6 Plant Water Relation

Can you recall?

1. Which are the various parts of plant body?
2. What are the functions of various parts of plant body?
3. Which plant tissues are involved in transport of water and minerals?

Use your brain power

You know that we need a water pump to lift water at top of the building. but, how does plants lift the water from soil upto canopy without any pump?

Plant obtains variety of substances like water, minerals, nutrients, food and gases like O_2 and CO_2, from its surroundings. Productivity in plants is mainly affected by the non-availibility of water.

Water is considered as **'elixir of life'**. Water constitutes almost 90 to 95% of most plant cells and tissues. Water helps the cells to maintain turgidity and shape. It shows following properties due to which it has great biological importance.

6.1 Properties of water:

It is in the liquid form at room temperature and is the best solvent for most of the solutes. It is inert inorganic compound with neutral pH when in pure form. Due to this, water is best transporting medium for dissolved minerals and food molecules. It is best aqueous medium for all biochemical reactions occurring in the cells. It is an essential raw material for photosynthesis. Water has **high specific heat**, **high heat of vaporization** and **high heat of fusion**. Due to this, it acts as **thermal buffer**. These various properties are due to hydrogen bonds between the water molecules.

Curiosity Box :

1. What is hydrogen bond?
2. What are the meanings of specific heat, heat of vaporization and heat of fusion?
3. What are adhesive and cohesive forces?

Water molecules have good adhesive and cohesive forces of attraction. Due to high surface tension and high adhesive and cohesive force, it can easily rise in the capillaries. It is therefore, a significant molecule that connects physical world with biological processes.

6.2 Water absorbing organ:

Root :

Root is the main organ of water and mineral absorption. In terestrial plants, plants absorb water in the form of liquid from the soil however, epiphytic plants like orchids absorb water vapours from air with the help of epiphytic roots having special tissue called **velamen**. Typical root is divisible into four different regions. In the zone of absorption, epidermal cells **(epiblema cells)** form unicellular hair like extensions called **root hairs**.

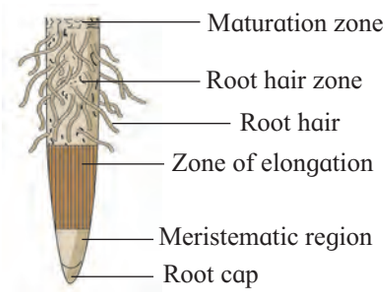

Fig. 6.1 a. : Root tip showing root hair zone

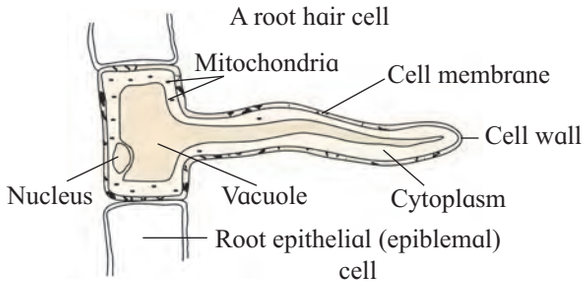

Fig. 6.1 b. : Structure of root hair

Structure of root hair :

Root hair is cytoplasmic extension (prolongation) of epiblema cell. Each root hair may be approximately 1 to 10mm long and tube like structure. It is colourless, unbranched, short-lived (**ephemeral**) and very delicate. It has a large central vacuole surrounded by thin film of cytoplasm, plasma membrane and thin cell wall, which is two layered. Outer layer is composed of pectin and inner layer is made up of cellulose. Cell wall is freely permeable but plasma membrane is selectively permeable.

6.3 Water available to roots for absorption:

Plants absorb water from the **rhizosphere (**the microenvironment surrounding the root). Water present in the soil occurs as gravitational (free) water, hygroscopic water, combined water and capillary water. Water percolates deep, due to the gravity, in the soil, is called '**gravitational water'**. This is not available to plants for absorption. Fine soil particles imbibe/ adsorb water and hold it. This is called '**hygroscopic water**'. Roots cannot absorb it. Water present in the form of hydrated oxides of silicon, aluminum, etc., is called '**combined water'**. It is also not available to plants for absorption. Some amount of water is held in pores present between the neighbouring soil particles, due to capillarity. This is called **capillary water** that is avilable for absorption.

6.4 Absorption of water by roots from soil:

Root hair absorbs water by employing three physical processes that occur sequentially- viz. **imbibition, diffusion and osmosis.**

a. Imbibition:

Imbibition is swelling up of hydrophillic colloids due to adsorption of water. Substance that adsorbs water / liquid, is called as **imbibant** and water/ liquid, that gets imbibed is called as **imbibate**. The root hair cell wall is made up of pectic compounds and cellulose which are hydrophillic colloids. During Imbibition, water molecules get tightly adsorbed without the formation of solution. Imbibition continues till the equilibrium is reached. In other words, water moves along the concentration gradient.

Imbibition is significant in soaking of seeds, swelling up of dried raisins, kneading of flour etc.

Use your brain power

Why do the wooden doors become very hard to close and open in rainy season?

b. Diffusion: Diffusion means to disperse. Diffusion can be defined as the movement of ions/ atoms/ molecules of a substance from the region of their higher concentration to the region of their lower concentration. The movement is due to the kinetic energy of the molecules. Diffusion continues till an equilibrium is reached. Thus, water passes into the cell by diffusion through a freely permeable cell wall. Water is now at the interface of cell wall and plasma membrane.

Diffusion results in the diffusion pressure (D. P.) which is directly proportional to the number of diffusing particles. Diffusion pressure of pure solvent (pure water) is always

Activity :

Try this at your home.

A. Take 10 ml of pure water in a suitable glass vessel and put 2 - 3 raisins in it. Observe the changes in raisins since the time you put them in water till they become fully swollen i.e. turgid. Why did raisins become turgid?

B. Take 10 ml of pure water and add 5 gms of either sugar or salt to it. Let it dissolve and then put the same turgid raisins in it and observe the changes in raisins. What changes did occur in raisins and why? Discuss your observations with your teachers.

more than the diffusion pressure of solvent in a solution. The difference in the diffusion pressures of pure solvent and the solvent in a solution is called **Diffusion Pressure Deficit** (DPD) or **Suction Pressure** (SP). The term was coined by B.S. Meyer (1938). Now a days, term **water potential** is used for DPD. In colloquial language, the term DPD is actually the thirst of a cell with which it absorbs water from the surroundings. Water arround cell wall has more diffusion pressure than cell sap. Due to this, water moves in the cell by diffusion. Diffusion is significant in plants in the absorption of water, minerals, conduction of water against the gravity, exchange of gases and transport and distribution of food.

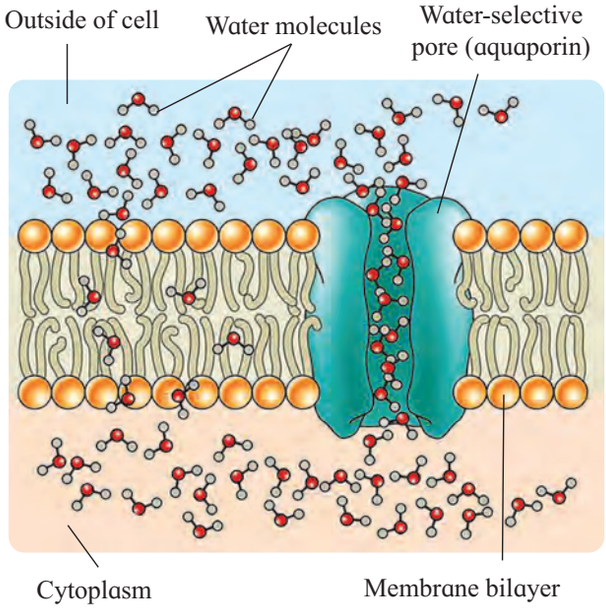

Fig. 6.2 : Diffusion of water into plant cell across the plasma membrane

Use your brain power

1. When you burn an incense stick in one corner of room, its fragrance spreads all over the room in a short time. How does it happen?
2. How does the water come out through the surface of porous earthen pot?

c. Osmosis : It is a process by which water enters into the cytoplasm of the root hair cell. Osmosis is a special type of diffusion of solvent through a semipermeable membrane. The cytoplasm of root hair cell contains minerals, sugars, etc. In other words, solution inside the cell is more concentrated (stronger) than outside the cell (weaker). Therefore, solvent from weaker solution enters into cytoplasm (i.e. to stronger solution) of cell through a semipermiable plasma membrane. This migration of solvent is called **Osmosis**.

Thus, water at the interface of cell wall and plasma membrane, enters into the cytoplasm of the root hair cell due to osmosis.

With respect to the concentration and osmotic migration, three types of solutions are recognized viz,

i. **Hypotonic** (weak solution or strong solvent) having low osmotic concentration.
ii. **Hypertonic** (strong solution or weak solvent) having high osmotic concentration.
iii. **Isotonic** having such a concentration of solution where there is neither gain nor loss of water in an osmotic system. In other words, concentration outside and inside the cell is same.

Osmosis is of two types viz, Exosmosis and Endosmosis.

Exosmosis : It is the diffusion of solvent from the cell outside. It causes flaccidity of cell.

Endosmosis : It is the diffusion of the solvent into the cell. It causes turgidity of cell i.e. cytoplasm becomes turgid. Turgidity increases the **turgor pressure** (T. P.) of the cell. T. P. is the pressure exerted by turgid cell sap on to the cell membrane and cell wall. In a fully turgid cell, DPD is zero. Cell wall being thick and rigid, exerts a counter pressure on the cell sap. This is called **Wall pressure** (W. P.). In a fully turgid cell, T. P. = W. P. but operating in opposite direction.

Osmotic pressure (O. P.) : The pressure exerted due to osmosis is osmotic pressure.

Osmotic pressure is a pressure of the solution, which is required in opposite direction, so as to stop the entry of solvent molecules into the cell. More simply, osmotic pressure of a solution is equivalant to the pressure which must be exerted upon it to prevent flow of solvent across a semipermeable membrane.

Therefore, D. P. D. = O. P. - T. P.
($\because$ T. P. = W. P.)
$\therefore$ D. P. D. = O. P. - W. P.

In a flaccid cell, T. P. is zero $\therefore$ DPD = OP
In a turgid cell, DPD is zero $\therefore$ TP = OP

Do you know ?

Improtance of T. P. : It keeps cells and organelles stretched; provides support to the non-woody tissues; essential for cell enlargement during growth; maintains shape of cell and facilitates opening and closing of stoma.

Improtance of Osmosis : It is responsible for absorption of water into root; maintains turgidity of cell; facilitates cell to cell movement of water; offers resistance to drought, frost, etc; also helps in the drooping of leaflets and leaves in vicinity of "touch me not" plant.

Facilitated diffusion : The passive absorption of solutes when mediated by a carrier, is called Facilitated diffusion. Particles that are lipid soluble can easily diffuse through lipoproteinous cell membrane. The diffusion of hydrophilic solutes has to be facilitated because their diffusion across the membrane is difficult. Membrane proteins provide such sites for facilitated diffusion. These proteins are aquaporins and ion- channels. These proteins help move substances across membranes without the expenditure of energy. Concentration gradient must be present for the molecules to be diffused through facilitated diffusion.

6.5 Water Potential (ψ):

According to the principle of thermodynamics, every component of a system is having a definite amount of free energy which is used to do work. Osmotic movement of water is on the basis of free energy. Free energy per molecule in a chemical system, is called its **chemical potential**.

Chemical potential of water is called **water potential**. It is represented by Greek letter *psi* (ψ). Water potential of protoplasm is equal but opposite in sign to DPD. It has negative value. The unit of measurement is in bars/ pascals/ atmospheres.

Water potential of pure water is always zero. Addition of any solute in it, decreases its *psi* (ψ) value. Therefore, it has negative value.

D. P. D. is now termed as water potential.
O. P. is now termed as osmotic potential.
T. P. is now termed as pressure potential. It has always positive value.

Water always flows from less negative potential to more negative water potential (i.e. from high water potential area to low water potential area). Difference between water potential of the adjacent cells decides movement of water through plasmodesmata across the cells.

Factors affecting water absorption:

i. Presence of capillary water is essential.
ii. Rate of water absorption is maximum at soil temperature between 20^0 to 30^0C.
iii. High concentration of solutes in soil water reduces the rate of absorption of water.
iv. Poorly aerated soil shows poor absorption rate.
v. Increased transpiration accelarates the rate of absorption of water in the irrigated soil.

6.6 Plasmolysis:

Exo-osmosis in a living cell when placed in hypertonic solution, is called **plasmolysis**. During plasmolysis, protoplast of cell shrinks and recedes from cell wall. Thus, cell becomes

flaccid. In a plasmolysed cell, a gap is developed between cell wall and the protoplast. This gap is filled up by outer solution.

In a plasmolysed cell, T. P. is always zero. When such cell is placed in hypotonic solution, endo-osmosis occur, making cell turgid. This is called **deplasmolysis**. In a fully turgid cell T. P. = O. P. hence, DPD is always zero.

6.7 Path of water across the root (i.e. from epiblema upto xylem in the stelar region) :

Water is absorped by root hair cell through imbibition → diffusion → osmosis, sequentially. Consequently the cell becomes turgid. Its turgor pressure increases, but its DPD value decreases. However, the immidiately adjacent cortical cell inner to it, has more DPD value, because its O. P. is more. Therefore, cortical cell will suck water from the turgid root hair cell. It then becomes turgid. The flaccid root hair cell now absorbs water from soil.

Water from the turgid cortical cell is sucked by inner cortical cell and the process goes on. Thus, a gradient of suction pressure (DPD) is devloped from cells of epiblema to the cortex of the root. Consequently water moves rapidly across the root through loosely arranged living cells of cortex, followed by passage cells of endodermis (in monocot roots) and finally into the cell of pericycle. Protoxylem is in the close proximity with pericycle.

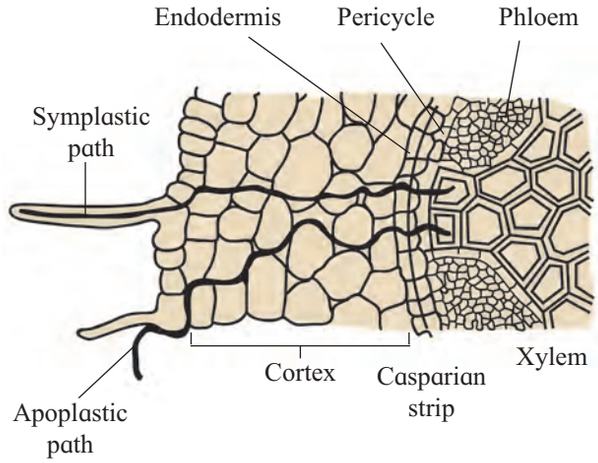

Fig. 6.3 : Pathways for water uptake by the root

Absorption of water being a continous process, a sort of hydrostatic pressure is developed in living cells of root. This is called **root pressure**. It is due to root pressure, water from pericycle is not only forced into the xylem, but also conducted upwards against the gravity.

Pathway of water across the root essentially occurs in two ways viz, **apoplast** and **symplast**.

Pathways
- **Apoplast**
- **Symplast**
  - **Vacuolar**
  - **Transmembrane**

When some amount of water passes across the root through the cell wall and the intercellular spaces of cortical cells of root, it is then called **apoplast pathway**. This pathway occurs up to endodermis.

The apoplastic (non-living) pathway provides a route toward the vascular stele through free spaces and cell walls of the epidermis and cortex. An additional apoplastic route that allows direct access to the xylem and phloem is along the margins of secondary roots. Secondary roots develop from the pericycle, a cell layer just inside the endodermis. The endodermis is characterized by the Casparian strip, a suberized layer that forces all to move in the symplast in order to enter the vascular system. Since secondary roots grow through the endodermis, a direct pathway to the xylem and phloem is available that bypasses the Casparian strip and allows to enter the vascular system without moving into the symplast (living tissue).

When water passes across from one living cell to other living cell through plasmodesmata, then it is called **symplast pathway**. It is also called transmembrane pathway.

6.8 Mechanism of absorption of water :

Mainly, there are two ways/ modes of absorption of water viz, passive absorption and active absorption.

a. Passive absorption :

It is the main way of absorbing water **through the roots** and **not by the roots** from soil into the plant. The driving force is transpiration pull and it thus proceeds through DPD gradient. There is no expenditure of energy (ATP) as water moves in accordance to the concentration gradient. Hence, it is passive absorption. About 98% of the total water absorbed in plants, occur passively. Passive absorption occurs during day time when transpiration is in progress. It stops at night when transpiration stops.

Rapid transpiration creates a tension in the xylem vessel due to negative water potential. This tension is transmitted to xylem in the roots. Consequently water is pulled upwards passively.

During passive absorption, no ATP is utilized. Obviously, the rate of respiration is not affected. In plants, water is mainly absorbed passively.

b. Active absorption :

Here, water is absorbed due to activity of roots. Root cells play active role in the absorption of water. The driving force is the root pressure developed, in the living cells of root. Active absorption occurs usually at night when transpiration stops due to closure of stomata. As water absorption is against the DPD gradient, there is expenditure of ATP (energy) generated through the respiratory activity of cells.

Active absorption may be of two kinds viz, osmotic and non-osmotic :

1. Osmotic absorption : Atkins and Priestly (1922) proposed that water is absorbed from soil into xylem of the root according to the osmotic gradient. To create osmotic conditions, there is an expenditure of energy. But such absorption does not directly require an expenditure of energy.

A gradient of DPD develops from cell of epiblema to pericycle due to activity of living cells of root. As the process is continuous, a hydrostatic pressure, called root pressure, is developed in root cells. This root pressure forces water from pericycle to xylem and then upwards to the stem.

2. Non-osmotic absorption : Kramer and Thimann (1959) proposed this theory. Sometimes, water is absorbed from soil against the concentration gradiant. Such absorption requires an expenditure of energy released during respiration, directly. Poor supply of oxygen retards water absorption. Moreover low temperature retards water uptake because of decrease in the rate of respiration. Use of metabolic inhibitors also retards the rate of respiration and thus the water uptake.

6.9 Translocation of water:

The transport of water with dissolved minerals from root to other aerial parts like stem and leaves, against the gravity, is called translocation or **ascent of sap**.

Translocation of water occurs through the lumen of conducting elements of xylem- tracheids and vessels, in all vascular plants. Ringing experiment has proved that xylem is the path of ascent of sap.

Several mechanisms/ theories have been put forth to explain the mechanism of translocation of water. The theories include- vital force theory, relay pump theory, physical force theory, root pressure theory, etc. We shall consider following three theories :

a. Root Pressure Theory (Vital Theory) :

According to this theory, the activity of living cells of root is responsible for translocation of water. J. Pristley proposed this theory. When a stem of potted plant is cut few inches above the soil by a sharp knife, xylem sap is seen flowing out/ oozing out through the cut end. This exudation at the cut end of stem is a good proof for the existence of root pressure. As water absorption by roots is constant and continous process, a hydrostatic pressure is developed in the living cells of cortex of root.

This is termed as **root pressure** by S. Hales. It is due to root pressure water along with dissolved minerals is not only forced into xylem but it is also conducted upwards against the gravity.

Root pressure seems to be largely an osmotic phenomenon and its development is an active process. The value of root pressure is +1 to +2 bars which is enough to pump water to a height of 10 to 20 meters. The factors like oxygen, moisture, temperature of soil, salt contents, etc. influence the root pressure.

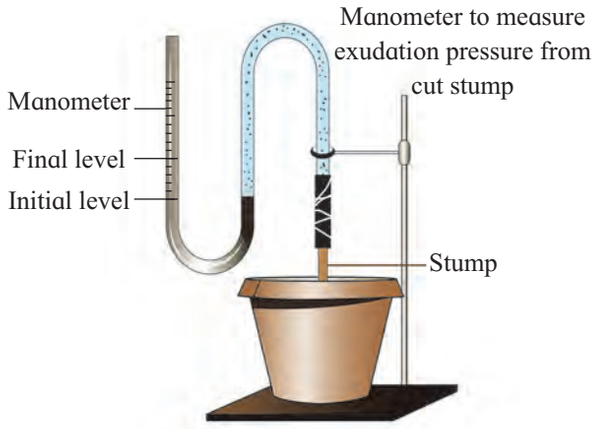

Fig. 6.4 : Experiment to demonstrate root pressure

Objections/ limitations of root pressure theory:

Although, ascent of sap takes place due to root pressure, there are certain objections raised, such as -

i. It is not applicable to plants taller than 20 meters.
ii. Ascent of sap can also occur even in the absence of root system.
iii. Root pressure value is almost nearly zero in taller gymnosperm trees.
iv. In actively transpiring plants, no root pressure is developed.
v. Xylem sap under normal condition is under tension i.e. it shows negative hydrostatic pressure or high osmotic pressure.

To sum up therefore, root pressure is not the sole mechanism explaining the ascent of sap in all plants of varying heights..

b. Capillarity theory (physical force theory):

According to this theory, physical forces and dead cells are responsible for ascent of sap.

This theory was put forth by Bohem in (1863). Wick dipped in an oil lamp, shows capillarity due to which oil is raised upwards. The conduction of water in a straw dipped in water, is raised to a certain height because of capillarity. The height to which water is raised depends on the diameter of the straw.

Capillarity is because of surface tension, and forces of cohesion (attraction between like molecules) and adhesion (attraction between unlike molecules). Xylem vessel/ tracheid with its lumen is comparable with straw. Water column exist because of combined cohesive and adhesive forces of water and xylem wall, due to capillarity. It is because of capillarity water is raised or conducted upwards against the gravity, to few centimeters only.

Objections/ Limitations of capillarity theory:

Few important objections are :

i. Capillary tube (xylem) must be continously and completely hollow from one end to the other end but tracheids in the xylem show closed end-walls.
ii. The lower end of capillary tube i.e. xylem must be in direct contact with soil water. However, there exists a barrier of root cortex between xylem and soil water.
iii. Narrower the capillary tube, greater is the height to which water column is raised. Thus, taller trees should show xylem vessels with very narrow bore (diameter). However, in nature the tall trees show xylem vessels having wider bore.

Hence, to sum up capillarity can not be the sole mechanism to explain ascent of sap in all the plants of varying heights.

c. Cohesion- tension theory (Transpiration pull theory) :

This is presently widely accepted theory explaining ascent of sap in plants. It was put

forth by Dixon and Jolly (1894). This theory is based on two principles.

Cohesion and adhesion, and transpiration pull :

A strong force of attraction between water molecules, is called **cohesive force**. While a strong force of attraction between water molecules and lignified wall of lumen of xylem vessel, is called **adhesive force**.

Due to combined cohesive and adhesive forces a continous water column is developed (formed) in the xylem right from root upto the tip of the topmost leaf in the plant.

Transpiration pull : The transpiration pull developed in the leaf vessel is transmitted down to root and thus accounts for the ascent of sap.

Excess water is lost in the form of vapour, mainly through the stomata found on leaf. This water loss increases D. P. D. of mesophyll cells. These cells withdraw water ultimately from xylem in the leaf. In otherwords, due to continous transpiration, a gradient of suction pressure (i.e. D. P. D.) is developed right from guard cells up to the xylem in the leaf. This will create a tension (called negative pull or transpiration pull) in the xylem. Consequently, water column is pulled out of xylem. Thus, water is pulled upwards passively against the gravity leading to the ascent of sap.

Objections/ Limitations of transpiration pull theory:

i. For transpiration pull to operate, water column should be unbroken and continous. However, due to temperature fluctuations during day and night, gas bubbles may enter in water column breaking the continuity.

ii. This mechanism assumes that tracheids are more efficient than the vessels, as their end walls support water column.

However, vessels are more evolved than tracheids and are more efficient.

iii. If plant leaves are smeared with vaseline in order to stop transpiration, even then ascent of sap occurs.

iv. Ascent of sap also occurs in deciduous plants that have shed all of their leaves.

These observations point to the fact that besides physical forces, activity of living cells seems to be necessary for lifting the water column up.

6.10 Transport of mineral ions :

Soil serves as main source for minerals. Minerals constitute most commonly occuring solid, crystalline inorganic materials obtained from earth's crust. Minerals play an important role in the day to day life of plant. Minerals are absorbed by plants in the ionic (disolved) form, mainly through roots and then transported.

Do you know ?

- Minerals that play important role in the day to day life, are called essential elements. About 36 to 40 elements are incorporated in the plant's life.
- Some minerals like C, H, O, P, N, S, Mg required in large quantity, are called **macro elements**. While minerals like Cu, Co, Mn, B, Zn required in small quantity, are called **micro elements**.

The analysis of plant ash demonstrates that minerals are absorbed by plants from soil and surroundings. Absorption of minerals is independent of that of water.

Absorbed mineral ions are pulled in upward direction along with xylem sap because of transpiration pull. This could be understood when the ascending sap is analysed. Mineral ions are needed in the areas of the plant viz. apical, lateral, young leaves, developing flowers, fruits, seeds and storage organs. Hence, from the source (root), these are pulled and transported ascendingly through the sap and gets unloaded by fine veins through the

process of diffusion in the vicinity of cells. Cells uptake them actively.

Soil would not be the only source for mineral uptake. Mineral ions can be remobilized within the parts of the plant. Older parts (like leaves in deciduous plants) export their ions to younger leaves before the fall. Most readily mobilized ions are like phosphorus, sulphur, nitrogen and potassium but the ions from structural components like calcium is not remobilized.

Internet my friend

1. The general roles of minerals in the life of plants.
2. The role of essential minerals in the day to day life of plants.

Analysis of xylem exudate also shows that some nitrogen travels as inorganic ions whereas much of it is carried in the organic form like amino acids and related compounds. Small amount of inorganic molecules of phosphorus and sulphur are also carried. It was a belief earlier that xylem transports inorganic and phloem transports organic molecules. However, it is not correct because some exchange of materials also occurs between xylem and phloem.

Do you know ?

- Different modes of passive absorption and active absorption of minerals in plants.
- Carrier concept of active absorption.

6.11 Transport of food :

All the plant parts require continous supply of food (photosynthate) for nutrition and developement. In higher plants, there is a great differentiation and division of labour. Chloroplasts are confined to green cells of leaves where food is synthesized. The non-green parts like root and stem must received food from leaves. The part where food is synthesized is called **source** and while part where it is utilized, is called **sink**. Food has to travel from source to sink. This movement of food from one part to the other part, is called translocation of food.

Path of translocation : Food is to be translocated to longer distances in higher plants. Hence plants must have adequate channels for the transport of food. Sieve tubes and vessels are structurally ideally suited for longitudinal (vertical) translocation. The ringing experiment, structure and distribution of phloem, chemical analysis of phloem sap and use of isotope ^{14}C, clearly point out that the phloem tissue is primarily responsible for flow of food in longitudinal downward direction. The horizontal (lateral) translocation occurs from phloem to pith or phloem to cortex via medullary rays in the stem.

Food is always translocated in the form of **sucrose** (soluble form) and always along the concentration gradient from source to sink. The transport of food occurs in **vertical** and **lateral** direction.

Vertical translocation : In vertical (longitudinal) transport, food is translocated in downward direction from leaves (source) to stem and root (sink). It also occurs in upward direction during germination of seed, bulbils, corm, etc. Upward translocation also occurs from leaves to growing point of stem, to developing flowers and fruits situated near the ends of the branches of stem.

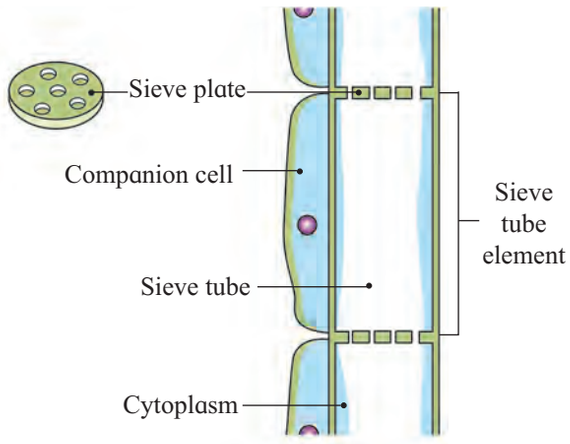

Fig. 6.5 : L. S. of sieve tube

Lateral translocation : It occurs horizontally/ laterally across the root and stem. When food is translocated from phloem to pith, it is called **radial** translocation and from phloem to cortex, it is called **tangential** translocation.

The transport of food through phloem is **bidirectional**. Phloem sap contains mainly water and food in the form of sucrose. But sugars, amino acids and hormones are also transported through phloem.

Mechanism of sugar transport through phloem :

Several mechanisms/ theories like diffusion, activated diffusion, protoplasmic streaming, electro-osmosis, pressure-flow, etc. are put forth. The most convincing theory is Munch's pressure flow theory or mass flow hypothesis.

Ernst Munch proposed that photosynthetic cell synthesizes glucose. Hence, its osmotic concentration increases. Due to endo-osmosis water from surrounding cells and xylem, is absorbed. The cell becomes turgid. Due to increase in turgor pressure, sugar from photosynthetic cell is forced ultimately into the sieve tube of the vein. This is called **loading of Vein**.

At the sink end, root cell utilizes sugar and also polymerizes excess sugar into the starch. Its osmotic concentration is lowered. Exo-osmosis occurs. Water in the root cell is lost to surrounding cells, thereby decreasing the turgidity of cell. Turgor pressure is lowered. Hence, a turgor pressure gradient is developed from sieve tube in the leaf to the root cell. Consequently, food is translocated along the concentration gradient, passively. This is **Vein unloading**. At the sink end sugar is used and excess water exudes into the xylem.

Main objection to this theory is that this mechanism does not explain bidirectional transport of food. More over, according to Munch, pressure flow is purely a physical process.

6.12 Transpiration :

Plants absorb water constantly and continously. Hardly 5% of the total water absorbed by roots that is utilised for cell expansion and plant growth. Remaining 95% water becomes surplus which is then lost into the atmosphere, through its aerial parts. Hardly 1% of surplus water is lost in the form of liquid and 99% of surplus water, is lost in the form of vapour. The loss of water in the form of liquid is called **guttation**. It occurs through special structures called water stomata or **hydathodes**. The loss of water in the form of vapour is called **transpiration** that occurs through leaves, stem, flowers and fruits. Most of the transpiration occurs through the leaves (called foliar transpiration). The actual water loss during transpiration occurs through three main sites - **cuticle**, **stomata** and **lenticels**. Accordingly, three types of transpiration are recognized viz. cuticular, stomatal and lenticular.

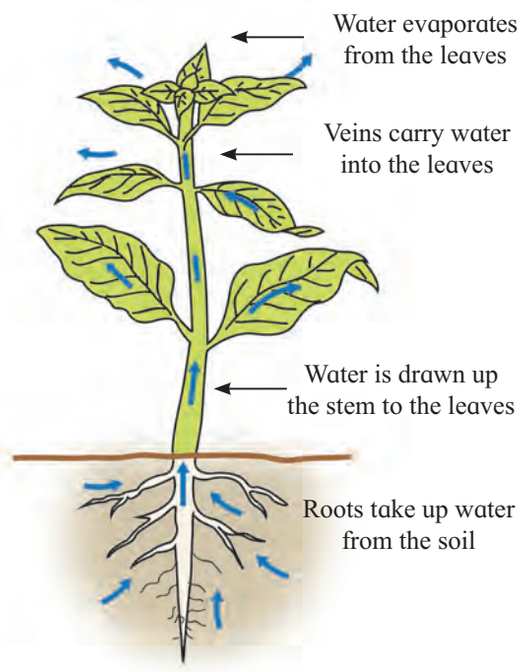

Fig. 6.6 : Transpiration

i. Cuticular transpiration:

Cuticle is a layer of waxy substance- cutin, present on outer surface of epidermal cells of leaves and stem. Cuticular transpiration occurs by simple diffusion and contributes 8-10% of the total transpiration. Cuticular transpiration

occurs throughout the day and its rate is inversely proportional to thickness of cuticle.

ii. Lenticular transpiration:

Lenticels are small raised structures composed of loosely arranged complementary cells. Each lenticel is a porous tissue consisting of cells with large intercellular spaces in the periderm of the secondarily thickened organs and the bark of woody stems and roots of dicotyledonous flowering plants. Lenticels are present in bark of old stem and pericarp of woody fruits but are absent in leaves. Lenticular transpiration contributes only about 0.1-1.0% of total transpiration. Rate of

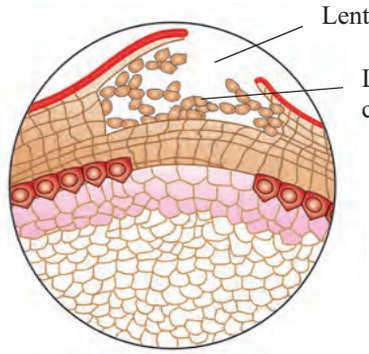

Fig. 6.7 : Structure of lenticel

lenticular transpiration is very slow. It also occurs throughout the day.

iii. Stomatal transpiration:

Stomata are minute apertures formed of two guard cells and accessory cells. They are located in the epidermis of young stem and leaves. Leaves generally show more number of stomata on the lower surface. Depending upon distribution of stomata on leaves, leaves are categorized into three types namely **epistomatic-** on upper epidermis (Hydrophytes- e.g. Lotus), **hypostomatic**- on lower epidermis (Xerophytes- e.g. *Nerium*) and **amphistomatic-** on both surfaces (Mesophytes- e.g. Grass). Stomatal transpiration occurs only during daytime. (Exception: Desert plants).

90 to 93% of total transpiration occurs through stomata and that too during day time only.

Do you know ?

- The number of stomata per unit area of leaf, is called **stomatal frequency**.
- The correlation between the number of stomata and number of epidermal cells per unit area, is called **stomatal index (I)**.

6.13 Structure of stomatal apparatus :

Typical stomatal apparatus consists of two **guard cells**, **stoma** and **accessory cells**.

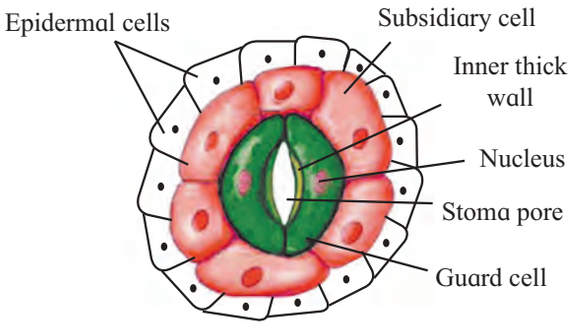

Fig. 6.8 (a) : Structure of guard cell

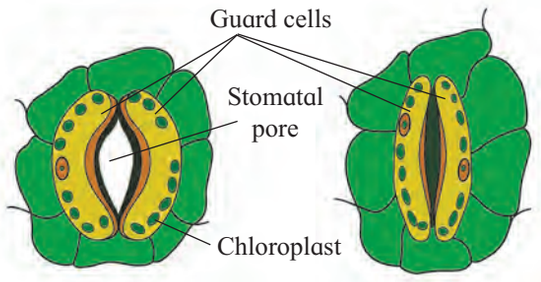

Fig. 6.8 (b) : Open and closed stoma

Stomata are minute, elliptical pores bounded by two kidney/ dumbbell shaped **guard cells**. Guard cell is a type of epidermal tissue which may be called as modified, epidermal parenchyma cell. They are kidney-shaped in dicotyledons and dumbbell-shaped in grasses (monocotyledons/monocots).

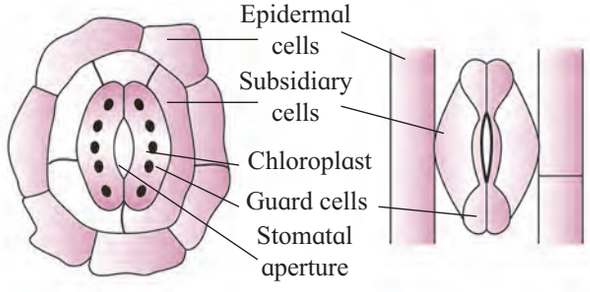

Fig. 6.9 : Types of guard cells

In *Cyperus*, both kidney- and dumbbell-shaped guard cells are present.

Guard cells are living, nucleated cells with unevenly thick walls. Inner wall (wall facing stoma) of guard cells is thick and inelastic, and its lateral (outer) wall is thin and elastic. Guard cells contain few chloroplasts which are capable of poor photosynthesis. Guard cells have ability to change their size and form due to which stoma opens (widens) or closes (narrows).

Stoma is an elliptical pore formed due to specific arrangement of guard cells. It is through the stoma, excess water is lost in the form of vapour.

Accessory cells : These are specialized epidermal cells surrounding the guard cells. Their number is variable and are the reservoirs of K^+ ions. These are also called **subsidiary cells**.

Opening and Closing of Stoma :

Opening and closing of stoma is controlled by turgor of guard cells. During day time, guard cells become turgid due to endosmosis. Thus turgor pressure is exerted on the thin walls of guard cells. Being elastic and thin, lateral walls are stretched out. Due to kidney or dumb-bell like shape, inner thick walls are pulled apart to open (widen) the stoma. During night time, guard cells become flaccid due to exosmosis. Flaccidity closes the stoma almost completely. Endosmosis and exosmosis occur due to diurnal changes in osmotic potential of guard cells. Different theories are proposed to explain diurnal changes in osmotic potential.

According to **starch-sugar inter-conversion theory** (Steward 1964), during day time, enzyme phosphorylase converts starch to sugar, thus increasing osmotic potential of guard cells closing entry of water thereby guard cells are stretched and stoma widens. The reverse reaction occurs at night brining about the closure of stoma.

Phosphorylase (Day)

Starch ⟶ ⟵ **Sugar**

Night

(Stoma closes) **(Stoma opens)**

According to theory of proton transport (Levitt-1974), stomatal movement occurs due to transport of protons H^+ and K^+ ions. During daytime, starch is converted into malic acid. Malic acid dissociates to form Malate and protons. Protons are transported to subsidiary cells and K^+ ions are imported from them. Potassium malate is formed that increases osmolarity and causes endosmosis. Uptake of K^+ ions is always accompanied with Cl^- ions.

At night, uptake of $K^+$and Cl^- ions is prevented by abscissic acid, changing the permeability of guard cells. Due to this guard cells become hypotonic and thereby become flaccid.

Significance of Transpiration :

Advantages:

i. It removes excess of water.

ii. It helps in the passive absorption of water and minerals from soil.

iii. It helps in the ascent of sap.

iv. As stomata are open, gaseous exchange required for photosynthesis and respiration, is facilitated.

v. It maintains turgor (turgidity) of the cells.

vi. Transpiration helps in reducing the temperature of leaf and in imparting cooling effect.

Disadvantages:

Excessive transpiration leads to wilting and injury in the plant. It may also lead to the death of the plant.

Transpiration is 'A necessary evil' :

For stomatal transpiration to occur, stoma must remain open, during day time. When stomata are open then only the gaseous exhange needed for respiration and photosynthesis, will take place. If stomatal transpiration stops, it will directly affect productivity of plant through the loss of photosynthetic and respiratory activity. Hence for productivity, stomata must remain open. Consequently transpiration can not be avoided. **Hence, Curtis (1926) regarded transpiration as 'a necessary evil'**.

Activity :

Prepare stomatal frequency chart for any six angiospermic plants in your area.

Plant Name	Details

Exercise

Q. 1 Multiple Choice Questions

1. In soil, water available for absorption by root is .....
   a. gravitaional water
   b. capillary water
   c. hygroscopic water
   d. combined water

2. The most widely accepted theory for ascent of sap is .....
   a. capillarity theory
   b. root pressure theory
   c. diffusion
   d. transpiration pull theory

3. Water movement between the cells is due to .....
   a. T. P. b. W. P.
   c. D.P.D. d. incipient plasmolysis

4. In guard cells, when sugar is converted into starch, the stomatal pore .....
   a. closes almost completely
   b. opens partially
   c. opens fully
   d. remains unchanged

5. Surface tension is due to .....
   a. diffusion b. osmosis
   c. gravitational force d. cohesion

6. Which of the following type of solution has lower level of solutes than the solution?
   a. Isotonic b. Hypotonic
   c. Hypertonic d. Anisotonic

7. During rainy season wooden doors warp and become difficult to open or to close because of .....
   a. plasmolysis b. imbibition
   c. osmosis d. diffusion

8. Water absorption takes place through .....
   a. lateral roots b. root cap
   c. root hair d. primary root

9. Due to low atmospheric pressure the rate of transpiration will .....
   a. increase
   b. decrease rapidly
   c. decrease slowly
   d. remain unaffected

10. Osmosis is a property of .....
    a. solute b. solvent
    c. solution d. membrane

Q. 2 Very short answer questions.

1. What is osmotic pressure?
2. Name the condition in which protoplast of the plant cell shrinks.
3. What happens when a pressure greater than the atmospheric pressure is applied to pure water or a solution?
4. Which type of solution will bring about deplasmolysis?
5. Which type of plants have negative root pressure?
6. In which conditions transpiration pull will be affected?
7. Mention the shape of guard cells in *Cyperus*.
8. Why do diurnal changes occur in osmotic potential of guard cells?
9. What is symplast pathway?

Q. 3 Answer the following questions.

1. Describe mechanism for absorption of water.
2. Discuss theories of water translocation.
3. What is transpiration? Describe mechanism of opening and closing of stomata.

4. What is transpiration? Explain role of transpiration.
5. What is significance of transpiration? Explain root pressure theory and its limitations.
6. Explain capillarity theory of water translocation.
7. Why is transpiration called ‘a necessary evil’?
8. Explain movement of water in the root.
9. Define and or explain the terms: Osmosis, diffusion, plasmolysis, imbibition, guttation, transpiration, ascent of sap, active absorption, DPD, turgor pressure, water potential, wall pressure, root pressure.
10. Distinguish between a) Osmotic pressure and turgor pressure b) Diffusion and osmosis.

Q. 4 Long answer questions.

1. Describe structure of root hair.
2. Write on journey of water from soil to xylem in roots.
3. Explain cohesion theory for translocation of water.
4. Write on the mechanism of opening and closing of stoma.
5. Explain the active absorption of minerals.

Project :

1. Prepare powerpoint presentation for different types of transpiration.