1 Water and nutrients in plant

1.1 Water balance of plant

Water plays a crucial role in the life of plant. It is the most abundant constituents of most organisms. Water typically accounts for more than 70 % by weight of non-woody plant parts. The constant flow of water through plants is a matter of considerable significance to their growth and survival. The uptake of water by cells generates a pressure known as turgor. Photosynthesis requires that plants draw carbon dioxide from the atmosphere, and at the same time exposes them to water loss. To prevent leaf desiccation, water must be absorbed by the roots, and transported through the plant body. Balancing the uptake, transport, and loss of water represents an important challenge for land plants.

Plants use water in huge amounts, but only **small part** of that remains in the plant to supply growth;

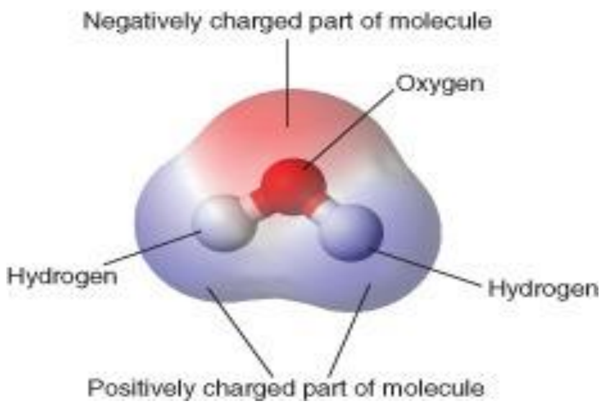
1. **97%** of water taken up by plants is lost to the atmosphere,
2. **2%** is used for volume increase or cell expansion,
3. **1%** for metabolic processes, predominantly photosynthesis.

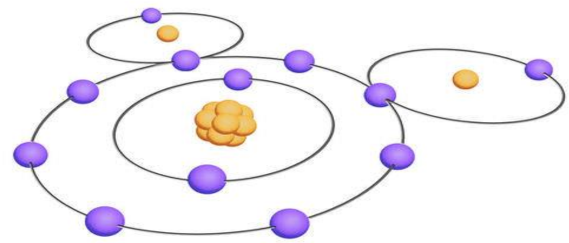
The uptake of CO2 is coupled to the loss of water. as **400 water** molecules are **lost** for **1 CO_2** molecule gained.

1.2 The structure and properties of water

1.2.1 Polar molecule

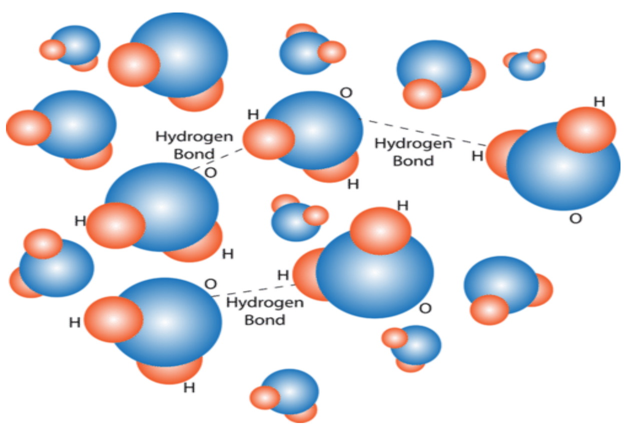
Each molecule of water consists of one atom of oxygen and two atoms of hydrogen, so it has the chemical formula H_2O. In each water molecule, the nucleus of the oxygen atom (with 8 positively charged protons) attracts electrons much more strongly than do the hydrogen nuclei (with only one positively charged proton). This results in a negative electrical charge near the oxygen atom (due to the "pull" of the negatively charged electrons toward the oxygen nucleus) and a positive electrical charge near the hydrogen atoms. A difference in electrical charge between different parts of a molecule is called **polarity**.
A **polar molecule** is a molecule in which part of the molecule is positively charged and part of the molecule is negatively charged.





Hydrogen Bonding

Opposite electrical charges attract one another. Therefore, the positive part of one water molecule is attracted to the negative parts of other water molecules. Because of this attraction, bonds form between hydrogen and oxygen atoms of adjacent water molecules. This type of bond always involves a hydrogen atom, so it is called a **hydrogen bond**. Hydrogen bonds are bonds between molecules, and they are not as strong as bonds within molecules. Nonetheless, they help hold water molecules together. Hydrogen bonds can also form within a single large organic molecule. For example, hydrogen bonds that form between different parts of a protein molecule bend the molecule into a distinctive shape, which is important for the protein's functions. Hydrogen bonds also hold together the two nucleotide chains of a DNA molecule.

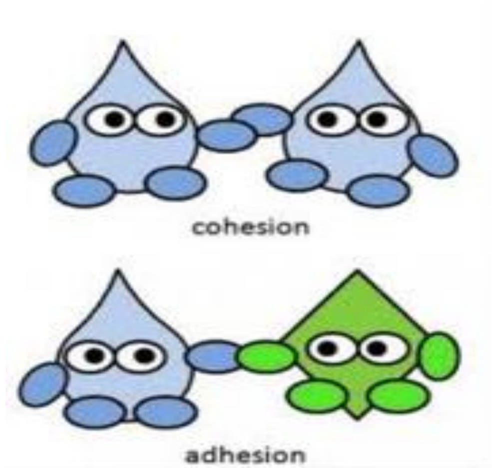


1.2.2 Cohesion and adhesion

Cohesion: water attracted to other water molecules because of polar properties.

Hydrogen bonds hold the substance together, a phenomenon called **cohesion**. Cohesion is responsible for the transport of the water column in plants Cohesion among water molecules plays a key role in the transport of water against gravity in plants. One **consequence of cohesion** is that water has exceptionally high **surface tension**,

Adhesion: water attracted to other materials. Adhesion, clinging of one substance to another, contributes too, as water adheres to the wall of the vessels.



Cohesion + **adhesion** + **surface tension** = **capillarity phenomenon** = water rises in capillary tubes = **water columns**

Capillary Action or capillarity is the **tendency of a liquid to move up against gravity** when confined within a narrow tube (capillary). Capillarity occurs due to three properties of water:

1. **Surface tension**, which occurs because hydrogen bonding between water molecules is stronger at the air-water interface than among molecules within the water.
2. **Adhesion**, which is molecular attraction between "unlike" molecules. In the case of xylem, adhesion occurs between water molecules and the molecules of the xylem cell walls.
3. **Cohesion**, which is molecular attraction between "like" molecules. In water, cohesion occurs due to hydrogen bonding between water molecules.

1.2.3 High specific heat

The specific heat is "the **amount of heat** per unit mass required to **raise the temperature** by **one degree Celsius**."

Water has a **high** heat capacity, because in order to raise the temperature of water, it takes much more energy to raise the temperature of water compared to other solvents because **hydrogen bonds** hold the water molecules together.

1.2.4 Universal solvent of life

Water is an excellent solvent. It dissolves greater amounts of a wider variety of substances than do other related solvents. The polarity of molecules can be measured by a quantity known as the **dielectric constant**.

Water has one of the **highest dielectric constant**, which is as high as **78.4**. The dielectric constant of **benzene** is **2.3** and **hexane** is **1.9**.

This versatility as a solvent is due in part to:

1. The **small size** of the water molecule.
2. Its **polar** nature: makes water a particularly good solvent for ionic substances and for molecules such as sugars and proteins that contain polar —OH or —NH2 groups.

1.3 Water movement

Translocation: is the movement of substances from one region to another. Mechanisms for translocation may be classified as either **active** or **passive**. It is sometimes difficult to distinguish between active and passive transport, but the translocation of **water** is clearly a **passive** process. Passive movement of most substances can be accounted for by bulk flow or diffusion.

1.3.1 Bulk flow:

Bulk flow accounts for some water movement in plants through the xylem tissues of plants. Movement of materials by bulk flow (or mass flow) is pressure driven. Bulk flow occurs when an external force, such as gravity or pressure, is applied. As a result, all of the molecules of the substance move in mass.

1.3.2 Diffusion:

Diffusion is driven principally by concentration differences. The molecules in a solution are not static, they are in continuous motion. Diffusion results in the net movement of molecules from regions of **high concentration** to regions of **low concentration**.

Fick's first law describes the **process of diffusion** stating that: *the rate at which one substance diffuses through another is directly proportional to the concentration gradient of the diffusing substance.*

Diffusion in solutions can be **effective** within **cellular dimensions** but is far **too slow** to be effective over **long distances**.

The average **time required** for a **glucose molecule** to diffuse across a cell with a diameter of **50 µm in water needs 2.5 second**.

Same glucose molecule to diffuse a distance of 1 m in water needs 32 years.

1.3.3 Osmosis:

The net movement of water **across a selectively permeable** barrier is referred to as osmosis. Membranes of plant cells are selectively permeable. The diffusion of water directly across the lipid bilayer is facilitated by aquaporin, which are integral membrane proteins that form water-selective channels across membrane.

1.4 The concept of 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:

- **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.

- **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**.

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

1.5 Absorption by roots

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.

1.5.1 Water present in soil is following type:

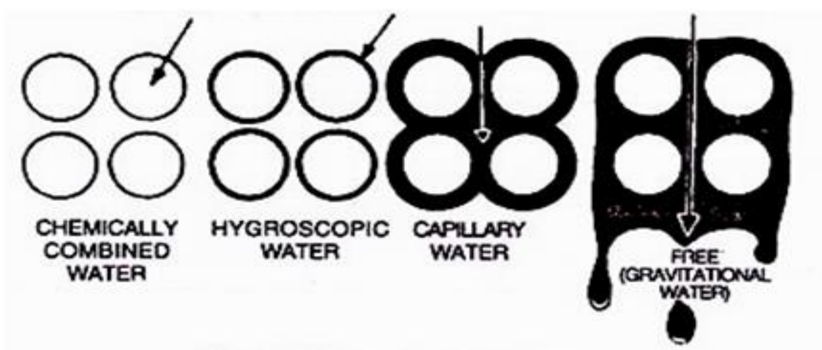
(a) Gravitational water: Form of water, which reaches at the soil water table due to the gravitational force after the rainfall. This form is not available to plants but available by mechanical methods or by tube well irrigation.

(b) Hygroscopic water: Thin film of water is tightly held by the soil particles is called hygroscopic water. This water is also not available to the plants.

(c) Chemically combined water: The amount of water present in the chemical compounds, which are present in the particles of soil. This is not available to the plants.

(d) Capillary water: Water exists between soil particles in small capillary pores is called Capillary water. It is the most common available form of water for absorption.

(e) Atmospheric humidity: This is water vapor present in air, which can be absorbed by hanging roots of the epiphytes due to presence of spongy velamen tissue and hygroscopic hairs.



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.

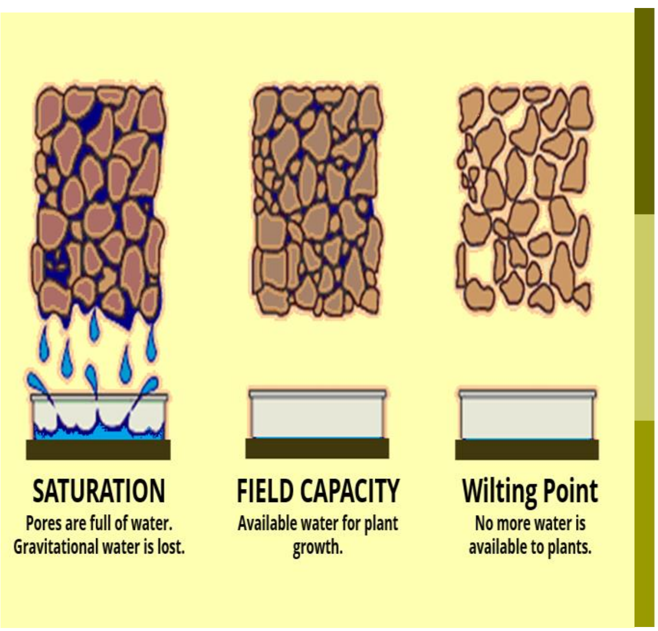
Field capacity (FC): It is the maximum water content that a given soil can retain by capillarity, after saturation and gravity drainage.

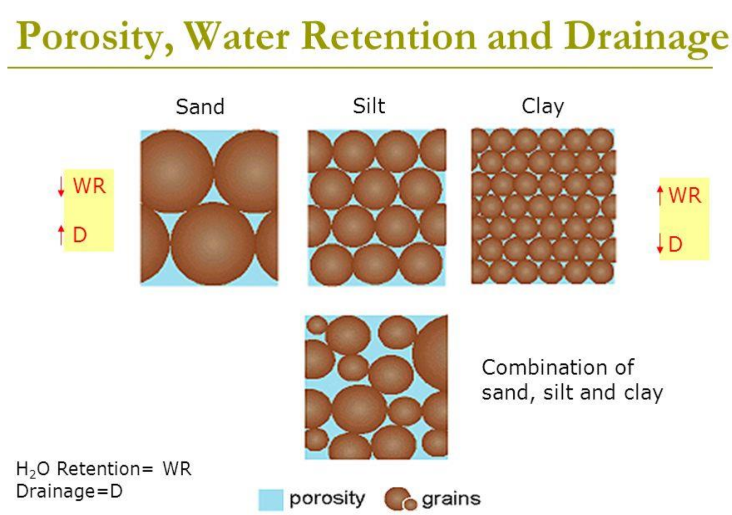
In general, clay soils or those with higher content of organic matter (upper to 5% of organic matter) represent a higher soil water holding capacity (average field capacity ranging from 35 to 40 % soil volume). In contrast, a sandy soil has a lower water holding capacity and field capacity typically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

Sand, with its larger particles and low nutritional content, **retains** the least amount of **water**, although it **is** easily replenished with **water**. Silt and **loam**, with medium-size particles, **retain** a moderate amount of **water**.

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 and stomatal closure
2. Osmotic adjustment
3. 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.