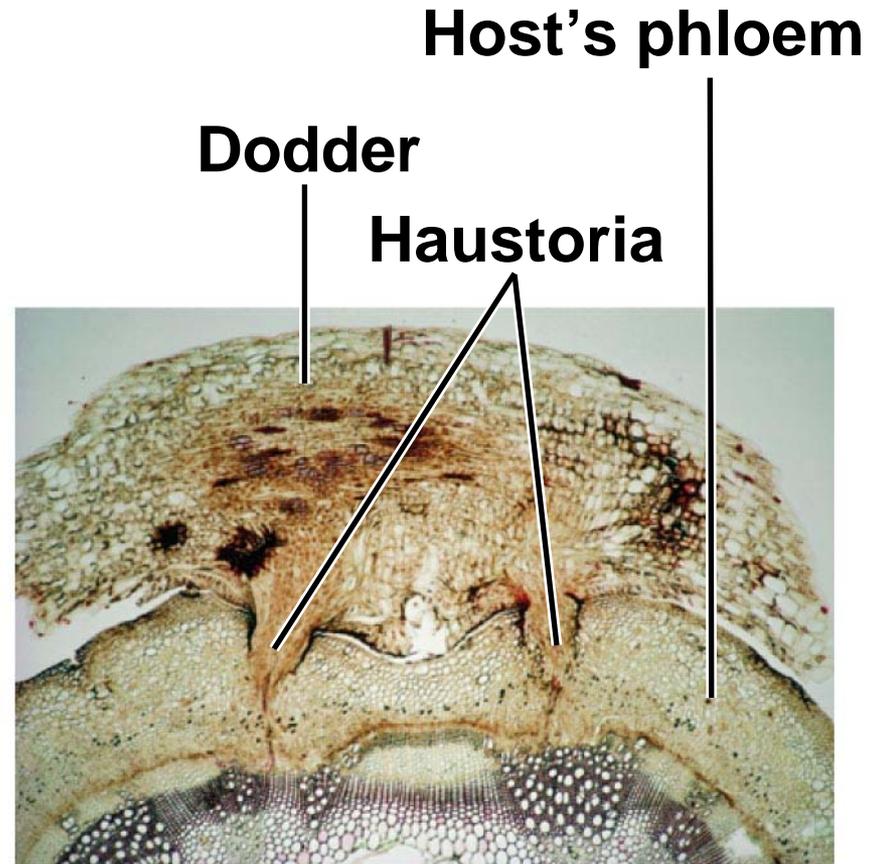


Dodder, a nonphotosynthetic parasite

Fig. 37-14c-2



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Indian pipe, a nonphotosynthetic parasite

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- Carnivorous plants are photosynthetic but obtain nitrogen by killing and digesting mostly insects

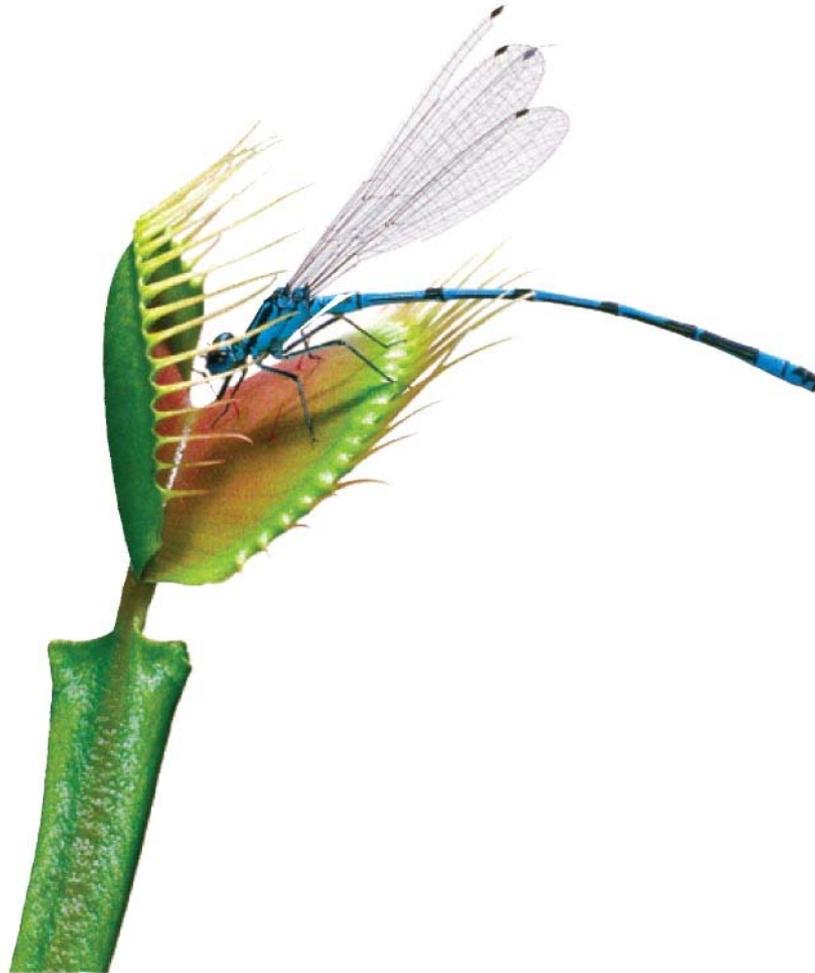
PLAY

Video: Sun Dew Trapping Prey



Venus flytrap

Fig. 37-14e-2



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Pitcher plants

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Fig. 37-14f-2



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Fig. 37-14f-3



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Sundews

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Fig. 37-UN1

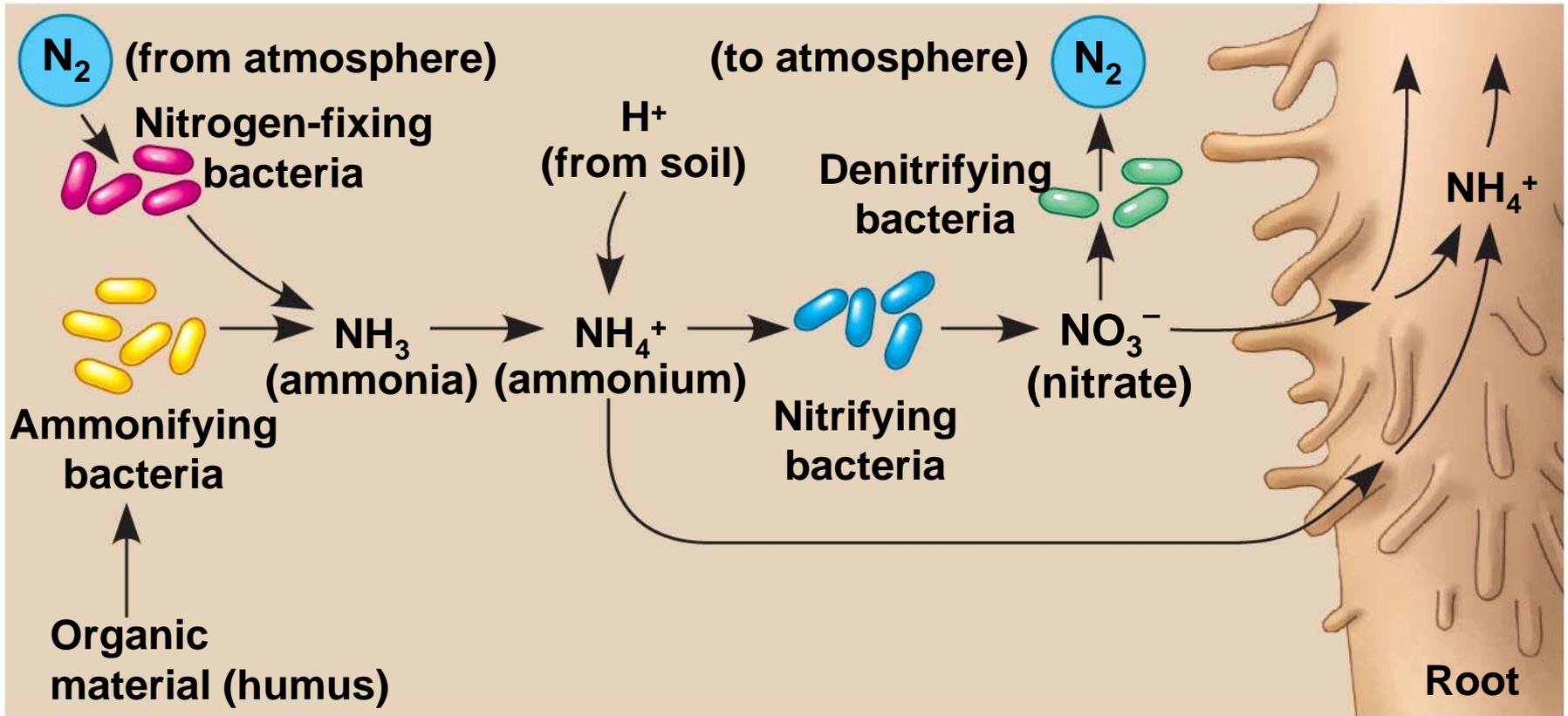
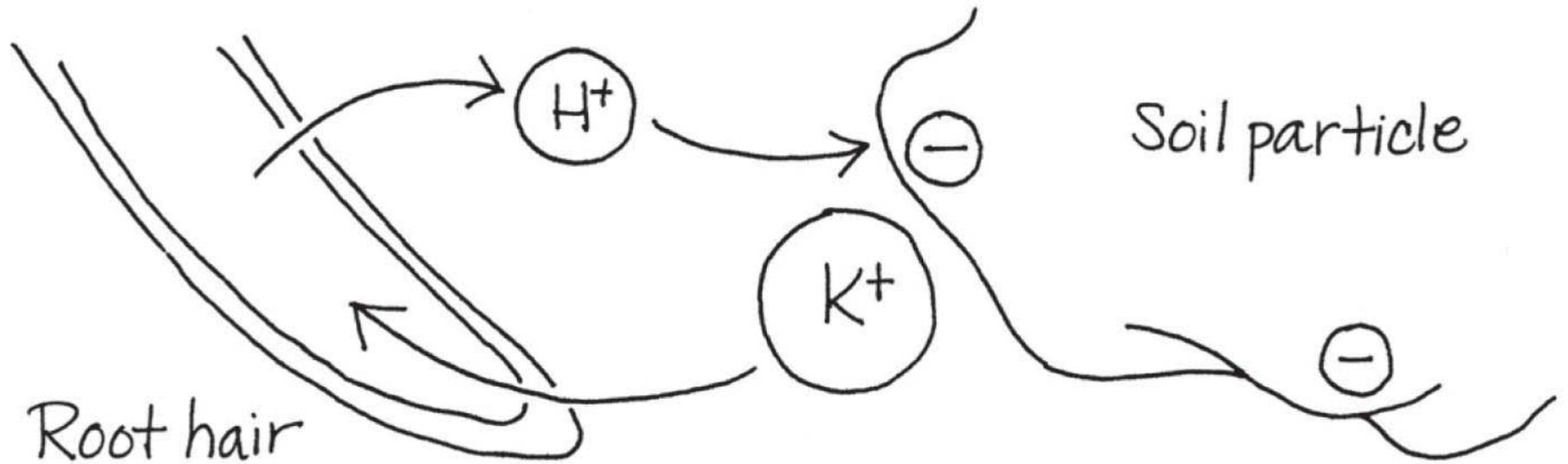


Fig. 37-UN2



You should now be able to:

1. Define soil texture and soil composition
2. Explain why plants cannot extract all of the water in soil
3. Define cation exchange and describe how plants can stimulate the process
4. Discuss the problems of topsoil erosion and farm irrigation in arid regions; suggest actions that can help mitigate these problems
5. Distinguish between and list the macronutrients and micronutrients

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6. Explain how a nutrient's role and mobility determine the symptoms of a mineral deficiency
 7. Summarize the ecological role of each of the following groups of bacteria: ammonifying, denitrifying, nitrogen-fixing, nitrifying
 8. Describe the basis for crop rotation
 9. Distinguish between ectomycorrhizae and arbuscular mycorrhizae
 10. Describe the adaptations for nutrition of parasitic, epiphytic, and carnivorous plants
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