Why is Water Potential Important to Plants?

The movement of molecules, specifically water and any solutes, is vital to understand in light of plant processes. This will be more or less a quick review of several guiding principles of water motion in reference to plants.

Molecular Movement

1. **Diffusion**—Diffusion is the net movement of molecules or ions from an area of higher concentration to an area of lower concentration. Think of it as a rebalancing. The molecules or ions are said to be moving along a diffusion gradient. Diffusion will continue until a state of equilibrium is reached.
2. **Osmosis**—Osmosis in plant cells is basically the diffusion of molecules through a semipermeable, or differentially permeable, membrane from a region of higher solute concentration to a region of lower solute concentration. The application of pressure can prevent osmosis from occurring. Plant physiologists like to describe osmosis more precisely in terms of potentials. ***Osmotic potential*** is the minimum pressure required to prevent fluid from moving as a result of osmosis. Fluid will enter the cell via osmosis until the osmotic potential is balanced by the cell wall resistance to expansion. Any water gained by osmosis may help keep a plant cell rigid or ***turgid***. The ***turgor pressure*** that develops against the cell walls as a result of water entering the cell's vacuole. This pressure is also referred to as the pressure potential. The crunch when you bite into a celery stick is as a result of the violation of the cell's turgor pressure. ***The osmotic potential and pressure potential combined make up the water potential of a plant cell.*** If there are two cells next to each other of different water potentials, water will move from the cell with the higher water potential to the cell with the lower water potential. Water enters plant cells from the environment via osmosis. Water moves because the overall water potential in the soil is higher than the water potential in the roots and plant parts. If the soil is desiccated then there will be no net movement into the plant cells and the plant will die.
3. **Plasmolysis**—the loss of water via osmosis and accompanying shrinkage of the protoplasm away from the cell wall. When this occurs, the cell is said to be ***plasmolyzed***. This process can be reversed if the cell is placed in fresh water and the cell is allowed to regain its turgor pressure. However, as with anything living, there is a point of no return and permanent or fatal damage to the cell can occur.

Water and its Movement Through the Plant

Roughly 90% of the water that enters a plant is lost via transpiration. Transpiration is the loss of water vapor through the leaves, just to refresh you. In addition, less than 5% of the water entering the plant is lost through the cuticle. Water is vital to plant life, not just for turgor pressure reasons, but much of the cellular activities occur in the presence of water molecules and the internal temperature of the plant is regulated by water. Recall that the xylem pathways go from the smallest part of the youngest roots all the way up the plant and out to the tip of the smallest and newest leaf. This internal plumbing system, paired with phloem and its nutrient transportation system, maintains the water needs and resources in the plant. The issue of the processes by which water is raised through columns—of considerable height at times—has been studied and debated for years in botany circles. The end result is the cohesion-tension theory.

The Cohesion-Tension Theory

Polar water molecules adhere to the walls of xylem tracheids and vessels and cohere to each other which allows an overall tension and form 'columns' of water in the plant. The columns of water move from root to shoot and the water content of the soil supplies the 'columns' with water that enters the roots via osmosis. The difference between the water potentials of the soil and the air around the stomata are capable of producing enough force to transport water through the plant—from bottom to top and thus goes the cycle.

The Pressure-Flow Hypothesis

This is essentially a ***source and sink hypothesis***. Food substances that are in solution flow from a source, which is generally where water is taken up by osmosis (roots; food storage tissues, such as root cortex or rhizomes; and food producing tissues such as mesophyll in leaves), and the food substances are then given up at a destination or a sink where the food resources will be utilized in growth. The idea is that the organic solutes are moved along concentration gradients existing between sources and sinks.

At the source, phloem-loading occurs and sugars are moved by active transport into the sieve tubes of the smallest veins. The overall water potential in the sieve tube drops and then water enters the phloem cells via osmosis. The resulting turgor pressure from the movement of the water is enough to drive the solution through the sieve network to the sink . The sugar is unloaded at the sink via active transport and water then exits the ends of the sieve tubes. The pressure drops as the water exits, which causes a mass flow from the higher pressure at the source to the now lowered pressure at the sink. Much of the water that exits the sieve tubes will diffuse back into the xylem where it can be recirculated, transpired once it reaches the source. In a nutshell the mass flow is caused by drops in turgor pressure at the sink as the sugar molecules are removed. This generates the next push of materials toward the sink.

Regulation of Transpiration

It is the responsibility of the stomata to regulate transpiration and gas exchange via the actions of the guard cells. The pores of the stomata are closed when turgor pressure in the guard cells is low, and they are open when turgor pressure is high. Changes occur when light intensity, carbon dioxide concentration or water concentration change. The guard cells of the stomata use energy to take up potassium ions from adjacent epidermal cells. The uptake opens the stomata because water potential in the stomata drops and water moves into the guard cells and increases turgor pressure.

Most plants keep their stomata open during the day and close them at night. However, there are plants that do the opposite and open their stomata during the night when overall water stress is lower. These plants have a specialized form of photosynthesis called CAM photosynthesis since the standard source of carbon dioxide is shut off as the stomata are closed during daylight hours. There are desert plants that are able to store carbon dioxide in their vacuoles in the form of organic acids that are converted back into carbon dioxide during the daytime for standard photosynthetic processes. As mentioned earlier, there are also adaptations such as sunken stomata which reduce the loss of water. Submerged or partially submerged plants generally do not have stomata on the underwater portions of their leaves.

High humidity will reduce transpiration rates while low humidity accelerates the process. There is a direct correlation between temperature and water movement out of the leaf. At high temperatures the rate of transpiration increases, while the opposite occurs at lower temperatures.

Water potential is the potential energy of water per unit volume relative to pure water in reference conditions. Water potential quantifies the tendency of water to move from one area to another due to osmosis, gravity, or mechanical pressure. Water potential has proved especially useful in understanding water movement within plants, animals, and soil. Water potential is typically expressed in potential energy per unit volume and very often is represented by the Greek letter (Ψ). Water potential integrates a variety of different potential drivers of water movement, which may operate in the same or different directions. Within complex biological systems, it is common for many potential factors to be important. For example, the addition of solutes to water lowers the water's potential (makes it more negative), just as the increase in pressure increases its potential (makes it more positive). **If possible, water will move from an area of higher water potential to an area that has a lower water potential.** One very common example is water that contains a dissolved salt, like sea water or the solution within living cells. These solutions typically have negative water potentials, relative to the pure water reference. If there is no restriction on flow, water molecules will proceed from the location of pure water to the more negative water potential of the solution.

Components of Water Potential

Many different factors may affect the total water potential, and the sum of these potentials determines the overall water potential and the direction of water flow:

$$\Psi = \Psi_p + \Psi_s$$

where:

- Ψ is the water potential
- Ψ_s is the solute potential,
- Ψ_p is the pressure component,

Pressure Potential

Pressure potential is based on mechanical pressure, and is an important component of the total water potential within plant cells. Pressure potential is increased as water enters a cell. As water passes through the cell wall and cell membrane, it increases the total amount of water present inside the cell, which exerts an outward pressure that is retained by the structural rigidity of the cell wall. By creating this pressure, the plant can maintain turgor, which allows the plant to keep its rigidity. Without turgor, plants lose structure and wilt.

The pressure potential in a living plant cell is usually positive. In plasmolysed cells, pressure potential is almost zero. Negative pressure potentials occur when water is pulled through an open system such as a plant xylem vessel. Withstanding negative pressure potentials (frequently called *tension*) is an important adaptation of xylem vessels.

Solute Potential

Pure water is usually defined as having a solute potential (Ψ_π) of zero, and in this case, solute potential can never be positive. The relationship of solute concentration (in molarity) to solute potential is given by the equation:

$$\Psi_s = -iCRT$$

where

i = ionization constant (for sucrose, this value is 1)

C = molar concentration of sucrose per liter at equilibrium (must be determined exerimentally)

R = pressure constant (.0831 liter bar/mole K)

T = temperature of solution in kelvins (K = °Celsius + 273)

Example: If C is experimentally determined to be .300 and T is 293 K, then

$\Psi_s =$ -(1) (.300mole/liter) (.0831 liter bar/mol K) (293 K)

$\Psi_s =$ -7.304 bars

So...why is water potential important to plants?

- As related to water movement through plants:
  - Ensures water moves into plant root
  - Helps movement of water within plant
  - Is a factor involved in transpiration

- Cell wall allows for increased pressure (turgor pressure)
- Pressure might counteract osmolarity