CHAPTER1 : Water in the soil

1.1. Role of water in soil

Water plays an essential role in soil as a medium for plant and animal life, dissolving and transporting nutrients from the soil to plant roots.

It is also a key factor in physical and chemical processes, acting as a medium for soil weathering reactions, gas movement and solute transport.

In addition, water maintains soil structure and enables biological activity by providing an environment necessary for decomposition and nutrient cycling.

Biological roles

- Plant nutrition: Soil water dissolves nutrients and transports them to plant roots. It is essential for photosynthesis.
- Life support: It is necessary for the life of microorganisms and other living organisms in the soil.
- Natural filtration: Water moving through the soil contributes to its natural filtering function, purifying drinking water.

Chemical and physical roles

- Reaction medium: Liquid water is the medium in which most chemical reactions that transform minerals and form soil take place.
- Transporter: It transports gases (such as CO_2), solutes and particles within the soil.
- Cohesion and stability: Water acts as a binder, holding soil particles together to maintain its structure. A lack or excess of water can lead to physical instability.
- Flow: It determines the movement of water in the soil, which can be infiltration, runoff, percolation or evaporation.

Importance for ecosystems

- Nutrient cycle: Water movement in the soil (runoff, drainage, percolation) exports nutrients and carbon to aquatic ecosystems, such as rivers and groundwater.

• Water management: The way soil manages water (its ability to store and release water) has a direct impact on plant growth and irrigation management.

1.2. Relationships between the three phases of soil

The three phases of soil are the solid phase (mineral and organic constituents), the liquid phase (soil water) and the gaseous phase (soil air). Their relationships are defined by their proportions and interactions: the solid phase forms the soil structure, while the voids between its particles are filled with water and air, the relative quantities of which vary depending on the soil type, saturation and porosity.

The three phases

• Solid phase: This is composed of mineral matter (sand, clay, silt, weathered rock) and organic matter (plant debris, decomposing animals).

• Liquid phase: This is the water that partially fills the voids, containing dissolved substances (ions, nutrients). It is essential for soil life.

• Gaseous phase: The air that circulates in the soil pores. Its composition is similar to atmospheric air, but with variations due to the respiration of roots and micro-organisms.

1.2. A. Relationships and Interactions

• Porosity:

The relationship between the three phases is determined by the soil's porosity, or the total volume of voids. High porosity means more space for water and air.

• Saturation:

The degree of water saturation in the soil directly influences the relationships. A completely saturated soil will have a minimal gas phase, while a dry soil will have a reduced liquid phase.

• Physical Properties:

The proportions of each phase influence soil properties, such as its water-holding capacity, permeability, aeration, density, and overall structure.

• Biological Activity:

The activity of living organisms (plants, animals, microorganisms) influences all three phases. They contribute to organic matter, soil structure, and the movement of water and gases

1.3. Forms of water in the soil

Water can be found in several states within the soil, these states being distinguished mainly by the intensity of the forces that bind the water and the grains.

A distinction is traditionally made between:

constitutional water, which forms part of the chemical/mineralogical composition of certain minerals (mainly clays);

water bound to the surface of the grains, which is integral to the grains;

capillary water, which is retained by the finest pores in the soil above the water table: the capillary rise zone may be completely or partially saturated;

free water, which can circulate in the soil pores under the effect of gravity: the volume occupied by this water defines the concept of effective porosity, which is smaller than geometric porosity;

ice, which forms depending on temperature conditions and primarily mobilizes free water. The formation of ice, and especially ice lenses through segregation, can cause significant damage to road structures, particularly when thawing occurs. Soils susceptible to the formation of ice lenses are those containing a significant proportion of fine particles.

1.4. Soil water retention forces

The forces that retain water in the soil include capillarity, caused by the surface tension of water and adhesion to soil particles. Other forces are matrix forces, which include capillarity, and osmotic forces due to dissolved salts. Soil texture and structure, particularly porosity, also influence water retention capacity.

Main retention forces

- **Capillarity:**

Water rises in the fine pores of the soil due to surface tension, a phenomenon similar to what happens in a capillary tube. This is one of the most important forces retaining water in medium and fine pores.

- **Matrix forces:**

These represent the overall force with which water is retained by the soil. They combine capillary forces, the adhesion of water molecules to pore walls, and other attractive forces.

- **Osmotic forces:**

These are due to the presence of mineral salts dissolved in the soil water. These forces attract water, but their effect is more pronounced when the soil is dry, as the salt concentration increases.

Factors influencing retention

- **Soil texture:**

The size of soil particles directly influences its retention capacity. Clay soils, with very fine particles and large exchange surfaces, retain more water than sandy soils.

- **Porosity and structure:**

exchange, retain more water than sandy soils.

- **Porosity and structure:**

Soil compaction and structure create pores of different sizes. Smaller pores retain water more strongly than larger pores.

- **Organic matter content:**

Organic matter improves soil structure and its ability to retain water.

Water availability

- **Field capacity:**

The moisture point at which the soil retains the maximum amount of water available after gravitational drainage.

- **Wilting point:**

The point at which water is retained so strongly that plants can no longer absorb it, even though water is still present in the pores.

- **Available water:**

This is the amount of water between field capacity and the wilting point that can be used by plants.

1.5.The states of water in the soil

Water exists in the soil in several forms, which can be classified according to their availability to plants. The main states are gravitational water, capillary water and bound or adsorbed water (also called hygroscopic water). Gravitational water is free water that fills the pores of the soil after saturation and flows under the effect of gravity, while capillary water is retained by surface tension in the pores and is accessible to plants. Hygroscopic water is strongly bound to soil particles and is inaccessible to plants.

Gravity water

- Found in soil voids after watering or heavy rain.
- Flows to deeper layers under the effect of gravity.
- Also known as saturation water.

Capillary water

- Is retained in soil pores by capillary forces.
- Is available to plants and is the main source of water they absorb.
- Its availability decreases as the soil dries out.

Bound or adsorbed (hygroscopic) water

- Forms a thin layer around soil particles.
- Is held very strongly by adhesive forces.
- Is generally unavailable to plants and only evaporates at high temperatures.
- Also known as 'hygroscopic water'.

Constitutional water

- Is integrated into the very structure of soil minerals.
- Is not available to plants or for evaporati

1.6. Soil water potential

Soil water potential is a measure of the energy of water, which determines its ability to move, and is influenced by several factors such as matric, gravitational, pressure, and osmotic potential. Water always moves from a higher (less negative) water potential to a lower (more negative) potential, such as from one part of the soil to a plant or to another soil.

Components of water potential

Matrix potential: This is the most important component, linked to the water retained by the adhesive forces of the soil on the grains. The more the soil dehydrates, the more negative this potential becomes.

Gravitational potential: Represents the energy due to gravity, which tends to pull water down. It is positive in saturated soil and becomes negligible as the soil dehydrates.

Pressure potential: Related to the pressure exerted on water in soil pores (e.g., under air pressure in pores).

Osmotic potential: Related to the concentration of salts dissolved in soil water.

Water behavior

Movement: Water moves from areas of high water potential (less negative, such as moist soil) to areas of low water potential (more negative, such as a thirsty plant) until the two are in equilibrium.

Wilting point: When there is too little water in the soil, the water potential becomes so low that it is impossible for the roots to extract it, causing the plants to wilt.

Saturated soils: In completely saturated soil, gravitational potential dominates, making the overall potential positive and pushing water downward.

1.7. The soil water balance

Is an accounting method that assesses water inputs (rain, irrigation) and outputs (evapotranspiration, drainage, runoff) to determine the amount of water available for plants or other uses. It is based on the principle of conservation of mass and is calculated using the equation: Water supply = Inputs (rain + irrigation) - Losses (evapotranspiration + drainage + runoff). A simplified approach is often used, considering available water inputs (rain + irrigation) and losses (evapotranspiration and drainage), which makes it possible to monitor changes in soil moisture, as highlighted in this geology course on the subject.

Components of the water balance

• **Inputs:**

• **Rainfall:** The amount of water from precipitation. An efficiency coefficient must often be applied to estimate the amount that actually infiltrates (for example, a 30 mm storm may only have 15 mm of efficiency).

• **Watering:** The amount of water provided by irrigation.

• **Losses:**

• **Evapotranspiration** (ET): Water that evaporates from the soil and is transpired by plants.

• **Drainage:** Water that infiltrates deep into the soil, beyond its retention capacity, and leaves the underground reservoir, towards the water table.

• **Runoff:** Water that flows over the surface of the soil, usually when the soil is saturated or rainfall is too intense.

Application and importance

- **Agriculture:**

Water balance helps optimise irrigation by determining when and how much water crops need. It allows irrigation decisions to be made before signs of drought appear.

- **Hydrology**:

Enables quantitative assessment of water resources and changes therein.

- **Land use planning:**

Enables reservoir management and hydrological forecasting.

Calculation and assessment

• **Simplified method:**

For agronomic purposes, we can estimate that: Available water quantity = (Storage + Rainfall + Watering) – Consumption (with an efficiency coefficient for rainfall).

• **Measuring storage:**

The water level in the soil can be measured at a given moment, or over a reference period (for example, after heavy rain that has filled the reservoir).

- **Moisture measurement:**

Moisture can be expressed as volumetric moisture.

1.8. Plants' water requirements

Plants' water requirements depend on their type, the size of their pot or location (in the ground or in a pot), the weather (temperature and sunlight), and the type of soil. Plants in the ground often need less water than potted plants, and it is essential to water differently depending on the season. To know when to water, check the soil moisture by inserting your finger 3 to 4 inches deep: if it is dry, it is time to water.

Factors influencing water requirements

- **Type of plant:**

Requirements vary considerably. For example, lawns may need 1 to 7 liters per day per square meter, while trees may need 10 to 100 liters. Squashes may need 2 to 5 liters per day, depending on their size.

- **Location:**

Potted plants dry out faster than those in the ground because their roots are more limited. Plants in the ground often have access to more water at depth, especially during prolonged droughts.

- **Weather:**

Hot, sunny periods increase water requirements. Potted plants exposed to the sun need more watering. In the event of a heatwave, monitor them closely.

- **Soil type:**

The nature and depth of the soil influence its water retention capacity.

When and how to water

- **Check the soil:**

The best method is to check the moisture level. Push your finger 3 to 4 inches into the soil. If it is dry, water.

• **Water correctly:**

• In pots: Potted plants need to be watered more frequently. A volume of water corresponding to about a quarter of the pot's volume is a good starting point.

• **In the ground:** As a general rule, plants in the ground need the equivalent of 2.5 cm of rain per week, which is about 25 liters of water per square meter, for the water to penetrate deep into the soil.

• **Avoid excess:**

Too much water can cause root rot. Too little can cause the plant to wilt.