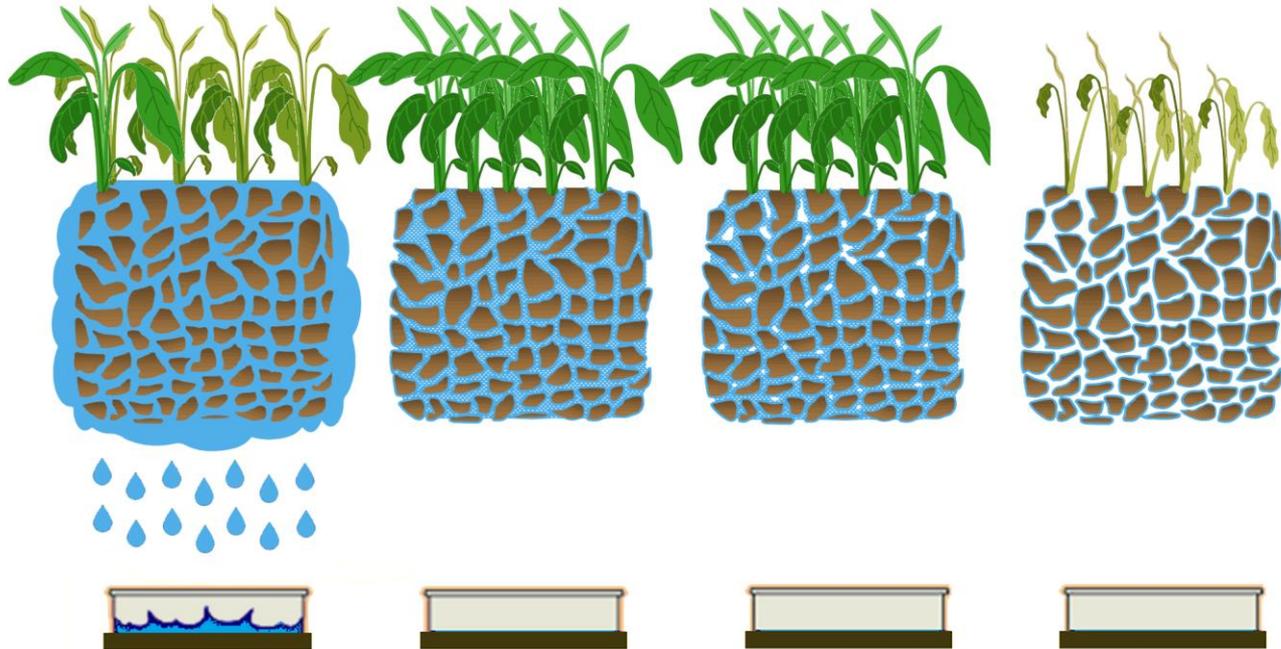


## ***B. Water in soil***

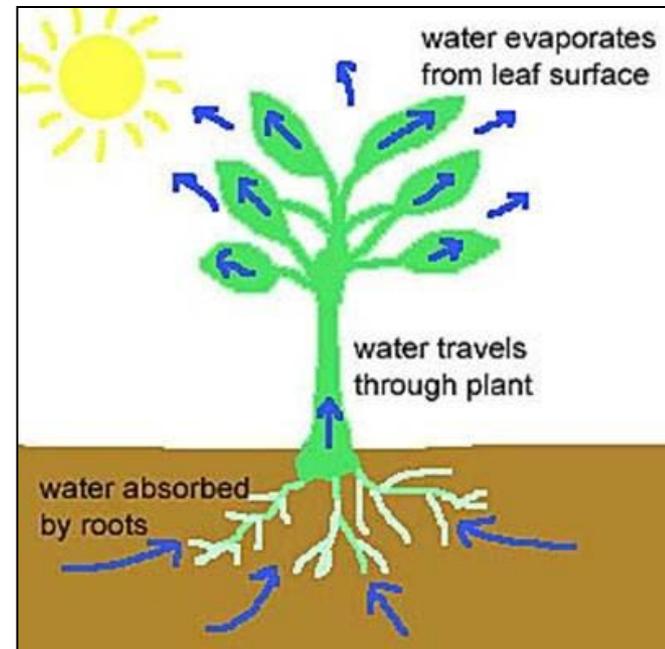


# Role of water in soil

Water is essential for all life on Earth. Too much water, or too little water, can be fatal.

Most plants (and animals) are largely composed of water, but even at close to 95% of plant mass, the water within a plant at any time represents a minor fraction of that which passes through the plant during growth, carrying nutrients and providing a moist surface for the transfer of gases in photosynthesis.

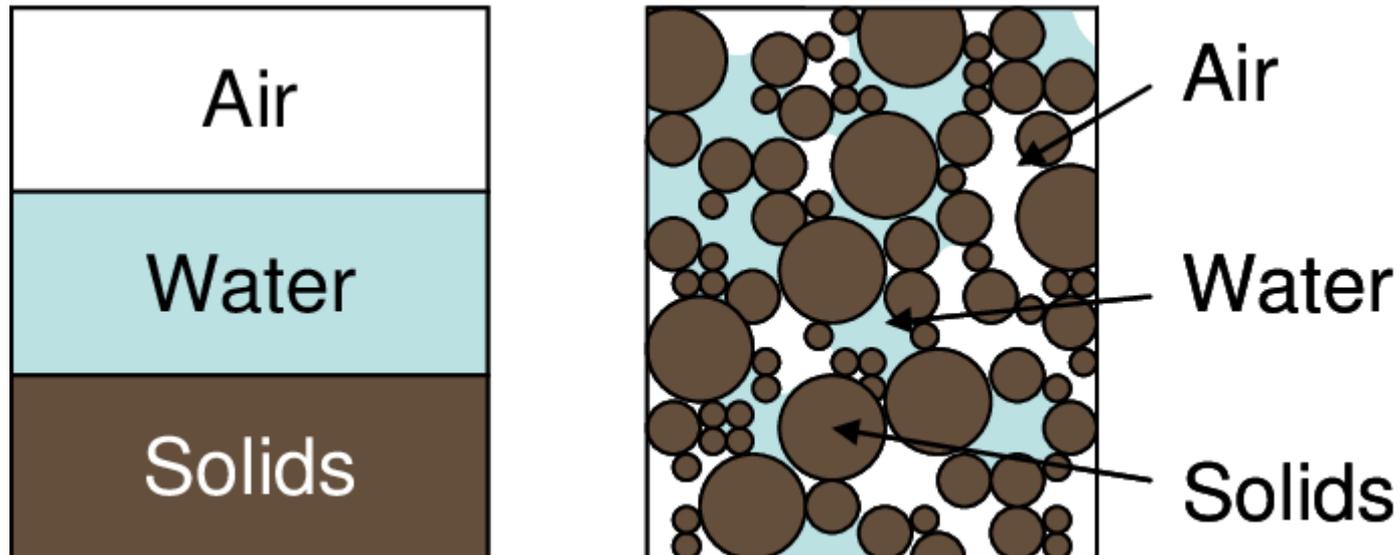
Water is an essential constituent of healthy, productive soils. It serves to bind and secure the physical particulates in soil structure and is the medium by which natural chemicals and essential trace element nutrients are transported to plants.



## 2. Relationships Between the Three Phases of Soil

At first glance, the soil can be schematically represented as being composed of a volume of solids and a volume of voids.

The solid volume consists of various minerals and organic matter particles. The voids occupy the free spaces between these particles (minerals and organic matter). In turn, the volume of voids is divided into a liquid phase and a gaseous phase.



## 2. Relationships Between the Three Phases of Soil

The gaseous phase complements the liquid phase, with gases replacing water as it recedes.

The volume of solids is considered constant, provided the soil is assumed to be non-deformable. The volume of voids is also referred to as total porosity. A good agricultural soil typically has a porosity of about 50%.

The volumes of solids, liquids, and gases are generally expressed in cubic meters (m<sup>3</sup>) or cubic centimeters (cm<sup>3</sup>), and sometimes as fractions or percentages (e.g., m<sup>3</sup>/m<sup>3</sup> or cm<sup>3</sup>/cm<sup>3</sup>). The relationships between the different volumes are represented by the following equations:

$$V_t = V_s + V_v = V_s + V_e + V_a \quad [1.1]$$

$$V_v = V_e + V_a \quad [1.2]$$

Where:

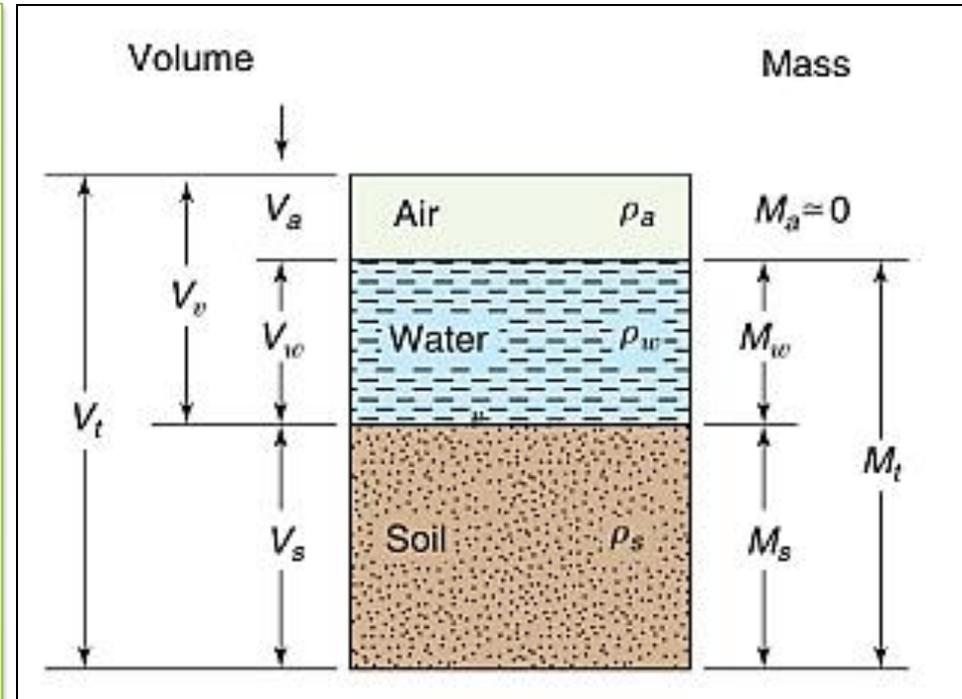
**V<sub>t</sub>** = total soil volume (cm<sup>3</sup>)

**V<sub>s</sub>** = volume of solids (cm<sup>3</sup>)

**V<sub>v</sub>** = volume of voids (cm<sup>3</sup>)

**V<sub>e</sub>** = volume of water or liquid (cm<sup>3</sup>)

**V<sub>a</sub>** = volume of air or gas (cm<sup>3</sup>)



### 3. Measurement of the Volumes Occupied by the Different Soil Phases

#### 3.1 Real and Bulk Densities

The fundamental parameters used to describe the general characteristics of a soil are based on the relationships between mass and volume that define its composition.

**The first** is the **real (or particle) density**, denoted as “ $\rho_s$ ,” which is the ratio of the mass of the solid components to their volume:

$$\rho_s = M_s / V_s \quad [1.3]$$

$\rho_s$  = particle (real) density of the soil (g/cm<sup>3</sup>)

$M_s$  = mass of solids (g)

$V_s$  = Volume of solids (cm<sup>3</sup>)

The particle real density of the soil components depends on the type of material:

- Clay minerals: 2.00 – 2.65 g/cm<sup>3</sup>
- Quartz and feldspars (silt and sand): 2.50 – 2.60 g/cm<sup>3</sup>
- Minerals containing metallic elements: 4.90 – 5.30 g/cm<sup>3</sup>
- Organic fraction: 1.30 – 1.40 g/cm<sup>3</sup>

The average values of particle density generally fall within the following range:

- Mineral soils: 2.60 – 2.70 g/cm<sup>3</sup>
- Organic soil: 1.40- 2.00 g/cm<sup>3</sup>

The second parameter, the **dry bulk density**, denoted as “ **$\rho_{as}$** ,” accounts for the

relative proportions of the solid volume and the voids in the soil:

$$\rho_{as} = M_s / V_t = M_s / (V_s + V_v) \quad [1.4]$$

Where:

**$\rho_{as}$**  = dry bulk density of the soil (g/cm<sup>3</sup>)

**$M_s$**  = mass of solids (g)

**$V_t$**  = total volume of the soil (cm<sup>3</sup>)

**$V_s$**  = solids volume (cm<sup>3</sup>)

**$V_v$**  = Voids volume (cm<sup>3</sup>)

The dry bulk density of a soil is always lower than its particle density, since the solid mass is related to the total apparent volume and not solely to the volume of solids.

The typical ranges of dry bulk density for different soil types are as follows:

•**Sandy soils:** 1.40 – 1.70 g/cm<sup>3</sup>

•**Clay soils:** 1.00 – 1.50 g/cm<sup>3</sup>

•**Peaty soils:** 0.30 – 1.00 g/cm<sup>3</sup>

The **density of the liquid phase**, denoted as “ **$\rho_e$** ,” is defined as the ratio of the mass of the liquid to its volume:

$$\rho_e = M_e / V_e \quad [1.5]$$

Where:

**$\rho_e$**  = density of the liquid (g/cm<sup>3</sup>)

**$M_e$**  = mass of the liquid (g)

**$V_e$**  = volume of the liquid (cm<sup>3</sup>)

Since the liquid phase primarily consists of water and dissolved elements (such as salts, nitrates, etc.), and since soils generally exhibit low concentrations of these elements and are subject to minimal temperature fluctuations, the liquid density is assumed to be that of pure water, which is 1.00 g/cm<sup>3</sup>.

### 3.2 Porosity

Porosity, denoted as “ $p$ ,” is defined as the ratio of the volume of voids to the total soil volume (also called the apparent volume). It characterizes the spaces between the soil particles:

$$p = V_v / (V_v + V_s) = 1 - (\rho_{as} / \rho_s) \quad [1.6]$$

$\rho_{as}$  = dry bulk density of the soil

$\rho_s$  = the real (or particle) density

In mineral soils, porosity typically ranges from 30% to 60%, while peat soils can have porosities of nearly 90%.

The relative volume of voids can also be expressed by the **voids index** “***e***,” which is not commonly used in agronomy but is widely used in engineering:

$$e = V_v / V_s \quad [1.7]$$

There is a relationship between the voids index and porosity:

$$e = p / (1 - p) \quad [1.8]$$

$$p = e / (e + 1) \quad [1.9]$$

The pore system, considered as a network of small pores and conduits communicating with each other, can be divided into several classes of porosity. The two most important are:

**Macroporosity:** The part of the pores where the majority of water and air transfers occur. Water movement mainly takes place under the influence of gravitational forces in macropores. These are the pores that are drained of their water following drainage. The water content between field capacity and saturation comes from the macropores

**Microporosity:** The part of the pores with small diameters that retain water after drainage.

These pores respond minimally to gravitational forces but are the site of capillary forces.

Diameters of 8-10  $\mu\text{m}$  are generally considered the boundary between macroporosity and microporosity.

### 3.3 Water Content

The amount of liquid or water contained in the soil varies over time and space. Its characterization is important and is defined by the volumetric water content and the gravimetric water content

The **volumetric water content** “ $\theta$ ” is defined as the ratio of the volume of water contained in the soil to its apparent soil volume (or total soil volume):

$$\theta = V_e / V_t \quad [1.10]$$

The **gravimetric water content** “ $w$ ” is defined as the ratio of the mass of water contained in the soil to the mass of the soil particles:

$$w = M_e / M_s \quad [1.11]$$

In hydrology, volumetric water contents are used because they facilitate calculations, whereas in agronomy, it is traditional to use gravimetric water contents. There is a relationship between the volumetric water content and the gravimetric water content of a soil:

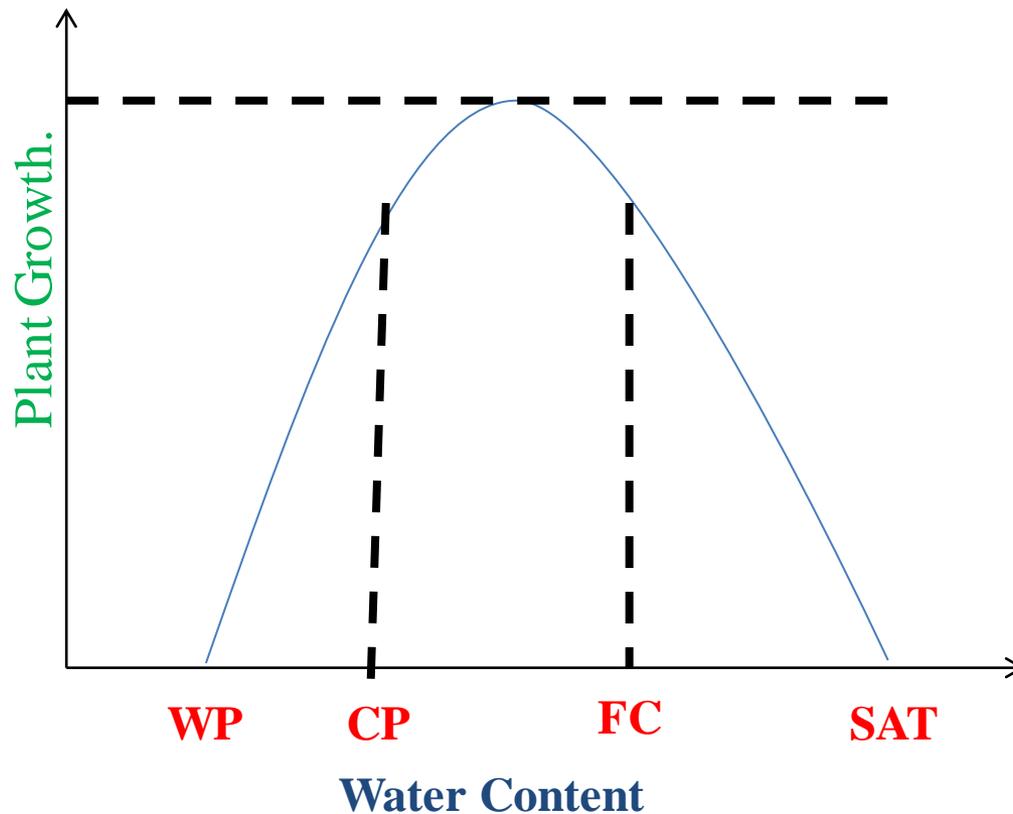
$\rho_{as}$  = dry bulk density of the soil

$\rho_e$  = The density of the liquid phase

$$\theta = \rho_{as} / \rho_e \quad [1.12]$$

### 3.3.1 Characteristic Water Contents

Various concepts and definitions related to soil moisture have been developed with practical applications in agronomy. The concepts of characteristic moisture contents are presented in the Figure below, and they are also related to the use of water by plants



**Characteristic Water Contents of Soils and Plant Growth.**

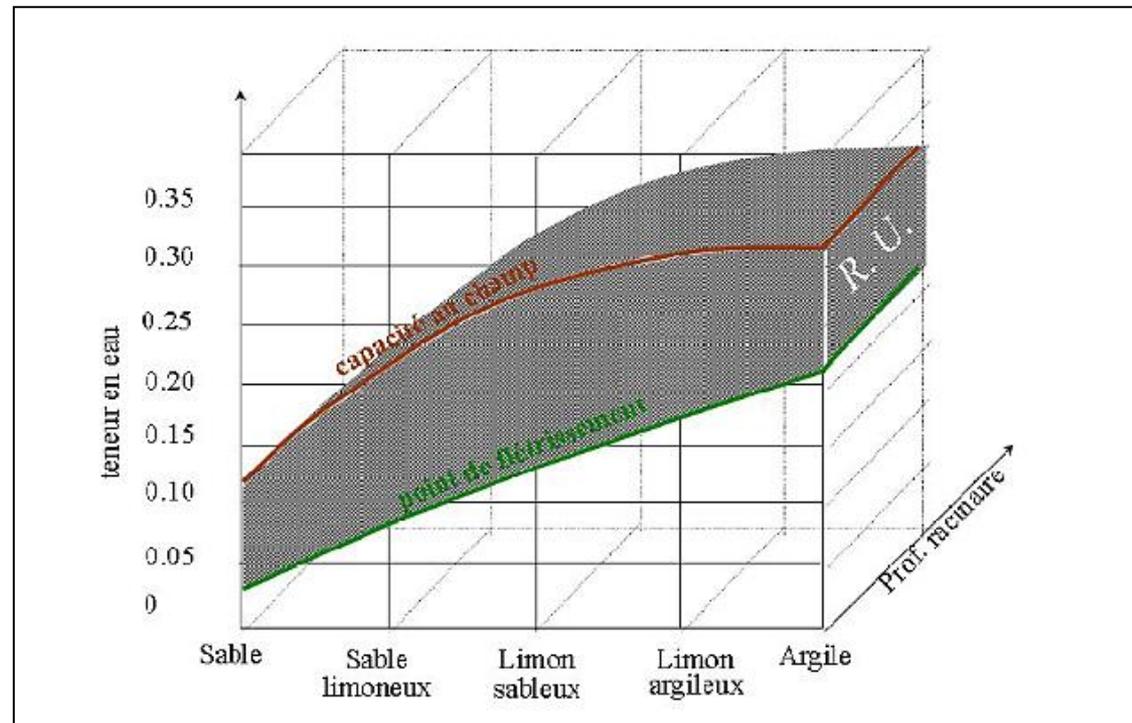
The definitions of characteristic moisture contents are:

- **Saturation (Sat):** Water content at soil saturation under field conditions. In reality, the soil never reaches complete saturation because a certain amount of air always remains trapped.
- **Field Capacity (FC):** Water content of the soil after the excess water has drained and downward flow has become negligible. This typically occurs one to three days after rainfall or irrigation.
- **Wilting Point (WP):** Water content of the soil at which the plant can no longer extract the water necessary for its survival, causing irreversible damage, leading to death.
- **Critical Point (CP):** The water content of the soil at which the plant begins to suffer from water stress, affecting its growth. This water content is used in irrigation management. It is also referred to as the **temporary wilting point** by some. This value is typically between one-third and two-thirds of the difference between the wilting point and field capacity, and it varies depending on **the type of plant, its growth stage, and the evaporative power of the air.**

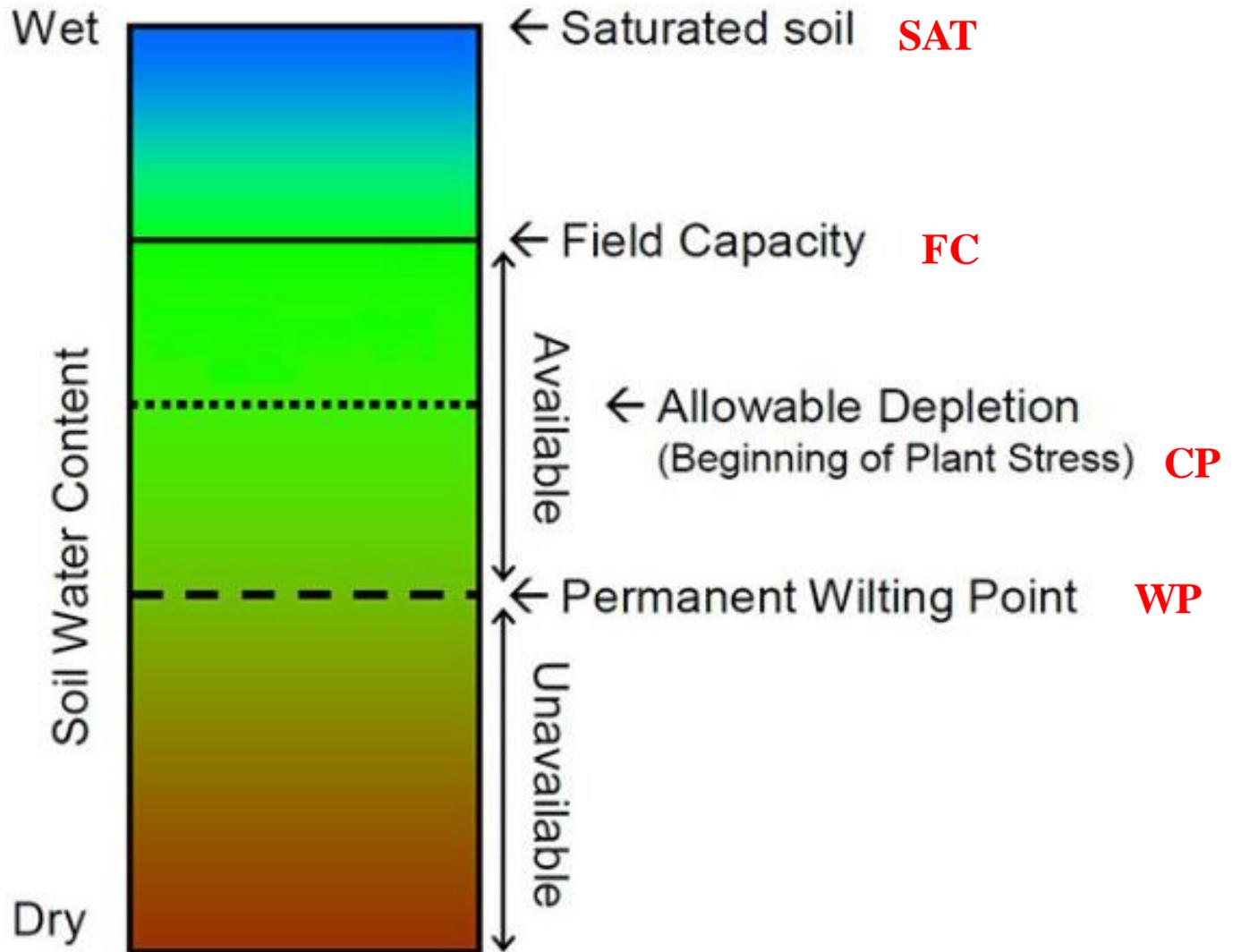
Two other concepts used in water management are derived from these, and they are:

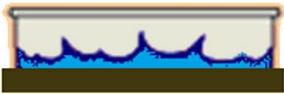
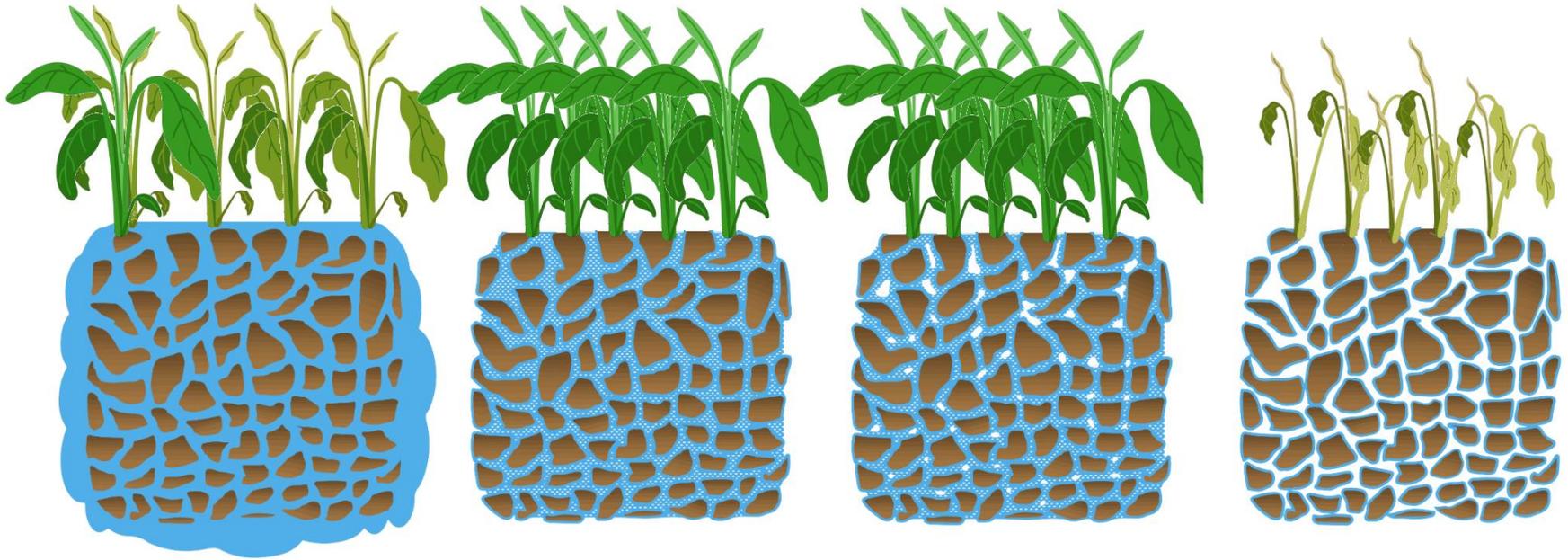
- **Useful Water Reserve (RU)**: The amount of water in the soil that plants can use. It is the difference between field capacity and the wilting point = **FC - WP**
- **Easily Available Water Reserve (RFU)**: The amount of water in the soil that plants can easily use for their growth without experiencing damaging stress. = **0.5 x RU**

All these definitions and the related concepts are based on a static and simplified model of water movement in the soil, which does not account for the dynamic movement of water in the soil.



# Soil Water Content





**SATURATION**  
Pores are full of water.  
Gravitational water is lost.



**FIELD CAPACITY**  
Available water for plant  
growth.



Between Field Capacity  
and Wilting Point.



**WILTING POINT**  
No more water is  
available to plants.

## **4. Forms of Water in the Soil**

### **4.1 Structural Water**

A portion of water is part of the chemical composition of rocks. This is the structural water of hydrated minerals. This fraction of water is completely unavailable at least until the rock undergoes weathering.

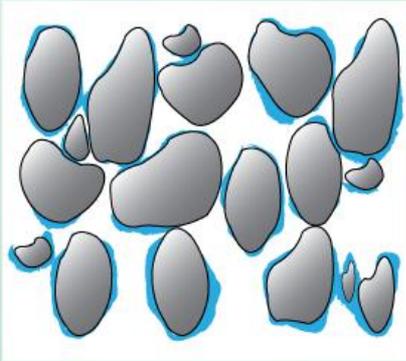
### **4.2 Hygroscopic Water**

This fraction of water is strongly adsorbed onto the surface of mineral and organic colloids (clay, humus), as well as various other minerals.

The forces binding this water to soil particles are stronger than the suction force of plant roots. Therefore, this water cannot be used by plants.

However, it may be involved in direct evaporation processes

## Hydroscopic Water

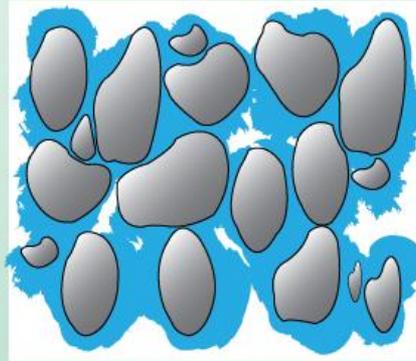


Water adheres to soil particles

Wilting Point  
15 bars



## Capillary Water

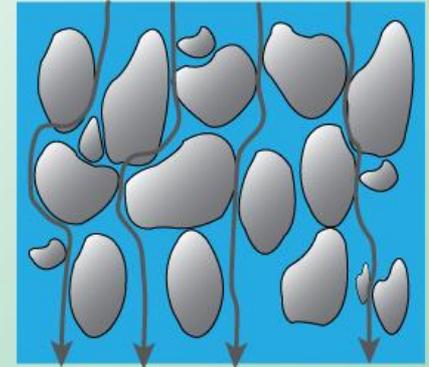


Water held in large pores

Available for crop use



## Gravitational Water

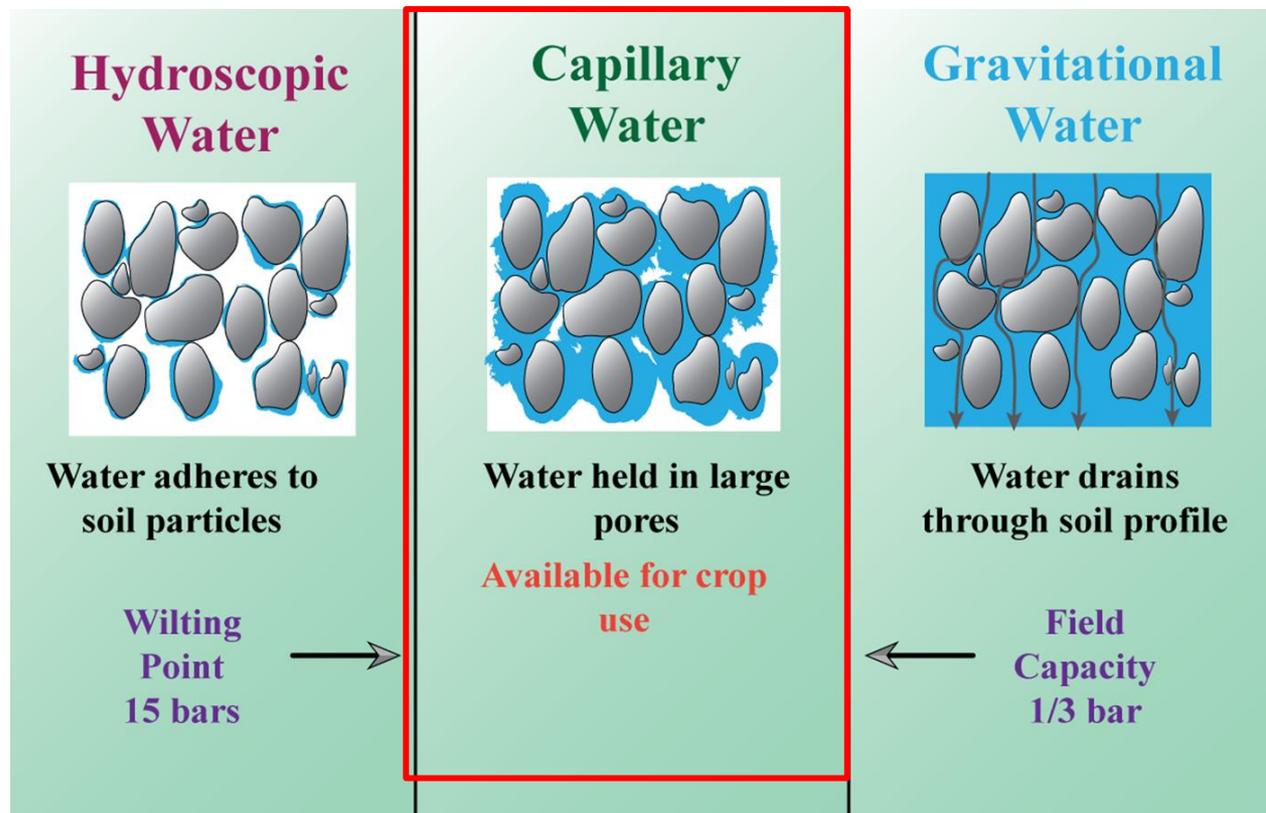


Water drains through soil profile

Field Capacity  
1/3 bar

### 4.3 Capillary Retention Water

A third fraction of water is what is referred to as **capillary retention water**. This water forms films within the soil's micropores. The forces that bind this water are less than 12 atmospheres, which means that plants can mobilize it through their roots. Naturally, this water can also evaporate. However, the gravitational forces are too weak to cause it to percolate, so it does not contribute to groundwater recharge.



Moreover, for this water to be accessible by evaporation or by plants, the continuity of the capillary films must be maintained.

Various cultivation practices, such as **weeding** (which reduces the number of evapotranspiring weed or propagating plant ‘unwanted’ roots) or **hoeing or tilling**, are well-known methods probably since the earliest days of agriculture that introduce discontinuities in the soil’s capillary films. These methods significantly reduce evapotranspiration and help preserve this capillary fraction also known as the **soil water reserve** at its highest possible level.

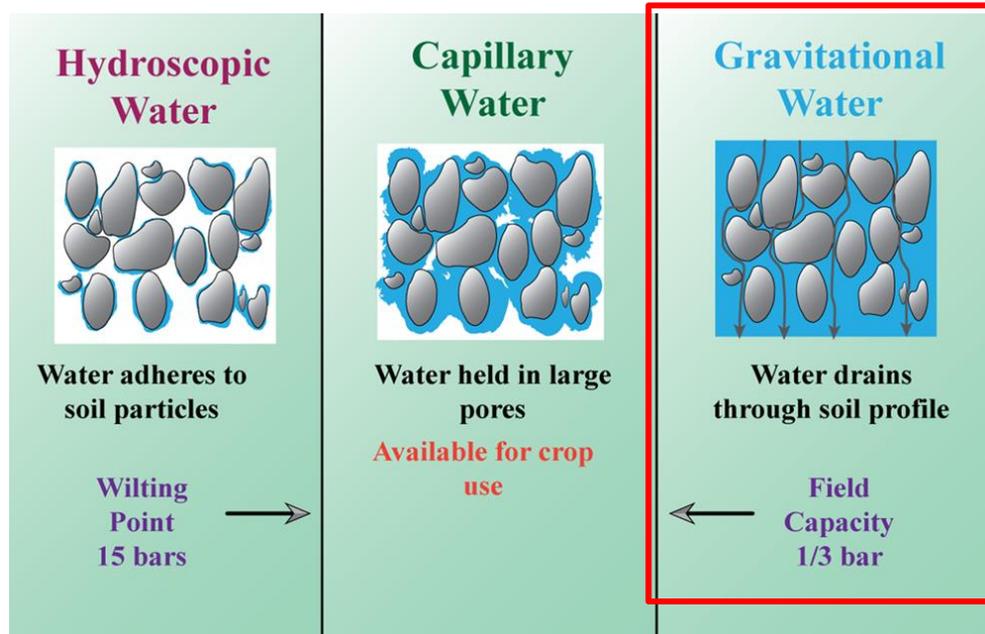


## 4.4 Gravitational Water

This water fills the macropores of the soil. The forces binding it to the soil minerals are too weak to counteract the effect of gravity. As a result, this water infiltrates and percolates downwards until it encounters a layer of less permeable rock.

At that point, the water accumulates, saturating the overlying rock layer and forming an **aquifer** (a **water table**, when the aquifer is close enough to the surface to be reached by digging a well).

This fraction of water is referred to as the **soil's hydrological reserve**.



## 5. Another classification of Water Status in Soil

By *water status* in the soil, we refer to its availability to plant roots in other words, the level of soil moisture that can be returned to the plant.

### 5.1 Available Water Capacity (AWC)

The *available water capacity (AWC)* of a soil, expressed in millimeters of water, corresponds to the amount of water that the soil can absorb and make available to the plant. The AWC is defined as the amount of water between the **field capacity** and the **wilting point**.

#### 5.1.1 Field Capacity Moisture

This refers to the moisture level of a soil that has drained freely under conditions where excess water has been removed by gravity.

### 5.1.2 Wilting Point Moisture

This corresponds to the soil moisture level at which water is held so tightly that it exceeds the suction power of plant roots. The surface tension is stronger than the root's ability to extract water. When the soil reaches this wilting point, the plant can no longer absorb water, leading to wilting and eventually plant death.

For most crops, the wilting point is reached when the soil retains water under tensions of about **15 to 16 bars**. For olive trees, the wilting point occurs at around **25 bars**, which directly translates to a higher available water capacity compared to other crops

## 5.2 Readily Available Water (RAW)

The *readily available water (RAW)* in a soil, expressed in millimeters of water, corresponds to the upper portion of the *available water capacity (AWC)* during which the plant does not need to regulate its evapotranspiration through the stomata.

The RAW is difficult to assess accurately because it varies between **30% and 60%** of the AWC, depending on the soil type.

### 5.2.1. Effect of Soil Texture on Available Water Capacity

Soil texture directly influences the moisture content at field capacity and at the wilting point, and therefore affects the available water capacity (AWC) as follows:

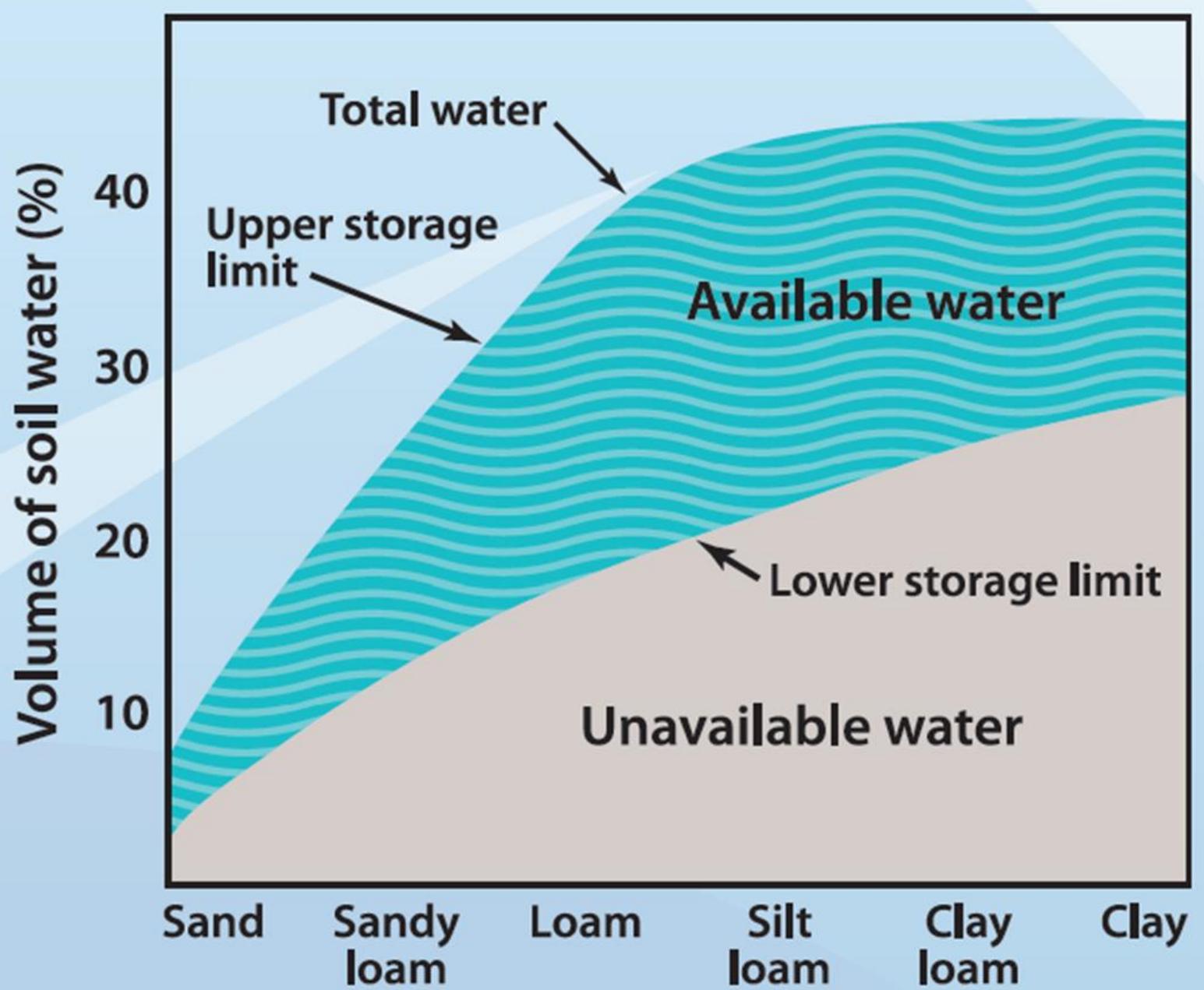
- **Coarse elements** (soil particles larger than 2 mm: stones, gravel, etc.) do not retain water.

Soils with a high proportion of coarse elements therefore have a **limited AWC**.

- **Sandy soils** have **low water retention capacity**, which results in a **low AWC**.

- Soils with a high proportion of **fine particles** (silt and clay) store **more water**; however, a large part of this water **remains unavailable** to plants.

- **Organic matter** has a **higher water retention capacity** than clay. However, it **releases water less easily**. Despite this, the **overall impact of organic matter is positive** for the AWC, which explains its importance in dryland farming.



## 6. Forces Responsible for Soil Water Retention

In the soil, water can move in various directions due to the forces at play that tend to limit its mobility. These forces include:

- **Gravitational force** (the action of gravity): causes water to flow downward into deeper layers.
- **Surface tension**, meaning the attraction of water to soil particles. This tension increases with **finer and more compact particles**.
- **Osmotic pressure**, due to the presence of salts in the soil; its effect is generally considered **negligible in the absence of vapor**.
- **Root suction force**, which causes water to be drawn toward the plant roots

Thus, the **mobility of water in the soil** depends on several factors:

- Soil moisture content:** In dry soils, water is **strongly held by soil particles**. Additionally, water moves from more humid areas toward drier areas. This explains **diffusion and capillarity phenomena**, where water moves from moist deeper layers toward drier surface horizons. In contrast, in water-saturated soils, **gravitational flow** predominates.
- Soil texture: Clay and humus retain water strongly** due to their fine particle size, polarity, and large exchange surface area.
- Soil compaction and porosity:** Water is **more strongly retained and moves more slowly** in compacted or **low-porosity soils**.