Transport and Transpiration in Multicellular Plants

Transport in plants
- H₂O & minerals
  - transport in xylem
  - transpiration
    - evaporation, adhesion & cohesion
    - negative pressure
- Sugars
- Gas exchange

Why does over-watering kill a plant?

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  - transport in phloem
    - bulk flow
    - Calvin cycle in leaves loads sucrose into phloem
    - positive pressure
- Gas exchange

Transport in plants
- Physical forces drive transport at different scales
  - cellular
    - from environment into plant cells
    - transport of H₂O & solutes into root hairs
  - short-distance transport
    - from cell to cell
    - loading of sugar from photosynthetic leaves into phloem sieve tubes
  - long-distance transport
    - transport in xylem & phloem throughout whole plant

Gas exchange
- photosynthesis
  - CO₂ in; O₂ out
  - stomates
- respiration
  - O₂ in; CO₂ out
  - roots exchange gases within air spaces in soil

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Why does over-watering kill a plant?
Cellular transport

- **Active transport**
  - solutes are moved into plant cells via active transport
  - central role of proton pumps
  - Cotransport with H+ ions

**Proton pumps**

- **Short distance (cell-to-cell) transport**
  - Compartimentalized plant cells
    - cell wall
    - cell membrane
    - cytosol
    - vacuole
  - Movement from cell to cell
    - move through cytosol
      - plasmodesmata junctions connect cytosol of neighboring cells
      - symplast
    - move through cell wall
      - continuum of cell wall connecting cell to cell
      - apoplast

**Routes from cell to cell**

- Moving water & solutes between cells
  - transmembrane route
    - repeated crossing of plasma membranes
  - symplast route
    - move from cell to cell within cytosol
  - apoplast route
    - move through connected cell wall without crossing cell membrane
    - fastest route but never enter cell

**Long distance transport**

- **Bulk flow**
  - movement of fluid driven by pressure
    - flow in xylem tracheids & vessels
      - negative pressure
      - transpiration creates negative pressure pulling xylem sap upwards from roots
    - flow in phloem sieve tubes
      - positive pressure
      - loading of sugar from photosynthetic leaf cells generates high positive pressure pushing phloem sap through tube

**Movement of water in plants**

- Water relations in plant cells is based on water potential
  - osmosis through aquaporins
  - transport proteins
  - water flows from high potential to low potential

- **Water & mineral uptake by roots**
  - Mineral uptake by root hairs
    - dilute solution in soil
    - active transport pumps
    - this concentrates solutes (~100x) in root cells
  - Water uptake by root hairs
    - flow from high H₂O potential to low H₂O potential
    - creates root pressure

- **Movement of water**
  - cells are flaccid: plant is wilting
  - cells are turgid
Root anatomy

Dicot and monocot root anatomy images.

Route water takes through root

- Water uptake by root hairs
  - a lot of flow can be through cell wall route
  - apoplasty

Controlling the route of water in root

- Endodermis
  - cell layer surrounding vascular cylinder of root
  - lined with impervious Casparian strip
  - forces fluid through selective cell membrane & into symplast
    - filtered & forced into xylem vessels

Mycorrhizae increase absorption

- Symbiotic relationship between fungi & plant
  - symbiotic fungi greatly increases surface area for absorption of water & minerals (phosphates)
  - increases volume of soil reached by plant
  - increases transport to host plant

Mycorrhizae

Images of mycorrhizae structures.
May apples and Mycorrhizae

Obligate mutualism!

Ascent of xylem “sap”

Transpiration pull generated by leaf

Rise of water in a tree by bulk flow

- Transpiration pull
  - adhesion & cohesion
  - H bonding
  - brings water & minerals to shoot
- Water potential
  - high in soil → low in leaves
- Root pressure push
  - due to flow of H₂O from soil to root cells
  - upward push of xylem sap

Control of transpiration

- Stomate function
  - always a compromise between photosynthesis & transpiration
  - leaf may transpire more than its weight in water in a day…this loss must be balanced with plant’s need for CO₂ for photosynthesis
  - a corn plant transpires 125 L of water in a growing season

Stomatal transpiration

- Cuticle
  - Prevents water loss
- Mesophyll
  - Site of photosynthesis
- Stomata
  - Openings allow gases and water to move in and out of leaf
- Guard cells
  - Open and close the stomata

Function of Guard Cells

How do the guard cells react to the availability of water?

- Dry – guard cells CLOSE
- Lots of H₂O – guard cells OPEN
Characteristics of guard cells

- **Microfibril mechanism**
  - guard cells attached at tips
  - microfibrils in cell walls
  - elongate causing cells to arch open = open stomate
  - shorten = close when water is lost
- **Ion mechanism**
  - uptake of $K^+$ ions by guard cells
  - proton pumps
  - water enters by osmosis
  - guard cells become turgid
  - loss of $K^+$ ions by guard cells
  - water leaves by osmosis
  - guard cells become flaccid
  - Abscisic acid can also close stomates

Regulation of stomates

- **Other cues**
  - light trigger
    - blue-light receptor in plasma membrane of guard cells
    - triggers ATP-powered proton pumps causing $K^+$ uptake
    - stomates open
  - depletion of $CO_2$
    - $CO_2$ is depleted during photosynthesis (Calvin cycle)
  - circadian rhythm = internal “clock”
    - automatic 24-hour cycle

Stomatal Control

- Stomates fill with water to open and empty of water (become flaccid) to close
- Overall, stomata need to open
  - Higher solute concentration = lower water potential = more negative = water flows in
  - The opposite is true for closing
  - Several factors influence these openings and closings...

**Light**

- Stomata of most plant open in the day and close at night
- CAM plants are the opposite (desert adaptation)
- Stomata opening are sensitive to red light and blue light
  - Blue light is more effective - stimulates opening by blue-light receptor zeaxanthin.
  - Allows stomata to be open in light that is conducive to photosynthesis

**Temperature**

- Stomatal aperture increases with temperature
  - 20-30°C is optimal—too hot means too much evaporation and the plant can wither, so stomata close
CO₂

- Low CO₂ concentration promotes stomatal opening
  - Necessary so enough CO₂ is available for photosynthesis
- High CO₂ concentration inhibits stomatal opening
  - CO₂ acidifies the guard cell

Water content

- Stomata open when the leaf contains enough water. When there is a water shortage, they close.
  - Helps prevent wilting from over transpiration

Hormones

- Cytokinins (CTKs) stimulate stomatal opening
- Abscisic Acic (ABA) stimulates stomatal closing
- Both affect overall solute concentration in the guard cells, causing water to move in or out

Transpiration Rates

- Transpiration depends on concentration gradients in the same way that mass flow does

Factors affecting rate of transpiration

- Many factors affect this water vapor concentration gradient
- Affect overall rate of transpiration

Light

- Plants transpire more rapidly in the light than in the dark.
- Light stimulates the opening of the stomata
- Light also increases temperature of leaf
**Temperature**
- Plants transpire more rapidly at higher temperatures because water evaporates more rapidly as the temperature rises.

**Humidity**
- When the surrounding air is dry, diffusion of water out of the leaf goes on more rapidly.

**Wind**
- When a breeze is present, the humid air is carried away and replaced by drier air.

**Soil Water**
- A plant cannot continue to transpire rapidly if its water loss is not made up by replacement from the soil.
- If absorption of water by the roots is less than the rate of transpiration...
  - loss of turgor occurs
  - stomata close.
  - Reduces the rate of transpiration.
  - If this extends to the rest of the leaf and stem, the plant wilts.

**Potometer**

**Translocation via phloem**
- Loading of sucrose into phloem
  - flow through symplast via plasmodesmata
  - active cotransport of sucrose with H⁺ protons
  - proton pumps

**Pressure flow in sieve tubes**
- Water potential gradient
  - “source to sink” flow
  - direction of transport in phloem is variable
  - Can be simultaneously up and down in different tubes, but only one direction in any given tube
  - sucrose flows into phloem sieve tube
  - water flows in from xylem vessels
  - increase in pressure due to increase in H₂O causes flow

What plant structures are sources & sinks?
Maple sugaring

Putting it all together

- **Obtaining raw materials**
  - *sunlight*
    - leaves = solar collectors
  - *CO₂*
    - stomates = gas exchange
  - *H₂O*
    - uptake from roots
  - **nutrients**
    - uptake from roots

Figure 24. Photosynthesis, respiration, leaf water exchange, and translocation of sugar (sucrose) in a plant.

Lignified walls provide structure to withstand negative pressure of transpiration

Vessel element

*Vessel elements have holes between them to allow unimpeded flow*

Monocot Root Cross Section (cs)

Sieve tube element

*Sieve plates maintain positive pressure in tube elements*

*Thin cytoplasm, no nuclei in sieve tubes*

Companion cell

Site of active loading of phloem—H⁺ pumped into apoplast, flow back into companion cell cotransporting sucrose
Dicot Root
Cross Section (cs)

Monocot Stem

Dicot Stem

Monocot Leaf
- Midrib shows vascular tissue: Can you ID?
- Leaves have parallel veins (visible here)
- Do you see the stomata?

Dicot Leaf
- These leaves have a more obvious midrib (central vein)
- Veins are perpendicular to the central vein.

Any Questions??