Water Relations in Viticulture

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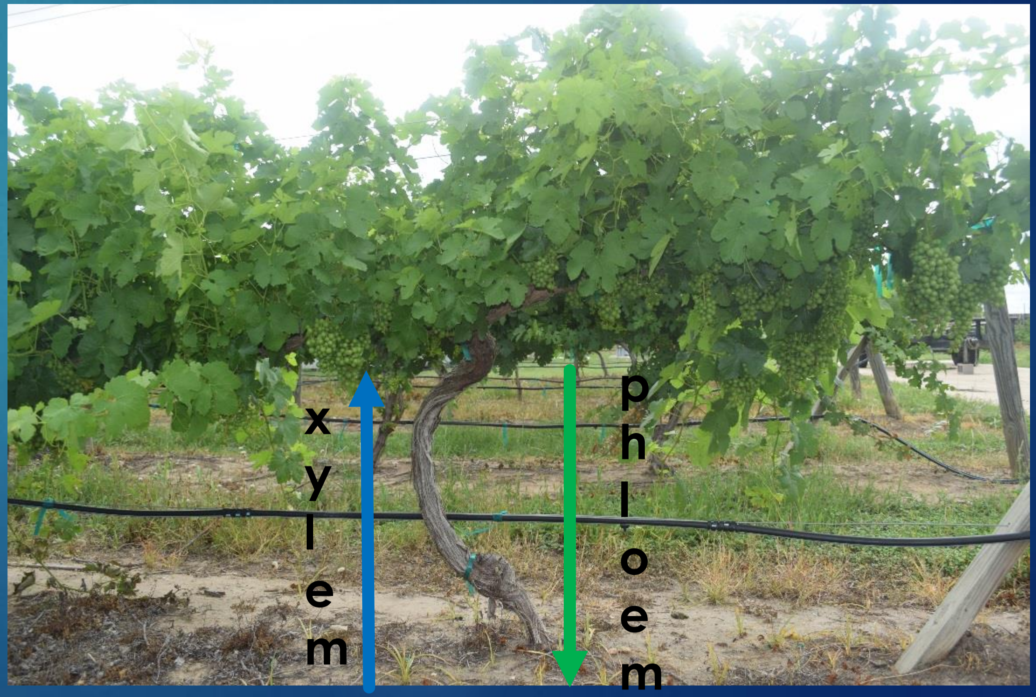
Overview

- Introduction
- Important Concepts for Understanding water Movement through Vines
  - Osmosis
  - Water Potential
  - Cell Expansion and the Acid Growth Theory
  - Transpiration
  - Stomatal Action

Introduction

- 70-95% of the fresh mass of grapevine cells consists of water
  - Acts as a solvent for gases, salts, and other solutes (nutrients and minerals), and is one of the reagents in photosynthesis.
  - Plays a pivotal role in growth: cells with enough water exert turgor pressure, causing enlargement of cells, therefore increasing tissue and organ size
- Plant water status depends on the imbalance between water uptake from the soil and water loss through evapotranspiration
  - Rate of uptake generally depends on root distribution and soil moisture availability



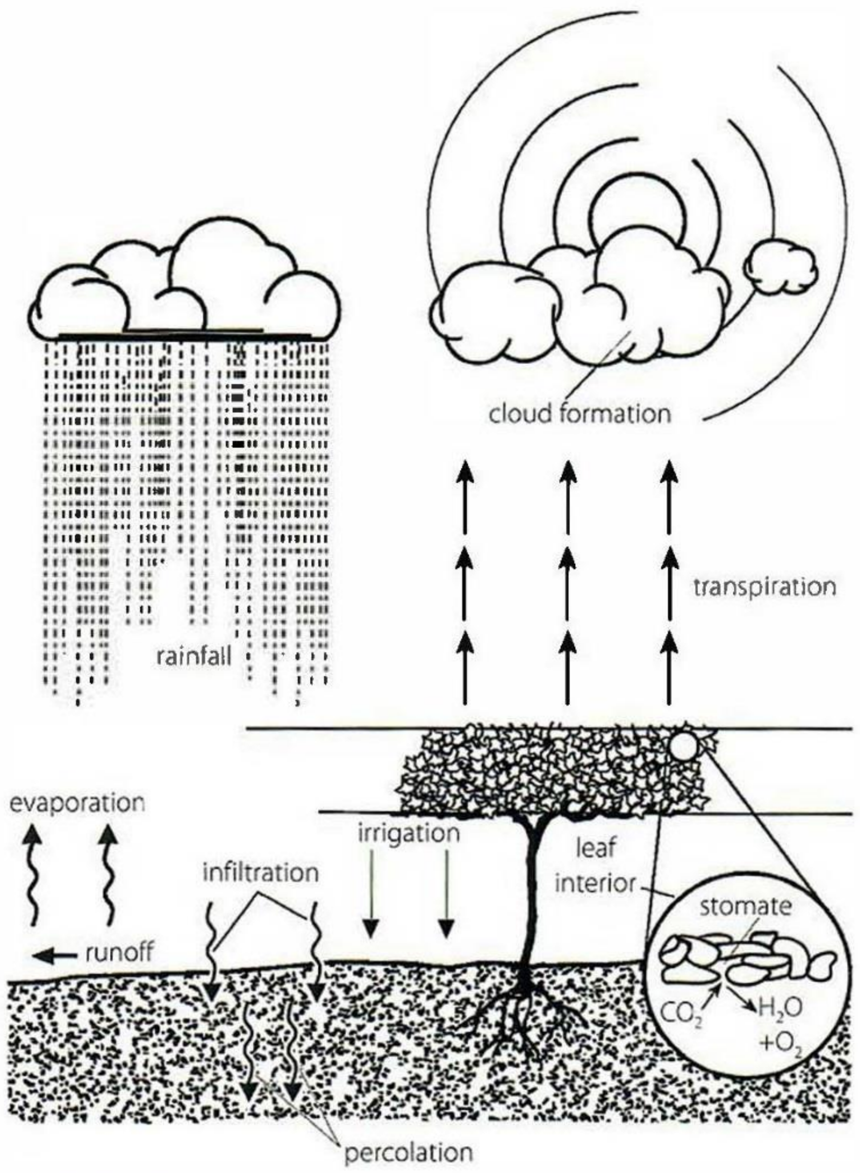


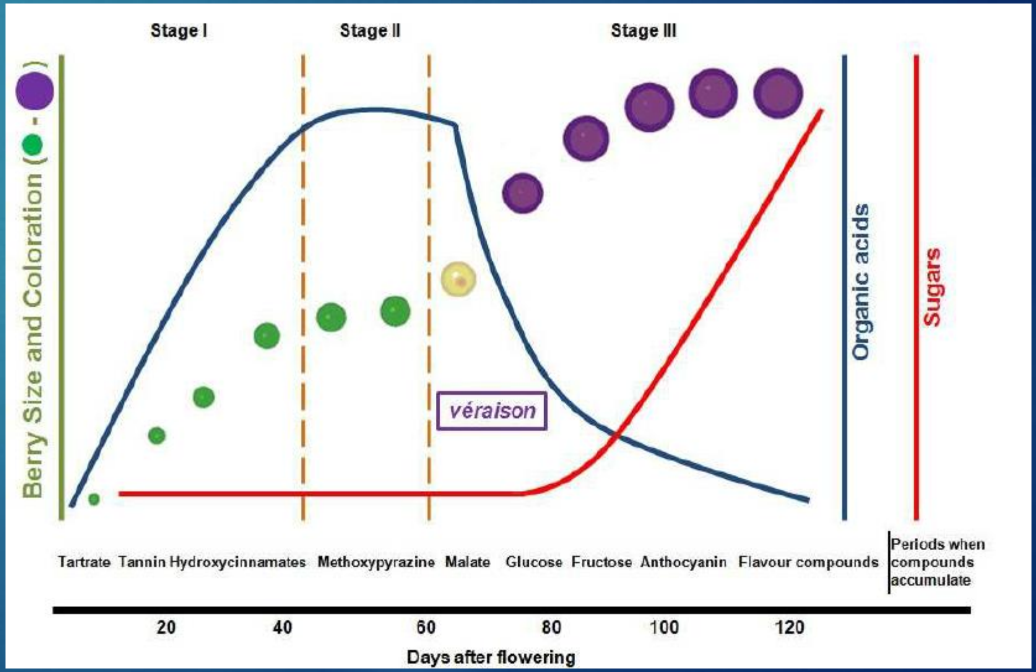
Figure 9.1 ▪ The vineyard hydrologic cycle.

Water enters the vineyard as rainfall or irrigation and is removed through gravity, runoff, evaporation, and transpiration through plant leaves.

Ross, D. S., Wolf, T. K. 2008. Wine Grape Production Guide for Eastern North America.

Introduction

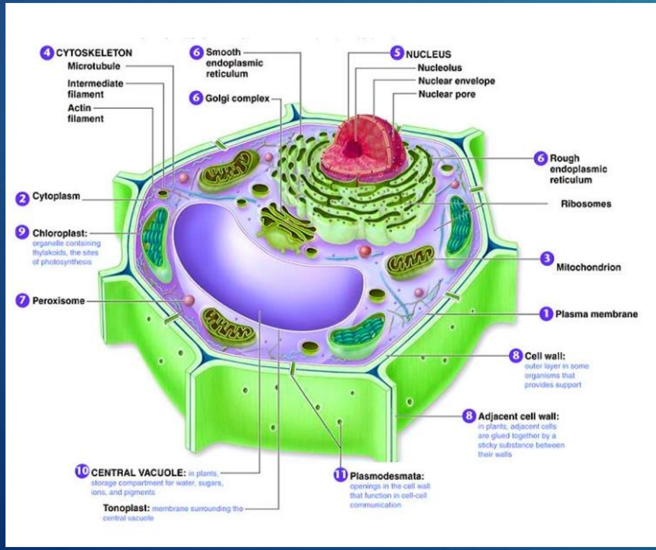
- Water use is lower early in the season (budbreak until around a month after)
  - As leaf area increases, so does vine water use, until leaves begin to senesce and fall from vines
- Water deficits affect vegetative growth to a greater degree than reproductive growth
  - Moderate deficits decrease shoot and trunk growth, as well as leaf area per vine
  - Deficits during berry development stage 1 will decrease cell division and elongation and, to a lesser degree, can affect solute concentration (mainly sugar) throughout berry development

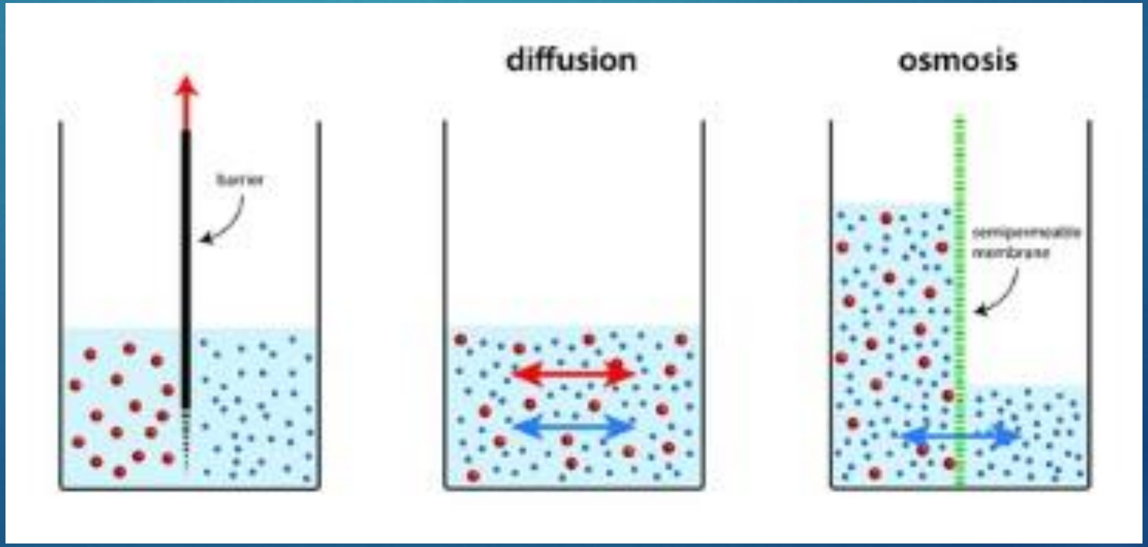


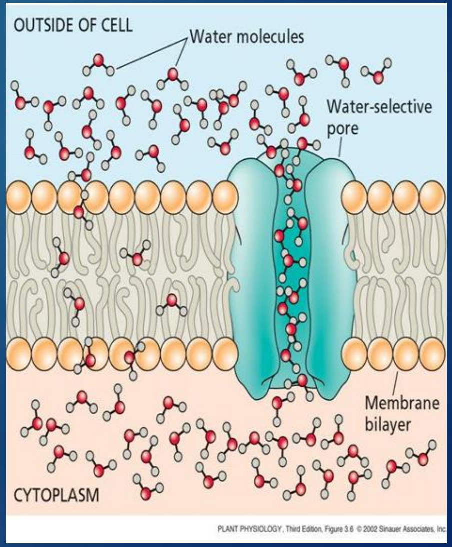
Credit: Henrique Noronha

Osmosis

- The movement of water from high water potential areas to low water potential areas across a semi-permeable membrane
- Some diffusion of water occurs through aquaporins, but ions and protons can't permeate these membrane channels due to their size and electric charge (hence, semi-permeable)
  - Cells use protons, Calcium, and the removal of phosphate groups from aquaporins to close them







Osmosis

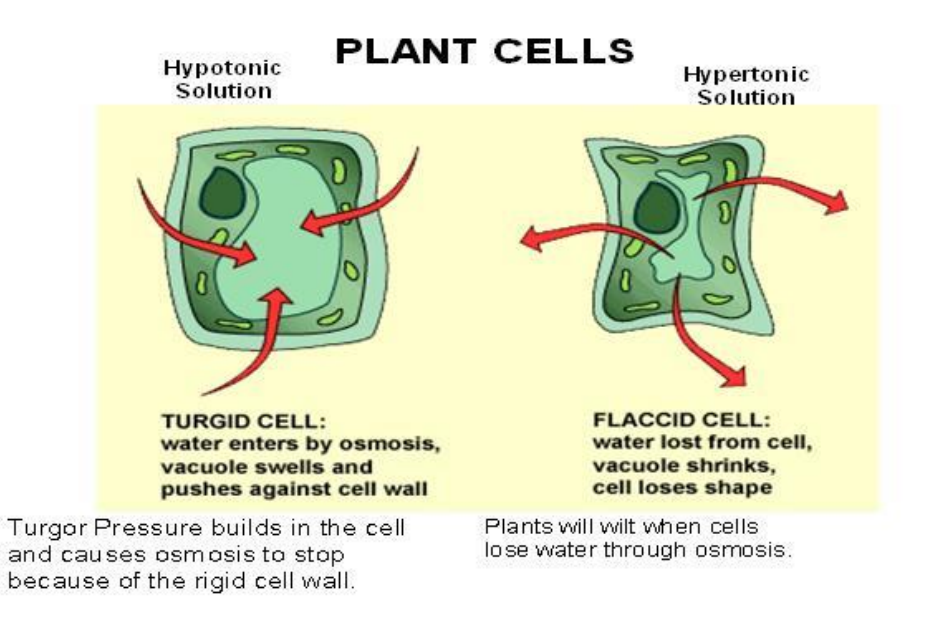
- Concentration of solutes like small organic molecules and dissolved ions is higher inside the cell than outside
- Sugars like sucrose, organic acids like malate, and inorganic ions like Potassium (K^+) and Chloride (CL^-) are the major osmotic solutes in plant cells
  - As they're repelled from pore openings in the membrane, they pull water with them, allowing water molecules to passively move through aquaporins (osmosis)
    - This pull on water molecules surrounding the cell created by solutes is called osmotic potential
  - The greater the concentration of solutes, the greater the pull, meaning more water will move into the cell to restore equilibrium.
- This movement creates a tension that drives an upward movement of water from the roots through the xylem

Osmosis

- As solutes attract water into a cell, it swells, and the membrane pushes against the cell wall
  - The cell wall is rigid, so it pushes back, raising the energy of the water

  inside the cell to that of water in the intercellular space

  - At this point ,the pressure (called turgor pressure) inside a cell is equal to that outside



Water Potential

- Solute and pressure forces are described as free energy per unit volume (force per unit area) generated by the movement of molecules
- Water potential indicates the availability (free energy) of water per unit area in any aqueous system (J m^{-3} or the pressure equivalent)
  - Can be applied not only to cell solutions, but also to soil, air, or any medium with variable water content
- Water potential= sum of component potentials arising from turgor pressure and solutes + interactions with solids (cell walls) and macromolecules + effects of gravity
- So: water potential is the measure of concentration of free water molecules (those which can freely pass through the cell membrane)
  - Pure water has a water potential of zero. With an increase in solutes, water potential becomes more negative

Water Potential

- The tension (negative pressure) with which leaves hold water is measured in milliPascals (mPa)
  - A wilted leaf will hold its remaining moisture with more tension than a fully hydrated leaf
- Leaf water potential changes over the course of a day
  - More negative as leaves lose moisture
  - (Generally) most negative during the hottest part of the day, then becomes less negative as vines recover their hydrated status in the evening and at night when temperatures are cooler
  - When leaf water potential reaches approx. -1200kPa, most of the stomata will be closed, retaining the remaining water inside
- Linearly related to soil water content- as the soil dries out, leaf water potential decreases

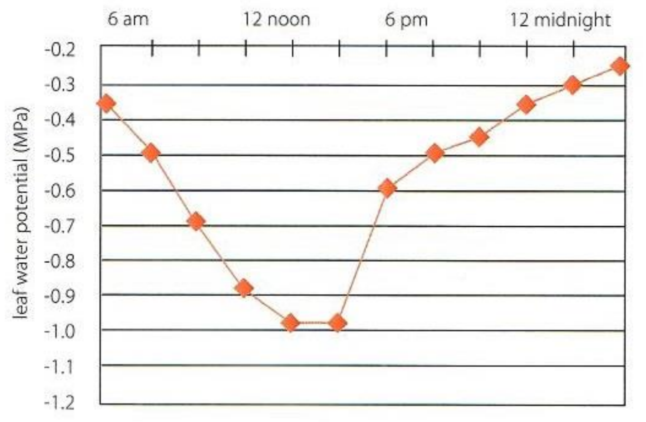


Figure 9.3 ▪ Changes in leaf water potential throughout the course of a day.
Degree of leaf stress is indicated by increasingly negative values.

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Water Potential

- Remember: In the absence of other forces, the movement of water during osmosis always moves from a region with lower solute concentration to that with higher
  - (greater water potential to lower water potential)
- Plants lower their water potential using osmotic solutes like sucrose and potassium to draw water into the cell
  - So, both adequate water supply and soluble molecules and ions are crucial for cell growth

Cell Expansion (Growth)

- Primarily driven by the uptake of water into the cytoplasm and vacuole of the plant cell
- The rapid expansion caused by the influx of water presses against the cell wall (turgor pressure)
  - turgor pressure causes rigidity of cells, so the plant can increase in size by adding new wall materials or "stacking cells"
  - At ~0.3-1 mPa (milliPascals) the pressure extends the wall outward to an irreversible point

Acid Growth Theory

- Water provides the pressure, but the rest is up to cell walls and their components, as well as several plant hormones
- As more water enters a cell, proton pumps move hydrogen ions to the cell wall
  - The high concentration of hydrogen lowers pH, which activates enzymes call expansins
- Expansins temporarily disrupt chemical associations and cross linking materials in the cell wall
  - This process makes the wall flexible enough to allow expansion and addition of new wall materials
- BUT: Water influx is what initiates this process

Cell Expansion

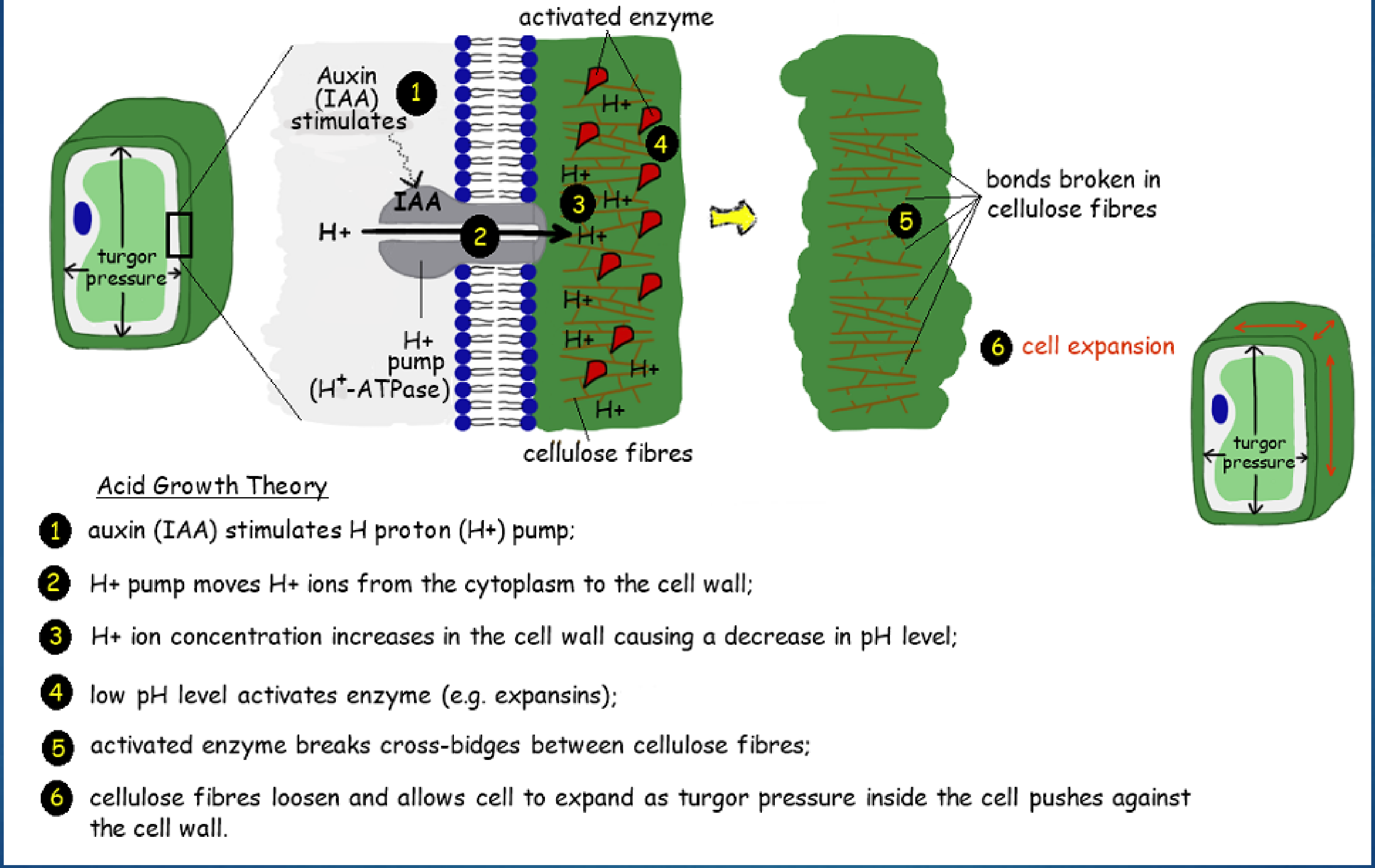
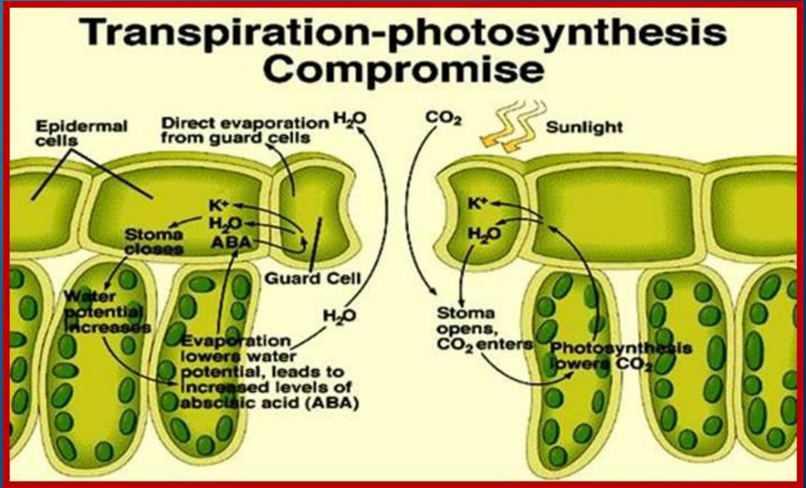


Image Credit:
Plant Biology,
Ibbiologyhelp.com

Transpiration

- The process of water evaporation from plant surfaces through stomatal pores
  - Cools the plant tissues and causes a tension that drives the uptake of water through the xylem
- Depends on the availability of energy to vaporize water and the resistances to liquid and vapor movement in the soil-plant-atmosphere system
- As water is discharged into the atmosphere, it meets several sources of resistance that slows the movement of water– mainly at the stomatal pore and the boundary layer (film of relatively still, moist air at the leaf surface)
  - Stomatal resistance is usually greater than resistance of the boundary layer, limiting transpiration, so that photosynthesis can occur

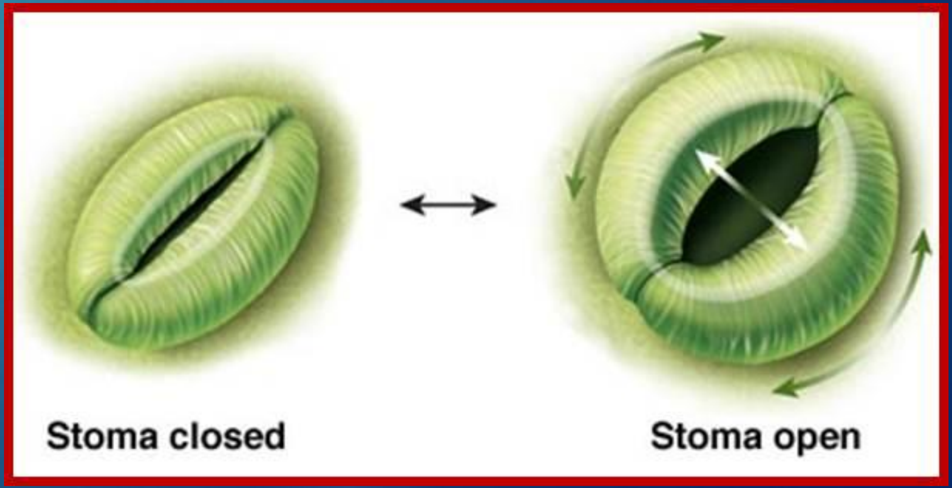


Transpiration

- Transpiration is driven by environmental factors that promote plant water loss, especially high temperature, wind, incident radiation, and low humidity
- Difference between the amount of moisture (water vapor pressure) in saturated air and the actual amount of moisture in the air at a given temperature is called the vapor pressure deficit (VPD)
  - As RH decreases, VPD increases (highly temperature dependent)
  - As the concentration gradient becomes steeper, water evaporation from leaves is stimulated
- Reduced transpiration comes at a cost: if stomata are closed to limit water loss, CO_2 uptake is lessened, thus photosynthesis is reduced.
  - Reduced photosynthesis can lead to numerous issues, including but not limited to, fruit failing to increase in soluble solids

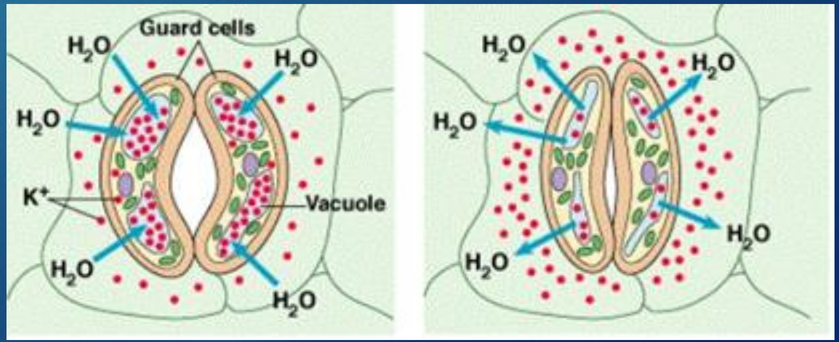
Stomatal Action

- Stomata are pores on the leaf surface through which water and oxygen are released and CO_2 is taken into the plant
  - Open when guard cells take up water and swell
- Act on a diurnal cycle
  - Typically: Open during the day and closed at night
- BUT, it's a bit more complex than that
  - High or low concentration of water in vines can cause stomata to open or close, respectively
    - When leaf water potential reaches approximately -1.2mPA, stomata close to conserve remaining water, regardless of light intensity
  - High or low concentrations of CO_2 can do the same
  - Windy conditions can cause stomata to close



Stomatal Action

- Potassium plays a large role on stomatal opening and closing
  - Guard cells take up potassium by active transport (requires energy), which causes water to follow by osmosis, opening stomata
  - Similarly, as potassium is pumped out of guard cells through ion channels, water follows, shrinking the cells and closing stomata
- Rootstock selection can play a role in stomatal action
  - Acts on both chemical and hydraulic root-to-shoot signals, which distally influence guard cells
  - Drought resistant (*berlandieri* x *rupestris*) and drought sensitive (*berlandieri* x *riparia*) rootstocks can shift the threshold of stomatal closure toward lower and upper leaf water potential



Stomatal Action

- Soil texture can influence stomatal aperture
  - Water-retaining soils (clay-rich) have been shown to enhance stomatal closure
- Increases in leaf nitrogen content leads to a wider stomatal aperture, since it stimulates photosynthesis
  - Levels off at high nitrogen content
- A decrease in RH from 85% - 45% can decrease transpiration rate by ≥80% via partial stomatal closure
- A rise in temperature will initially cause stomata to open because it stimulates photosynthesis, but very high temperatures lead to stomatal closure because respiration is stimulated

Take home message

- Water is a crucial part of vine growth, photosynthesis, temperature regulation, and many, many other processes
- Water movement through grapevines occurs through a complex series of highly regulated actions from osmosis to transpiration
- Plants are well evolved to regulate themselves regarding water status, until stressed by environmental factors such as high temperatures and drought