Lecturer: Olalekan Sakariyawo PhD

Course: PCP 301

Department: PP& CP

Water Requirements in Plant

Learning Expectations:

1. Functions of water in crop plant
2. Physical and chemical properties of water
3. Thermodynamic description of water
4. Driving forces of water in SPAC
5. Soil-Plant-Atmosphere Continuum (SPAC)
6. Water deficit, water use strategy and crop yield

Functions of water in Crops:

1. Cell Enlargement: The growth process in plant is directly related to the uptake and transportation of water into the cell. Presence of water deficit would greatly compromise growth process
2. Structural support
3. Evaporative cooling
4. Substrate for biochemical process in crops
5. Transport of solutes in the crop plant

Physical and chemical properties of water

1. Bipolarity: The angular arrangement of oxygen and hydrogen in water molecule leads to the emergence of bipolarity. The covalent bond resulting from this bipolarity results in hydrogen bond when two water molecules are found together in a medium. All the properties the physical and chemical properties of water are as a result of this hydrogen bond between water molecules.
2. Liquid at physiological temperature: Because of the strength of this hydrogen bond, water remains a liquid at physiological temperature, despite this comparative smaller molecular weight with respect to other molecules.
3. Incompressibility: As a liquid, water is incompressible, observing all the laws of hydraulics.
4. High Latent heat of Evaporation: The amount of heat needed to transform 1 gram of water into vapour is high, owing to the strong hydrogen bond greater than Van der Waals force. This particular property is very important most especially during transpiration of water vapour leading to evaporative cooling.
5. Cohesion and adhesion: Attraction of similar molecules leads to cohesion. This property was presumed to explain the upward movement of water in the xylem. Adhesion is the attraction of dissimilar molecules between water and other polymers. This wetness property has important property has important implications in water relations.

Thermodynamic description of water

To better describe water quantitatively, it was observed that thermodynamic concepts could be used. In this case the property of water was described with respect to its potential energy, which is its capability to do work. Pure water was conventionally adopted as the standard water potential, above which it is impossible to obtain higher magnitude of value. The value for pure water is zero. The unit for expressing water potential is Mega Pascal.
The components of water potentials are as follows:

1. Solute potential
2. Turgor pressure potential
3. Matric potential
4. Gravitational potential

Solute water potential is determined by the concentration of the solute present. It decreases with increase in solute concentration, thus its negative value. Turgor pressure potential value could be positive or negative. In a flaccid cell, where there is a net outward movement of water molecule, the value for turgor pressure potential is negative, creating tension; conversely with net inward movement of water into the cell, leading to turgid cell, the value becomes positive or positive hydrostatic pressure. The balance between negative value of solute potential and positive value of Turgor Pressure potential creates a balance, leading to negative water potential, since it is a rarity to have pure water in a cell. Matric Potential is as a result of the adhesion property of water, it is most prominent during the movement of water in the soil. Gravitational potential increases when water is raised above a height above a reference point. Water flows down gravitational potential gradient, all things been equal. At the microscopic level of the plant vascular tissue one may omit the role of gravitational and matric potential components of water potential, though their relevance increases with the increase in organizational level of the plant.

1 Atmosphere = 760mmHg @ Sea level, 45^0 latitude
= 1.013 bar
= 0.1013MPa
= 1.013×10^5 Pa

Water potential components:

$\Phi w = \varphi s + \varphi t + \varphi m + \varphi g$

Where:
Φw – Water potential
Φs – Solute potential
Φt – Turgor potential
Φm – Matrix potential

Φg – Gravitational potential

Tab.1 Driving forces of water in SPAC

Process	Driving forces
Diffusion	Concentration gradient **Fick's Law** $Js = -\Delta s \Delta c/\Delta x$ Where; Js – Rate of solute diffusion Δs – Diffusion coefficient, measures ease of substance movement via a medium Δc/Δx – Concentration gradient Δc – Difference in concentration Δx – Difference in distance
Bulk Flow	Pressure gradient Volume = $\pi r^4 \Delta P/\Delta x/8$□ Where: Volume - Flow rate r – Radius π – Viscosity of liquid ΔP – Difference in pressure Δx – Difference in distance ΔP/Δx – Pressure gradient
Osmosis	Composite forces (Concentration and pressure gradient)

Tab.2 Transport of water in plant (Soil-Plant-Atmosphere Continuum)

Medium/Interface	Process	Driving force	Pathway
Soil	Water movement in the soil/Bulk Flow	Pressure gradient	Soil Particles
Soil-Plant Interface	Water uptake	Composite force $\varphi_w = \varphi_s + \varphi_p$	o Apoplast o Symplast o Trans-membrane
Plant	Long distance transport (Cohesion-tension)	Pressure gradient	Xylem
Plant-Atmosphere	Transpirational pull of water	Gradient of water vapour concentration (Diffusion)	o Stomata o Cuticle o Lenticle

Models of water uptake in plants

Cohesion-tension Model

This model proposes that transpiration of water from the plant leads to the emergence of cohesion among similar water molecules, leading to the build up of negative hydrostatic pressure or tension. The emergence of tension increase tensile strength, which is the ability of water molecule to resist pulling force and by capillary action, water is being pulled up along the xylem. Where gas bubble are trapped in the water column, with an indefinite expansion of this bubble, a collapse of tension in the liquid phase is been observed, thus leading to cavitations. This phenomenon breaks the water column, resulting in reduced water uptake by plant.

Check this URL for animated version of this model:
http://academic.kellogg.edu/herbrandsonc/bio111/animations/0031.swf

Other resources:

http://www.mm.helsinki.fi/mmeko/kurssit/ME325/kuljetusprosessitkertaus.pdf
http://www.uoguelph.ca/plant/courses/pbio-3110/
www.mm.helsinki.fi/mmeko/kurssit/.../kuljetusprosessitkertaus.pdf

Root Pressure Model
An alternative model for the uptake and transportation of water in the plant is the root pressure model. The mechanism is as follows; absorption of solute leads to a reduction of solute potential in the plant cell, by concentration gradient water is being transported along the xylem tissue creating increase in positive hydrostatic pressure or root pressure, thus facilitating water uptake. Excessive uptake of water could lead to guttation, a phenomenon whereby liquid droplets are formed at the edges of the leaf most especially in the morning.

Water deficit, water use strategy and crop yield

Disequilibrium experienced between water supply and demand creates water deficit in plants. Alternatively, the concept could be envisaged as a situation when water content in the cell/ tissue is less than highest water content exhibited at hydrated state. In fields, drought conditions leads to water deficit accompanied with high temperature. This is a climatic condition.

The response of plant to water stress, which is when water is limiting, is varied and physiological responses are observed at different levels of organisation of the crop. Strategically, plant could avoid or tolerate water deficit. In avoidance, the plant could synchronise his phenology with the growing season in other to optimise the available resources for proper growth and development. With tolerance there must be specific mechanism to ensure availability of water and water use efficiency. Tolerance or resistant strategy involves:

1. Desiccation tolerance at high water potential
    a. Water saver, use water conservatively; example succulent
    b. Water spender, aggressive consumption of water; example Ephemerals
2. Desiccation tolerance at low water potential, possess the ability to function while dehydrated; xeromorphic plants/ non-succulent. There are two strategy for desiccation tolerance at reduced water deficit:
    a. Acclimation, which is transient and phenotypic in nature
    b. Adaptation, which is constitutive and genotypic in nature

Dimension of acclimation are as follows:

I. Osmoregulation – the process of accumulation of solutes in cells independent of cellular volume change. The implication is reduced water potential, osmotic potential and through water uptake increased cellular turgor. The solutes accumulated could be:
    a. Compatible –
        i. Nitrogen containing, e.g. Proline, glycine betaine
        ii. Non-Nitrogen containing, e.g. sugar alcohol (Sorbitol, mannitol)
    b. Non-compatible, e.g. Inorganic ions
II. Reduced growth

III. Phenological variability or phenotypic plasticity (Determinate and indeterminate growth)
IV. Energy dissipation through
    a. Reduced growth of leaf
    b. Changes in leaf orientation (Para and diaheliotropism)
    c. Leaf modification
        i. Wilting
        ii. Rolling
        iii. Pubescence

Dimensions of adaptation:

1. Crassulacean Acid Metabolism (CAM)
2. Metabolic changes via gene expression; synthesis of new protein types such as aquaporin, Ubiquitin, Late Embryonic Abundant protein.

From the cellular level, emergence of water deficit results in the decrease in the cellular water content, leading to shrinkage of cell and the relaxation of cell wall. Decrease in volume leads to increase in solute concentration, favouring reduced turgor pressure. Experimental results indicated that there is a synthesis of endogenous growth inhibitors (ABA and C_2H_2), changes in pH value and inorganic ion distribution. The consequence of these changes is the reduction in the expansion of leaf or leaf growth as expressed in the number of leafs or other growth parameters of the shoot. In the case of severe water deficit, reduction in total leaf area, increase senescence and leaf abscission accompany water deficit. If water deficit is mild the plant experiences reduction in transpiration rate via stomata closure increased heat dissipation and increasing resistance to liquid phase water flow.

At the crop level, reduced crop growth through stomatal regulation, as a result of water stress is reflected in reduced Leaf Area Index, thus compromising the radiant energy absorption capacity and its utilization efficiency (Radiant Energy Utilisation Efficiency). What is eventually experienced is reduced internal concentration of Carbon Dioxide and reduced Transpiration rate through the stomata. With reduced internal concentration of $C0_2$, carbon assimilation is equally affected reflecting in reduced Harvest Index and ultimately yield.