CHAPTER 39: NUTRITION AND TRANSPORT IN PLANTS

CHAPTER SYNOPSIS

Plants require nine macronutrients; each nutrient approaches or exceeds 1% of a plant's dry weight. Included among these are carbon, hydrogen, oxygen, and nitrogen. Several micronutrients are also required, although they are only needed in trace amounts. Iron, chlorine, copper, manganese, and zinc are among these elements. It is frequently difficult to ascertain the identity of micronutrients. Plants are grown hydroponically, presumably free of all nutrients except those added to their growing solution. They are examined for abnormal symptoms that are then attributed to any missing elements. Soil is important to a plant because it provides various minerals needed for growth. It also holds the water necessary for plant survival. The ability of a soil to hold water is associated with its particle size and composition. Soils with a very small particle size tend to retain water and make it unavailable to plants. The best soil for plant growth contains a mixture of particles so that water drains quickly when it is abundant, but yet sufficient water is held when it is not.

Under natural conditions, nutrients are added to soils through decomposition of plants and animals. Sometimes plants can take up nutrients faster than they are replaced, depleting the soil and reducing its fertility. When a crop is harvested, fewer nutrients are returned through decomposition. A second crop may not grow properly if certain nutrients are lacking. Various farming practices help maintain soil fertility. These include crop rotation and allowing a field to lie fallow for one or more growing seasons. It is also a good practice to plow leftover plant materials back into the soil, just as it is advantageous to leave grass clippings on a lawn that has been cut. Nitrogen, phosphorus, and potassium are supplied to plants in the form of fertilizer. Organic fertilizers are not nutritionally superior to synthetic fertilizers, although they do provide additional humus that improves the water holding ability of the soil. Excess fertilizer is a substantial source of pollution in some areas. Carnivorous plants grow in acid soils, nearly devoid in nitrogen. These unique plants trap insects and small animals as a source of nitrogen. They literally digest their prey with enzymes secreted from special glands. The most familiar carnivorous plants are the venus flytrap, pitcher plants, bladderworts, and sundews. Some plants obtain nitrogen from the atmosphere through the actions of special nitrogen fixing bacteria associated with their roots. Nearly all vascular plants have symbiotic associations with various forms of fungi. These mycorrizae enhance the transfer of some micronutrients and greatly increase the surface area across which nutrients are absorbed.

Most animals possess pumping organs to transport fluids through their bodies. Plants lack such pumps and rely upon passive forces to transport water and minerals up from the roots and to transport the products of photosynthesis throughout the plant body. The driving force for water movement is the transpiration of water at the leaves. The water molecules that are lost there are replenished by new water molecules drawn in at the roots. The structure of xylem elements reduces cavitation in extremely tall plants. Cavitation bubbles cannot rise further than the upper end of a single element; transport continues in parallel elements. Transpiration is the loss of a plant's water through its leaves. A plant needs to minimize its water loss, but cannot always have its stoma closed since that would prohibit the entry of carbon dioxide, necessary for photosynthesis. Transpiration is regulated in various ways, including the opening and closing of leaf stomata. This process requires the expenditure of energy to change the water pressure in the two guard cells that surround each stoma. Carbon dioxide concentration, light, and temperature all affect transpiration. Seasonal dormancy, seasonal leaf loss, and leaf morphology also help regulate water loss.

Although plants need water to survive, too much of a good thing can be life threatening too. Plants can literally drown from too much water. Hormone levels are altered producing abnormal growth patterns. Obviously, too much water is less damaging to dormant plants than to actively growing ones. Excessive water also smothers plants as it prevents them from obtaining sufficient oxygen. This is less of a problem if the flooding is associated with moving water that contains sufficient oxygen, compared to standing water that becomes devoid of oxygen. Many kinds of plants have adapted to constantly wet habitats. They have evolved mechanisms to transport oxygen from plant parts above water to those below it. A few plants have adapted to life with salt water. The harmful salt is excluded, actively secreted, or merely diluted with fresh water.

Nutrient movement in plants is an active, carrier-mediated process. Ions move through plant cell protoplasts rather than through their cell walls. Carbohydrates are transported through phloem tissue in special transport forms, of which sucrose is the most common. The mass flow of carbohydrates results from the hydrostatic pressure of osmosis. Sucrose is actively loaded into the sieve tubes at the source, water molecules follow as a result of the osmotic gradient. Sucrose is unloaded from the sieve tubes at the sink, water again moves along the osmotic gradient. Sucrose moves through the plant, between the source and the sink, as a result of the movement of water at each location.

CHAPTER OBJECTIVES

ä Differentiate between macronutrients and micronutrients in terms of identity, amounts required by a plant, and physiological importance.

ä Understand how soils differ in term of particle size and ability to hold water.

ä Explain why it is necessary to fertilize soils in which crop plants are grown.

ä Understand the positive and negative aspects of commercial versus organic fertilizers.

ä Know why carnivorous plants capture and digest small animals.

ä Explain how symbiotic bacteria and fungi enhance plant growth.

ä Know the forces that work together to produce the upward movement of water in plants.

ä Know where and how minerals are absorbed in vascular plants.

ä Define guttation and explain the conditions under which it occurs.

ä Explain how vascular plants reduce the harmful effects of bubbles that form in their xylem.

ä Understand the importance of transpiration and its association with water conduction in vascular plants.

ä Understand how humidity affects transpiration and water conduction through plant tissues.

ä Explain how transpiration is regulated by plants and the environment.

ä Understand the effects of flooding and how plants have adapted to such conditions.

ä Describe how plants adapt to salt water habitats.

ä Understand how the products of photosynthesis are translocated throughout the plant body.

ä Differentiate between the loading and unloading of sucrose and the location of the source and the sink as they relate to nutrient translocation.

KEY TERMS

aerenchyma
aquaporin
bulk flow hypothesis
capillary water
crop rotation
field capacity
fertility
guttation
humus
loam
mass-flow hypothesis
minerals
osmotic potential
permanent wilting point
potentials
pressure flow hypothesis
pressure potential
root pressure
sink
solute potential
source
topsoil
translocation
transpiration
water potential

CHAPTER OUTLINE

39.0 Introduction

I. PLANTS REQUIRE INPUT OF ENERGY TO GROW

A. What Are a Plant's Needs?
1. What inputs does a plant need to survive?
2. How do parts of plant share life essentials?
3. Plants require various nutrients acquired through photosynthesis and from soil
4. Some plants obtain nutrients more directly fig 39.1

B. Transport Process Must Occur for Plants to Function
1. Carbohydrates carried from leaves to other parts
2. Water transported from roots to other plant parts
3. Fluid transport via phloem and xylem

39.1 Plants require a variety of nutrients in addition to the direct products of photosynthesis

I. PLANT NUTRIENTS

A. Plants Fix Atmospheric CO_2 to Provide a Major Source of Nutrition
1. Makes simple sugars using sun's energy
2. CO_2 enters plant through stomata
3. O_2 also moves through stomata
   a. Product of photosynthesis
   b. Used in cellular respiration to release chemical bond energy

B. Two Kinds of Inorganic Nutrients Are Required by Plants tbl 39.1
1. Nine macronutrients are required in relatively large amounts
   a. Include carbon, hydrogen, oxygen, nitrogen, potassium, calcium, phosphorus, magnesium, and sulfur
   b. Each nutrient approaches or exceeds 1% of plant's dry weight
   c. Importance has been known for the last century
2. Micronutrients are required in trace amounts fig 39.2
   a. Include iron, chlorine, copper, manganese, zinc, molybdenum, boron
   b. Constitute several hundred to less than one part per million
   c. Importance only recently recognized
3. Important nutrients determined by hydroponic culture
   a. Known or suspected nutrients left out of culture medium
   b. Plants grown and studied for abnormal symptoms fig 39.3
   c. Micronutrients in growing vessel may supply sufficient amount to plant
      1) Dose of molybdenum to fix deficient soils is extremely small
      2) Requires only 34 grams per hectare (2.5 acres) every 10 years

   d. Expensive process occasionally commercially practical
4. Level of molecules better measured via analytical chemistry
   a. Study effects of increased CO_2 due to global warming
   b. Leaves of some plants increase in size
   c. Decreased nitrogen to carbon ratio
   d. Plants less nutritious to herbivores

II. SOIL

A. Plant Growth Affected by Composition of Soil
1. Soil produced from weathered rocks
2. Composition is mixture of ingredients
   a. Includes sand, rocks, clay, silt, humus, minerals, and organic matter
   b. Pore spaces exist between particles, contain air and water
   c. Mineral fraction related to composition of rocks

B. Composition of Soil
1. Earth's crust includes 92 naturally occurring elements tbl 2.1
2. Elements combined into inorganic compounds called minerals
3. Also contains microorganisms that recycle organic debris
   a. One hectare of soil under wheat field contains 5 metric tons of carbon
   b. Equals weight of 100 sheep
4. Topsoil
   a. Most roots found in this layer of soil
   b. Composed of mineral particles + living organisms + humus fig 39.4
   c. Topsoil may be lost by erosion or poor landscaping
   d. Soil nutrient and water-holding capacity affected
5. Half of soil volume is occupied by empty space
   a. Filled with air or water
   b. Not all water in soil is available to plants
      1) Some water drains through immediately due to gravity
      2) Some held in small soil pores less than 50 mm in diameter
      3) Water in small pores available to plants
      4) Water becomes depleted through evaporation or root uptake
      5) Plants wilt and die unless more water added

C. Cultivation
1. Nutrients recycled, continuously available in natural communities
2. Dramatic changes when replaced by cultivated crops
   a. Soil exposed to erosion and loss of nutrients
   b. Cultivated areas must be supplied with additional mineral nutrients
3. Value of crop rotation
   a. Grow different crops in subsequent years
      1) Example: Corn then soybeans
      2) Crops remove different nutrients from soil
      3) Soil doesn't remove same nutrients two years in a row
      4) Soybeans are valuable to soil
         a) Add nitrogen back to soil
         b) Have nitrogen-fixing bacteria in nodules on roots
   b. Fields may be allowed to lie fallow
      1) No crop grown for year or two
      2) Natural processes rebuild soil nutrients

c. Plow leftover plant materials into soils — fig 39.5
   1) Maintain soil fertility
   2) Analogous to leaving grass clippings, leaves on lawn
   3) Crop residues include stems, roots, husks, leaves
   4) Decomposers turn plant material into humus

D. Fertilizers
   1. Replace nutrients lost in cultivated fields
   2. Additional minerals include nitrogen, phosphorus, potassium — tbl 39.1
      a. Required in large quantities
      b. Most likely to become deficient in soils
      c. May be source of pollution in certain circumstances
   3. Organic fertilizers
      a. Include manure and dead animal remains
      b. Are not nutritionally superior to inorganic fertilizers
         1) Provide additional source of humus
         2) Enhance capacity to hold water and nutrients
         3) Nutrient availability may be improved

39.2 Some plants have novel strategies for obtaining nutrients

I. NUTRITIONAL ADAPTATIONS

A. Carnivorous Plants
   1. Some plants obtain nutrients directly from other organisms
      a. Carnivorous plants usually grow in acidic soils like nitrogen-deficient bogs
      b. Plants obtain nitrogen by capturing and digesting small animals
      c. Grow in otherwise unfavorable conditions
   2. Adaptations of carnivorous plants — fig 39.5
      a. Plants lure and trap insects, small animals
      b. Digest prey with enzymes secreted from various glands
   3. Venus flytrap
      a. Grows in bogs of North and South Carolina
      b. Each side of leaf has three sensitive hairs
      c. Trigger halves of leaf to snap together when touched — fig 39.1
      d. Leaf movement occurs via growth mechanism
   4. Sundews
      a. Glandular trichomes secrete sticky mucilage and digestive enzymes
      b. Small animals entrapped and digested
      c. May share common ancestor with flytraps
   5. Pitcher plants
      a. Attract insects with bright flowerlike colors within pitcher-shaped leaves
      b. May also have sugar-rich solutions for attraction
      c. Insects slide into cavity of leaf, filled with water and digestive enzymes
   6. Bladderworts
      a. Small aquatic plants
      b. Sweep animals into bladderlike leaves by rotating trapdoor

B. Nitrogen Fixing Bacteria
   1. Plants need ammonia to build amino acids
      a. Most available nitrogen in form of atmospheric gas
      b. Plants lack enzymes and pathways for this conversion
      c. Some bacteria are able to do this conversion

2. Some bacteria live in close association with plant roots
   a. Some become housed in special plant tissues called nodules fig 39.6
   b. Root nodules formed by legumes and a few other plants
   c. Hosting bacteria is energetically costly, but worthwhile in nitrogen-deficient soils
   d. Root hairs do not respond to bacteria in high nitrogen levels

C. Mycorrizae
1. Symbiotic associations with fungi occur in 90% of vascular plants
   a. Play important role in enhancing phosphorous transfer to plant
   b. Also enhances transfer of some micronutrients
2. Greatly extend surface area across which nutrients are absorbed

39.3 Water and minerals move upward through the xylem

I. OVERVIEW OF WATER AND MINERAL MOVEMENT THROUGH PLANTS

A. Local Changes Result in the Long Distance, Upward Movement of Water
1. Water enters through roots, travels upward through xylem
2. Water may travel 10 stories to reach top of trees fig 39.7
3. How does water get from roots to top of tree?
   a. Moves through spaces between protoplasts of cells
   b. Moves through plasmodesmata (connections between cells)
   c. Moves through cell membranes and continuous tubing of xylem
4. Interconnecting, water-conducting xylem elements extend through plant
   a. Water enters through roots and moves to xylem
   b. Water rises through xylem and some exits through leaf stomata
5. Movement of cellular water plays role in bulk water transport of water
   a. Occurs over much shorter distances
   b. Root Casparian strip forces water to move through cells fig 38.18
   c. Most water moves across membranes, not in intercellular spaces
   d. Some water moves across membranes by osmosis through lipid bilayer
   e. Osmosis enhanced by movement through aquaporin water channels
      1) Transport channels found in plants and animals
      2) Exist in vacuoles and plasma membranes in plants
      3) Some appear or open only during drought stress
      4) Allow for faster movement than osmosis
      5) Help maintain cell water balance
      6) Also get water between plant cells and xylem
6. Movement of water in the xylem
   a. Involves some “pushing” from the pressure of water entering roots
   b. Most force results from “pulling” due to water evaporation
      1) Due to transpiration of water through leaf and surface stomata
      2) Water molecules are cohesive, stick to each other with hydrogen bonds
      3) Are also adhesive to walls of tracheid or xylem vessels
   c. Forms stable column of liquid reaching great heights

B. Water Potential
1. Forces acting on water in plant called potentials
2. Pressure potential is a physical pressure and is generally positive
   a. Turgor pressure results as water enters cell vacuole
   b. Water through hose is another physical pressure
   c. Solute or osmotic potential is smallest amount to stop movement by osmosis
      1) Based on concentration gradients of solute and solvent across membrane
      2) Water enters cell by osmosis

3) Continues until solute potential is offset by cell's resistance to expansion
4) Pressure can prevent osmosis from occurring, generally a negative number

3. Water potential = pressure potential + solute potential
   a. Represents total potential energy of water in plant
   b. Pure water without applied pressure has water potential of zero
   c. Water moves to cell with more negative water potential
4. Water moves along gradient in plant
   a. From water potential in soil (close to zero at roots)
   b. To successively more negative potentials in roots, stems, leaves, and atmosphere
5. Forces that result in upward movement of water in plants
   a. Osmotic absorption at roots
   b. Negative pressure caused by evaporation
6. Process defined as transpiration fig 39.8

II. WATER AND MINERAL ABSORPTION

A. Value of Root Hairs

1. Most water enters through root hairs fig 39.8
   a. Root hairs always turgid due to solute potential
   b. Transport of minerals requires expenditure of ATP energy
2. Root hair plasma membranes contain various protein transport channels
   a. Proton pumps transport specific ions against huge concentration gradients
   b. Ions, plant nutrients, get in roots and are transported to plant via xylem

B. Water and Minerals Pass into Conducting Elements of Xylem

1. Nonselectively follow along cell walls and spaces between cells fig 39.9
2. Selectively go through plasma membrane and through protoplasm of adjacent cells
3. Water and mineral passage stopped at Casparian strip
   a. Endodermal cells selectively control mineral movement
   b. Endodermis, cortex, and epidermis control which ions reach xylem
4. Transpiration helps water and dissolved ions enter root cells fig 39.10
   a. Transpiration may cease at night due to high relative humidity of air
   b. Negative pressure component of water potential becomes very small
   c. Active transport of ions still occurs in roots
   d. Water passes inward via osmosis, called root pressure
   e. Active transport increases solute potential of roots
   f. Water moves into plant, up xylem without transpiration
5. Phenomenon called root pressure
   a. Pressure strong enough to force water from cut ends of plant
   b. Strong pressure causes guttation, water is forced out of cells in veins fig 39.11
   c. Occurs only in very short plants

III. WATER AND MINERAL MOVEMENT

A. Water and Mineral Movement through the Xylem

1. Water is pulled up through a tree
   a. Air moving across leaves causes loss of water by evaporation
   b. Pull created at open upper end of tube in tree
   c. Produces tensions on water column through tree, down to roots
   d. Column of water has tensile strength
      1) Arises from cohesion due to hydrogen bonds between molecules
      2) Strength is inversely proportional to diameter of tube
      3) Smaller tube has greater tensile strength
      4) Forces strong because plant transporting vessels are small

        5) Narrow diameter creates strong cohesive forces
    e. Molecules also adhere to sides of vessels for more stabilization
  2. Air bubbles in column would cause column to fail
    a. Anatomy of tracheids and vessels prevents formation of bubbles
        1) Connected by pits in walls
        2) Air bubbles larger than openings, cannot pass through them
        3) Bubbles cannot change shape to squeeze through
    b. Deformed cells or freezing can cause bubbles to form
        1) Bubbles remain in cells in which they are form
        2) Water continues to rise in parallel columns
        3) More likely to occur when seasonal temperature changes
        4) Active xylem occurs peripherally, toward vascular cambium
  3. Minerals enter roots by active transport
    a. Removed from root, relocated to metabolically active regions
        1) Some found in xylem during certain seasons
            a) Phosphorus, potassium, nitrogen
            b) Sometimes iron
        2) Helps conserve essential nutrients
        3) May move from deciduous regions to areas of active growth
    b. Minerals relocated via xylem must follow upward flow
    c. Some nutrients cannot reenter xylem conduit
        1) Includes calcium
        2) Cannot move once deposited in a plant part

B. Transpiration of Water from Leaves
  1. Majority of water taken up by roots is lost to atmosphere
    a. Exit leaves through stomata in form of water vapor
    b. Water first passes into intercellular spaces between mesophyll
    c. Water in spaces renewed by flow from leaf veinlets
  2. Conflicting requirements of photosynthesis and water retention
    a. Plant must have continual source of water to survive
        1) Must minimize water lost to atmosphere
        2) Must admit CO_2
    b. Plant features evolved to balance these two situations
  3. Transpiration rate dependent on weather conditions
    a. Includes humidity and time of day
    b. Transpiration decreases after sun sets
  4. Sun is ultimate source of potential energy for water movement
    a. Water potential is product of negative pressure from transpiration
    b. Driven by warming effects of sunlight
  5. The regulation of transpiration rate
    a. Control short term loss of water by closing stomata
        1) Must counter balance water loss with need for CO_2
        2) Intercellular spaces must be moist for CO_2 to enter cells
    b. CO_2 must dissolve in water before it can enter plant cells
        1) Dissolves mainly in water on walls of intercellular spaces
        2) Walls kept moist by flow of water from roots
    c. Changing water pressure in guard cells regulates stomata
        1) Guard cells are only epidermal cells with chloroplasts
        2) Distinctive curved shape, cell wall thicker next to stomatal opening
        3) Turgid cells have bowed shape, open stomata
    d. Turgor in guard cells results from active uptake of K+ ions
        1) Increase in K^+ concentration causes water potential in guard cells
        2) Causes water to enter osmotically

3) Cells accumulate water, become turgid, stomata open fig 39.12a
4) When K^+ passively leaves guard cells, water follows
5) Guard cells lose turgor, stomata close fig 39.12b

e. Cl^- accompanies K^+ in some plants to maintain electrical neutrality
f. Plant wilts when water is scarce, guard cells lose turgor, stomata close
1) Guard cells may be turgid in morning with photosynthesis
2) May lose turgor in evening independent of water availability
3) When guard cells are turgid, stomata open, CO_2 enters
4) When guard cells are flaccid, CO_2 is excluded and water loss is retarded

g. Abscissic acid effects passage of K^+
1) Allows K^+ to rapidly pass out of guard cells, stomata close
2) Hormone produced in leaves under water stress
3) Binds to receptors on guard cell plasma membrane
4) Control duration of stomatal opening via several stimuli

6. Other factors regulating transpiration
a. Concentration of CO_2
1) Guard cells loose turgor with high concentrations
2) Stomata close because there is no need for more CO_2
3) Water is conserved

b. Temperature: Stomata close when temperature is above 30° to 34°C
c. In dark, stoma will open if CO_2 is low
d. CAM photosynthesis allows plants to conserve water by taking in CO_2 at night and fixing it during the day
e. Seasonal dormancy regulates water loss
1) Deciduous plants lose leaves during dry seasons, including winter
2) Annual plants exist only in the form of seeds

f. Leaf morphology regulates water loss
1) Thick, hard leaves with few stomata are more resistant to drying
2) Wooly trichomes trap humid layer of air near the leaf surface
3) Stomata may be present in pits in the leaf surface

C. Plant Responses to Flooding
1. Flooding depletes available oxygen in soil plants may “drown”
a. Blocks normal reactions in roots
b. Affects transport of minerals and carbohydrates

2. Result in abnormal growth patterns
a. Changes in hormone levels
b. Ethylene increases
c. Giberillins and cytokinins decrease

3. Flooding associated with moving water is less damaging
a. Brings in new supplies of oxygen
b. Standing water does not bring in oxygen

4. Flooding during plant dormancy is less harmful than if actively growing
5. Oxygen deprivation may cause physical changes in roots
a. Halts water flow through plant, dries out leaves
b. Stomata generally close with such stress
c. Closing stomata may maintain some leaf turgor

6. Adapting to life in fresh water
a. Many plants have evolved to live in continuously wet places fig 39.13
b. Common adaptation is formation of aerenchyma fig 39.14
1) Loose parenchyma tissue with large air spaces
2) Prominent in water lilies and other aquatic plants

c. Oxygen transported from above water level to below water level through passages
1) Supplies oxygen to submerged parts of plant

        2) Allows oxidative respiration to occur
    d. Some plants for aerenchyma only when needed
        1) In corn, ethylene induces its formation
        2) Becomes abundant in flooded conditions
    e. Additional responses to flooding
        1) Forming larger lenticels to facilitate gas exchange
        2) Formation of additional adventitious roots
7. Adapting to life in salt water
    a. Example: Mangroves
    b. Must supply oxygen and control salt balance
    c. Salt excluded, actively secreted, or diluted
        1) Mangroves have arching silt roots connected to spongy air roots
        2) Roots called pneumatophores fig 39.15
        3) Spongy air roots have lenticels on above water portions
        4) Oxygen enters roots, transported to submerged roots
    d. Succulent leaves contain large amounts of water to dilute salt that reaches them
    e. Other plants secrete salt through specialized glands or block its uptake

39.4 Dissolved sugars and hormones are transported in the phloem

I. PHLOEM TRANSPORT IS BIDIRECTIONAL

A. Carbohydrate Translocation through the Phloem
1. Carbohydrates manufactured in leaves distributed through phloem
2. Process called translocation
3. Carbohydrates may be concentrated in storage organs like tubers
    a. Generally stored in the form of starch
    b. May be converted to transportable forms like sucrose
4. Pathway of sugar transport studies with radioactive tracers
    a. Use radioactive carbon dioxide $^{14}CO_2$
    b. Becomes incorporated into glucose, used to make sucrose
    c. Sucrose transported in phloem
    d. Sucrose moves both up and down in phloem
5. Translocation studied using aphids fig 39.16
    a. Aphids thrust stylets into phloem cells
        1) Cut feeding aphid from stylet
        2) Liquid in phloem flows through mouthpart
    b. Study pure form of phloem liquid
6. Sucrose comprises most of dry matter of phloem liquid
    a. Liquid composed of 10% to 25% dry matter, mostly sucrose
    b. Movement may be as rapid as 50 to 100 centimeters per hour
7. Phloem also transports plant hormones

B. Energy Requirements for Phloem Transport
1. Mass-flow hypothesis, also called pressure flow or bulk flow hypothesis
    a. Carbohydrates flow from source
    b. Sink is region where they are utilized
    c. Sources include areas of photosynthesis
    d. Food storage tissues can be either sources or sinks
    e. Sinks also occur at growing tips of roots and shoots, developing fruit
2. Phloem loading fig 39.10
    a. Sucrose actively loaded into phloem of leaf veinlets
    b. Energy requiring process, companion and parenchyma cells provide ATP
    c. Change in solute potential allows water to pass into sieve tubes

d. Turgor pressure in sieve tubes increases
e. Drives fluid through plant's sieve tube system
f. At sink, water leaves as carbohydrates are actively removed
g. Turgor pressure drops
h. Results in mass flow
    1) Goes from more positive pressure at source
    2) Flows to more negative pressure at sink

3. Water diffuses back into xylem, recycled or lost through transpiration

INSTRUCTIONAL STRATEGY

PRESENTATION ASSISTANCE:

It is important to stress our dependency on plants: as a primary and secondary food source, for the production of oxygen and for the utilization of carbon dioxide. They also provide a soothing habitat for humans as witnessed by their use in homes, shopping malls, and building landscaping. Plants are remarkable organisms; they cannot migrate if the habitat changes or hide from the desert heat. They must be adaptable to enormous environmental changes in order to survive and indeed flourish.

Certain mosquito larvae and other small invertebrates complete their entire life cycle within the pitchers of pitcher plants. They can survive only there and somehow cope with the hazardous environment and are not themselves digested!

Not only do bogs lack nitrogen-fixing bacteria, they also lack bacteria that degrade plant and animal materials. Bogs eventually compress under their own weight, forming peat and ultimately low quality coal. Recently, many relatively well-preserved human bodies have been exhumed from peat bogs. Some of these are several hundreds of years old. Not only is their clothing still intact, but often researchers can determine the last meal.

Vegetables wilt in the refrigerator as a result of transpiration through their leaves. This is more pronounced in newer energy efficient appliances that dehumidify the interior. This effect can be reduced by keeping veggies in sealed containers and removing unwanted leaves. Celery keeps quite well by placing the cut petioles (not stems) in a jar of fresh water.

It is recommended that all but a few leaves be removed from cuttings that are being rooted to prevent excess water loss as well.

VISUAL RESOURCES:

Demonstrate the uptake of water by xylem tissue with a plant having light colored leaves or flowers, or a cut flower. The uptake increases with the rate of transpiration and would hardly occur at all if the plant or flower is placed in a relatively humid, transparent, sealed container.

Show a short video on the unique and marvelous strategies of the carnivorous plants. Some people find it quite easy to keep them growing by feeding them low fat hamburger. Personally, I'd rather feed a dog!