# Chapter 9
# PLANT PHYSIOLOGY

**After studying this chapter, students will be able to:**

- Define mineral nutrition in plants.
- Categorize minerals nutrients of plants into macronutrients and micronutrients.
- State that nitrogen is important in protein synthesis and magnesium for chlorophyll formation.
- Conceptualize transport and its needs.
- Explain the internal structure of root and root hair.
- Describe how roots take up water and mineral salts by active and passive absorption.
- Describe transpiration and relate this process with cell surface and stomatal opening and closing.
- Describe temperature, wind and humidity as the factors affecting the rate of transpiration.
- Describe the mechanism of transport of water and salt in plants.
- Explain the mechanism of food translocation by the theory of Pressure Flow Mechanism.
- Describe the process of gaseous exchange in plants
- Describe the mechanisms/adaptations in plants for excretion of wastes.
- Explain osmotic adjustments in plants.

Plants exhibit remarkable efficiency in carrying out essential life processes. This chapter will explore the world of plant physiology. We will study the mechanisms that enable plants to nourish themselves, transport water and nutrients, exchange gases with the environment, and maintain a stable internal environment.

**Autotrophic** organisms obtain water, carbon dioxide and minerals from their environment and prepare their food e.g., some bacteria, all algae, and all plants.

**Heterotrophic** organisms obtain their food from other organisms e.g., most bacteria, and all protozoans, fungi and animals.

## 9.1- NUTRITION IN PLANTS

Nutrition means the processes in which food is prepared or obtained and converted into body substances for growth and energy. **Nutrients** are the substances required by organism for energy, growth, repair, and maintenance.

### Mineral Nutrition in Plants

We know that plants get their food from a process called photosynthesis. They use sunlight to turn carbon dioxide and water into sugar. But for the synthesis of other biomolecules, they need other materials from soil. Such materials are called mineral nutrients. These are special chemical elements absorbed from soil that are essential for the plants to grow. The minerals which are required in larger quantities are called **macronutrients** e.g. carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulphur, calcium, and magnesium. While, the minerals which are required in lower quantities are called **micronutrients** e.g. iron, molybdenum, boron, copper, manganese, zinc, chlorine, and nickel.

Following table describes the roles of important macro and micronutrients in plants.

**Table: Role of Mineral Nutrients in Plant Life**

| Macronutrients | Role in Plant Life |
|---|---|
| Carbon | Major component of all biomolecules |
| Hydrogen | Major component of all biomolecules |
| Oxygen | Major component of biomolecules, necessary for cellular respiration |
| Phosphorus | Component of ATP, nucleic acids, and coenzymes, necessary for seed germination, photosynthesis etc. |
| Potassium | Regulates the opening and closing of the stoma |
| Nitrogen | Component of proteins, chlorophyll and enzymes |
| Sulphur | Component of proteins, vitamins and enzymes |
| Calcium | Activates enzymes, is a structural component of cell walls, influences water movement in cells |
| Magnesium | Component of chlorophyll, activates many enzymes |

| Micronutrients | Role in Plant Life |
|---|---|
| Iron | Necessary for photosynthesis, activates many enzymes |
| Molybdenum | Component of the enzyme that coverts nitrates to ammonia |
| Boron | For sugar transport, cell division, and certain enzymes |
| Copper | Component of several enzymes |
| Manganese | Involved in the activities of enzymes of photosynthesis and respiration |
| Zinc | Required in a large number of enzymes |
| Chlorine | Involved in osmosis of water |
| Nickel | Required in a nitrogen metabolism |

## Roles of Nitrogen and Magnesium

**Nitrogen** is a necessary part of all proteins, enzymes and nucleic acids. It is also a part of chlorophyll. Nitrogen helps plants for rapid growth, increasing seed and fruit production and improving the quality of leaf. Plant roots absorb nitrogen in the form of **nitrates**. Nitrogen deficiency slows down the growth of plant. It also results in insufficient production of chlorophyll and so leaves begin to turn yellow. It is called chlorosis.

Carnivorous plants trap and digest small animals. Such plants fulfil their needs of nitrogen from the prey animals.

**Magnesium** is part of the chlorophyll. It also activates many plant enzymes needed for growth. It also helps in fruit formation and germination of seeds. Plant roots absorb Magnesium in ionic form ($Mg^{2+}$). If sufficient amounts of magnesium are not available, plants begin to break the chlorophyll in leaves. This causes the yellowing of leaves i.e., chlorosis. After prolonged magnesium deficiency leaves may also drop.

When a plant faces N or Mg deficiency, it transports these elements from older to younger leaves. So, the yellowing of leaves is seen in old leaves first. If deficiency continues, this symptom progresses to the young leaves.


**FIGURE 9.1: (a) Chlorosis due to Nitrogen deficiency, (b) Chlorosis due to magnesium deficiency**

## 9.2- TRANSPORT IN PLANTS

Transport means the movement of substances such as water, nutrients, hormones, and waste products within an organism. This movement is essential for cellular functions, growth, and responses to environmental changes.

Plants get water and mineral nutrients (salts) from the soil. These materials are transported to the aerial parts of the body. Similarly, the food prepared by leaves is transported to other parts of the body. In all land plants (except mosses and liverworts), the transport of water, salts and food is carried out by xylem and phloem tissues. **Xylem** is responsible for the transport of water and salts while **phloem** is responsible for the transport of food. Before studying the mechanism of transport of water and salts in plants, let us see how plants absorb water and salts from the soil.

**Recalling**

- **Passive Transport:** It is the movement of ions or molecules across cell membrane from a region of higher concentration to a region of lower concentration. This movement does not require energy. Diffusion and osmosis are examples of passive transport.
- **Active Transport:** It is the movement of ions or molecules across cell membrane from a region of lower concentration to a region of higher concentration, using energy.
- **Osmosis:** It is the movement of water molecules through a semi-permeable membrane from a region of lower solute concentration to a region of higher solute concentration. This movement does not require energy.

## Internal Structure of Root and Uptake of Water and Salts

We know that roots are the organs which absorb water and salts from the soil. The internal structure of a root shows the following features that help the roots to perform this function.

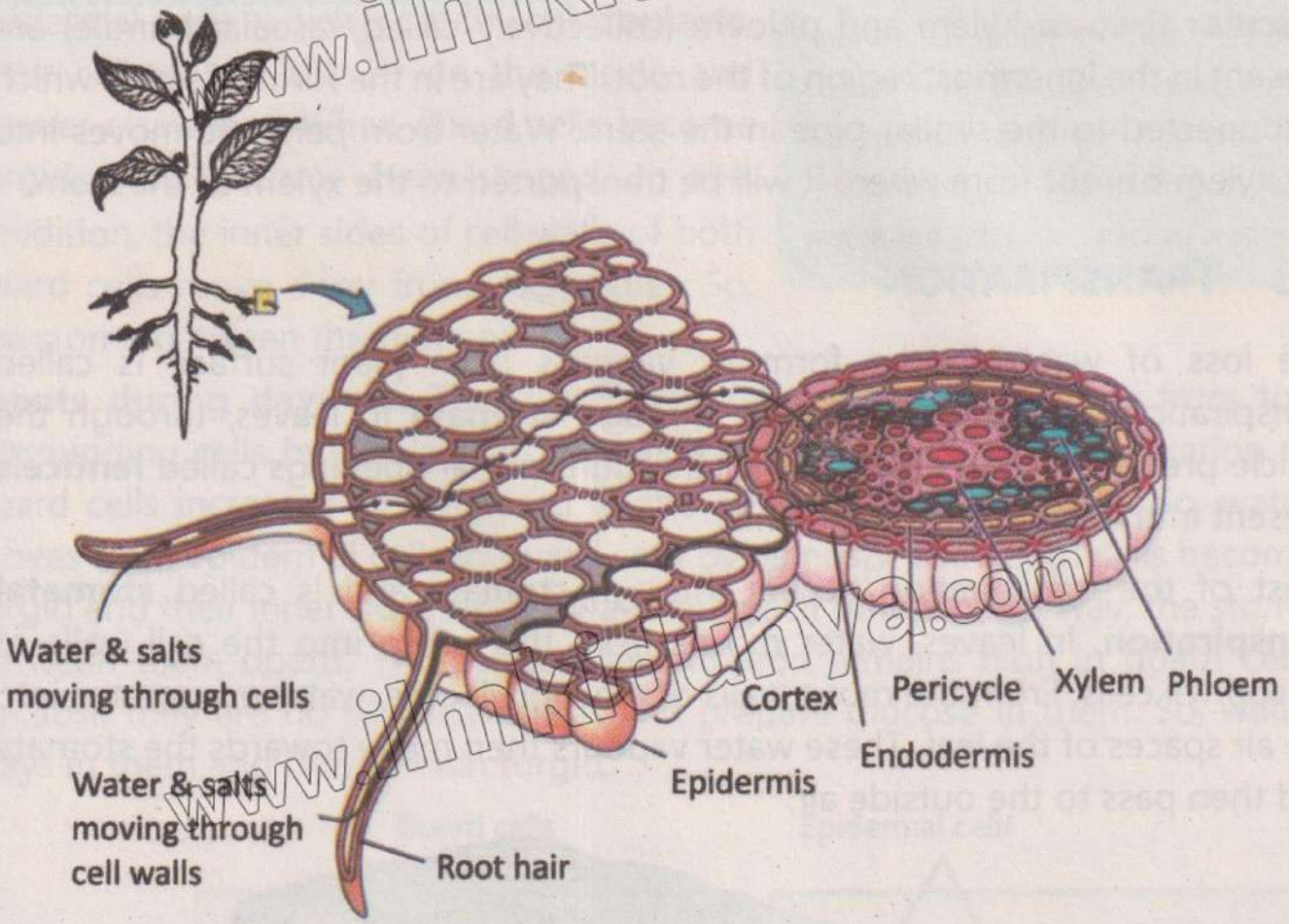


**FIGURE 9.2: Uptake of water and salts by root**

**Epidermis and Root Hairs:** The outermost covering of the root i.e. epidermis is a single layer of cells. Many cells of epidermis have tiny hair-like extensions into the spaces among soil particles. These extensions called root hairs are in direct contact with soil water. Root hairs have large surface area. The soil water has a lower concentration of salts as compared to root hairs. Root hairs take in more salts by **active transport**. Due to the difference in the concentration of salts in soil and root hair, water moves by **osmosis** (passive transport) from soil to the root hairs. From root hairs, the water with dissolved salts moves to the other cells of epidermis.

**Cortex:** It is broad zone of cells just inside the epidermis. Water moves from epidermis to cortex.

**Endodermis:** It is the innermost boundary of cortex that receive water from cortex.

**Pericycle:** It is a narrow layer of cells present on the inner side of endodermis.

Inside the root, water and salts take two pathways to reach the center.
(i)- through the cells
(ii)- through cell walls and intercellular spaces.

**Vascular tissues:** Xylem and phloem (collectively called vascular bundle) are present in the innermost region of the root. They are in the form of a pipe which is connected to the similar pipe in the stem. Water from pericycle moves into the xylem of root from where it will be transported to the xylem of the stem.

## 9.3- TRANSPIRATION

The loss of water in the form of vapours from plant surface is called transpiration. This loss may occur through **stomata** in leaves, through the cuticle present on leaf epidermis, or through special openings called **lenticels** present in the stems of some plants.

Most of the transpiration occurs through stomata and is called **stomatal transpiration**. In leaves, water moves from the xylem into the cell walls of mesophyll cells. From the moist walls of mesophyll cells, water evaporates into the air spaces of the leaf. These water vapours then move towards the stomata and then pass to the outside air.

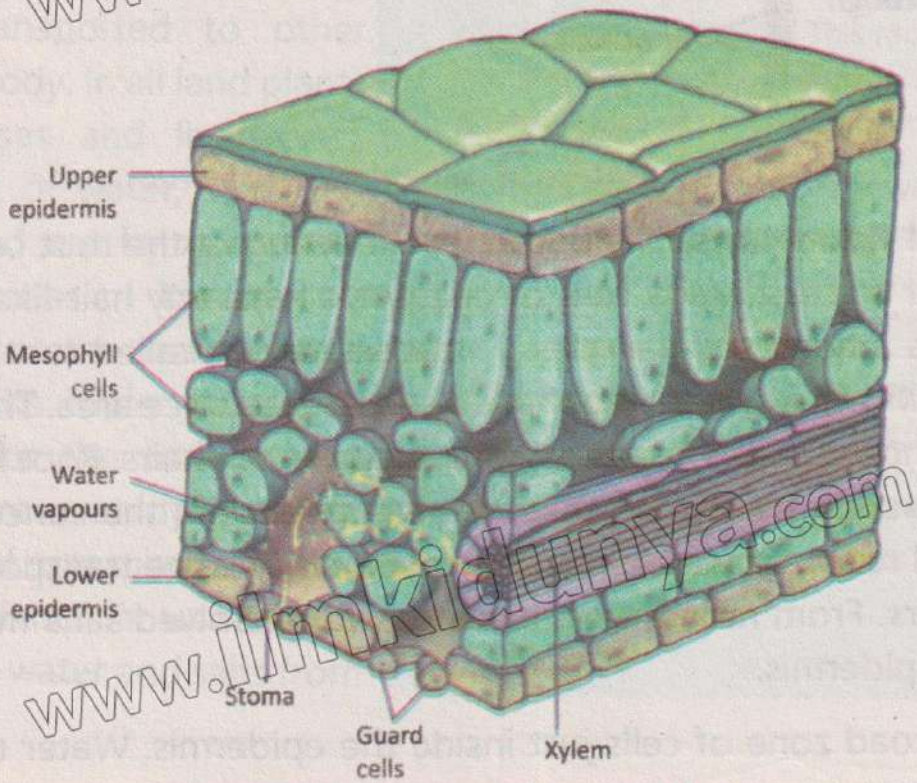


**FIGURE 9.3: Events of transpiration**

## Mechanism of the opening and Closing of Stomata

Stomata open and close because of changes in the turgor pressure of their guard cells. The sausage-shaped guard cells are the only epidermal cells which contain **chloroplasts**. Their cell wall is thicker on the inside and thinner elsewhere. When guard cells become turgid, they become bean-shaped. In this condition, the inner sides of cell walls of both guard cells move away from each other. So, the stoma between them opens.

> Transpiration is a necessary evil. Although transpiration is the loss of water from plant but, yet it creates a pull on the water columns in the xylem tissue of leaves, stem and root. This pull is responsible for the transport of water and salts from root to leaves.

**Events during daytime:** The guard cells take in potassium ions from the surrounding cells by active transport. As a result, the solute concentration of guard cells increases as compared to the other cells of epidermis. So, water moves from epidermal cells to guard cells by osmosis. The guard cells become turgid and their inner sides move away from each other. In this way, the stoma between them opens. The solute concentration remains high in guard cells because they are do photosynthesis and prepare glucose in them. So, water stays in them and they remain turgid.

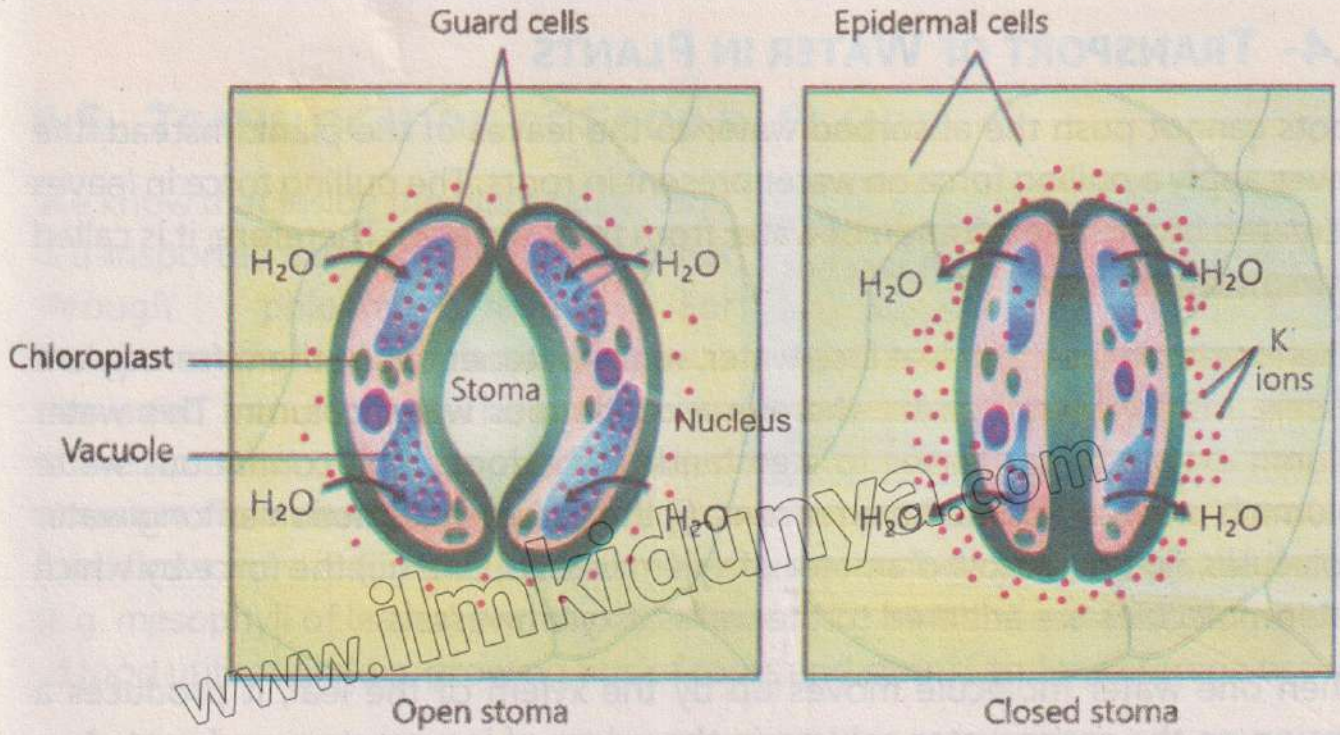


**FIGURE 9.4: Opening and closing of stoma**

**Events during evening:** At evening, the glucose concentration falls in guard cells and potassium ions also move back to epidermal cells. As a result, water moves out from guard cells and they lose turgor. Their inner sides touch each other and the stoma closes.

## Factors Affecting the Rate of Transpiration

Transpiration is affected by several factors. For example:

- **Temperature:** Increase in temperature results in an increase in the rate of transpiration. It is due to the fact that at higher temperature, water evaporates more quickly.
- **Wind:** Wind speeds up transpiration by carrying away humid air surrounding the leaves, allowing for more water to evaporate.
- **Humidity:** The higher is humidity (the percentage of water vapour in the atmosphere); the lower is the rate of transpiration.
- **Surface area and distribution of stomata:** Leaves with more surface area transpire more than the leaves with narrow blades. In most plants the number of stomata on the lower leaf surface is greater than on the upper surface. Therefore, the rate of transpiration from the lower surface is greater than from the upper surface.

## 9.4- Transport of Water in Plants

Roots cannot push the absorbed water to the leaves of the plant. Instead, the leaves apply a pulling force on water present in roots. The pulling force in leaves is created by the transpiration of water from their surfaces. Therefore, it is called **transpirational pull**.

When mesophyll cells of leaf lose water, more water enters in them from xylem vessels. Inside xylem vessels, there is a continuous water column. This water column extends from leaves to stem and to the roots. The continuous water column is created due to three reasons: (i) the forces of attraction among water molecules, (ii) the narrow diameter of xylem vessels, and (iii) the force by which water molecules are adhered to the walls of xylem vessels.

When one water molecule moves up by the xylem of the leaf, it produces a tension on the entire water column in the xylem of leaves, stem and root. As a result, the entire water column is pulled upwards.

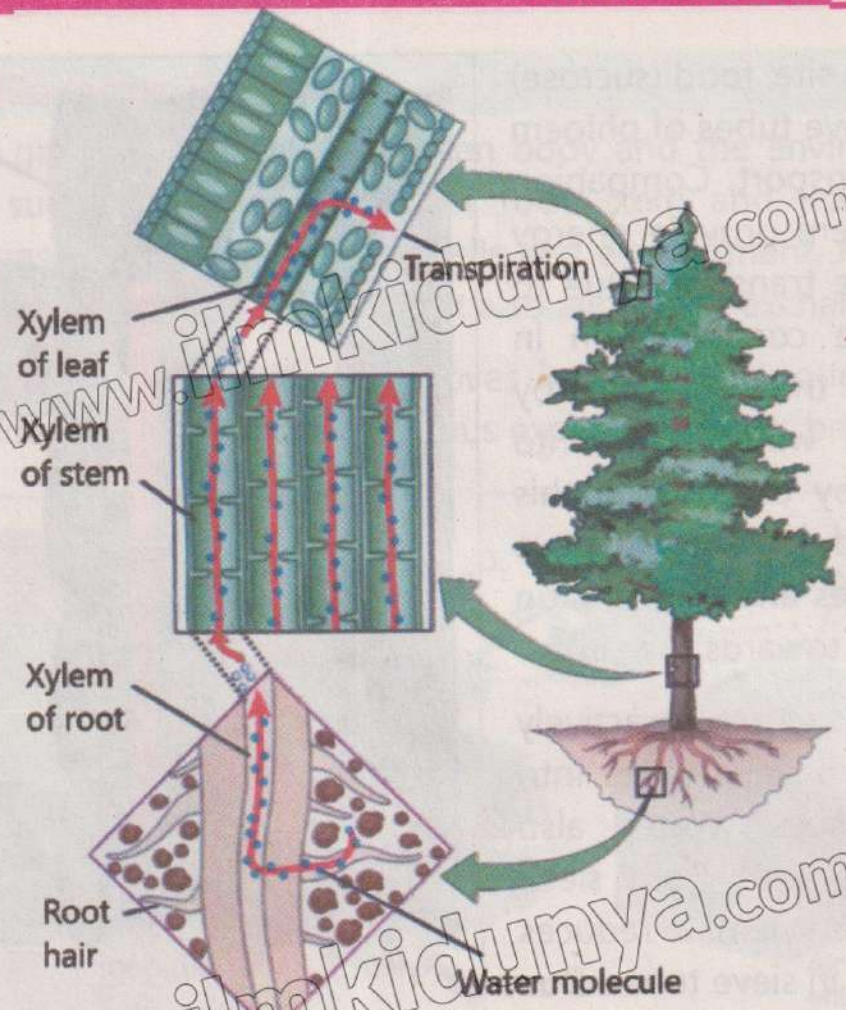


FIGURE 9.5: Transport of water in plants

## 9.5- TRANSLOCATION OF FOOD IN PLANTS

We know that inside the plant body, food is transported from one part to the other through phloem tissue. For transportation in most plants, glucose is converted into sucrose. The mechanism of the transport of food in plants is called **pressure flow mechanism**. According to pressure flow mechanism, dissolved food flows from a **source to a sink**. The sources include photosynthetic tissues (e.g. mesophyll of leaves) and storage tissues (e.g. roots). Sinks include the sites of food utilization (e.g. growing tips of roots and stems) and the storage tissues.

Xylem is a one-way passage for water and salts (from roots to leaves). Phloem is a two-way passage for food. The direction of food movement is decided by supply and demand in the sources and sinks.

At the source site, food (sucrose) enters the sieve tubes of phloem by active transport. Companion cells of phloem provide energy for this active transport. Due to higher solute concentration in sieve tubes than the nearby xylem tissue, water flows into sieve tubes by osmosis. In this way, the fluid pressure in sieve tubes increases and the solution of food flows towards the sink.

At the sink, sucrose is actively unloaded from sieve tubes into the sink tissues. Water also moves by osmosis from sieve tubes into the xylem. It reduces fluid pressure in sieve tubes. Due to higher fluid pressure at the source than the sink, food flows in bulk towards the sink.

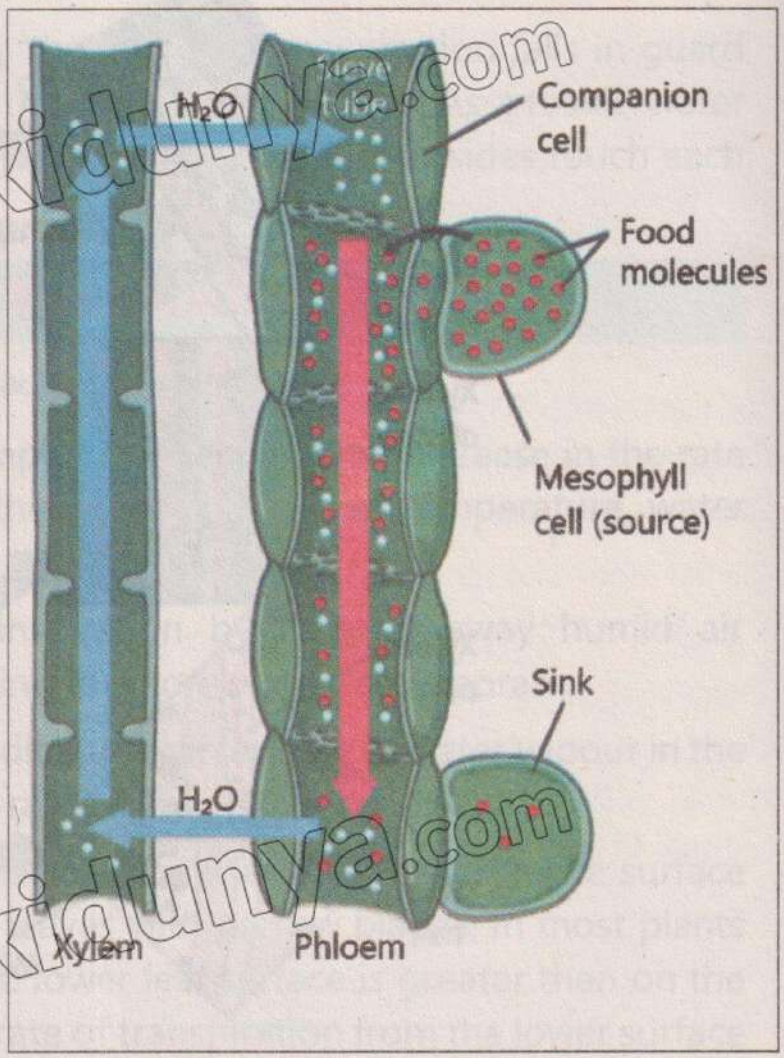


FIGURE 9.6: Transport of food

## 9.6- GASEOUS EXCHANGE IN PLANTS

During the daytime, all plant cells are carrying out cellular respiration while their green parts are carrying out photosynthesis.

- In photosynthesis, they use carbon dioxide and release oxygen. They take carbon dioxide which they produce in respiration. They also take carbon dioxide from the environment.
- In respiration, they use oxygen produced during photosynthesis. They release carbon dioxide to the environment.

So, during daytime leaves are releasing oxygen and taking carbon dioxide from the environment. During night, all cells are carrying out respiration while there is no photosynthesis. So, the plant is taking in oxygen from environment and releasing carbon dioxide.

## Process of Gaseous Exchange

In plants, the gaseous exchange between body and the environment occurs through the surface. The epidermis of root, stem and leaves allows the exchange of gases between the inner cells and environment. At some parts a thick **cuticle** is present over epidermis. It also allows the exchange of gases.

In leaves and young stems, the air moves in and out through the stomata present in epidermis. Inside body, gaseous exchange occurs between cells and air.

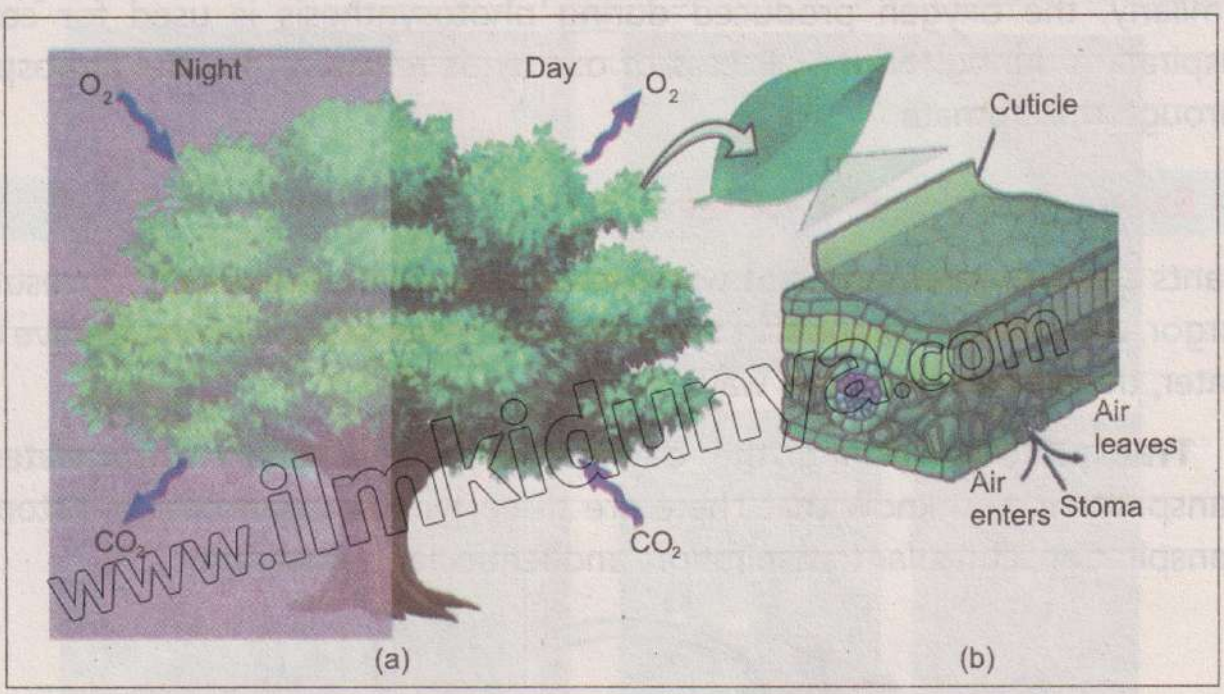


**FIGURE 9.7: (a)- Gaseous exchange in plant; (b) Gaseous exchange in a leaf**

In woody stems, the entire surface is covered by bark. Gaseous exchange cannot occur through bark. The bark contains special pores called **lenticels**, which allow the gaseous exchange with the environment.

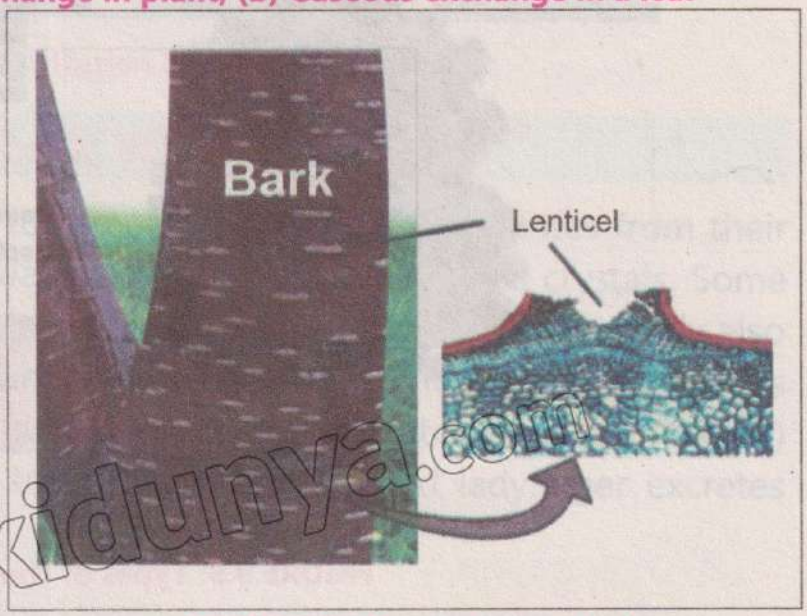


**FIGURE 9.8: Lenticels in a bark**

## 9.7 MECHANISMS FOR EXCRETION IN PLANTS

### a- Excretion of Extra Carbon dioxide and Oxygen

During the day, plants use the carbon dioxide produced in cellular respiration for photosynthesis. However, at night, when photosynthesis is not occurring, carbon dioxide becomes a waste product. Plants release this excess carbon dioxide through their general surfaces and stomata.

Similarly, the oxygen produced during photosynthesis is used for cellular respiration during the day. Excess of oxygen is released into the atmosphere through the stomata.

### b- Excretion of Extra Water

Plants store large amounts of water in the vacuoles of their cells. It results in turgor, which provides support to the soft parts of the body. If plants have extra water, they remove it in two ways.

**1. Transpiration:** During the day, plants remove their extra water by transpiration. You know that there are three types of transpiration: stomatal transpiration, cuticular transpiration, and lenticular transpiration.

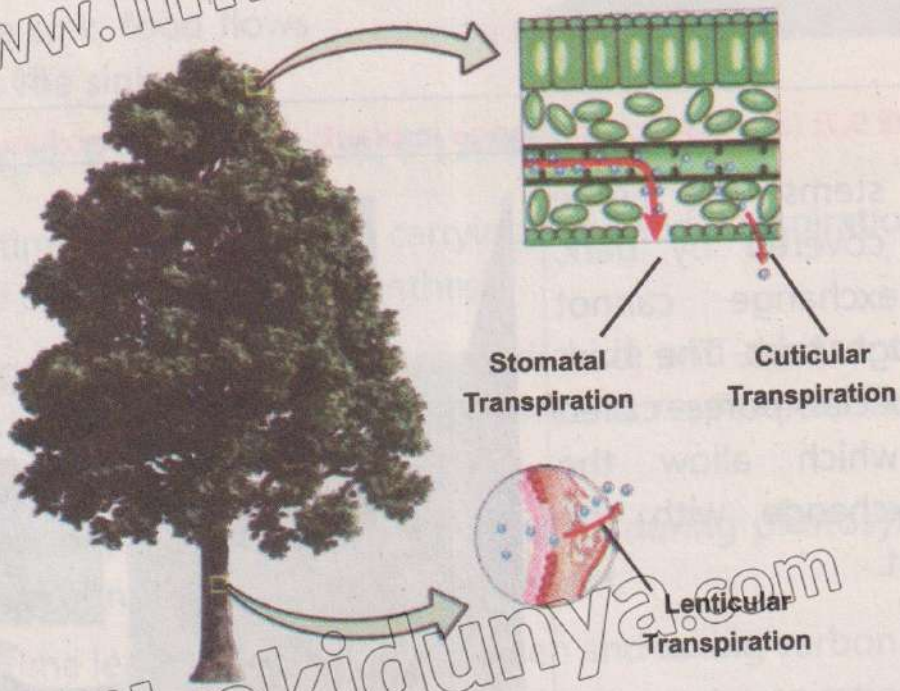


FIGURE 9.9: Types of transpiration

**2. Guttation:** At night, when stomata are closed, many plants store excess water in their xylem tissue. This water is removed during the day. Some plants, such as grasses, have a specialized mechanism called guttation to remove excess water at night. Guttation involves the release of water droplets through small pores located at the tips or edges of leaves. This process helps to regulate the plant's water content.

Guttation is different from dew formation. Dew means the water drops on the surface of leaves formed by the condensation of water vapours present in the air.

**FIGURE 9.10: Guttation in different leaves**

## c-Excretion of other Metabolic Wastes

Plants adopt different methods to remove other metabolic wastes from their bodies. Some plants can store wastes in the form of harmless crystals. Some plants keep their wastes in their leaves. When their leaves fall, plant body also gets rid of these wastes. Some plants excrete their wastes through special pores by applying force. For example, rubber plant excretes latexes, Acacia (keekar) tree excretes gums, coniferous trees excrete resins, and ladyfinger excretes mucilage.


FIGURE9.11: Excretion in Plants

## 9.8- OSMOTIC ADJUSTMENTS IN PLANTS

On the basis of habitats, there are four types of plants.

1. **Mesophytes** are the terrestrial plants which are adapted to survive in moderate environment that are neither too dry nor too wet. They have well-developed root system that efficiently absorbs water. A cuticle on their surfaces minimizes water loss during hot and dry periods. Moreover, they keep their stomata closed to reduce transpiration. Examples of mesophytes include maize (corn), clover, and rose.
2. **Hydrophytes** live in freshwater (ponds, and lakes etc.) or in wet soil. In these plants, the absorption of water occurs through the whole surface. They use different ways to remove extra water from their bodies. For example, many hydrophytes have broad leaves which float on the surface of water. These leaves have large number of stomata on their upper surfaces. Water moves out through these stomata. The most common example of such plants is water lily.
3. **Xerophytes** live in extremely dry environments (deserts). They have deep roots to absorb water from almost dry soil. Their body surface has very few stomata. It is also covered with thick waxy cuticle to reduce the loss of water. Some xerophytes e.g. *Cacti* (*singular: Cactus*) store water in their specialized stems or roots. Such stems or roots are soft and juicy and are called **succulent organs**.
4. **Halophytes** live in habitats with salty waters (e.g. sea or salty marshes). Water tries to move out from their hypotonic bodies into the hypertonic environment. Such plants absorb salts from outside and make their

bodies hypertonic. In this way, water does not move out of cells. The excess salt can be stored in cells or excreted out from salt glands on leaves. Many sea grasses are included in this group.

(1)- Closed stomach in the leaf of tomato (a mesophyte)

(2)- Broad leaves of waterlily (a hydrophyte)

(3)- Succulent stem of *Cactus* (a xerophyte)

(4)- Salt crystals on the leaf of a sea plant (a halophyte)

**FIGURE 9.12: Osmotic adjustments in Plants**

## KEY POINTS

- Nutrition means the processes in which nutrients are obtained or prepared and converted into body substances for growth and energy.
- Plants need nitrogen for protein synthesis and Magnesium for chlorophyll formation.
- Roots have tiny root hairs, which are actually the extensions of epidermal cells of roots.
- Roots absorb water from the soil through root hairs using osmosis, moving water into the plant's vascular system.
- Transpiration is the loss of water from plant surface through evaporation.
- Water moves up the plant through xylem vessels, reaching leaves and other parts. This process is driven by transpiration pull.
- Water molecules stick together (cohesion) and to the walls of xylem vessels (adhesion) It allows them to form a continuous column from roots to leaves.
- As water transpires from leaves, it generates a pull in the xylem, drawing water upward from the roots.
- Transport of food occurs from the areas of supply (sources) to the areas of metabolism or storage (sinks).
- In leaves, sugar molecules are actively loaded into phloem sieve tubes.
- The high concentration of sugars in phloem draws water from xylem into the phloem by osmosis. It increases pressure at the source (leaves).
- At the sink, sugars are water move out of phloem. It reduces fluid pressure in sieve tubes. So, food flows in bulk from source towards the sink.
- At the sink, sugars are removed from the phloem. It reduces pressure and allows water to return to the xylem.
- Stomata in leaves regulate water loss and gas exchange, balancing the needs of the plant.
- On the basis of habitat (availability of water), there are four types of plants i.e., mesophytes, hydrophytes, xerophytes, and halophytes.

# EXERCISE

**A. Select the correct answers for the following questions.**

1. Which of the following plant nutrients is required in large amount?
   a) Iron b) Zinc
   c) Potassium d) Boron
2. Which element is required by plants for the formation of chlorophyll?
   a) Phosphorus b) Calcium
   c) Magnesium d) Sulphur
3. The primary function of root hairs is:
   a) Transport of nutrients b) Storage of food
   c) Increase surface area for absorption d) Synthesis of proteins
4. Root hairs absorb salts from soil by;
   a) Diffusion b) Osmosis
   c) Active transport d) Filtration
5. Water moves from the soil into root cells by:
   a) Osmosis b) Active transport
   c) Diffusion d) Bulk flow
6. The transpiration is regulated by;
   a) Mesophyll b) Guard cells
   c) Xylem d) Phloem
7. Under which condition, there will be high rate of transpiration?
   a) High humidity b) Low light intensity
   c) Wind d) Waterlogged soil
8. Which ion plays a role in the opening of stomata?
   a) Sodium ($Na^+$) b) Potassium ($K^+$)
   c) Calcium ($Ca^{2+}$) d) Magnesium ($Mg^{2+}$)
9. In most plants the food is transported in the form of:
   a) Glucose b) Sucrose c) Starch d) Maltose
10. What is TRUE according to the pressure flow mechanism of food transport?
    a) Water enters the source, creating pressure
    b) Water is pulled from the sink
    c) Movement of food in phloem is due to gravity
    d) Solutes move from low to high concentration

11. Succulent organs are present in:

a) Xerophytes
b) Hydrophytes
c) Mesophytes
d) Halophytes

## B. Write short answers.

1. Define mineral nutrition in plants.
2. Define macronutrients and micronutrients and give examples.
3. State the roles of nitrogen and magnesium in plants.
4. Define transpiration and its types.
5. How is the transpirational pull important in plants?
6. Transpiration is the loss of water from plants. Is it a harmful phenomenon? If no, what is its importance?
7. Differentiate between:
   i. Xylem and phloem
   ii. Transpiration and guttation
   iii. Hydrophytes and halophytes
   iv. Hydrophytes and xerophytes
   v. Lenticular transpiration and stomatal transpiration
8. How do the plants of rubber and keekar excrete their wastes?

## C. Write answers in detail.

1. Describe the events involved in the opening and closing of stomata.
2. Explain the internal structure of root and describe the uptake of salt and water by root.
3. Describe temperature, wind and humidity as the factors affecting the rate of transpiration.
4. Describe the mechanism of transport of water and salt in plants.
5. Explain the mechanism of food translocation by Pressure Flow Mechanism.
6. How do the plants excrete extra water and salts from their bodies?
7. Describe the process of gaseous exchange in plants
8. Describe the mechanisms/adaptations in plants for excretion of wastes.
9. Explain osmotic adjustments in in hydrophytes, xerophytes and halophytes.

## D. Inquisitive questions.

1. Why do plants transpire more on a windy day compared to a humid one?