Plant Water Relations: Absorption, Transport and Control Mechanisms

Absorption and water flow through plants

Independent of the species, plants **require** from the soil a **water** volume that overcomes its **metabolic necessities**. Through the **transpiration process** plants **transmit** to the **atmosphere** the **majority** of the water absorbed from soil (generally around **90%**). From this perspective, it is noted that the plant water requirements are defined primarily by the atmosphere **evapo-transpirative** demand, which is a passive process. Figuratively we can compare a plant water flow with the principles of **oil flow** in the **wick** of an old **fashion lampion.**

Water potential

The **water content** in the **soil, plants and atmosphere** is usually described as water potential (Ψ). This is based on the **relation** between the **water content** in the part of a system and **pure water** at the same temperature and atmospheric pressure, measured in pressure units (**mega pascal-MPa** or **bars**-Bar). By definition, the potential of free pure water at atmospheric pressure and at a temperature of **25°C** corresponds to **0** (**zero**) MPa. The contrast in the **water potential** between **two points** invariably determines the **direction** of **water transport** in a system.

The most widely used description of the water status of plants has been introduced by **Slatyer and Taylor**. The **water status** in plants is measured by **water potential**, Ψ, a measure of free energy available to do work, as in "move water". The simplified form is:

$$\Psi = \Psi s + \Psi p$$

in words, the above equation means the two components of water potential are:

1. Solute potential (**Ψ s**): Solute potential reflects **how much stuff** (particle) is in the water. Any water with stuff dissolved in it has a **negative** solute potential (Ψs), since solutes bind with water molecules and lessen their ability to move and do work.

2. Pressure potential (**Ψ p**): Pressure potential is the **amount of force** being exerted on a solution. In living cells, this pressure comes from the contents of the cell pushing against the cell wall. The cell wall pushes back, causing turgor pressure. Turgor pressure causes plant parts to be firm and erect.

Concerning the component of the water potential can be **positive** or **negative**. For example, if we observe a **turgid cell** of a **root cortex** or a **leaf mesophyll**, the hydrostatic pressure is **positive**. However, in a **xylem vessel** subjected to a **stressful condition** in a **transpiring plant** this component of pressure is **negative**.

Finally, we should emphasize that the gravitational potential (**Ψg**) - ignored in most cases - is very important in studies of the **water potential** of **tree species**, where plant **height exerts** a great influence on **water flow**. Considering that this gravitational component fluctuates at a rate of **0.1 MPa** for every **10 meters** of vertical displacement, it is suggested to consider if when plant height is **10 m** or **more**.

$$\Psi = \Psi s + \Psi p + \Psi g$$

Water dynamics in soil-plant-atmosphere system

Soil water

The **water potential** in **soil** affects water **reservoir** and its availability for plants; hence it has a large impact on plant growth and production. Furthermore, the **soil water** content exerts a **great influence** on some **physical** and **chemical properties** of **soil**, such as the **oxygen content**, which interferes with:

1. **Root breathing**,
2. **Microbial activity**
3. **Soil chemical status**.

Water potential is directly **dependent** on **soil physical characteristics**, and varies with time and space, depending on **soil water balance**. That balance is determined by **input** (rain, irrigation) and **output** of the soil (drainage, evaporation and root absorption). It is noteworthy that the amount of rain affecting **soil water reservoir** is only the effective **precipitation**. This is the amount of precipitation that is actually added and stored in the soil.

For example, during drier periods **less than 5 mm** of daily rainfall would not be considered effective, as this amount of precipitation would likely evaporate from the surface before soaking into the ground.

With regard to the physiological aspect, it is important to point out that the water content in soil is associated with three terms: **field capacity**, the **permanent wilting point** and the **available water content**.

Field capacity (FC)

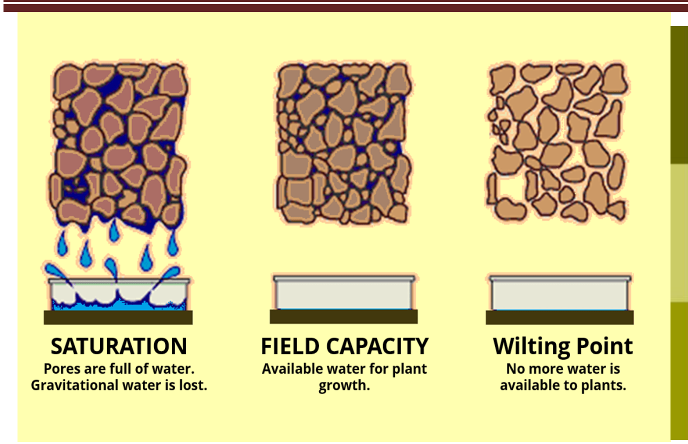
It is the **maximum** water content that a given soil can **retain** by **capillarity**, **after saturation** and gravity drainage.

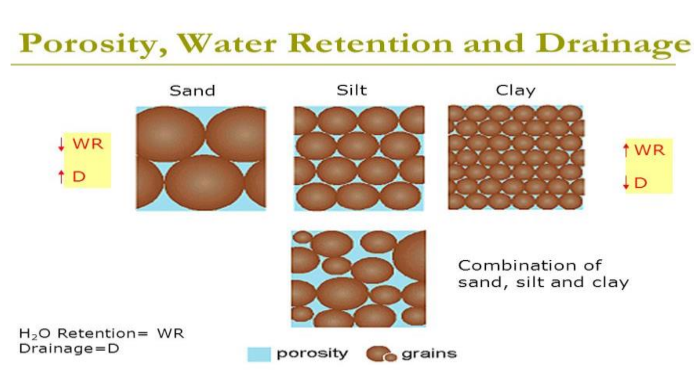
In general, **clay** soils or those with **higher content of organic matter** (upper to **5%** of organic matter) present a higher soil water holding capacity (average field capacity ranging from **35 to 40 % soil volume**). In contrast, a sandy soil has a **lower** water holding capacity and field capacity typically ranges from **10- 15% soil volume**.

Wilting point (WP)

This term is also known as the **permanent wilting point,** and can be defined as the **amount of water per unit weight** (**or volume**) of soil that is so **tightly retained** by the soil matrix that roots are **unable to absorb** causing the wilting of plant. In others words, it corresponds to the water potential of soil under which plants **cannot maintain turgor** pressure, even if a series of defense mechanisms have been triggered:

1. Increased Abscicic acid (ABA) hormone synthesis
2. Stomatal closure
3. Osmotic adjustment
4. Leaf fall





Available water content

The water content of the soil **between** field capacity and the permanent wilting percentage is considered available water, or water that is available for uptake by plants. The range of available water is relatively high in **sandy** soil as compared to silty soils, somewhat less in clay, and relatively low in sand. In a drying soil, plants will begin to show signs of water stress and reduced growth long before the soil water potential reaches the permanent wilting percentage.

Water absorption by the roots

The water flow of a plant is primarily controlled by the **transpiration rate**. In this flow system it is essential indeed that there are no limitations on water absorption by the root system. As the roots absorb water, there is a reduction in the water potential in the soil that is in contact with the roots (**rhizosphere**). This process establishes a water potential gradient between the rhizosphere and a neighboring region of the soil which presents a higher water potential and which coordinates the water movement towards the roots of a transpiring plant. This water movement in the soil occurs mainly through **mass flow** due to the fact that the water filled **micro pores** of the **soil** are interconnected. Therefore, water flows from **soil to root** at a rate depending on the **water potential gradient** between soil and plant which is affected by:

1. Plant water need
2. Hydraulic conductivity of the soil
3. Soil type and soil water content.

Sandy soils have **higher conductivity** due to **greater porosity**, but they also **retain less water** in relation to clay soils or soils rich in organic matter.

The water absorption by the roots is related to its surface directly in contact with soil. Thus, longer and younger (less suberized) roots with **more root hairs** are essential for increasing the **contact surface** and **improve the water absorption** capacity of the soil.

In humid regions, as tropical rain forest, plants usually do not require very extensive root systems (i.e. root: shoot ratio < 0.15), because a small volume of soil can meet the demands of transpiration. This condition in turn induces a reduction of the root: shoot ratio. On the other hand, in dry regions, the plants **invest more in their roots**, increasing the root:

shoot ratio such that the roots can **represent upper** to **90%** of a plant biomass in some species of a desert climate.
With the **water reaching the roots,** the absorption process is directly dependent on the water **potential gradient** between the **rhizosphere and the root xylem**.

The water **intake in the roots** can follow **three ways** into the root tissue in relation to the **route of the epidermis to the endoderm** of the root, called radial water transport:

1. **Apoplastic,** where the water moves through the intercellular spaces and does not pass through any membranes, exclusively occupying the continuous network of the cell walls.

2. **Symplastic**, where the water moves exclusively from one cell to another through plasmodesmata connections.

3. **transmembrane**, which corresponds to a mixed path between the first two, where the water goes in one direction through the root tissue, entering (symplastic) and exiting (apoplastic) cells.

With regard to water absorption control in the roots, plants also have membrane water **transporter proteins** (water-channel proteins), called **aquaporins**. The number of these proteins available for the root surface is variable throughout the day, being **higher** during the **photoperiod** due to the **higher demands** of photo-transpiration.

Ascension of water through the plant: Vascular system

The presence of plants outside the water environment has been related to the evolution of the **vascular system**, which allows for the speedy upward movement of water to meet the demand of transpiration from the leaves. The need for a vascular system is more evident when we observe a tree during a hot day, which demands a **large flow of water** (for example, **200 to 400 liters day-1**) to fit a transpiring surface that is situated along elevated positions, and in some species is higher than **100 meters.**

The water flows from the roots to the shoot of the plant through the **xylem**. The general mechanism to explain this upward movement of water is the **cohesion-tension theory,** which was proposed in the late 19th century. Basically, this theory holds that the water evaporated in leaves establishes a tensile strength in the xylem, where the hydrogen bonds provide a continuous **intermolecular attraction** (**cohesion**) between the water molecules from the leaf to the root. Thus, the water column in the xylem lumen is driven out of a region with a **higher water potential**, i.e. from the root and the stem, to a region with a **lower water potential**, as the leaves, and finally toward to the air that can reach **very low water potential** (e.g. -100 MPa, at 50% of air relative humidity).

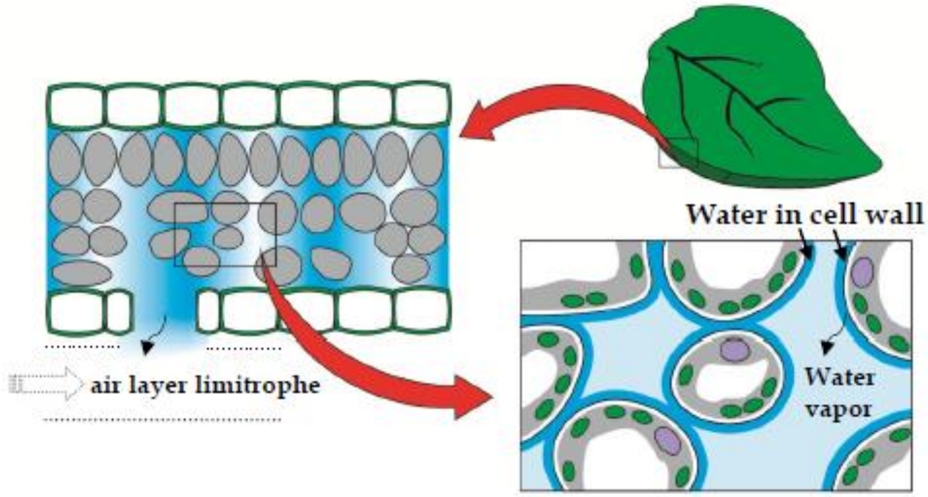
Leaf water and transpiration

In leaf mesophyll there is an extensive system of **intercellular spaces** - present in cell walls - which correspond to the internal surface of water **contact** with the **air**. By this interface between the cell walls and the intercellular spaces is established a **water potential gradient**. Due to the water evaporation in the surface of the cell walls which are in contact with the air in the intercellular spaces, it is established that the tensile strength is transmitted to the xylem that drives the upward flow of the water column from the root and is produced in the internal evaporation process in the leaves. The water vapor moves from leaf intercellular spaces to the atmosphere predominantly through stomatal diffusion. This process of the loss of water vapor by the leaves is called **transpiration** and corresponds to the majority (**90%**) of the volume of water absorbed by plants. Transpiration has a number of positive effects:

1. Helps with mineral transport
2. Leaf cooling
3. Induce water stress when soil is dry.

In the continuum soil-plant-atmosphere of water flow, there are two major factors determining the water potential of a plant:

1. The water potential of the soil, which characterizes the water supply
2. Transpiration, which defines the loss of water.



Throughout the water route between the leaf and the air there are two components that can exert resistance to the diffusion process:

1. **Stomatal resistance**, which is coordinated by the stomatal opening
2. **Resistance of the air boundary layer**, which is located closest to the leaf surface and it, is directly influenced by wind speed. The higher the speed of the wind, the greater is the frequency of air renewal in this layer surrounding the leaf.

Morphological and **anatomical** variations among leaves can **interfere** with the **speed** of displacement of this thin layer of air, restricting the rate of transpiration in dry environments. Among these modifications:

1. The presence of hair.
2. The stomata located at the lower surface of the leaf.
3. The shape and size of the leaves.