INTRODUCTION

Plant physiology, is a science that studies the biological, chemical, and biochemical mechanisms of plants, as well as the functioning of their cells, tissues, and organs. In essence, it seeks to uncover the secrets of plant life in areas such as **nutrition, growth, development, reproduction,** and **germination**.

It is divided into two main parts:

- **Nutrition and metabolism**
- **Growth and development**

Part 1: Nutrition

1: Review of Basic Concepts

1.1. Organization of a Plant

The plant kingdom is traditionally divided into two major groups based on the structural organization of plants: **Thallophytes** and **Cormophytes**.

A. Thallophytes

These are plants with a very simple structure called a **thallus**. The thallus is made up of similar cells without physiological differentiation, meaning that no roots, stems, leaves, or conducting vessels can be distinguished. Some thallophytes are unicellular, while others are multicellular.

B. Cormophytes

This group is composed of higher plants**,** which are always multicellular organisms whose eukaryotic cells are organized into tissues, and these tissues in turn form organs that are much more complex than a thallus. This complex body structure is called a **cormus**, hence the name **cormophyte**.

Root

Roots perform the following functions: they anchor the plant (in the soil or on a support), absorb water (by osmosis), take up mineral nutrients, store food reserves, and sometimes participate in reproduction. Roots can take on various forms: fibrous (fasciculated) or taproot, tuberous, adventitious, bearing tubercles, with pneumatophores, or associated with a bulb.

Stem

The stem performs the following functions: it grows (through the meristem), transports raw and elaborated sap, and bears buds, leaves, flower buds, flowers, and fruits. Sometimes, it also serves to store nutrients, reproduce, climb, creep, attach, or anchor the plant. Depending on the species and variety, stems can appear in many forms and textures, and they may transform to perform different functions. In some cases, stems can be modified into stolons, tendrils, tubers, bulbs, or rhizomes.

Leaf

Functions:

- Transpiration and respiration through the stomata
- Nutrition by photosynthesis (or sometimes by traps, in carnivorous plants)
- Storage of water or nutrients (in succulent leaves)
- Reproduction (by cuttings or vegetative propagation)
- Defense (by producing gases, thorns, or other protective structures)

Flower and Fruit

The flower contains the reproductive organs of the plant, which are involved in sexual reproduction: the stamens and the pistil.

Once pollination has occurred, the flower transforms into a fruit, inside which the seeds develop and mature.

1.2. Organization of a plant cell

The cell represents the fundamental structural and functional unit of all living organisms. There exists a wide variety of cell types, each performing a specific function. The term *cell* includes both eukaryotic and prokaryotic cells.

The eukaryotic cell:

A eukaryotic cell is a cell that possesses:

- A true nucleus bounded by a nuclear envelope, containing the genetic material in the form of DNA.
- A highly structured cytoplasm containing numerous specific organelles.
- A plasma membrane that separates it from the external environment and encloses the cytoplasm.

Specific features of the plant cell

The cell wall

It provides rigidity to the cell while still allowing water and solutes to pass through.

- **The middle lamella** is the outermost part of the cell wall. It is pectic in nature and acts as a cementing layer that ensures adhesion between neighboring cells.
- **The primary wall** is composed of cellulose and hemicellulose. It is flexible and extensible, allowing cell growth. It is deposited between the middle lamella and the plasma membrane.
- **The secondary wall** forms during cell differentiation. It is thicker than the primary wall and is deposited between the primary wall and the plasma membrane. It is made of cellulose and hemicellulose, as well as lignin, suberin, and cutin.

The primary wall is characteristic of young plant cells. It gives the cell the plasticity needed for division, elongation, or differentiation. Cells in the root or apical meristems typically possess a primary wall.

In contrast, the secondary wall is characteristic of mature or dead cells. They perform various functions such as conducting raw sap (*xylem*), providing protection (*cork*), or mechanical support (*sclerenchyma*).

The vacuoles

They play a regulatory role in various physiological functions such as pH, ionic concentration, and osmotic pressure, and occupy more than 40% of the total cell volume. Their membrane is called the **tonoplast**. Vacuoles can store water, mineral elements, organic substances, and pigments. Through their solute concentration, vacuoles regulate the turgor pressure of the cell.

The plastids

These are intracellular organelles that are ovoid or spherical in shape, measuring a few micrometers in length. There are several types:

a. **Chloroplasts:** Organelles found only in chlorophyll-bearing plants. Like mitochondria, they are surrounded by a double membrane. The interior of the chloroplast, called the stroma, contains green “discs” known as thylakoids. The green color of the thylakoids is due to the presence of chlorophyll.

b. **Chromoplasts:** They contain carotenes (yellow and orange pigments) or xanthophylls (pale yellow pigments). They are found in the cells of many colorful fruits, such as tomatoes, and in some flowers.

c. **Amyloplasts:** These are plastids that contain very few internal membranes but many starch grains.

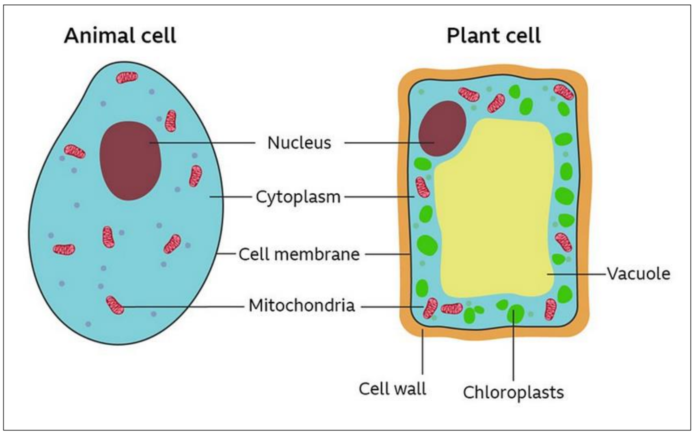

Figure 1 Animal and plant cell

2. Water nutrition

The nutrition of green plants is very different from that of animals. For centuries, crops have been grown in soil from seeds. Nowadays, it is possible to grow plants without soil — this is known as **hydroponics**. This technique can only be applied because we know the nutritional requirements of green plants. What are these requirements?

Water and mineral salts are absorbed from the soil by the root hairs of plant roots. Farmers install irrigation systems in their fields to water their crops and increase their yield.

Water is essential for the formation of **sap** and thus plays a role in circulation processes, ensuring the transport of nutrients to the different organs of the plant. It also takes part in regulatory proces**ses**, such as transpiration.

Water in the soil

For plants, the soil is the almost exclusive source of water and minerals. The largest amount of absorbed water comes from the soil. Water exists in the soil in three particular forms:

1. **Hygroscopic water:** This comes from atmospheric humidity and forms a thin film around soil particles. It is held very tightly and cannot be used by living organisms.
2.
3. **Capillary water:** Found in pores ranging from 0.2 to 0.8 mm in diameter. It is absorbed by plants and allows the activity of bacteria and small protozoa.
4.
5. **Gravitational water:** Temporarily occupies the largest pores of the soil and flows downward under the effect of gravity.

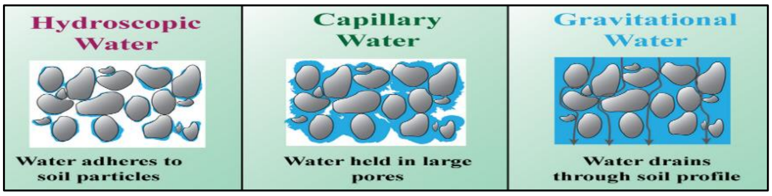

Figure 2 Water in the soil

In the plant (its large vacuole serves as a water reservoir), the **xylem** and **phloem** are the vessels that transport the two types of sap.

- The **xylem** is made up of dead tissues through which **raw sap** (water + mineral salts) circulates.
- The **phloem** consists of living tissues through which **elaborated sap** (water + mineral salts + organic substances) circulates.

The amount of water contained in a plant is always the result of a balance between water intake (mainly from the soil) and water loss through transpiration**.**

The different states of water in the plant

a. **Free water:** This is the general imbibition water, which circulates easily or remains stagnant in the vacuoles.

b. **Bound water:** This is the water immobilized within the cell by hydrogen bonds around alcoholic, amino, or carboxylic groups. Cellulose, in particular, binds a considerable number of water molecules along the carbohydrate residues of its molecular chains.

c. **Constitution water:** This is the water that stabilizes the tertiary structure of certain protein macromolecules and cannot be removed without causing their denaturation. (Bound water and constitution water together make up about 3 to 5% of the total water in a tissue.)

To measure the water content of plants, the plant material is usually dried. Drying can be carried out in an oven at a high temperature (**105°C for 24 hours**). The amount of water contained is determined by the difference in weight between the fresh matter and the dry matter.

Variation of water content in the cell:

Turgidity is an essential biological phenomenon in plants, characterized by the swelling state of plant cells. It is caused by the absorption of water through osmosis, where water enters the cells via the cell membrane, creating an internal pressure known as ***turgor pressure*****.**
Turgidity occurs when water moves from outside the cell (where the solute concentration is lower) to inside the cell (where the solute concentration is higher) through a semi-permeable membrane. The central vacuole of plant cells plays a crucial role in turgidity, as it stores water and other substances, thereby contributing to the cell's internal pressure.

Plasmolysis is the opposite state of turgidity. It occurs when water leaves the vacuole by osmosis. This outflow of water happens either due to a lack of water in the external environment or because the surrounding solution is more concentrated than the cell's internal environment. In such situations, water moves by osmosis from the inside of the cell to the outside.
Thus, the cells of a plant exposed to drought or to water that is too rich in salts will lose their water and undergo plasmolysis. The soft parts of the plant will then shrivel, and the plant will die from water stress if it cannot quickly reabsorb water.

Hypertonic solution has a high concentration of dissolved substances (solute) and therefore a low (very negative) water potential. It draws water from another solution by osmosis.

Hypotonic solution has a low concentration of dissolved substances (solute) and thus a higher (less negative) water potential.

Isotonic condition: this occurs when the surrounding medium has the same solute concentration or the same osmotic pressure as the vacuolar fluid.

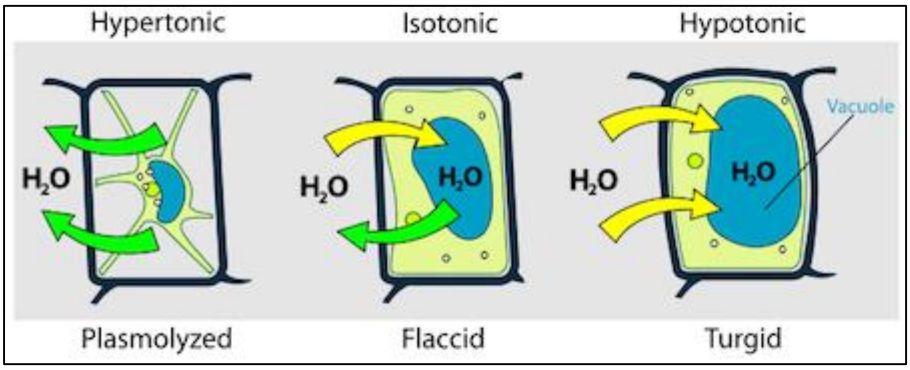

Figure 3 Water states of the plant cell

Note:
Under natural conditions, the root hair cell is always hypertonic compared to the soil solution; therefore, it absorbs water passively by osmosis.
A plant watered with a solution that is too concentrated in mineral salts wilts and dies because not only do the root cells stop absorbing water, but they also lose water, leading to their plasmolysis.

Water potential

Water potential determines the direction of water movement between the different parts of a plant, between the soil and the plant, and between the plant and the atmosphere. Water always moves from regions with higher water potential to regions with lower water potential.

This potential is always negative. The movement of water thus occurs from the area that retains the most water (the most hydrated) toward the area that retains the least (the least hydrated).

When the soil dries out, its water potential decreases, becoming more negative.

The water potential of pure water at **25°C** and **1 atm** pressure is fixed by convention at **$\Psi = 0$**. All solutions have a lower (and therefore more negative) water potential than pure water **($\Psi < 0$).**

Water molecules always move from a higher (less negative) water potential to a lower (more negative) water potential.

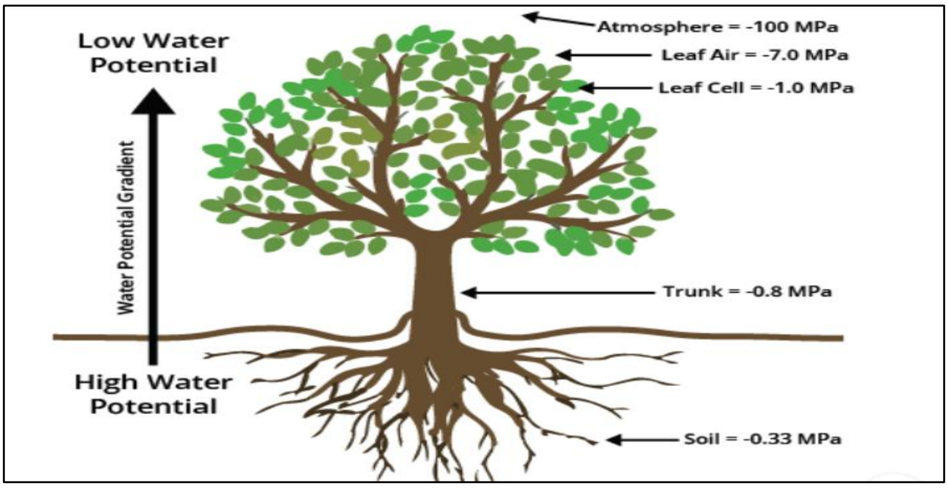

Figure 4 Water potential

Penetration of water into the plant:

Water Absorption by the Roots:

Water enters the plant mainly through the root hairs. Root hairs are highly elongated cells (length: 0.7 to 1 mm; diameter: 12 to 15 µm) forming a visible fuzzy layer slightly behind the root apex. They are very numerous (200 to 500/cm², and up to 2000/cm² in grasses often totaling more than one billion per plant).

They have a temporary existence (lasting from a few days to a few weeks) and are continuously renewed as the root grows. They are fragile and disappear under acidic conditions or in the absence of oxygen.

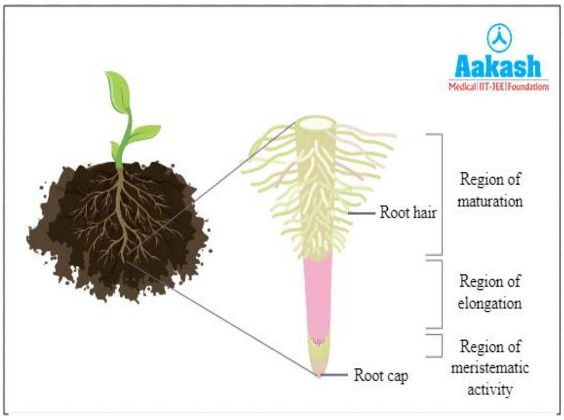

Figure 5 Root parts

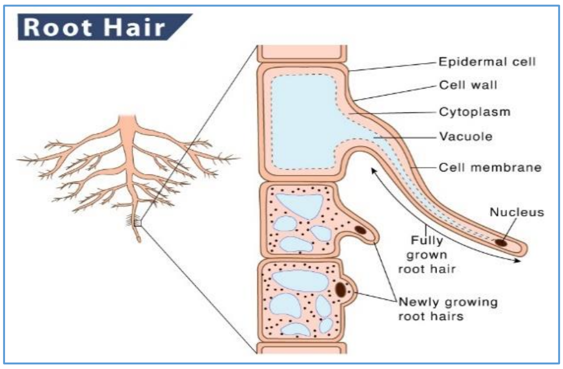

Figure 6 Root hair

Mechanism

Water inside the vacuoles forms a solution of mineral salts and metabolites, creating an osmotic pressure that draws water from the outside into the cell, as the membranes can be considered semi-permeable. Nowadays, this phenomenon is described in terms of **water potential**, a thermodynamic quantity that allows the prediction of water movement.

Osmosis is a passive transport of water that enables a cell to gain or lose water by moving from a **hypotonic solution** (low solute concentration) to a **hypertonic solution** (high solute concentration).

Water transport within the plant:

Water is absorbed by the root hairs of the young roots. It must then reach the xylem vessels. To do so, three pathways are possible:

- **(a) Vacuolar pathway:** water moves from cell to cell, passing through the vacuoles.
- **(b) Symplast pathway:** water moves through the plasmodesmata, passing from one cytoplasm to another via cell junctions.
- **(c) Apoplast pathway:** water moves along the cell walls without crossing the plasma membranes.

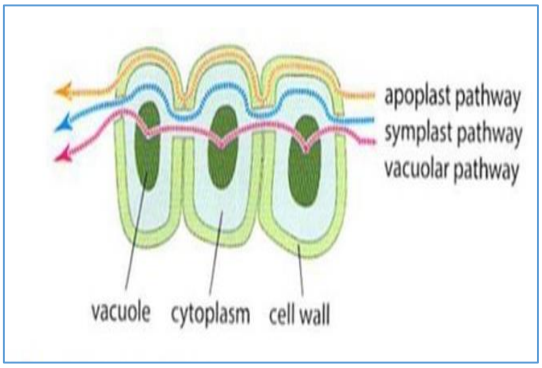

Figure 7 Water transport

3. Plant transpiration

Plant transpiration is an essential mechanism that maintains the water balance in plants. This continuous process is defined as the release of water in the form of vapor from the leaves into the atmosphere.

Less than 5% of the water absorbed by plants is actually used for growth, and an even smaller amount is involved in biochemical reactions.
The plant’s water balance is maintained through the loss of water vapor, which occurs mainly through the leaves; more than 90% of the water escapes via the foliage.

Transpiration takes place at two levels:

1. To a lesser extent, through the **cuticle** of the leaves (simple evaporation). This type of water loss represents about 5 to 10% of the total transpiration and is called **cuticular transpiration**.

2. Mainly through the **stomata**; this is referred to as **stomatal transpiration**.

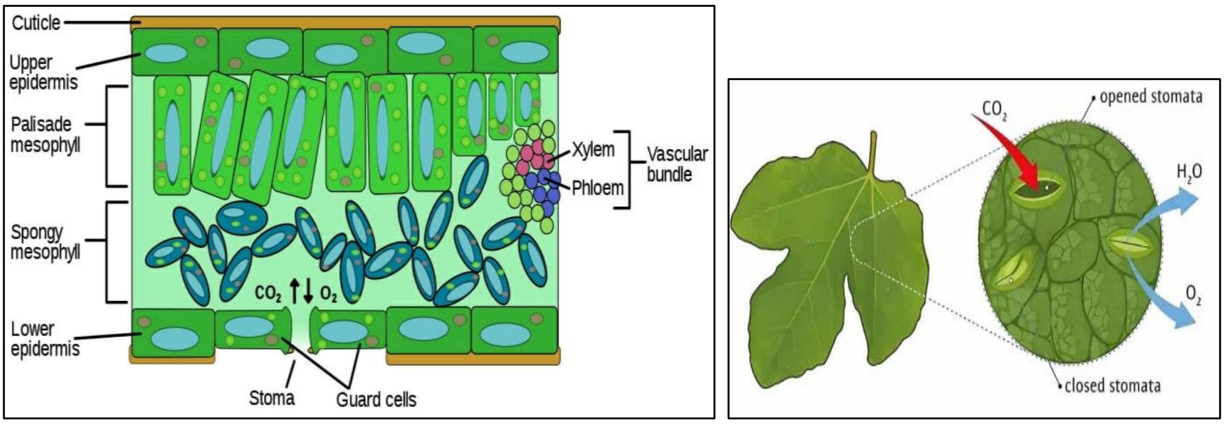

Figure 8 Leaf structure

The stomata

The stomata consist of two guard cells, which are deformable depending on their water content and delimit an opening called the pore (ostiole).
This pore communicates with the sub-stomatal chambers of the spongy mesophyll.

The guard cells regulate the opening and closing of the stomata.
When they accumulate water, they swell and take on a crescent shape, causing the pore to open. When they lose water, they shrink, becoming elongated and thin, which closes the pore

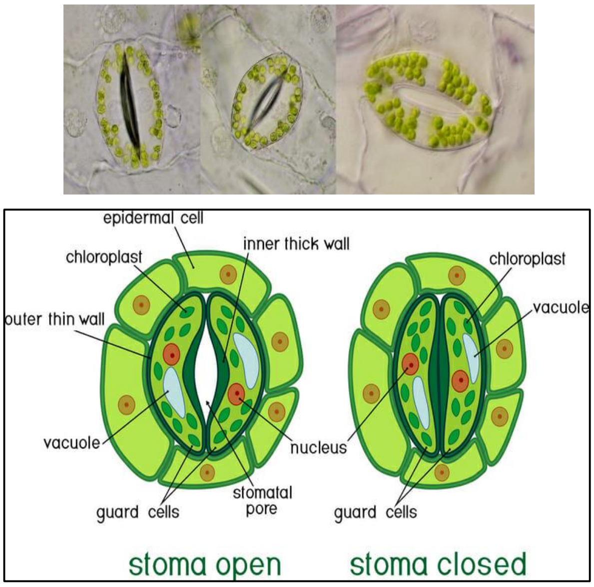

Figure 9 Stomata

Mechanisms of stomatal opening

Stomatal transpiration varies according to the opening and closing of the stomata.
The opening or closing of stomata results from a deformation of the guard cells, which depends on osmotic forces.
These forces correspond to variations in the intracellular potassium **(K^+)** concentration, which is the main factor responsible for changes in osmotic pressure. Potassium is therefore essential for the proper functioning of the stomata.

When the potassium concentration increases, a hypertonic environment is created inside the guard cells, causing water to enter by osmosis. The cells then become turgid, leading to stomatal opening.

The more the plant transpires, the more effective the suction force becomes, allowing greater water absorption from the soil. Thus, water absorption is closely linked to transpiration, which creates a continuous upward flow of water from the roots through the stem to the leaves.

However, if the amount of water lost by transpiration exceeds the amount absorbed, a water deficit occurs.
During such a deficit, the tissues undergo wilting. If this wilting is mild and temporary, it is reversible, but if it is severe or prolonged, it becomes irreversible, leading to the death of the plant.

Factors influencing transpiration

Transpiration is influenced by internal (plant-related) and external (environmental) factors.

I. Internal factors

At the plant level, stomatal transpiration depends on the plant's anatomy. Several structural factors can therefore be distinguished:

- **Leaf surface area**: This corresponds to the total surface of the plant's leaves. Since stomata are located mainly on the leaves, a reduction in leaf surface (such as leaf fall or leaves reduced to needles) leads to a decrease in transpiration.
- **Leaf structure**: In fact, certain plant species living in arid climates show specific anatomical adaptations. The guard cells have thickened inner walls surrounding the stomatal pore (ostiole), which provides protection against excessive water loss.
- **Stomatal density**: Stomatal density refers to the number of stomata per unit surface area or per leaf. A higher density generally increases the potential rate of transpiration.

II. External factors

1. **Temperature**: Higher temperature increases the rate of evaporation and thus transpiration.
2. **Humidity**: When air humidity is low (dry air), transpiration increases. When humidity is high, transpiration decreases.
3. **Light**: Light stimulates stomatal opening and increases leaf temperature; both raise transpiration.
4. **Wind**: Wind removes the moist air layer around the leaves, enhancing transpiration.
5. **Soil water availability**: If the soil is dry, water absorption by roots decreases, stomata close and transpiration falls.