BLY 122
Chapter 36 Water and Sugar Transport in Plants

I. Water Potential and Cell-to-Cell Movement of Water

A. Plants lose water to the environment via transpiration.
   1. Transpiration occurs when two conditions are met:
      a. Stomata are open; happens during the day when photosynthesis occurs
      b. When the environmental air is drier than the air inside the leaves
   2. Plants replace water lost by transpiration with water absorbed from the roots.
      a. This process is passive; it does not require ATP.
      b. Movement of water up a plant occurs due to differences in the potential energy of water.
      c. There is a water potential gradient between the roots and leaves.

B. Cell-to-cell movement is dependent on solute potential and pressure potential.
   1. Solute potential (φ_s) = difference in solute concentration between two solutions.
      a. In a cell with solute concentration equal to solute concentration of surrounding solution, the solute potentials are the same (isotonic) and no net movement of water occurs.
      b. For a cell in a solution with a solute concentration less than that of the cell, solute potentials are different and water moves into the cell.
      c. Osmosis is the process by which water moves across the semipermeable cell membrane.
      d. Solute potential is also known as osmotic potential.
   2. Pressure potential (φ_p) describes any kind of physical pressure on water; in a cell, pressure potential consists of turgor pressure and wall pressure.

C. Water potential (φ) is the sum of solute potential (φ_s) and pressure potential (φ_p).
   1. Water potential is the tendency of water to move from one location to another depending on the solute and pressure potentials at the other location.
   2. Water potential is measured in the unit known as megapascal (MPa).
   3. Water potentials of cells are usually negative because solute potentials of cells are negative.
   4. Pressure potential from turgor pressure is positive, thus increasing water potential and increasing the probability that water will move out of cell.
   5. Water moves from regions of high water potential to regions of low water potential.

D. Water Potentials in Soils, Plants and the Atmosphere
   1. Plant tissues, root and shoot systems, and entire plants have measurable water potentials.
   2. Soil and air have water potentials.
   3. Water potential differences between soil, plants, and air create a water potential gradient that dictates the direction of water flow in a system.

II. Root Pressure and Short-Distance Transport

A. Root Anatomy
   1. The epidermis is the outermost layer of cells; protects the root and produces root hairs that increase the absorptive area of the root.
   2. Cortex consists of ground tissue (parenchyma cells) that stores carbohydrates.
   3. Endodermis is a ring of cells that separates the cortex from the vascular tissue.
   4. Pericycle is a population of potentially meristematic cells that can produce lateral roots.
   5. Vascular tissues are in the center of the root.

B. Water moves along a water potential gradient from the soil through the root to the vascular tissues.
   1. Water enters via the root hairs and moves through the cortex following one of two paths.
   2. Once water reaches the endodermis, it can no longer travel via the apoplast.

III. Transpiration and Long-Distance Water Transport

A. Movement of water in some plants is based on the phenomenon of capillarity.
   1. When a thin glass tube is placed in a pan of water, the water creeps up the tube.
   2. This happens because of surface tension, adhesion, and cohesion.
   3. Only very small plants can depend on water transport via capillarity alone.

4. Larger plants depend on capillarity combined with the "pulling" force of transpiration to move water over long distances.

B. Transpiration is the loss of water from aerial plant parts.
   1. Leaf area below stomatal pore is filled with moist air.
   2. When stomatal pore opens, humid air inside leaf is exposed to dry air in atmosphere.
   3. Steep water potential gradient between the dry air and moist leaf space results in exit of water through pore.
   4. Humidity in space decreases as water leaves and evaporates from cell walls.
   5. Menisci form at water-air interfaces of cell walls.

C. Surface tension at air-water interface pulls water up from soil.
   1. As water evaporates from the leaf via transpiration, a steep water potential gradient leads to deepening of menisci, and inward pull (surface tension) on remaining water molecules becomes stronger.
   2. This generates a pulling force on water molecules that form a continuum of cohesively bonded molecules throughout the entire plant (through the xylem, roots, and ultimately the soil).

D. Important Components of the Cohesion-Tension Theory
   1. Expenditure of energy by plants is not required.
   2. Water moves along a water potential gradient by bulk flow.
   3. In dry conditions stomata close to conserve water, but carbon dioxide available for photosynthesis decreases—the photosynthesis-transpiration compromise.

E. Adaptations to Limit Water Loss
   1. Plants in dry environments need to cope with soils that have very low water potentials and must conserve as much water as possible.
   2. Morphological traits reduce water loss in plants native to dry habitats.
      a. Sunken stomata with hairs
      b. Stomata on lower epidermis
      c. Thick cuticle on leaf surfaces
   3. Obtaining carbon dioxide under water stress
      a. CAM plants have stomata open at night to collect carbon dioxide, store it for use in the day. This allows them to keep stomata closed during the day.
      b. C_4 plants efficiently fix CO_2 under hot, dry conditions, limiting the amount of time their stomata need to be open.

IV. Translocation—the Movement of Sugars in Plants

A. Sugars move from sources to sinks.
   1. Source is tissue where sugar enters the phloem.
   2. Sink is tissue where sugar exits the phloem.
   3. Sinks and sources vary depending on time of year.
      a. In growing season, leaves and stems are sources; apical and lateral meristems, seeds, fruits, and storage cells in roots are sinks.
      b. Early in growing season, root storage cells are sources, and developing leaves are sinks.
   4. Location of sources and sinks was demonstrated by tracking radioactively labeled sugars in sugar beets.
      a. Results: Sugars moved from a mature leaf, a source, to growing leaves, the sink.
      b. Sugars moved from leaves (the source) to roots (the sink).
   5. Sources and sinks are physically related.
      a. Sugars from a source move to a sink on the same side of the plant.
      b. Sources on the upper part of the stem send sugar to sinks at apical meristems; sources on lower part send sugar to sinks in roots.
      c. Phloem in leaves on one side of plant connects with phloem in stem and roots on same side.
   6. Sugars are transported rapidly.

B. Sugars Move through Cells in Phloem Tissue
   1. Two cell types comprise phloem tissue.
      a. Sieve-tube elements
      b. Companion cells

2. Early demonstration that phloem transports sugars
    a. Bark removed from tree; water transport continues, sugar transport stops.
    b. Phloem tissue contains high concentration of sucrose.

C. The Pressure-Flow Hypothesis for Sugar Transport
  1. Hypothesis for sugar movement
    a. Sugars are transported from source to sink along a turgor pressure gradient in the phloem.
    b. Force responsible for movement is generated by turgor pressure differences at source and sink tissues.
  2. Events at the source
    a. Sucrose moves from source cells to companion cells, then to sieve-tube elements.
    b. Phloem sap at source has high sucrose concentration, low water potential.
    c. Adjacent xylem cells have high water potential and water moves from xylem into sieve-tube elements along a water potential gradient.
    d. Turgor pressure at source increases.
    e. Sugars move by bulk flow along the pressure gradient.
  3. Events at the sink
    a. Cells in the sink remove sucrose from phloem sap.
    b. Water potential in sieve-tube elements increases as sucrose is removed until it is higher than water potential in adjacent xylem cells.
    c. Water flows from sieve-tube elements into xylem along water potential gradient.
    d. Turgor pressure of phloem at sink drops.
    e. Outcome is a continuous loop of water flow driven by water potential gradients between xylem and phloem and unidirectional movement of sucrose molecules driven by pressure potential gradient in phloem.
  5. Phloem loading at source requires ATP
  6. Phloem unloading at sink
    a. Energy is required at some point in the process.
    b. Mechanism varies with different sinks in the same plant, as well as between different plant species.
    c. Sugar beets employ two different mechanisms for unloading at different sinks.

Chapter Vocabulary

solute potential/osmotic potential
turgor pressure
wall pressure
turgid

pressure potential
water potential
paschal/megapaschal
plasmolysis
wilt
water potential gradient

solution
solute

isotonic
hypotonic

epidermis
root hairs
cortex
endodermis
pericycle
vascular tissues
apoplast
symplast
Casparian strip
suberin
root pressure
guttation

transpiration
capillarity
surface tension

meniscus

halophytes

cohesion
adhesion
cohesion-tension theory
xylem sap

dendrograph
pressure bomb
negative result
root bomb
xylem pressure probe
bulk flow

photosynthesis-transpiration compromise
C_4 photosynthesis
CAM photosynthesis
rubisco
bundle-sheath cells

translocation
source
sink
pressure-flow hypothesis

sieve-tube elements
sieve plates
companion cells
phloem loading
passive transport
active transport
facilitated diffusion
proton pump
cotransporter
symporter

phloem unloading
tonoplast