Chapter 2 : Absorption, Transport and water loss in plants (water and nutriments in plant)

Water is the most important component on earth. It can exist in three states : solid, liquid and vapour. Water covers around 70% of earths surface. The life on earth cannot exist without water. Water chemically made up of hydrogen and oxygen.

Water is the most important component of living cells. It enters the plants through roots and then moves to other parts. It is also lost by transpiration through the aerial parts of plants, mainly through the leaves. There are several phenomena involved in the movement of water about which you will study in this lesson.

Importance of water to plants

1. Water is the main constituent of protoplasm (about 90-95%).
2. Water serves as a medium of translocation of minerals from the soil and the food manufactured by the leaves in plants.
3. Most of the metabolic reactions take place in the medium containing water. The presence of water is an essential factor for enzyme activity.
4. Water is one the raw material for photosynthesis.
5. Water is one of the by product of cellular respiration. Rate of respiration is greatly influenced by the availability of water.
6. Many plant movements are controlled by water. Ex. Opening and closing of stomata and flowers, dehiscence mechanism of fruits is controlled by water.
7. Water is essential for germination of seed and pores.
8. water is essential to keep the cell turgid. Turgidity is the first step towards growth.

Objectives

After completing this lesson, you will be able to :

- define the terms permeability, diffusion, osmosis and plasmolysis.
- define and differentiate between the active and passive absorption.
- explain imbibition, water potential, turgor pressure and wall pressure, wilting.
- describe the pathways of water from root hair up to leaf.
- describe the mechanism of translocation of solutes in plants.

1. Concept of water relations

The transport of substance with in the plants and environment take place by physical processes like diffusion, osmosis and imbibition.

Permeability : Permeability is the property of a membrane to allow the passage of the substances through it. The plant cell wall is permeable because it allows both solvent and solute molecules to pass through it. Cuticle layer is impermeable. All biological membranes (cell membrane, mitochondrial membrane, nuclear membrane etc.) are selectively permeable as they allow penetration of only solvent molecules but not the solute molecules.

1.1. Diffusion :

The movement of molecules or ions of solid, liquid and gas from the higher concentration region to their lower concentration region by utilizing inborn kinetic energy (intrinsic energy) is known as diffusion.

Example:

- When a crystal of $CuSO_4$ (Potassium manganate) is placed in a beaker containing water for some time it becomes purple colour due to the diffusion of $CuSO_4$ molecules in the medium of water.
- When a incense is burn in one of the corner of closed room the scent is perceived at the other end of the room.

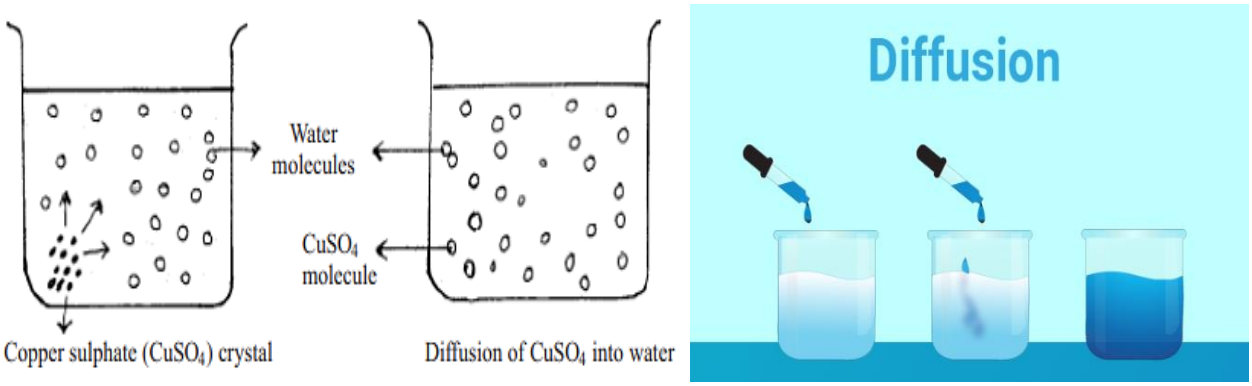


Fig. 1 : Diffusion of Copper Sulphate ($CuSO_4$) in water.

Diffusion pressure (DP):

The pressure exerted by the kinetic activity of diffusing particle is called Diffusion pressure (DP). In the plant body chemical molecule or ions move from one cell to the other along their concentration gradient and diffusion pressure gradient.

Importance of diffusion in plant

- Cell to cell movement of substance is done through diffusion.
- It is also responsible for loss of water through the plant surface during transpiration.
- The exchange of gases such as O_2 and CO_2 during photosynthesis and respiration is due to diffusion.

1.2. Osmosis

« Diffusion of water molecule from lower concentrated solution region to the higher concentrated solution region through the semipermeable membrane is called Osmosis ».

Or : « Diffusion of water from the solution with higher water potential to the solution with lower water potential through the semipermeable membrane is called Osmosis ».

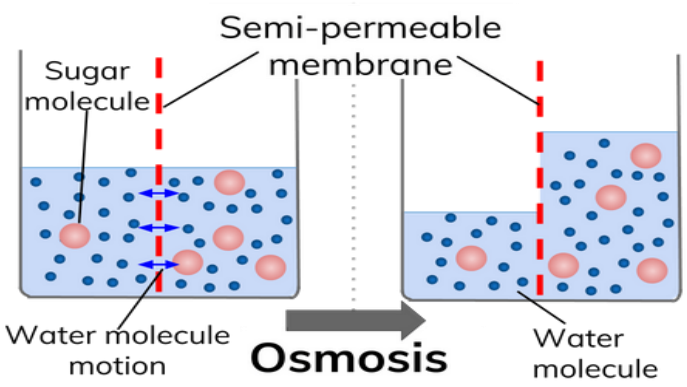


Fig. 2 : Osmosis - Movement of water molecules through a semipermeable membrane.

➢ **Osmotic pressure (OP):**

The pressure by which osmotic entry of the water into the solution through the semipermeable membrane can be prevented is called osmotic pressure.

➢ **Membrane of plant cells :**

There are three kinds of membranes in living plant cells :

a. Permeable membrane: It allows free movement of both solutes and solvent molecules. Ex: Cellulose cell wall.

b. Impermeable membrane: The membrane which prevents the passage of both solvents and solute molecules. Ex: Suberised walls of cork cells and cutinized walls of epidermal cells.

c. Semi-permeable membrane: A membrane which permits only the solvent molecules to pass through and not solute molecules is called semi-permeable membrane. Ex: cell membranes of all organisms.

d. Selectively permeable membrane: The membrane which allows all solvent particles and some selected solute particle to pass through it at different rate is called selectively permeable membrane. Ex: Plasma membrane of the cell, Tonoplast of the vacuole in the cell.

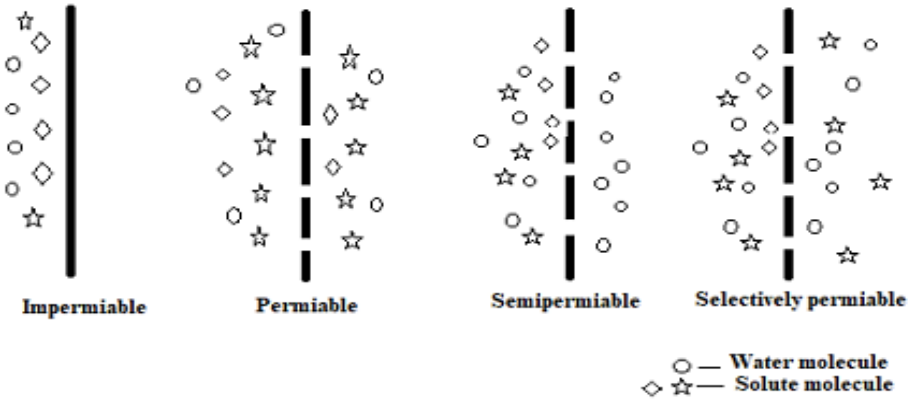


Fig. 3 : different types of membrane

- **Types of osmosis:**

1. Endosmosis: Diffusion of water inside the cell across the plasma membrane is called endosmosis. It takes place when the plant cell is place in water (or) in hypotonic solution.

2. Exosmosis: Diffusion of water out of the cell across the plasma membrane is called exosmosis. It takes place when the plant cell placed in hypertonic solution.

- **Types of solution based on the concentration**

1. Hypotonic solution: External solution whose concentration is less than the concentration of the cytoplasm of the cell is called hypotonic solution.

2. Hypertonic solution: External solution whose concentration is more than the concentration of the cytoplasm of the cell is called hypertonic solution.

3. Isotonic solution: external solution whose concentration is equal to the concentration of cytoplasm of the cell is called isotonic solution.

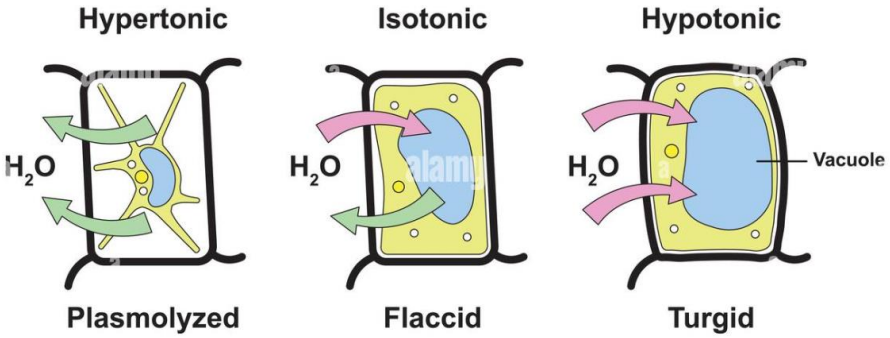


Fig.4 : Osmosis and Turgor Pressure in Plant Cells

Plasmolysis: Shrinkage of protoplasm in the cell due to exosmosis is called plasmolysis and such cell is called plasmolysed cell. Plasmolysis takes place when the plant cell is placed in hypertonic solution.

Deplasmolysis: Regaining of normal condition by the plasmolysed cell due to endosmosis is called Deplasmolysis. Deplasmolysis takes place when the plant cell is placed in hypotonic solution or water.

Turgor pressure (TP): The hydrostatic pressure which is developed inside the cell due to osmotic entry of water is called Turgor pressure. Turgor pressure pushes protoplast against the cell wall and keep the cell in turgid condition.

Wall pressure (WP): The counter pressure exerted by the cell wall on the protoplasm to resist the turgor pressure is called wall pressure.

- **Importance of Osmosis**

• It is involved during absorption of water from the soil by the root hairs.

• It is also involved during cell to cell diffusion of water in the plant body.

- **Difference between Diffusion and Osmosis**

Diffusion	Osmosis
1. Diffusion is the movement of a given substance from the place of its higher concentration to an area of its lesser concentration, irrespective of whether separated or not separated by a semipermeable membrane.	1. Osmosis is a special type of diffusion of solvent molecules such as water from lower concentration of solution to higher concentration of solution when the two are separated by a semi permeable membrane.
2. The diffusion may occur in any medium. The moving particles may be solid, liquid or gas.	2. It occurs in liquid medium and only the solvent molecules such as water move from one place to another.

Osmotic Pressure and Osmotic Potential

When pure water is separated from a solution by a semipermeable membrane, pure water tends to enter the solution by osmosis. Now the maximum pressure required to prevent the osmotic entry of water in a solution even though the concentration of water in the solution is low as compared to that in pure water, is called **osmotic pressure**.

1.3. Imbibition

The absorption of water by dry hydrophilic colloidal substance is know imbibant and the process is known as imbibition. The pressure exerted by the imbibant due to the imbibition is called imbibitional pressure (IP).

Exemple : Before cooking chick pea or gram, it is soaked in water overnight. Next morning the dry chick pea looks well swollen as it has imbibed water.

Imbibition in plant cells refers to the **absorption** and adsorption of water by protoplasmic and cell wall constituents. Water is absorbed as a result of both diffusion and capillary action. Imbibition is a process that accounts for only when solid plant material (dry wood, dead or living air dried seeds) comes in contact with water. In case of living dry seeds water is initially adsorbed by imbibition and thereafter water entering into the inner tissues, is absorbed by osmosis. Imbibition produces a large pressure, so much so that dry wood can even break a piece of rock in the presence of water. Because of imbibition, the wooden doors, during rainy season, swell up and it becomes difficult to close the door.

- **Importance of Imbibition**

• It is involved during the absorption of water by dry seed coat of the seed during its germination.

• It is also involved during transport of water through the cell wall in the plant body.

- **Water potential**

Utilizable form of kinetic energy of a molecule in the system is called free energy. Free energy with respect to chemical is called chemical potential. Chemical potential with respect to water is called water potential.

The difference in chemical potential or free energy of pure water and chemical potential or free energy of water in the solution or cell is called water potential. Water potential is represented by Greek letter Ψ (Psi) and its value is expressed in terms of base or pascal.

- **Component of water potential:** Water potential of the cell is determined by the following three components :

1. Matrix potential (Ψm): The amount of pressure by which water potential of the cell is reduced due to presence of colloids is called matrix potential. It is expressed in terms of base of negative sign (-base).

2. Solute potential (Ψs): it is also called osmotic potential. The amount of pressure by which water potential of the cell is reduced due to dissolved solutes is called solute potential. It is expressed in terms of base of negative sign (-base).

3. Pressure potential: The amount of pressure by which water potential of the cell is increased due to the turgor pressure developed inside the cell. It is expressed in terms of positive sign (+base).

$$WP = \Psi p + \Psi s$$

In a turgid cell Ψ_s and Ψ_p will be same. There is no net movement of water. $\Psi_w=0$.

In a flaccid cell $\Psi p=0$, Hence $\Psi_w= \Psi_s+0$ that is, $\Psi_w= \Psi_s$.

2. Absorption of water by plants

Soil is the major source of water for plants. The root system is the principal organ for water absorption. Soil water is also called rhizic water. There are three main types of soil water - gravitational water, capillary water, and hygroscopic water - and these terms are defined based on the function of the water in the soil.

• **Gravitational Water:** Gravitational water is free water moving through soil by the force of gravity. It is largely found in the macropores of soil and very little gravitational water is available to plants as it drains rapidly down the water table in all except the most compact of soils.

• **Capillary Water:** Capillary water is water held in the micropores of the soil, and is the water that composes the soil solution. Capillary water is held in the soil because the surface tension properties (cohesion and adhesion) of the soil micropores are stronger than the force of gravity. However, as the soil dries out, the pore size increases and gravity starts to turn capillary water into gravitational water and it moves down. Capillary water is the main water that is available to plants as it is trapped in the soil solution right next to the roots if the plant.

• **Hygroscopic Water:** Hygroscopic water forms as a very thin film surrounding soil particles and is generally not available to the plant. This type of soil water is bound so tightly to the soil by adhesion properties that very little of it can be taken up by plant roots. Since hygroscopic water is found on the

soil particles and not in the pores, certain types of soils with few pores (clays for example) will contain a higher percentage of it.

2.1. Structure of root hair

A root hair is a delicate prolongation of the outer wall of a cell of proliferous layer of root. It has a cell wall of two layers. Outer layer is composed of hydrophilic pectic compounds and inner layer is cellulose, materials have greater capacity to imbibe water. Inner to cell wall is present plasma membrane which enclosed the cytoplasm a large vacuole filled with cell sap and the nucleus. Root hair cell sap is stronger than the surrounding soil solution. The plasma membrane cells are selective permeable membrane.

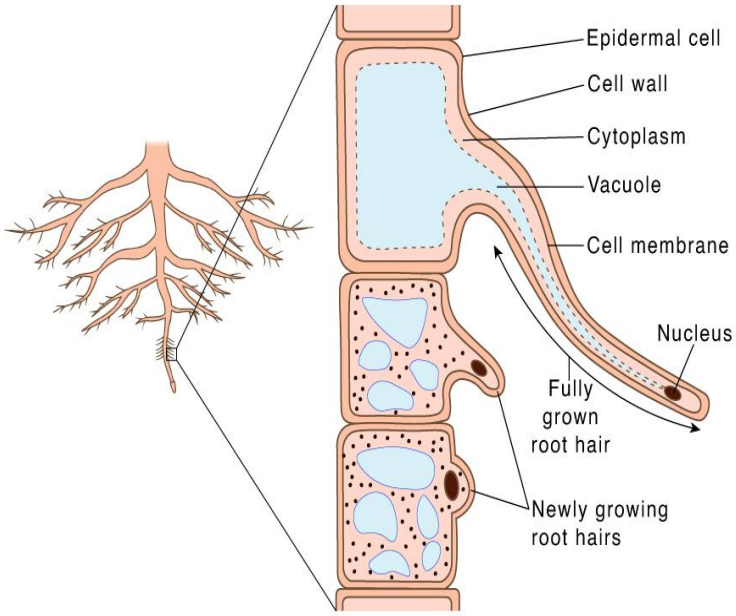


Fig.5 : structure of root hair

2.2. Concept of symplast and apoplast

- **Symplast:** The term is used to describe protoplast of living cells. It is represented by the cytoplasm of all the living cells in a plant body connected to each other through the plasmodesmata.
- **Apoplast:** The term is used to describe the protoplast of dead cells. It is represented by the inner connected cell wall, intercellular spaces, cell wall of endodermal cells containing casparian thickening, cell walls of the cells in the pericycle and was of the xylem tracheids and vessels. The apoplast is continues throughout the plant body.

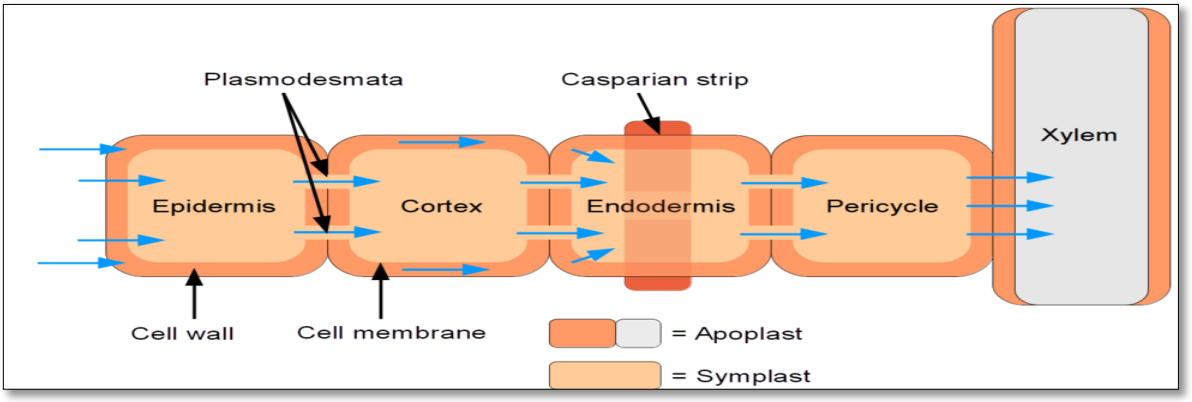
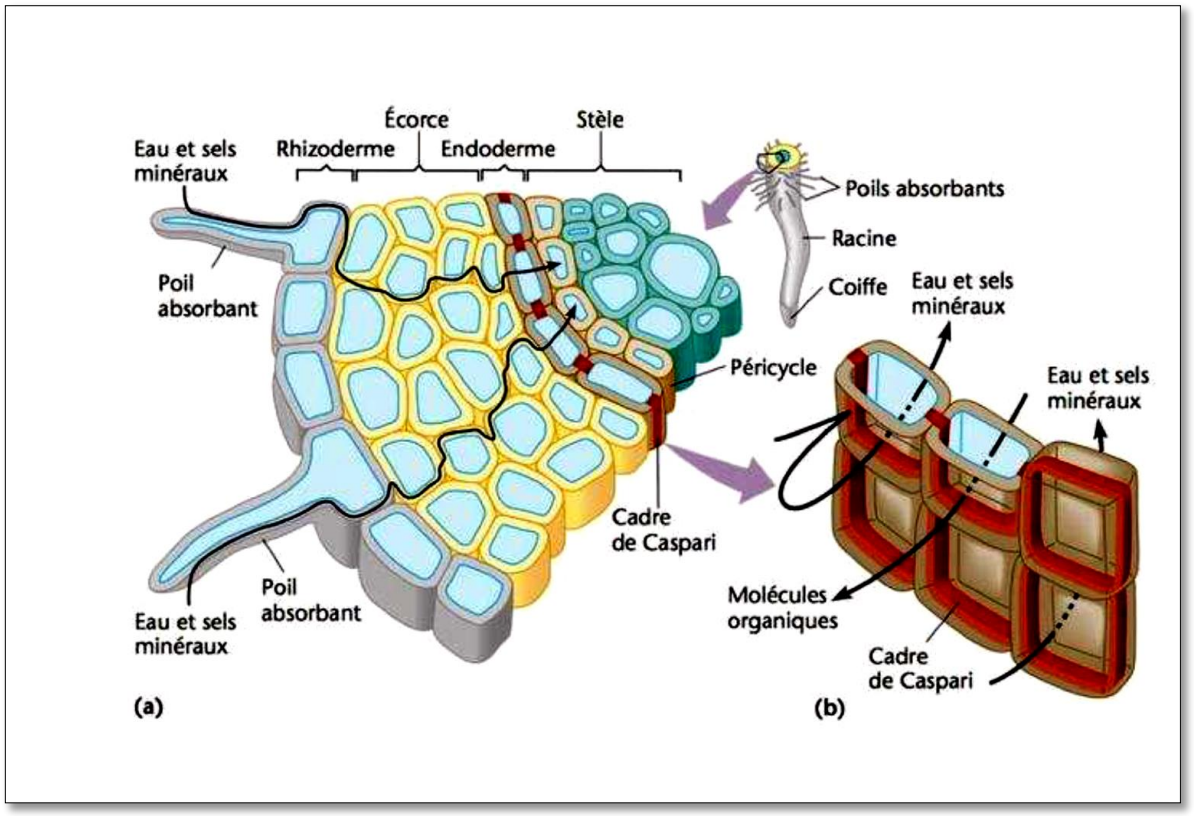


Fig.6 : concept of symplast and apoplast



2.3. Mechanism of absorption of water : There are two mechanisms of absorption of water :

1. Active absorption of water.
2. Passive absorption of water.

2.3.1. Active absorption of water : This is a process in which cells expand metabolic energy. This process occurs in roots. Root hair is intimate contact with water films in the particles. The cell sap of root hair has high osmotic pressure. The soil solution is hypotonic to cell sap and has higher water potential. Due to the difference in water potential soil water moves into roots by endosmosis. The mechanism which brings about the absorption of water osmotically active root hair cells is called active absorption. This mechanism requires metabolic energy. This type of absorption is said to be takes place only when there is higher atmospheric humidity and stomata are closed, such conditions are observed only during night time.

2.3.2. Passive absorption of water: Absorption of water when the plants are actively transpiring through stomata is known as passive absorption. The forces responsible for absorption originate in shoot. In this method, roots acts as channels through which water moves and metabolic energy is not making use of. Large amount of water is lost from the leaves by transpiration. This loss creates a suction force in the transpiring mesophyll cells. These cells withdraw water from xylem elements. The suction force is transmitted through xylem elements of the stem and roots. As a result, xylem elements of the root draw water from the cortical cells. Thee cortical cells withdraw water from the

soil. This results in the movement of water from the soil across the cortex into xylem as a continues channel. The roots merely act as absorbing surface. It is estimated that 98% of the total movement in to roots is due to passive absorption the passive absorption is most active in rapidly transpiring plants.

3. Ascent of sap

The water after being absorbed by the roots is distributed to all parts of the plant (excess of which is lost through transpiration). In order to reach the topmost parts of the plant, the water has to move upward through the stem. This upward movement of water from roots to aerial parts of the plant is called as Ascent of Sap.

Ascent of sap can be studied under the following two heads; Path of Ascent of Sap, and Mechanism of Ascent of Sap.

• **Path of Ascent of Sap:** It is well established that the ascent of sap takes place through xylem. It can be shown by the Ringing Experiment A leafy twig from a tree is cut under water and placed in a beaker filled with water. A ring of bark (all the tissues outer to vascular cambium) is re-moved from the stem. After sometime it is observed that the leaves above the ringed part of the stem remain fresh and green. It is because wa-ter is being continuously supplied to the upper part of the twig through xylem.

• **Mechanism of Ascent of Sap** In small trees and herbaceous plants, the ascent of sap can be explained easily, but in tall trees like Australian Eucalyptus, some conifers. where the water has to rise up to the height of several hundred feet, the ascent of sap, in fact, becomes a problem. Although the mechanism of ascent of sap is not well understood, a number of theories have been put forward to explain it.

3.1. Various theories are proposed to prove Ascent of SAP

1. Vital Theories
2. Root Pressure Theory
3. Physical Force Theories

3.1.1. Vital Theories: According to the vital theories upward movement of water takes place due to vital activities of living cells of the plant bordering xylem. Two postulated are put forward by vital theories concept they are; Relay pump theory and Pulsation theory.

a) Relay pump theory: According to Godlewski (1884) ascent of sap takes place due to the pumping activity of the cells of xylem parenchyma which are living. The cells of the medullary rays which are also living, in some way change their osmotic pressure.

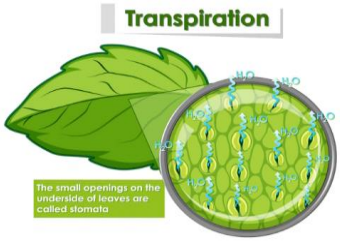
b) Pulsation theory: According to Bose (1923) upward translocation of water takes plate due to the pulsatory activity of living cells of inner most cortical layer just outside the endodermis.

3.1.2. Root Pressure Theory: It is proposed by Priestly (1916). According to this theory the water, which is absorbed by the root-hairs from the soil collects in the cells of the cortex. Because of this collection of water, the cortical cells become fully turgid. In such circumstances the elastic walls of the cortical cells, exert pressure on their fluid-contents and force them towards the xylem vessels. Due to this loss of water these cortical cells become flaccid, again absorb water, become turgid and thus again force out their fluid contents. Thus, the cortical cells of the root carry on intermittent pumping action, as a result of which considerable pressure is set up in the root. This pressure forces water up the xylem vessels. Thus, the pressure, which is set up in the cortical cells of the roots due to osmotic action, is known as the root pressure.

3.1.3. Physical theories: According to physical theories the ascending movement of water is due to the result of physical force and the living cells do not takes place in the water movement.

- **Cohesion Tension Theory (Cohesion-Tension and Transpiration Pull Theory)** The theory was put forward by Dixon and Joly in 1894. It was further improved by Dixon in 1914. Therefore, the theory is also named after him as Dixon's theory of ascent of sap. Today most of the workers believe in this theory. The theory is based in three physical principles.
  - **A.** Continuous Water Column.
  - **B.** Cohesion and adhesive force of water molecule.
  - **C.** Development of Tension or Transpiration Pull.

4. Loss of water from the plant



4.1.Transpiration : It is the process of lossing water from plants in the form of steam.

4.2. Guttation : is the process of extrusion of liquid droplets from the leaves through special structures called water stomata or hydathodes. During early morning in summer, when relative humidity is very high, small droplets appear on the vein endings of grasses or serrate margins of certain leaves.

4.3. Bleeding : It is the phenomenon of water leaving through mechanical damage that occurs in plant tissues such as wounds and scratches.

- **Difference between transpiration and guttation**

Sl no	Transpiration	Guttation
1	water lost in the form of water vapour	Water lost in the form of water droplets
2	Occurs through stomata, cuticle and lenticel	Occurs through water stomata or hydathode
3	Large amount of water is lost	Comparatively less amount of water is lost
4	Transpired water is pure	Gutted water contains dissolved salts and sugars
5	It has cooling effect on leaves	No cooling effect on leaves
6	It takes place in almost all terrestrial plants	It occurs in some of the herbaceous plants growing in the moist place
7	Occurs in the presence of light and high temperature	Occurs during the cold hours of the early morning or at night
8	Occurs under dry condition	Occurs under humid conditions
9	Favours the loss of water through diffusion	Does not favour the loss of water through diffusion
10	Mainly controlled by the opening and closing of stoma	Depends on the availability of water in the plant and the humidity
11	Can result to wilting	Never results in wilting