Introduction: *Planting Hope in the Wake of Katrina*

- Many plants can remove toxins such as heavy metals from soils by taking them up with their roots and storing them in their bodies.
- The use of plants to clean up polluted soil and groundwater is called phytoremediation.
Introduction: *Planting Hope in the Wake of Katrina*

- Concerns associated with phytoremediation include
  - Release of toxins into the air via evaporation from plant leaves
  - Disposal of plants with high concentrations of pollutants
  - Possible toxicity to animals that eat plants with high concentrations of pollutants
THE UPTAKE AND TRANSPORT OF PLANT NUTRIENTS
32.1 Plants acquire their nutrients from soil and air

- Plants take up carbon dioxide from the air to produce sugars via photosynthesis; oxygen is produced as a product of photosynthesis.

- Plants obtain water, minerals, and some oxygen from the soil.

- Using simple sugars as an energy source and as building blocks, plants convert the inorganic molecules they take up into the organic molecules of living plant tissue.
32.1 Plants acquire their nutrients from soil and air

- Inorganic molecules taken up by plants
  - Carbon dioxide
  - Nitrogen
  - Magnesium
  - Phosphorus
32.1 Plants acquire their nutrients from soil and air

- Organic molecules produced by plants
  - Carbohydrates
  - Lipids
  - Proteins
  - Nucleic acids
32.2 The plasma membranes of root cells control solute uptake

- Minerals taken up by plant roots are in a watery solution.

- Water and minerals are absorbed through the epidermis of the root and must be taken up by root cells before they enter the xylem.

- Selective permeability of the plasma membrane of root cells controls what minerals enter the xylem.
There are two pathways by which water and minerals enter the xylem:

- **Intracellular route**—water and solutes are selectively taken up by a root epidermal cell, usually a root hair, and transported from cell to cell through plasmodesmata.

- **Extracellular route**—water and solutes pass into the root in the porous cell walls of root cells; they do not enter any cell plasma membrane until they reach the root endodermis.
32.2 The plasma membranes of root cells control solute uptake

- The cells of the endodermis contain a waxy barrier called the **Casparian strip**
  - Water and solutes that have entered the root without crossing a cell plasma membrane are blocked
  - Specialized cells of the endodermis take up water and minerals selectively
  - The Casparian strip regulates uptake of minerals that enter the root via the extracellular route
Extracellular route, via cell walls; stopped by Casparian strip.

Intracellular route, via cell interiors, through plasmodesmata.

Key:
- Dermal tissue system
- Ground tissue system
- Vascular tissue system

- Root hair
- Epidermis
- Cortex
- Phloem
- Xylem
- Casparian strip
- Endodermis
- Plasmodesmata

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Extracellular route, via cell walls; stopped by Casparian strip

Intracellular route, via cell interiors, through plasmodesmata

Root hair

Plasmodesmata

Casparian strip

Xylem

Epidermis

Endodermis

Cortex
32.3 Transpiration pulls water up xylem vessels

- **Xylem sap** is the solution carried up through a plant in tracheids and vessel elements.
- Xylem sap is pulled up through roots and shoots to the leaves.
- Evaporation of water from the surface of leaves, called **transpiration**, is the driving force for the movement of xylem sap.
- Water’s **cohesion** and **adhesion** allow water to be pulled up to the top of the highest trees.
Transpiration-cohesion-tension mechanism

- Water’s cohesion describes its ability to stick to itself.
- Water’s adhesion describes its ability to stick to other surfaces; water adheres to the inner surface of xylem cells.
- A steep diffusion gradient pulls water molecules from the surface of leaves into much drier air.
- The air’s pull on water creates a tension that pulls on water in the xylem; since water is cohesive, it is pulled along, much as when a person sucks on a straw.
32.3 Transpiration pulls water up xylem vessels
Transpiration

- Outside air
- Stoma
- Air space within leaf
- Mesophyll cells

Cohesion in the xylem

- Water molecule
- Cohesion by hydrogen bonding
- Xylem cells

Flow of water

Xylem sap
Transpiration

Outside air

Stoma

Air space within leaf

Mesophyll cells

Xylem sap

Cohesion and adhesion in the xylem

Cohesion by hydrogen bonding

Cell wall

Xylem cells

Water molecule

Water uptake from soil

Root hair

Soil particle

Water

Flow of water
32.4 Guard cells control transpiration

- Plants must open pores in leaves called stomata to allow CO\textsubscript{2} to enter for photosynthesis
- Water evaporates from the surface of leaves through stomata
- Paired guard cells surround each stoma
- Guard cells can regulate the amount of water lost from leaves by changing shape and closing the stomatal pore
Stomata open when guard cells take up water

- Potassium is actively taken up by guard cells from nearby cells
- This creates an osmotic gradient and water follows
- Uneven cell walls of guard cells causes them to bow when water is taken up
- The bowing of the guard cells causes the pore of the stoma to open

When guard cells lose K$^+$ ions, the guard cells become flaccid and the stoma closes
Several factors help regulate guard cell activity

- In general, stomata are open during the day and closed at night
- Sunlight signals guard cells to accumulate $K^+$ and open stomata
- Low $CO_2$ concentration in leaves also signals guard cells to open stomata
- Plants have natural rhythms that help them close stomata at night to conserve water
- Plants may also close stomata during the day to conserve water when necessary
Phloem transports the products of photosynthesis throughout the plant

- Phloem is composed of long tubes of sieve tube members stacked end to end
- **Phloem sap** moves through sieve plates in sieve tube members
- Phloem sap is composed of sucrose and other solutes such as ions, amino acids, and hormones
- Sugars are carried through phloem from sources to sinks
32.5 Phloem transports sugars

Animation: Translocation of Phloem Sap in Spring

Animation: Translocation of Phloem Sap in Summer
Sieve plate

Sieve-tube member
A **sugar source** is a plant organ that is a net producer of sugar via photosynthesis or breakdown of starch

- Leaves produce sugars via photosynthesis
- Roots and other storage organs produce sugar via breakdown of starch

A **sugar sink** is a plant organ that is a net consumer of sugar or one that stores starch

- Growing organs use sugar in cellular respiration
- Roots and other organs store unused sugars as starch

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32.5 Phloem transports sugars
The pressure flow mechanism

- At sources, sugars are actively loaded into sieve tube members.
- High solute concentration caused by the sugar in sieve tubes causes water to rush in from nearby xylem cells.
- Flow of water into sieve tubes increases pressure at sources.
- At sinks, sugars are unloaded from sieve tubes and solute concentration decreases; water is lost and pressure is low.
- The pressure gradient drives rapid movement of sugars from sources to sinks.
Sugar sink

High sugar concentration
High water pressure

Sugar source

Sugar sink

Low sugar concentration
Low water pressure

Xylem

Phloem

1. Sugar
2. Water
3. Sugar
4. Water

Source cell

Sink cell

Sieve plate
Aphid feeding on a small branch

Aphid’s stylet inserted into a phloem cell

Severed stylet dripping phloem sap

Honeydew droplet

Stylet of aphid

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Aphid feeding on a small branch
Aphid’s stylet inserted into a phloem cell
Severed stylet dripping phloem sap
PLANT NUTRIENTS
AND THE SOIL
32.6 Plant health depends on a complete diet of essential inorganic nutrients

- **Essential elements** are those that a plant must obtain to complete its life cycle of growth and reproductive success.

- There are 17 elements essential to plant growth and reproduction:
  - **Macronutrients**—plants require relatively large amounts of these elements.
  - **Micronutrients**—plants require relatively small amounts of these elements.

- Both types of nutrients have vital functions.
32.6 Plant health depends on a complete diet of essential inorganic nutrients

- Macronutrients—components of organic molecules
  - Carbon
  - Hydrogen
  - Oxygen
  - Nitrogen
  - Sulfur
  - Phosphorus
  - Potassium
  - Calcium
  - Magnesium

Make up 98% of plant dry weight
32.6 Plant health depends on a complete diet of essential inorganic nutrients

- Micronutrients—often act as cofactors
  - Chlorine
  - Iron
  - Manganese
  - Boron
  - Zinc
  - Copper
  - Nickel
  - Molybdenum
Complete solution containing all minerals (control)   Solution lacking potassium (experimental)
The availability of nutrients in soil affects plant growth and health.

Growers can often determine which nutrients are missing from soil by looking at plant symptoms.

Nutrient deficiencies can be alleviated by adding inorganic chemical fertilizers or compost to soil.

Nitrogen is the element that most commonly limits plant growth in nature.
32.8 Fertile soil supports plant growth

- Soils are affected by geography and climate
- Soil horizons are layers of soil with different characteristics
  - A horizon—topsoil subject to weathering; layer contains **humus** (decayed organic matter) and many soil organisms
  - B horizon—clay and dissolved elements
  - C horizon—rocks of the “parent material” from which soil is formed

Animation: How Plants Obtain Minerals from Soil

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A soil’s physical and chemical characteristics affect plant growth

- Soil particle sizes influence the amount of water and air present in a soil.
- Soil particles and plant roots participate in cation exchange—the transfer of positive ions such as calcium, magnesium, and potassium from soil to plant roots.
- Soil particles tend to bond cations and can make uptake by plants difficult.
- Anions are readily taken up by plants and not affected as much by soil.
Air space
Water
Root hair
Soil particle surrounded by film of water
Air space
Water
32.9 CONNECTION: Soil conservation is essential to human life

- Human practices in agriculture have degraded soils
  - Irrigation can cause build up of salts in soils
  - Plowed lands are subject to erosion by wind and rain, which removes topsoil
  - Chemical fertilizers are costly and may contaminate groundwater
32.9 CONNECTION: Soil conservation is essential to human life

- Soil conservation efforts are needed to reduce the problems associated with agriculture
  - Efficient drip irrigation
  - Practices to reduce erosion
  - Alternatives to traditional fertilization
32.10 CONNECTION: Organic farmers follow principles of sustainable agriculture

- The USDA has established guidelines for foods labeled “organic”

- Organic farming guidelines are intended to
  - Sustain biological diversity
  - Maintain soil quality
  - Reduce or eliminate use of chemical pesticides
  - Avoid use of genetically modified plants
  - Reduce or eliminate use of chemical fertilizers

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Agricultural research is improving the yields and nutritional values of crops.

- Advances in genetic engineering have led to many improvements in crop plants:
  - Resistance to disease and insects
    - Reduces the need to use pesticides
  - Resistance to weed-killing herbicides
    - Reduces the need to till the soil, which causes erosion
  - Improved nutritional quality
    - Less land needed to feed more people
PLANT NUTRITION AND SYMBIOSIS
32.12 Most plants depend on bacteria to supply nitrogen

- Most of the nitrogen in the biosphere is in the atmosphere as $\text{N}_2$ gas
- Plants can only absorb nitrogen as ammonium or nitrates from the soil; they cannot absorb it from air
Soil bacteria can convert \( N_2 \) gas from the air into forms usable by plants via several processes:

- **Nitrogen fixation**—\( N_2 \) is converted to ammonia.
- **Amonification**—conversion of organic matter into ammonium.
- **Nitrification**—conversion of ammonium to nitrates, the form most often taken up by plants.
Atmosphere

Soil

Nitrogen-fixing bacteria

$N_2$  $N_2$  $N_2$

$H^+$  $NH_3$  $NH_4^+$  (ammonium)

$NO_3^-$  (nitrate)

Amino acids, etc.

Nitrogen-fixing bacteria

Ammonifying bacteria

Organic material

Root
32.13 EVOLUTION CONNECTION: Mutually beneficial relationships have evolved between plants and their symbionts

- Most plants form symbioses with fungi called mycorrhizae
  - Mycorrhizae act like extensions of plant roots, increasing the area for absorption of water and minerals from soil
  - Mycorrhizae produce enzymes that release phosphorus from soil, making it available to plant hosts
  - Mycorrhizae release growth factors and antibiotics into the soil
  - Mycorrhizal symbioses have evolved with plants and were important to plants successfully invading land
32.13 EVOLUTION CONNECTION: Mutually beneficial relationships have evolved between plants and their symbionts

- Some plants form symbioses with nitrogen-fixing bacteria
  - Legumes (peas, beans, alfalfa, and others) form root nodules to house nitrogen-fixing symbionts in the genus *Rhizobium*
  - Other plants, such as alders, form symbioses with other kinds of nitrogen-fixing bacteria
  - Plants that form these associations are rich in nitrogen

- Both mycorrhizae and nitrogen-fixing bacteria benefit by receiving sugars from the plants they colonize
Bacteria within vesicle
The plant kingdom includes epiphytes, parasites, and carnivores.

- **Epiphytes**
  - Grow anchored on other plants
  - Absorb water and minerals from rain

- **Parasites**
  - Roots tap into the host plant’s vascular system
  - Incapable of photosynthesis
  - Absorb organic molecules from host plant

- **Carnivores**
  - Trap and digest small animals such as insects
  - Absorb inorganic elements from prey
  - Found in nutrient poor environments
The plant kingdom includes epiphytes, parasites, and carnivores.
Transpiration:

- Regulated by guard cells surrounding stomata.

Cohesion and adhesion in xylem:

- Cohesion of H$_2$O molecules to each other and adhesion of H$_2$O molecules to cell walls.

Water uptake:

- Via root hairs.
Nitrogen-fixing bacteria

Air

Soil

Amino acids, etc.

Nitrogen-fixing bacteria

NH$_3$

(NH$_4^+$)

(ammonium)

Nitrifying bacteria

NO$_3^-$

(nitrate)

NH$_4^+$

Organic material

Ammonifying bacteria

Root

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Transport in plants involves movement of water and minerals from leaves through to (a) root system. Sugar transport involves movement from (d) beet root through to (c) sugar storage, driven by (f) pressure flow. Sugar transport is driven by (e) osmotic pressure.
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<th>Time (hr)</th>
<th>Temperature (°C)</th>
<th>Humidity (%)</th>
<th>Light (% of full sun)</th>
<th>Transpiration Rate (g/m²/hr)</th>
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You should now be able to

1. Describe phytoremediation and its uses
2. Explain how water and minerals are taken up by plant roots
3. Describe the transpiration-cohesion-tension mechanism for movement of water through plants
4. Describe how guard cells regulate transpiration
5. Explain how sugars are transported through plants from sources to sinks
You should now be able to

6. Give examples of essential elements and tell why they are important

7. Explain how soil characteristics and fertility influence plant growth

8. Give examples of ways that agriculture can degrade soil and practices that help conserve soil

9. Describe organic agriculture and its aims
10. Give examples of ways genetic engineering has been used to preserve the environment and improve crops

11. Explain why soil bacteria are important to all plants and plant nutrition

12. Describe the symbiotic relationships that have evolved between plants and microorganisms and how those relationships improve plant nutrition

13. Differentiate between epiphytes, parasites, and carnivorous plants; describe what each of these kinds of plants gets from its “host” or “prey”