Study material Plant water relations
Unit I B.Sc III Year

The various phenomena which explain the absorption of water by the plants from the soil by the help of roots are.

Imbibition

The absorption of the water by the solid particles of a substance with out forming solution is called imbibition. Solid substance which take part in imbibition is called imbibant. The liquid which is imbibed is called imbibate. The imbibate is held in between the particles of imbibant due to capillarity and remains stick to the surface of the imbibant due to adsorption. Plant imbibants are hydrophilic colloids eg. starch, lignin, pectin, cellulose, proteins gelatin agar etc. Imbibition increases the volume of imbibant but the increase is less than the volume of imbibate absorbed. It is caused by compression of water which releases energy in the form of heat called heat of wetting or heat of hydration. The swelling imbibants also develop a pressure called imbibition pressure or matric potential. It is equal to reduction in the chemical potential of water due to imbibition by imbibant.

Factors affecting imbibition .

1.Texture :- When the substance is loose more is imbibition when compact less is imbibition.

2.Temperature: - Imbibition increases with the increase of temperature by increasing kinetic energy of the system.

3.Pressure: - Rate of imbibition decreases if pressure is against imbibant.

4.Electrolyte:- These decrease the process of imbibition by neutralizing the charge of imbibant with the result water from the surface of imbibant is withdrawn.

5. PH :- Imbibition is influenced by PH of the medium. A negatively charged colloid like cellulose will imbibe maximum in alkaline medium or higher PH while it will absorb least in the acidic medium or in lower PH.

Importance of imbibition

1. Absorption of water by young cells.
2. Initial absorption of water by the root hairs.
3. Cell to cell movement of water.
4. The absorption of water by the germinating seeds is mostly caused by imbibition.
5. At the time of seed germination the seed coat breaks because it swells to a lesser degree than the kernel which is made of proteins lipids and starch while the seed coat is made of cellulose and lignin.

6. It is often observed that the fruits of some plants have DPD higher than their osmotic pressure e.g. Cotton bolls. The excess DPD is imbibitional. It helps fruits not only to retain water but also maintain inflow of water even under conditions of water scarcity.
7. In older times rocks boulders were broken by inserting wooden pegs and wetting their free ends. It produced an imbibition pressure sufficient to break rocks
8. Imbibition pressure developed by grass seeds often breaks the concrete pavements.
9. The warping of wooden frames during the rainy season is due to imbibition.

Diffusion

The tendency of the molecules, atoms and ions of solids liquids and gases to get evenly distributed throughout the available space on account of their random kinetic motion is called diffusion. The random kinetic motion of particles is due to kinetic energy present in them.
Diffusion is also defined as the movement of particles of different substances from the region of their higher concentration to the region of their low concentration.

Independent diffusion: - A diffusion system often contains two or more substances e.g. Carbon dioxide, oxygen and water vapours are involved in diffusion through the stomata of leaf. The three substances diffuse independently according to their own concentration gradients provided they do not react with one another chemically. This is known as independent diffusion. The diffusion pressure of the individual substance is then known as partial pressure e.g. In photosynthetic leaf water vapours and oxygen diffuse out while CO_2 enters the leaf depending upon the differences in their partial pressure in the leaf interior and exterior.

Diffusion Pressure :- Diffusing molecules or ions exert a pressure is called diffusion pressure. This pressure is developed due to collisions of molecules and ions during their movement. The diffusion pressure can also be defined as the potential ability of a molecule or ion to diffuse from an area of its greater concentration to an area of low concentration. This diffusion pressure is directly proportional to the concentration of diffusing particles in the system.

On the basis of diffusion pressure, diffusion can be defined as the net movement of molecules or ions from the region of their higher diffusion pressure to the region of their lower diffusion pressure on account of their inherent kinetic energy.

Factors affecting rate of diffusion :-

1. Density :- Rate of diffusion of a substance is inversely proportional to the square root of its relative density (Graham's law of diffusion). Rate of diffusion decreases with the density of medium eg. hot water has less density as compared to cold water which has high density.

$$r = \frac{1}{\sqrt{d}}$$

where r is rate of diffusion and d is density.

The gases having higher densities show slower rate of diffusion whereas those possessing lower densities show faster rate of diffusion e.g. Density (atomic mass) of Hydrogen is 1 and of Oxygen is 16.

$$rH = \frac{1}{\sqrt{1}} = 1 \qquad rO = \frac{1}{\sqrt{16}} = \frac{1}{4}$$

So hydrogen will diffuse 4 times faster than Oxygen.

2. Temperature :- A rise in temperature increases the rate of diffusion by increasing kinetic energy of the molecules.

3. Diffusion pressure gradient :- Rate of diffusion is directly proportional to the difference of diffusion pressure at the two ends of a system and inversely proportional to the distance between the two.

4. Size and mass of diffusing particles :- If the size and mass of diffusing particles is smaller the rate of their diffusion will always be faster.

5. Solubility of solutes :- The rate of diffusion increases with the rate of solubility of solute in solution .Thus more the solubility of a solute in a solution more will be its rate of diffusion.

Diffusion is faster in gases, slower in liquids and slowest in solids.

Importance of diffusion

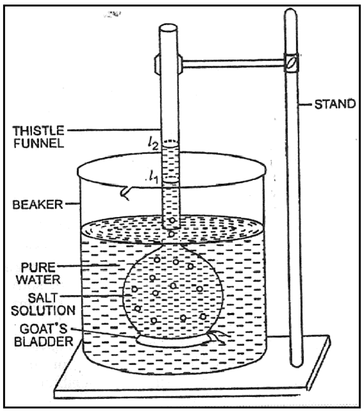
1. Exchange of gases Co_2 and O_2.
2. Transpiration:- Loss of water vapours from the leaves to atmosphere.
3. Absorption of water and mineral ions.
4. It is means of spreading ions and other substances through out the protoplasm.
5. Aroma of the flowers spreads by the process of diffusion.
6. Diffusion is an effective means of transport of substance over a very short distance and help in the translocation of food material.
7. Water moves over the cell walls (apoplast) through diffusion.
8. Osmosis is the phenomenon of diffusion of water through a cell membrane according to its chemical potential.

Osmosis or osmotic flow

Osmosis is defined as the passage of water from a region of higher water concentration through a semi permeable membrane to a region of low water concentration.

Or is defined as the movement of water molecules from a region of their high concentration (low concentration solution) to a region of their low concentration (high concentration solution) through a partially permeable membrane is called osmosis.

<u>Demonstration of Osmosis :-</u> Take a long stemmed thistle funnel Close tightly its wide mouth with animal bladder or parchment paper (Potasium ferrocyanate). Tie it firmly with waxed thread. Scissor the free edges of the membrane and apply rubber solution to seal it air tight and fill the funnel with 10% sugar solution. Invert the Funnel in a beaker containing pure water so that the membrane is completely immersed. Mark the level (A) of sugar solution in the stem of funnel. Leave the apparatus undisturbed for a couple of hours. A rise in the level (B) of sugar solution is noted. This rise in the level of the sugar in the stem of thistle funnel is due to osmosis. The sugar present in the thistle funnel will not diffuse in the beaker because the membrane is semi permeable.



Experimental demonstration of osmosis

<u>Water potential</u>

The chemical potential of the water is called its water potential denoted by symbol **Ψ** (Psi). It is the quantitative expression of the free energy associated with the water. In thermodynamics terms free energy represents the potential for performing work. So water in liquid or in gaseous form move about rapidly and randomly from one location to another. The greater the concentration of water molecules in a system the greater will be kinetic energy (free energy) of the water molecules in that system and the higher is its so called water potential. Pure water therefore has the highest water potential this is used as reference. Theoretically the water potential of the pure water at atmospheric pressure is taken as zero i.e. 0 MPa. So all solutions will have low water potentials than pure water therefore has negative values of water potential.

Water potential can be measured in energy units ($Jmol^{-3}$). These are equivalent to pressure units such as Pascal, (1 mega Pascal = 10 bars one bar = 0.987atmospheres). Which is the common measurement unit for water potential?

In terms of water potential osmosis is defined as the movement of water from a solution of its high water potential to a solution of its low water potential when the two solutions are separated by partially permeable membrane.

<u>Water potential of a system</u> :- This is defined as the difference between the water potential of the pure water and water potential of the water present in the solution at atmospheric pressure and at well defined temperature.

The three major factors contribute to the cell water potential are concentration, pressure and gravity.

$$\Psi w = \Psi s + \Psi p + \Psi g$$

The terms Ψs, Ψp, and Ψg denotes the effects of solutes pressure and gravity respectively on the free energy of the water.

When dealing with the water transport at the cell level the gravitational component (**Ψg**) is generally omitted because it is negligible compared to the osmotic potential (solute potential) and the hydrostatic pressure (pressure potential). Thus the above equation can be simplified as .

$$\Psi w = \Psi s + \Psi p$$

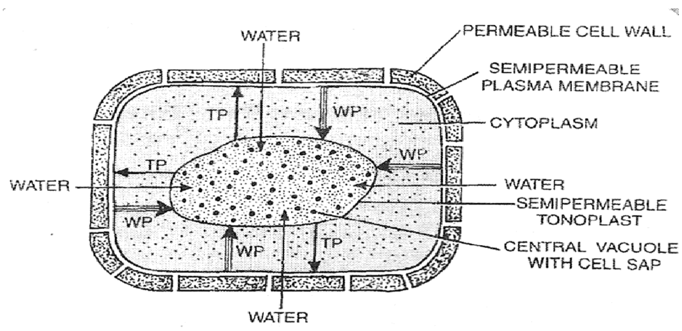
Solute potential (Ψs) or Osmotic potential :- It represents the effect of dissolving solute molecules on water potential. Solutes reduce the water free energy of the water by diluting the water. This is primarily an entropy effect that is the mixing of solutes and water increases the disorder of the system and thereby lowers free energy. Solute potential is always negative. The more solute molecules present the lower is water potential (more negative) for a solution at atmospheric pressure.

Pressure potential (Ψp) or Hydrostatic pressure :- It is the hydrostatic pressure of the solution. Positive pressure raises the water potential e.g. water potential of blood plasma is raised to positive value by the high blood pressure in the glomerulus of the kidney. Also when water enters plant cells by osmosis pressure may build up inside the cell making the cell turgid and increasing the pressure potential. The positive hydrostatic pressure within cells is called turgor pressure. Negative pressure reduces the water potential so value of **Ψp** can also be negative e.g. in xylem where it is under tension it may be negative.

Importance of water potential:

1. It is an important force which determines the water status of a plant organ or cell. A cell will lose water to nearby cells if its water potential is high and absorbs the same if the potential is low. The cells suffering from water deficit or water stress are therefore able to avoid injury by obtaining water from other cells.
2. Leaves growing higher up on the trees have lower water potential than the ones nearer the ground. They therefore can exert a higher force to pull the water column towards them.
3. A negative water potential develops in xylem. It is important for moving water over long distances.
4. Developing fruits are able to continuously withdraw water even in case of water scarcity because of lower water potential.
5. Because of lower water potential root hairs are able to absorb water from soil solution.
6. Xerophytes and halophytes have very low water potential in order to hold water.
7. The air dried seeds and spores are able to perennate and avoid temperature (low and high) injury and drought due to very low water potential (-60 to -100 atm).

Cell as an osmotic system The cell wall of the plant cells is usually permeable to substances in solution so is not an osmotic barrier. The cell contains a large central vacuole whose contents the cell sap or vacuolar sap contribute to solute potential of the cell. The two important membranes are the cell surface membrane and the tonoplast. In plant water relations the cell surface membrane cytoplasm and tonoplast act together as one partially permeable membrane. Therefore a typical cell is osmotic apparatus.



Cell as an osmotic system

Solutions

Solvent together with solute constitutes the solution.

Types of solutions :- From biological point of view the solutions are of three types.

Hypertonic solution :- Those solutions whose concentration and osmotic pressure are more than the concentration and osmotic pressure of the cell sap are called hypertonic solution.

Hypotonic solution :- Those solutions whose concentration and osmotic pressure are less than the concentration and osmotic pressure of the cell sap are called hypotonic solution.

Isotonic solution :- Those solutions whose concentration and osmotic pressure are equal to that of the concentration and osmotic pressure of the cell sap are called isotonic solution.

Types of osmosis :- Osmosis is of two types

1.**Endosmosis :-** When water enters in the cell through semi permeable membrane it is called endosmosis. Endosmosis occurs when a cell is put in a hypotonic solution.

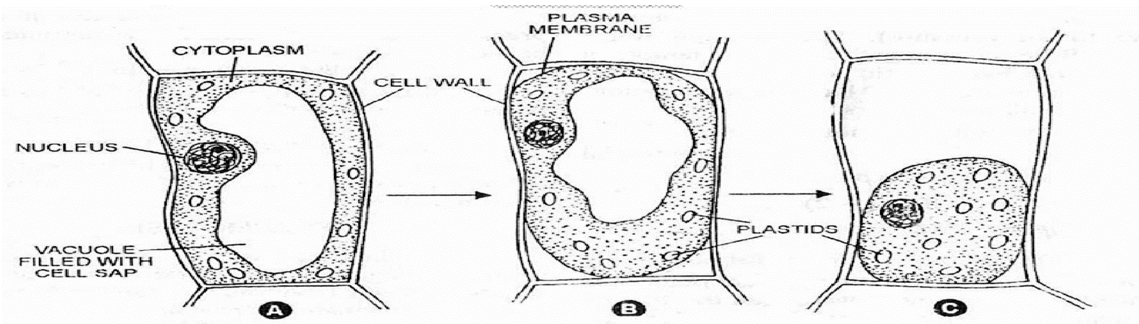
2.**Exosmosis :-** When water comes out of the cell through semi permeable membrane it is called exosmosis. Exosmosis occurs when a cell is put in a hypertonic solution.

When a cell is paced in an isotonic solution cell neither gains nor loses the water.

Plasmolysis

When exosmosis occurs cell loses water and its protoplast (the living content of the cell) shrinks and eventually pulls away from the cell wall. This process is called plasmolysis and the cell is called plasmolysed. The point at which plasmolysis is just about to happen is called incipient plasmolysis. The stage when the cell wall has reached its limit of contraction and cytoplasm has detached from cell wall and assumes spherical shape is called evident plasmolysis.

The process of plasmolysis is usually reversible without permanent damage to the cell. If a plasmolysed cell is placed in pure water or a solution of high water potential than the contents of cell (hypotonic solution) water enters the cell by osmosis. As the volume of protoplast increases it begins to exert the pressure against the cell wall and stretches it. The cell wall and protoplasm attains its original shape and size. The phenomenon is known as deplasmolysis and the cell is said to be fully turgid.



(A).Turgid cell ***(B). Incipient plasmolysis*** ***(C). Plasmolysed cell***

Significance of plasmolysis

1. The osmotic pressure of the cell can be measured by the plasmolysis. It is roughly equal to the osmotic pressure of the solution that causes incipient plasmolysis in the cell.

2. Plasmolysis is helpful in determining whether a particular cell is living or dead as plasmolysis does not occur in a dead or non living cell.

3. Salting of prickles, meat, fishes etc. and addition of sugar to jams jellies cut fruits etc. prevent their decay by microbes as the latter get killed due to plasmolysis or due to high concentration of salts and sugar.

4. By salting, weeds can be killed from tennis courts and the growth of plants can be prevented in the cracks of the wall.

5. It shows that the cell wall is elastic and permeable.

Osmotic pressure

It is the maximum pressure which can develop in an osmotically active solution when it is separated from its pure solvent by a semi permeable membrane under ideal conditions. This is the pressure required to stop the movement of water completely.

Factors affecting osmotic pressure: - Factors affecting the osmotic pressure are discussed as under.

1. Concentration of solute particles :- The concentration of solute particles in solution is directly proportional to the osmotic pressure. The osmotic pressure of concentrated solutions is always greater than the osmotic pressure of solutions of low concentration. If the concentration of solute particles is increased in any solution its osmotic pressure is also increased.

2. Temperature :- The temperature is also directly related to osmotic pressure. If the temperature of the solution is increased its osmotic pressure is also increased.

3. Ionization of solute particles: - If the solute particles are present in the solution in ionic form and their concentration is increased the osmotic pressure of the solution is increased.

4. Light :- Light has an important role on osmotic pressure. In sunlight the synthesis of carbohydrates takes place due to photosynthesis which increases the concentration of the protoplasm resulting the increase in osmotic pressure of cell sap.

5. Hydration of solute molecules: - Sometimes a few molecules of solutes remain bound with water molecules. It is called water of hydration. The solution which possesses water of hydration shows high osmotic pressure because these water molecules which remain bound with the solute molecules are not the part of the solution.

Role of osmosis in plants

1. Absorption of water by roots hairs.
2. Cell to cell movement of water occurs through out the plant body.
3. Opening of the stomata through its regulation of the turgidity of guard cells. This turgidity of guard cells is due to osmotic entry of water in guard cells.
4. Osmotic pressure helps in the growth of young cells by playing role in cell elongation.
5. Osmosis helps in the dehiscence of fruits and sporangia.
6. Turgidity of plant cells.
7. High osmotic concentration in plants increases the resistance against freezing temperature and drought.
8. Many movements in plants are controls by cell turgor which occurs due to osmosis. E.g. *Mimosa pudica.*
9. Osmosis keeps all the organs of plant body fully expanded.
10. Autochory of some fruits is dependent upon release of turgor pressure, which is developed due to osmotic entry of water.
11. Osmosis provides mechanical support to non woody plants by making its cells fully turgid.

Diffusion pressure deficit (DPD)

Pure water has maximum diffusion pressure it is lowered by the addition of solutes to it. The reduction in the diffusion pressure of the water in a solution over its pure state is called diffusion pressure deficit.

Because of presence of diffusion pressure deficit a solution will always tend to make up the deficit by absorbing water. So is also called suction pressure.

DPD = OP – TP

Or. DPD = OP – WP ∵ TP = WP

DPD is diffusion pressure deficit. OP is osmotic pressure TP is Turgor pressure and WP is wall pressure

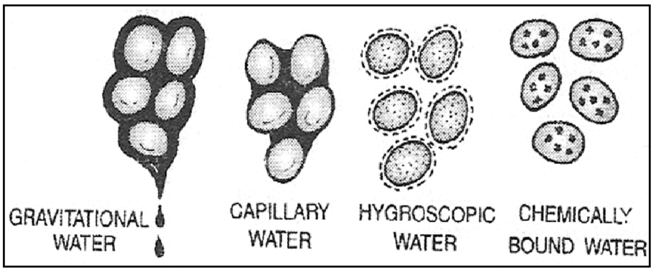
As per the Newton's third law of motion, to every action there is equal and opposite reaction. So in plant cells the turgor pressure of the cell developed due to osmotic entry of water will be equal to the wall pressure which prevents the cell from getting burst because being hard and resistant wall. Develops an equal and opposite pressure to turgor pressure.

Availability of water to plants

Soil is the source of all water and mineral salts to plants. A productive soil generally consists of mineral particles 4o % by volume, organic matter 10 % by volume, soil water 25 % by volume and soil air 25 % by volume. The water in the soil ultimately comes from the rains which occur in the soil in four forms.

1.Capillary water:- This water is present in the micropores of soil having a diameter of 20µ or below. The amount of capillary water which can be present in the soil depends on the abundance of micropores. It is kept in these pores due to capillarity against the force of gravity. This is the only water available to the plant for absorption.

2.Gravitational water:- In a well watered saturated soil excess of water percolates down the deeper layers due to force of gravity reaches the water table. So is below the reach of roots of plants and is thus not available to plants. The water percolates through the soil macropores larger than 50µ. After percolation gravitational water joins ground water. An underground run off is produced if an impermeable stratum occurs along the slope. It produces a spring if an outlet is available along the path.



3.Hygroscopic water:- It is the water which is adsorbed or imbibed by soil colloids .This water is not available to plants because it is held by strong attractive forces by soil colloids. The forces reduce water potential much below the one found in plants.