WATER RELATIONS OF PLANTS

Water Relations of Plants

INTRODUCTION :

* Plant physiology includes the study of various vital activities of the plant.
* **Stephan Hales** is known as father of plant physiology.
* **"J.C. Bose** is known as father of Indian plant physiology".
* Plants grow in soil and absorb water and minerals which is available in soil. Therefore water has great importance for plants. Water forms 80-90% of fresh weight of plant. Water functions as a reactant as well as a product.
* Before understanding the water relations, we should know the following processes.

DIFFUSION

* The movement of molecules or ions of solid, liquid or gas from an area of its greater concentration to an area of its lesser concentration is called **diffusion**.
* The diffusion continues till the dynamic equilibrium is established. At this stage the movement of molecules is equal in both directions therefore, diffusion process stops due to equal movement of molecules.
* On account of their kinetic energy which is present in the molecules, the substances are distributed throughout the available space.
* The movement of the molecules depends upon kinetic energy during diffusion. The movement of molecules occur from its higher energy towards its lower energy. The diffusion one substance is independent of the other.

DIFFUSION PRESSURE

* The diffused molecules or ions show a tendency to exert pressure while diffusing from the region of its higher concentration to the region of its lower concentration. This pressure is known as **diffusion pressure**. This is developed due to difference in the concentration of molecules of the materials. Diffusion pressure is high at greater concentration and it is low at lesser concentration. Diffusion pressure of a pure solvent is always higher than its solution.

* Water molecules moves from its higher concentration to its lower concentration in plants.

Factors affecting the rate of diffusion

(1) Temperature :

The rate of diffusion is directly proportional to the temperature, it means rate of diffusion increases with rise in temperature.

$$\text{Rate of diffusion } \alpha \text{ temperature}$$

Diffusion stops approximately at 0ºC.

(2) Density :

* Rate of diffusion is inversely proportional to square root of its relative density. It means rate of diffusion lowers down with increasing density.

$$\text{Rate of diffusion } \alpha \frac{1}{\sqrt{\text{density}}}$$

* The diffusion of materials is in the following sequence according to their density $\rightarrow$

Gas > Liquid > Solid

[Rate of diffusion is highest in gas and lowest in solid]

(3) Pressure :

The rate of the diffusion is directly proportional to the pressure, it means rate of diffusion increases with increase in pressure.

* Rate of diffusion α Pressure

(4) Size of molecules :

* The diffused molecules/atoms/ions are inversely proportional to their size and mass.
* The rate of diffusion decreases with increase in their size.

Significance of Diffusion :

(1) Exchange of gases like CO_2, O_2 occurs through diffusion.

(2) Absorption of essential elements from the soil takes place through this process.

(3) The distribution of hormones which are synthesized in the plants takes place through diffusion.

(4) The process of transpiration is a diffusion process. The evaporation of water from the intercellular spaces is linked with diffusion during the transpiration.

(5) The ions of the mineral materials entered into the plant body only through the diffusion during the passive absorption.

(6) The process of osmosis is a special type of diffusion process.

PERMEABILITY

* The exchange of materials through the membrane is called **permeability**.
* The membrane are divided into following types on the basis of their permeability :

(i) Permeable membrane :

Such membrane allow movement of both - solutes and solvent through them e.g. **cellulosic cell wall.**

(ii) Impermeable membrane : These type of membranes do not allow the movement of substances through them e.g. **cutinized cell wall.**

(iii) Semipermeable membrane :

Such membrane allow the passage of solvent molecules but do not allow the passage of solutes. e.g. **parchment membrane, celloidin membrane.**

(iv) Selective permeable Membrane or differentially permeable membrane :

Such membrane allow selective solutes to pass through them along with the solvent molecules.

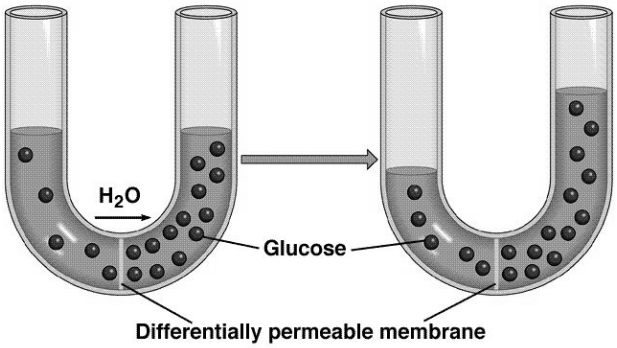
e.g. **Plasma membrane, Tonoplast.**

This membrane is permeable for CO_2, N_2, O_2 gases and alcohol, ether and water, But impermeable for polysaccharides and proteins.

OSMOSIS

* Osmosis was discovered by Abbe Nollet.
* The detailed explanation of osmosis has been given by **Traube**.
* Osmosis is movement of solvent or water molecules from the region of their higher diffusion pressure or free energy to the region of their lower diffusion pressure or free energy across a semipermeable membrane.
* Passage of water through the semipermeable membrane is an example of osmosis.
* The water moves into the cell during the osmosis is called **Endosmosis**.

  When the water starts moving out of the cell then it is called **Exosmosis**.



OSMOSIS

Osmotic Pressure or O.P.

* The osmotic pressure of water is zero. This is due to presence of solute in the solution.
* "Osmotic pressure is the pressure which is developed in a solution in which solution and water is seperated by semipermeable membrane or as the hydrostatic pressure developed in a solution which is just enough to stop the entry of the solvent into the solution when the two are separated by a semipermeable membrane".
* "The osmotic pressure of a solution is directly proportional to the concentration of solute in it".
* The osmotic pressure shows maximum variation in the plants cells.
* The highest osmotic pressure is found in the halophytes.
* The lowest osmotic pressure is found in aquatic plants or hydrophytes.
* The highest osmotic pressure is found in halophyte plant named *Atriplex confertifolia* which is approximately 202.5 atmosphere.
* Generally osmotic pressure is less during the night and higher at noon in summer.
* Osmotic pressure of a solution is measured by "**Osmometer**". (Pfeffer).
* The value of osmotic pressure depends upon the concentration of the solution. More solute present in the solution will increase the the OP of the solution.

The osmotic pressure can be out by various methods found :

(i) By the formula of Vont Hoff's :

$$OP = mRT$$

Here m = molar concentration

R = Gas constant [0.082 mole/molecules]

T = Absolute temperature

the osmotic pressure of 1 mole. glucose solution at 0ºC

$OP = > 1 \times 0.082 \times 273$

$= > 22.4$ atm.

this formula is only applicable on non ionising or non electrolysis.

The O.P. of electrolytes is found out by the following formula-

$$OM = MRT\ I$$

Where I is the constant of ionisation of electrolytes.

* The osmotic pressure of electrolytes is higher then that of non electrolytes.
* For example - solution of 1 M NaCl and 1M glucose the molar concentration of both solution are equal.

Then O.P. of 1M NaCl is higher than solution of 1M glucose. Therefore, water moves from lower O.P. towards the higher O.P.

(ii) By B.P.

$$\text{O.P.} = \frac{22.4 \times \text{Elevation of B.P.}}{0.52}$$

(iii) Freezing Method

$$\text{O.P.} = \frac{22.4 \times \text{depression of freezing point}}{1.86}$$

Factors affecting osmotic pressure :

(1) Concentration :

The osmotic pressure of solution increases with increase in the concentration of solutes.

(2) Temperature :

Osmotic pressure is proportional to the temperature $\Rightarrow$ OP a temperature

lt means O.P. of solution increases by the increase in temperature.

(3) Dissociation of solutes also increase the OP of solution.

Significance of Osmosis :

(1) Root hairs of the roots absorb water from the soil through the process of osmosis.

(2) The conduction of water from one cell to another cell in plant and distribution of water in plant through the phenomenon of osmosis.

(3) Turgidity is developed by the process of endosmosis which helps to maintain a definite shape of leaves, stem and flowers. Turgidity also provides mechanical strength to the plants.

(4) The opening and closing of stomata also depends upon the process of osmosis.

(5) The leaves of *Mimosa pudica* ("Touch me not") are dropping down only by contact and dehiscence of fruits and sporangium are depends upon turgor changes after osmosis.

(6) The resistance is increased due to high osmotic concentration against the dry climate and cold temperature [below 0ºC]

(7) The growth of the young cells depend as the result of osmosis. The other daily activities also takes place by osmosis and plasmolysis.

(i) The fresh water growing plants and animals either willt or die when they are keeping in marine water.

(ii) Bacteria and fungus of meat and fishes are destroyed by saltation.

(iii) Fungus and bacteria of jam, jelly, sweet pickles and sharbat are destroying by sugar solution.

(iv) Weeds can be destroyed by pouring salty water (saline) into the roots.

(v) High amount of the salt inhibit the growth of bacteria in pickels.

Osmotic potential : (ψ_s)

* Osmotic pressure is a confusing term because it is develops due to osmosis. It is potential pressure in normal condition. So the term **osmotic potential** is used.
* Osmotic potential or solute potential is represented by ψ_S. ψ(Psi) is Greek word and is measured in Bars. [1 Bar = 0.987 atmospheric pressure]. Water potential represented by negative sign.
* OP = 22.4 atm = > osmotic potential = – 22.4 atm. (1 M glucose solution).
* "When a solution is separated from pure water by a semipermeable membrane, water flows from the region of higher water potential [Pure water] to the region of low water potential [solution]"

Turgor pressure or T.P. and Wall pressure or WP

* Turgor pressure is not applicable for free solution. This is only applicable for living cells. Turgor pressure is also known **hydrostatic pressure**.
* When a cell is immersed in water, the water enters into the cell because osmotic pressure of the cell sap is higher. The cell content press upon the wall or develop a pressure against the membrane which is called turgor pressure (T.P.)
* The turgor pressure is counter balanced by an equal and opposite pressure of the thick cell wall on the enclosed solution, known as **wall pressure**. It means the amount of pressure exert by cytoplasm on the cell wall is same and in opposite direction as pressure exerted by the cell wall towards the inner side on the cytoplasm.
* Therefore, wall pressure and turgor pressure are equal to each other.

T.P. = WP

* Animal cell burst when place in pure water because wall pressure is absent due to absence of cell wall.

  For example the consequence of endosmosis an the animal can be demonstrated by placing RBCs of human blood in distilled water contained in a dish. When examined after some time, the RBCs are found to have burst open leaving their cell membranes as empty cases.
* A flaccid cell has zero turgor pressure.
* The highest value of turgor pressure is found in turgid cell and it is equal to the osmotic pressure.
* Fully turgid cell has OP = TP
* The value of turgor pressure is negative during the plasmolysis of the cell.
* Now a days, turgor pressure is known as "**pressure potential**" and it represented as ψ_P.
* The value of pressure potential is positive.

Significance of T.P.

(1) The protoplasm of the cell attached with the cell wall due to turgidity of the cell and cell becomes stretched. It maintains the normal shape of the cell in which physiological processes are going on.

(2) The spatial 3-D structure of mitochondria, chloroplast and microbodies are maintained due to turgor pressure which is essential for their physiological activities.

(3) Turgor pressure is essential for maintaining the definite shape of delicate organs.

(4) Turgor pressure helps in cell elongation.

(5) Plant movement like, movement of guard cells of stomata, wilting movement and seismonastic movements etc. are dependent upon turgor pressure.

(6) Turgor pressure is essential for sprouting plumules and radicles from the seed.

Turgor pressure provide essential support to the plumule to come out of the soil and help in penetration of radicle into the soil.

(7) Turgor pressure help in growth of the plant as well as it is responsible maintaining (erect) position of the plants.

Diffusion pressure deficit : (DPD) or S.P. -

* The term "**diffusion pressure deficit**" [DPD] was used by **B.S. Meyer**. This is characteristic of water in solution. But generally, it is called DPD of solution or cell.
* The DPD of any solution is the difference between the diffusion pressure of the water which is present in the solution and diffusion pressure of pure water".
* DPD determines the direction of osmosis and the power of absorption of the cell.
* The definition DPD as follows in relation to plant:
* This is the amount of that pressure by which water is sucked into the cell or expels out side the cell. therefore, it is known by various name like **suction pressure** or **Absorption potential** or **suction force** etc.
* This is also known as **demand of water deficit**. DPD $\propto$ concentration of solution.
* The diffusion of water or solute takes place from the region of lower DPD to the region of higher DPD in the process of osmosis.

$$\text{Lower DPD} \xrightarrow[\text{water}]{} \text{Higher DPD}$$

Normally, osmotic pressure is greater than the turgor pressure in a cell. The difference between osmotic pressure and turgor pressure is called **suction pressure** or DPD.

* The diffusion pressure deficit is the power (capacity) of water absorption.
* The DPD of any free solution is equal to the osmotic pressure of that solution.

Therefore - DPD = OP

* But, wall pressure develops due to turgor pressure through the process of osmosis. It increases the diffusion pressure of the solution of cell and decreases the DPD. This relation can be expressed by the following equation $\rightarrow$

DPD = OP – WP

DPD = OP – TP ($\because$ TP = WP)

* If a cell is placed in pure water or less concentrated of a solution then cell sap, then water enters into the cell as a result turgor pressure develop in the cell. The cell starts swelling due to the turgor pressure. Simultaneously, concentration of cell sap decreases due to continuous inflow of water. Therefore OP is decreases due to this. Eventually, when value of TP will be equal to the OP then DPD will be zero.

At this stage cell becomes in a fully turgid state. Therefore in a fully turgid cell-

DPD = OP – TP

When OP = TP

So that OP – TP = 0

DPD = 0

* If, the cell in a flaccid state then its T.P. and WP would be zero and value of DPD would be equal to OP.

Therefore, $\dfrac{\text{TP or WP} = 0}{\text{DPD or S.P.} = \text{OP}}$

* If a flaccid cell placed in water then water enters into cell because DPD of the cell sap is higher.
* Sometimes the value of turgor pressure is negative as in plasmolysed cell. In this state

DPD = OP – TP

$\therefore$ [TP = – ve]

DPD = OP – [– TP] = OP + TP

DPD = OP + TP

* So that the DPD of the plasmolysed cell is greater than osmotic pressure. It means

DPD = OP + TP

or

* The demand of water in plasmolysed cell is greater.
* It means when the osmotic pressure and turgor pressure will be equal, in that time DPD will be zero. Water will not enter in that type of cell.
* But, when turgor pressure is lesser than the osmotic pressure then some DPD will be definitely present in the cell and water would enter into the cell.
* When two different concentration of solution is separated by semi permeable membrane then entry of water depends on DPD.
* The osmotic pressure of [A] cell is 25 atm. and turgor pressure is 10 atm and OP of another cell 30 atm. & TP = 25 atm.
* The DPD of [A] cell is = 15 [OP – TP = 25 – 10 = 15 atm] and DPD of [B] cell is 5 atm = (30 – 25 = 5 atm.)
* It means entry of water would be from the [B] cell towards the [A] cell.

A - Cell		B - Cell
OP = 25 atm	⟵	OP = 30
TP = 10 atm	⟵	TP = 25
DPD = 15 atm	⟵	DPD = 5
Greater DPD	←	Lesser DPD

↑

Entrance of water

WATER POTENTIAL – ψ OR ψ_w

* Now a days DPD of the water in solution is called "Water potential".
* The hypothesis of water potential has been given by **Taylor** and **Slatyer (1960)**.
* The water potential of pure water is zero, the pure water have greater free energy. The free energy lowers down by are addition of solutes.
* The difference between the free energy of molecules of pure water and free energy of molecules of water of the solution is called water potential of the system.
* Water always flows from higher water potential to lower water potential.
* Water potential is represented by Greek word ψ_w(Psi) and it is measured in bars. Water potential is equal to DPD but opposite in sign. Its value is **negative**.
* According the thermodynamics osmotic pressure is called **solute - potential** or **osmotic potential**. It is represented by ψs and shown by negative sign (– ve)
* Turgor pressure is known as **pressure potential**. It is represented by ψP. It is represented by positive sign (+ ve).
* 1 Bar = 10^6 dynes/sq. cm or 0.987 atm.
* Osmotic potential represent the concentration of the solutes. Water potential (= ψW) is negative in the presence of soluted. So that osmotic potential is also negative.

* According to this hypothesis their relation is as follows.

ψ or $\psi w = \psi s + \psi p$ $\psi w = -$ ve

$\psi W = \psi s + \psi p$ $\psi s = -$ ve

$\psi p = +$ ve

* According to the above hypothesis the relation of the three phases of the cell by the water potential will be as follows :

(A) In case of fully Turgid cell -

* There is no flow of water in a turgid cell, because the cell is in equilibrium condition with water which is present out side the cell. So that water potential will be zero at this state. Because osmotic potential and pressure potential are equal in the cell.

* For example - if the value of osmotic potential of a cell is – 10 and pressure potential (ψp) is + 10 then water potential will be zero as-

$\psi w = \psi s + \psi p$

$\psi w = -10 + 10$

$\psi W = 0$

(B) In case of Flaccid cell :

* Turgor pressure is zero at this stage. It means pressure potential will also be zero. If osmotic potential of the cell is – 10 bars then

$\psi W = \psi S + \psi P$

$\psi W = -10 + 0$ bar $\because \psi P = 0$

$\psi W = -10$ bar

(C) In Plasmolyed cell :

* The pressure potential (ψP) means turgor pressure is negative in this stage, therefore water potential (ψw) of this cell will be more negative [more – ve]

* Such if the value of osmotic potential is – 10 bar of a plasmolyed cell and value of pressure potential is – 2 bars then its water potential (ψw) will be – 12 bars.

$\psi W = \psi S + \psi P$

$\psi W = -10 + (-2)$ bars

$\psi W = -12$ bars.

* So that, this is the conclusion in which water always flows from higher water potential towards the lower water potential.

* For example if the water potential of 'A' cell is – 10 bars and water potential of 'B' cell is – 12 in two cells, then water will be flow from 'A' cell to 'B' cell.

TYPES OF SOLUTIONS

(i) ISOTONIC SOLUTIONS :

If solution in which a cell is placed, has equal osmotic pressure to that of cell sap, the outer solution is called **isotonic solution**.

In this type osmotic concentration of the both solutions is same. In such type of solution is neither endosmosis nor exosmosis occurs.

(ii) HYPOTONIC SOLUTION :

If the osmotic concentration of outer solution is less than that of the cell sap, the outer solution is called **hypotonic solution**. If a cell is placed in such solution endosmosis takes place as a results, a cell swells up. e.g. Raisins swell up when placed in distilled water.

(iii) HYPERTONIC SOLUTION :

If the osmotic concentration of a solution is higher than that of the other (cell sap) solution the solution is known as **hypertonic solution**.

If a cell placed in this type of solution, exosmosis takes place. It means water of the cell sap is diffused out into the outer solution resulting in the cell becoming flaccid.

e.g. Grapes placed in higher concentration of sugar solution which becomes flaccid (contracts).

PLASMOLYSIS

* If a plant cell placed in a hypertonic solution, water molecules diffuse out from the cell. As a result of exosmosis, the protoplasm of the cell is detached from the cell membrane (cell wall) and starts shrinking in the centre. This is called **plasmolysis**.

* The various sequences of plasmolysis are as follows →

(i) In a turgid cell, the cell sap pushes away the protoplasm so that it remains with contact of cell wall.

(ii) When it placed in a hypertonic solution, the volume of the cell reduces due to shrinking of cell because some amount of water of cell sap is diffused out by exosmosis. Turgor pressure decreases by which cell wall is not pushed by the protoplasm, so that shrinking cell wall reduced in total volume of the cell. This situation, is called the first **stage of plasmolysis** or **limiting plasmolysis**.

(iii) If the diffusion of water to the outside is continued by the exosmosis then central vacuole contracts and with this protoplasm also shrinks but cell wall is not contracting. So that protoplasm is seems to detaching from the corners of cell wall. This condition is known as second phase of the plasmolysis or "**Incipient plasmolysis**".

* Hypertonic solution is present in between the cell wall and protoplasm.

(iv) The shrinking of protoplasm is continuous due to continuous exosmosis, it detached from the cell wall and assumed a spherical shape. This phase is known as "**Evident plasmolysis**" / full plasmolysis.

* According to the shrinkage shape of protoplasm, it is of two types :

(1) Convex plasmolysis :

The protoplasm is completely contracted and becomes convex shaped in this stage.

(ii) Concave plasmolysis :

The protoplasm is not contracted completely and it is attached with the cell wall at some places through the protoplasmic fibres or plasmodesmata. These fibres are called **fibres of Hetch**.

Because of these fibres, protoplasm seems to be concave shaped.

Deplasmolysis :

If a plasmolysed cell is kept in a hypotonic solution, the protoplasm expands and again resumes its normal condition. This is called 'deplasmolysis'.

This is occurs because of endosmosis.

Significance of Plasmolysis :

(1) A living cell is distinguished from the non living [dead] cell through plasmolysis. Because plasmolysis does occur in dead cell.

(ii) The osmotic pressure of any one cell can be measured by limiting plasmolysis.

(iii) If the plasmolysis remains for long duration in a cell then it dies. To destroy the weeds, salts are placed in their roots.

* Fish and meat are prevented from spoilage by salting which inhibits the growth of bacteria and fungus.
* Higher concentration of sugar in jams and jellies stops the growth of bacteria and fungus.
* High amount of manure near the root causes death of the plant due to plasmolysis.

IMBIBITION

* Adsorption of undisolved liquid by the any solid materials is called **imbibation** or adsorption of water by hydrophilic colloids is known as **imbibition**.
* This is a physical process by which a dry solid colloid material swells up by absorption of water. The cell wall is made up of by colloidal substances as cellulose, pectin, hemicellulose etc. All these are hydrophillic in nature. Therefore they imbibe water.
* The adsorption of liquid takes place on the materials in the process of imbibition.
* Proteins, Agar - agar, starch etc. all substances are imbibants.

  Agar - agar can absorbs 99 times more water than that of its weight. Some of the proteins absorb 15 times more water. Affinity should be present between imbibants and liquid material.
* Cellulose comparatively has very less power of imbibition. The seeds have good amount of colloidal materials so that they are good imbibant materials.
* Imbibition mainly is diffusion of water. The DPD of dry imbibant material is zero. So that when they come in contact of water or solution water starts diffusing into the imbibant materials.
* When the diffusion pressure of the imbibant material is equal to the diffusion pressure of the outer liquid in a saturation state then kinetic equilibrium is established.
* Excluding of liquid form, imbibition is also found in vapour forms. Wooden doors absorb water in the form of vapours and swells up during the rainy season.

Effects of Imbibition :

(1) Swelling :

The volume of the materials increased in the process of imbibition. But the total volume is found less by the sum of the both volumes.

Imbibant material + water = swelling.

10 + 90 = less than 100 (always)

(2) Liberation of Heat :

The heat is released during **imbibition**. The water molecules becomes motionless due to imbibition by which they lose kinetic energy. This energy again appears in the form of heat. This is known as "**heat of wetting**".

(3) Imbibition pressure :

A huge pressure is developed in a material limited in space due to imbibition. The value of this pressure is reaches up to many thousands atmospheric pressure. This method is used in ancient period for breaking of rocks.

Dry wood is filled in the natural grooves of rocks and water is poured over them. The rocks are broken due to their swelling.

Factors Affecting the Imbibition :

1. Temperature :

Imbibition is directly proportional to the temperature.

2. Texture of Imbibant :

The imbibition is found less in compactly arranged material like wood, and more in lighter or soft material like gelatin.

3. **pH** $\rightarrow$ The negative charged colloids like cellulose shows greater imbibition in alkaline (high pH) environment (medium).

Positive charged colloids show more imbibition in acidic medium.

Protein because of being **amphoteric** shows very less imbibition in neutral medium and it shows more imbibition in acidic and alkaline medium.

4. Electrolytes :

Electrolytes neutralise the charges of the imbibants or reduce the imbibition process by influencing osmotic pressure.

5. Pressure :

Imbibition decreases with increasing pressure.

Imbibition of dry kelp is 33% at 1 atm. and 16% at 41 atm.

Significance of Imbibition :

(1) Absorption of water during the seed germination is only through imbibition.

(2) Breakage of seed coat during the seedling is due to imbibition process proteins, fats and starch is present in the kernel. This kernel swells up more as compared to the seed coat which breaks the seed coat. Seed coat is made up of cellulose.

(3) Many hydrophillic colloids are present in the cell wall and protoplasm of plant. Absorption of water takes place in young cells through the imbibation process.

(4) Resurrection in many plants like *Selaginella*, Lichen takes place due to the process of imbibition.

(5) Hydrophilic materials reduce the amount of free water which protect the cell during dryness and it protects from the lowest temperature during the winter.

(6) The DPD of the some fruits is higher than their osmotic pressure. Higher DPD is due to imbibation, so that they can absorb water in extreme xeric conditions(dry).

(7) Many dry fruits (cotton balls, pods of Moong, Urad) dehiscence through the absorption of water in dry conditions by imbibition.

The water enter into the aerial roots and dry fruit through imbibition.

(8) Newly formed wood swells up in rainy season.

pH - value : By Sorrenson it indicates the acidity or alkalinity of substance.

ABSORPTION OF WATER

UTILITY OF WATER FOR PLANTS

* Water is a very essential component of protoplasm. Water forms 80-90% of fresh weight of plant.
* Water is the major component of the protoplasm.
* Translocation of minerals and gases in plants from one place to another occur only in dissolved forms. Water participate in many vital activities of the plants.
* All the organic and inorganic material are translocated only through water. The cells of the plant remains in turgid condition. It helps in the growth of the plant. Water is essential for germination of seeds. All the enzyme action only takes place in the presence of water. Plant movements is due to the turgidity of the cells. Translocation of nutrients and chemical reaction of plants take place in aqueous solution.
* Water compensates the loss of water in transpiration. Water participates in condensation and hydrolysis of water activities which are going in the cells of the plant.
* Loam soil is essential for healthy growth of plants. This is most fertile soil in which 50% sand + 50% silt or both are present.

SOIL WATER

The source of water in soil is rain. Some of the water goes into the water reservoir, which is called **run off water**. Rest of the water enter into the land. Water present in soil is of three types $\rightarrow$

(a) Gravitational water :

In a well saturated soil, the water percolates downward under gravitational influence. This is called soil water table. This water is not available to the plant because it lies far below the reach of the roots. available by tube-well irrigation.

(b) Hygroscopic water :

This thin film of water which is tightly held by the soil particles is called hygroscopic water. This water is also not available to the plants and is absorbed by some shallow rooted plants.

(c) Chemical water :

The amount of water present in the chemical compounds which is present in the particles of soil. This is not available to the plants.

(d) Capillary water :

Water exists between soil particles and in smaller capillary pores is called capillary water. It is available to the plants. Because it is useful to the roots of the plants, plants only absorb this water.

(e) Atmospheric :

Roots of epiphytes

HOLARD : "It is that total amount of water which is lies in the soil".

Holard = Chresard + Echard

Chresard : This is that water which is found in soil, useful to the plants.

Echard : "This water is not absorbed by the plants".

* The maximum amount of water reaches up to the stable resource due gravitational force and remaining amount of water helds between the soil particles is called field capacity. OR "Accumulation [Holding] capacity of water which is found in soil is known as field capacity". Water holding capacity of smooth clay has higher capacity.

  Sandy soil has lowest water holding capacity.
* Minerals are found in soil, results soil solution is formed. The osmotic pressure of this solution is depend on their concentration.

WATER ABSORPTION BY ROOTS

Water is absorbed either by the whole surface of the roots or by the rhizoids but in pteridophytes and spermatophytes absorption of water takes place through the root.

Root has the following four distinct regions :

(i) Root cap region :

A thin, small and smooth cap like structure is present at the apex of the root called the root cap.

(ii) Meristematic region :

This region lies just below the root cap. The cells of this region divide continuously. The rate of ion absorption is highest in this region.

(iii) Elongation region :

This is 3-4 mm thick region which lies behind the meristematic region in which new cells grow in length is called elongation region. Absorption of water is very slow from this region.

(iv) Maturation region OR root hair region :

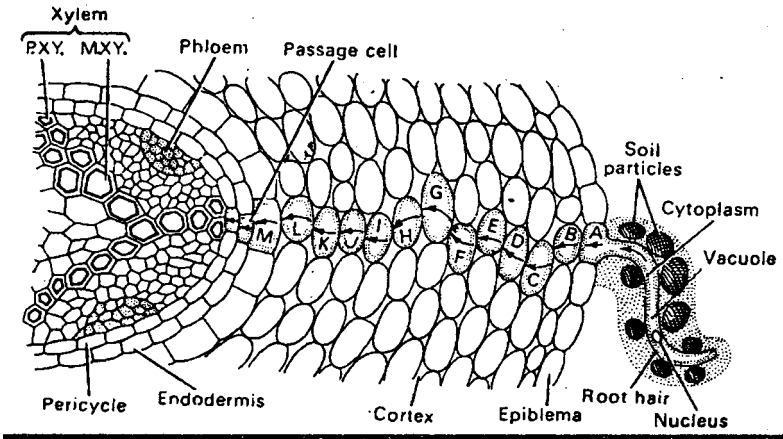
This region lies behind the elongation region in which differentiation of cell takes place to perform different functions. Root hairs are only found in this region. The maximum absorption of water takes place from this region. These root hairs increase the absorption area of roots.

* Osmotic pressure of cell : sap is greater than that of osmotic pressure of soil solution. The osmotic pressure of cell - sap is about 3 atm.

The life duration of root hairs is of few days only.

* As soon as root grows new root hairs arise simultaneously.

PATH OF WATER ABSORPTION



PATH OF WATER ABSORPTION IN ROOT

Soil solution $\rightarrow$ Root hairs (Epiblema) $\rightarrow$ Cortex $\rightarrow$ Endodermis (passage cells) $\rightarrow$ Pericycle cells $\rightarrow$ Protoxylem $\rightarrow$ Metaxylem.

* The water situated in the soil is has to reach up to the xylem of root. Root hairs remains in contact with water.

* First of all, water enters into the epidermis of root hairs. From here water reaches up to the endodermis through the cortex. The wall of endodermis are suberised. But cells lies in front of the protoxylem are thin walled known as passage cells. These cell transfer water to the xylem. From here water reaches the xylem from endodermal cells through the thin walled pericycle cells.

(a) Symplast :

Living part of the cell is known as symplast. This is the living passage. Water inter into cell membrane from the cell wall through this passage then it goes into the cytoplasm from the cell membrane. Cytoplasm and cytoplasmic fibres constitutes this part (symplast).

(b) Apoplast :

This is the non living part of the plant. Cell wall, intercellular space and xylem cavity associated together to form apoplast. [Term apoplast, 'R' symplast by Munch].

MECHANISM OF ABSORPTION OF WATER

Water is absorbed by two different ways :

(1) Active water absorption.

(2) Passive water absorption.

(1) Active water absorption :

* This process occurs as a result of activities in the root. This process takes place at that time when transpiration is going slowly and water is sufficient in the soil. In active absorption, water may be absorbed through an expenditure of energy which is produced by metabolic activities.
* The term 'active & passive absorption' was used for the first time by **Renner**.
* This absorption is of two types.

(A) Osmotic active water absorption :

* **Dutrochet** was the first to propose this theory. This theory was introduced by **Atkins**, and **Priestley**. The cell wall acts as permeable membrane and plasma membrane acts as semipermeable membrane in root hairs. Water is absorbed through osmosis when the osmotic concentration of soil water is less than that of the cell sap. The outer most pectin layer of root hair absorb water from the soil solution (Endosmosis). At this time DPD of the soil solution is less than that of the DPD of root hair. Therefore water comes into the root hair from the soil.
* The absorption of soil solution root hairs becomes turgid and their osmotic pressure decreases DPD of the 'B' cell increases due to decreasing of OP and increasing T.P. and water comes into 'A' cell from the 'B' cell of the root hair. Magnitude DPD of 'B' cell decreases due to entrance of water and DPD of the adjacent 'C' cell increases. So that water enters into the 'C' cell from the 'B' cell due to higher DPD. Therefore water reaches up to xylem via 'C' cell i.e. cortex, endodermis and pericycle.
* Hence according to the osmotic theory on the basis of increasing diffusion pressure deficit [DPD] water reaches up to the xylem. In this sequence absorption of water continues.

$$\text{Pericycle} \xrightarrow{\text{ATP}} \text{Xylem}$$

(B) Non osmotic Active water absorption :

* This theory was proposed by **Thimann.**

Water is absorbed in those conditions where the osmotic pressure of soil solution is greater than that of the osmotic pressure of cell sap of root hair. In this situation water is not absorbed by osmotic process. Energy is used in this condition which is produced by metabolic activities of living cells of root. The cells of root produced energy in the form of ATP by which water is absorbed from the soil against the osmotic gradient.

* A positive (+ ve) pressure is developed in xylem of the roots due to the activity of living cells of roots. This is called "**Root pressure**".

* The term 'root pressure' has been given by **Stephan Hales**.
* This root pressure helps in absorption of water. This pushes water from xylem of root towards the xylem of stem.
* Root pressure is measured by **manometer**.

  It has been found that plant throw out liquid (water) with a force when the stem is cut above the ground this phenomenon is called "**bleeding**" or 'exudation'. This phenomenon occurs due to root pressure.
* Such factors which increase the rate of respiration, that is also increase the active absorption and those factors which decrease the rate of respiration, also decrease the active absorption. It means active absorption is related with respiration.
* Generally the value of temperature quitient Q_{10} of physical processes in is between 1.2 to 1.3, while temperature quotient of active water absorption and respiration is in between 2 - 3 which is the indication of energy dependent process.

(2) Passive water Absorption :

* Passive absorption takes place through the fast transpiration in the aerial parts and some force develops in the shoot.
* Root remains inactive (passive) in passive absorption. It mean absorption of water through the root rather than by the root. The amount of water decreases in the mesophyll cells of leaves due to transpiration. This loss of water increase the DPD. For the compensation of this loss, these cell pulls water from neighbouring cells. In this way water is pulled from one cell to another cell and through the endodermis, pericycle and lastly from the xylem.
* Fast transpiration causes higher DPD in xylem. Resulting a negative tension developed. This tension is known as "**suction force**" or "**Transpiration pull**".
* A unbroken water column established from the xylem of the leaves to the xylem of roots is due to transpiration pull.

  Water absorbed with the help of roots is due to negative transpiration pull.

  The rate of passive absorption of water is higher. The total loss of water is compensated by only through this absorption. This absorption is neither energy required nor active participation of root.
* The highest absorption of water take place in plant only through the passive technique. (96%)

Factors affecting water Absorption.

(1) Available soil water :

* Plant absorbs capillary water which is present in soil. Absorption of water is depend on the amount of capillary water present in the soil. Absorption increases by increasing amount of capillary water.
* If, water is present in higher amount in the soil then such type of soil is called "**Water logged soil**"
* This soil is physiologically dry and which is lack of air. because of this anaerobic respiration takes place in roots in such type of soil. As a result, alcohol is formed. Roots degenerate due to formation of alcohol. Dry soil is physically dry.

(2) Soil temperature.

* Soil temperature affects the following mechanisms :

(i) It aefects the chemical potential of water.

(ii) It affects the permeabilility of cell membrane.

(iii) It is essential for the activity of enzymes.

(iv) Soil temperature affects the viscosity of capillary water.

* Generally, normal absorption of water take place at temperature of soil between 20 - 30%.
* Increasing or decreasing soil temperature lower down the rate of absorption of water.
* If temperature of soil is higher then enzymes start degeneration and absorption of water decreases.
* The rate of absorption is also decreases with decreasing soil temperature. Because at low temperature:

(i) Movement of capillary water decreases. It implies increased viscosity of water.

(ii) Decreased permebility of cell membrane and cytoplasm becomes viscous.

(iii) Enzymes of roots becomes inactive.

* Above reason are responsible for reduction in the absorption of water.
* Cold soil is physiologically dry. **Hekistotherms** of Alpines plants are only growing in this soil.

(3) Soil Air :

* Absorption of water proceeds more rapidly in well aerated soil.

  Deficiency of oxygen in soil causes improper respiration in roots. In addition of that bacteria produced toxicity by the formation of CO_2 and organic acids in anaerobic environment.
* Defficiency of O_2 affects the process of osmosis. It reduces the rate of absorption.
* Poorly aerated soil is physiologically dry.

(4) Soil Salt :

* The rate of the absorption is inversely proportional to the concentration of minerals present in soil.

$$\text{Water Absorption} \propto \frac{1}{\text{concentration of soil minerals}}$$

* Water absorption is only takes place in appropriate soil solution. When the concentration of soil minerals is more which decrease the rate of absorption. Therefore saline soil is physiologically dry. Halophytes grow only in this soil.
* So that for proper absorption, concentration of soil solution should be normally less than that of root hairs.

(5) Transpiration :

* According to **Kramer** the rate of water absorption is directly proportional to the transpiration. The rate of absorption increases due to increase in transpiration. Hence passive water absorption increases due to transpiration.
* The 99% of absorbed water is transpired by the plants. Only 1% of water is available to perform the various vital activities of the plants.
* The rate of the absorption is maximum during the summer noon but water absorption decreases. In this condition plant shows "Temporary wilting". Because cells contract due to decreasing turgidity of cells. Hence plants droop.
* But, rate of the absorption increases during the evening as compared to the transpiration which increase the turgidity of the cells, and drooping of the plant stops.
* When wilted plant will not recover after water is added to soil. This is called "Permanent wilting".

Wilting Coefficient :

* The amount of that water is shown in the percentage of dry weight which is remains in the soil during the permanent wilting is called "**Wilting coefficient**'.

Other methods of water absorption :

(a) By Mycorrhiza :

* The root hairs are not developed in some **conifers** plants and in the families Salicaceae, Betulaceae, Fagaceae and Abetineae.
* Fungus mycelium associated with in these roots in place of the root hairs are known as mycorriza' in which fungus mycelium are absorbatory organs in the roots.
* These fungus mycelium absorbs water and minerals and transfer to the roots.

  These fungus mycelium obtains their food from the roots.

(b) By Velamen :

* Velamen are found in epiphytes such as orchids and Asparagus plants.
* Absorption of water vapour of air takes place in these plants through the adventitious roots. These roots have specialised tissue on the outer side of their cortex called **velamen**.
* Velamen tissues are spongy and thickened.Modified Multilayered epidermis (Exodermis)) by many cells which absorbs atmospheric moisture, dew and rainy water.

(C) By Hygroscopic hairs :

* Hairs and arise from the aerial part of the epiphytic plants which absorbs atmospheric moisture are called **hygroscopic hairs**.

ABSORPTION OF MINERAL SALTS

* Soil is the main source of mineral salts. These mineral salts are absorbed by the (sub terminal) meristematic region of the roots.
* Mineral salts are present with soil particles and water in colloidal forms. Conduction of minerals salts is through the xylem. There are two methods of absorption of mineral salts.

(A) Passive absorption

(i) By Diffusion :

* Mineral salts are diffused from the higher concentration towards the lower concentration in this method.

(ii) By carbonic acid exchange theory :

* CO_2 is produced by respiration in roots in this method which is combined with water to form carbonic acid. Carbonic acid dissociates into H^+ and HCO_3^- ions. The exchange of negative (– ve) and positive (+ ve) ions of the soil solution takes place by the positive and negative ions present in the root.

(iii) By contact exchange theory :

* Exchange in oscillating ions of same charge by H^+ or OH^-.

(iv) By Donan Equilibrium :

* Against concentration gradient without ATP.

(v) By mass flow

(B) Active Absorption :

* Mineral salt ions enter into the higher concentrated cell sap from the lower concentrated soil solution by expenditure of energy ATP in this method.
* Some carriers are present in the plasma membrane which are made up of proteins for negative and positive ions which combines with ions to form "**Ion - carrier complex**". It breaks off from the

internal surface of the plasma membrane and transfer their ions into the cell. This process completed by expenditure of ATP.

(Cytochrome acts as carrier of molecules and Lecithine works as carrier of negative and positive ions)

(i) Cytochrome pump theory - Lundegardh and Burstorme.

(ii) Protein – Lecithin theory – By Bennet Clark.

(iii) Carrier concept - Von der honert.

(iv) Contractile Protein theory (Goldecare).

* Salt Respiration $\rightarrow$ Respiration increased by salt absorption.
* Anion Respiration $\rightarrow$ Respiration increased by Anions.

ASCENT OF SAP

Introduction :

* Plants absorb water through the roots. This absorbed water reached up to leaves through the stem branches. Most of the water is lost by the transpiration from the leaves. Only small amount of water utilized in vital activities of the plant.
* "The upward movement of absorbed water by the under ground roots towards aerial parts of the plant against the gravitation is called **Ascent of sap**".
* Process of ascent of sap takes place from a small plant to a quite large plant e.g. in *Sequoia semipervense*.

It has been experimentally proved that water moves upwards through the vessels and tracheids of xylem.

Experiment No. 1 - Balsam :

Take aqueous solution of eosine in a beaker and immerse the cut end of (stock) of balsam plant in it. After sometimes strips of red colour are seen in the stem. The transverse section of this stem confirms because only vessels and tracheids are stained with eosine dye. So that it is proved that the ascent of sap take place through the xylem.

Experiment No. 2 - Ringing Experiment :

* First of all ringing experiment was carried by **Hartig, Malpighi** and **Stephen Hales**.
* We take a branch with leaves immersed in beaker which is filled with water. Now remove all the tissues which are present above the xylem [cortex, cambium and phloem]. Now placed this experiment in a suitable environment for 2 - 3 days. Then we observe that leaves did not wilt. This experiment makes it clear that water moves up only through vessels and tracheids of the xylem.
* Ringing [girdling] experiment has been done only in dicotyledons because their vascular bundles lies in a ring. While vascular bundles are scattered in monocotyledons, so that this experiment can not be possible.

THEORIES OF ASCENT OF SAP

* Many theories have been put forwards by various co-workers to explain the mechanism of ascent of sap.

(1) Vital Force Theory (2) Root Pressure Theory (3) Physical Force Theory

(1) Vital force theory :

Vital theories presumes that ascent of sap is due to the vital activity of living cells of the plants. the opinion of the various scientist for ascent of sap as follows :

(A) Westermaier's theory :

Westermaier was the first man who proposed his view about the vital force theory. He explained that force for upward conduction of watr is provided by the xylem parenchyma cells and vessels and tracheids are simply acting as water reservoirs.

(B) Theory of Godlewski :

* He proposed that ascent of sap is brought about by periodic changes in osmotic pressure of xylem parenchyma and medullary rays. A pumping action starts as a result of this changes that causes ascent of sap. So that a sort of stair case movement of water took place in the plant. Thus it is known as "**Relay pump theory**" or "**Clambering theory**".
* Osmotic pressure of parenchyma increased, water from the xylem vessel diffused into it. this water moves up because of atmospheric pressure during this period, value of osmotic pressure of parenchyma decreased (lower down) and hence this water recieved by xylem which is lies at higher level.

(C) Pulsation theory of J.C. Bose :

* J.C. Bose is known as father of Indian plant physiology. He proposed **pulsation theory**.
* He assumed that the pulsatory activity like heart beat is found in the inner cortical cells which are situated just above the endodermis. Resulting of this pulsatory activity, water forced or pumped into cavities (Vessel) of xylem and water moves upward.
* He conducted his experment on a plant - **Desmodium gyrans** (Indian telegraph plant) which is member of papillionaceae family.
* J.C. Bose measured this pulsation activity by **"Electric probe" (Galvanometer) apparatus Molish :** A scientist named **Molish** who supported the pulsation theory of J.C. Bose and he introduced a detail description of pulsation theory.
* According to him the pulsatory activity increased to 14 seconds by the application of narcotics drugs on the plant.

*** Objections :**

The view of vital theory discarded by **Straburger** and **Boucheries**. They proved by their experiment that the living cells are not essential for ascent of sap. Because when the living cells are killed (destroyed) by picric acid or $HgCl_2$ solution even then ascent of sap continues.

(2) Root Pressure Theory :

* This theory was proposed by Priestley.
* **Root pressure :** A positive pressure is present in the xylem sap of roots.
* The term root pressure was coined by **Stephan Hales. Priestley** called it "**hydrostatic pressure**" Root pressure is also known as 'exudation pressure'.
* The highest value of root pressure is found in those plants which are growing in well aerated and sufficient amount of soil during the humidity in the atmosphere.
* Root pressure usually develops during the night when absorption is maximum and transpiration is minimum.
* The maximum value of root pressure falls in the range of 2 - 3 atmosphere.
* The liquid which flows from the freshly decapitated stem of the plant is called **bleeding**. This is also

due to root pressure.

* **Guttation** is also takes place due to root pressure.
* Ascent of sap through the root pressures only possible in small and herbaceous plants. Therefore it is ony applicable for small and hebaceous plants.
* The process of ascent of sap can not be explained by root pressure because it has following limitations :

(1) Gymnosperms lack root pressure and the conifers are very tall plants.

(2) The maximum transpiration is found during the summer and plants require more water but in that time root pressure is found to be very less.

(3) The rate of ascent of sap is found rapidly even in the absence of root pressure.

(4) The rising up of water can not be possible at 2 atmosphere in tall plants. Upto 200 feet height plants require 10 atmosphere root pressure to push the water to the top of the plants.

(5) A negative root pressure is found in some of the desert plants.

(6) Root pressure is found less in summer and more in winter.

(7) Root pressure takes place in the special conditions when the rate of absorption is higher and transpiration rate is minimum.

* Hence, root pressure is not significant in most of the plants. It is only effective in low transpiring herbaceous plants.
* Therefore, theory explain partially the mechanism of ascent of sap.

(3) Physical Force Theory :

According to this theory, the ascent of sap takes place by the vessels and tracheids through some physical forces. The following theories stated under this heading.

(A) Capillary force theory :

This theory was proposed by **Boehm**. According to him the vessels and tracheid which are present in xylem, acts as capillaries and water rises up by surface tension in their capillaries.

Limitation of this theory as follows :

(a) Xylem vessels are not freely immersed into the water.

(b) The ends of vessels and tracheids are closed while ends of capillaries are open.

(c) The diameter of the capillaries should be very thin because capillary with narrow lumen encourages the entry of more water. But in tall plants the diameter of vessels and tracheids is more. At this height capillary force does not operate.

(d) Tall plants like Gymnosperms having tracheids instead of vessels which have many transverse septum. Therefore, tracheids are homologous as capillary. But still ascent of sap occurs.

(e) Lifting power of capillary is not much and can not account for the rise of water exceeding 3 meters. It is capable for few centimeters rise only.

* Capillary theory is completely discarded on the basis of above reasons.

(B) Imbibation force theory :

* This theory was proposed by **Von Sachs**.
* According to him water rises up in the wall of the xylem cells through the imbibition end through their lumen. But now it has been clear that water rises up only through the lumen not by the walls.
* The wall of vessels and tracheids of xylem are lignified and lignin is impermeable to water.
* Thus this theory also discarded.

(C) Chain theory :

This theory proposed by **Jamin**.

According to this theory, the molecules of water and air are arranged alternatively to form a chain.

Ascent of sap takes place due to spreading of air in the chain.

(D) Transpiration pull - cohesion force theory :

* This theory also known as "**Water column theory**" or "**Cohesive force theory**"
* This theory was proposed by **Dixon** and **Jolly**.
* This is the most accepted theory at the present time and it accounts satisfactory explanation for the rising of water. This theory is based on the following facts :

(A) TRANSPIRATION PULL

* Water is lost continuously from the leaves of the plants as a result of transpiration. Water vapour move out from the leaves. As a result of loss of water from the mesophyll cell. Diffusion pressure deficit always remain higher in the mesophyll cells. Due to this mesophyll cells absorb water from adjoining internal mesophyll cells and compensate this loss of water. This loss ultimately compensating by xylem which leads water deficit in the xylem. Rapid transpiration develops a pull or tension in xylem which is called **transpiration pull**. It is about 20 atmospheres.

  This pull is called "Negative pressure" because it is develops from aerial parts to the under ground part of the plants.

(b) COHESION FORCE OF WATER

* A force of mutual attraction present between the water molecules is called "**Cohesive force**".
* Water molecules are held together continuously by cohesive force and to form a continuous water column. This cohesive force is up to 45 – 270 atmosphere.

(c) ADHESIVE FORCE

Water molecules are also attached with the wall of vessels and tracheids through a force called adhesive force.

* Both forces work together and maintain the continuity in between water and cell wall.
* Cohesive force and adhesive force works continuously in the cavity (lumen) of xylem. Both the forces are responsible for maintaining unbroken continuity of water column from the roots to the leaves.
* **MacDougal** called as "**Hydrostatic system**" of this continuous water column.
* This water column pulled upwards continuously without breaking from the roots to the leaves by transpiration. Vessels and tracheids of xylem workds as pipe (Tubes).
* The process of ascent of sap a continues through the medium of above mechanisms.

Evidences in support of Dixon's theory :

(1) Normally, the rate of absorption is equal to the rate of transpiration water does not come out from the cut end of the stem during transpiration. When this cut end is watered, it absorb water inside the stem. This justifies the water tension in the stem.

(2) **McDougal** is found that daily contraction in stem of the trees with the help **dendrograph apparatus**.

* Maximum contraction is found during a maximum transpiration.

(3) The maximum value of osmotic pressure of the cells of leaves is found during noon. Because the amount of water is minimum in that time.

* **Objection to Dixon's theory :**

(1) The presence of air bubbles in the xylem which may break the continuity of water column.

(2) Ascent of sap continues even after overlapping cuts.

* **Removal of objections :**

Although air bubbles are present in the xylem, but they are unable to move much distance because

(i) xylem vessels do not continue for long distances, pits are present between them.

(ii) Tracheid are also present along the vessels as alternative path. Pits are also present in them.

(iii) Membrane and wall is present on the pits which is permeable. to water, but air bubbles do not pass out through them. Air bubbles may dissolve in water. Root pressure also helps to remove air bubbles.

* The rate of transpiration is higher than that of rate of ascent of sap during the day time and is called absorption lag.

* **Russel and Wooley** found the ratio 50 : 1 by comparative study of water movement in apoplast and symplast.

* The origin of root pressure is an active process.

Factors affecting Ascent of sap :

(1) Amount of water in soil. (2) High temperature

(3) High atmospheric humidity (4) High atmospheric pressure

(5) Wind velocity (6) Number of stomata in leaves.

TRANSPIRATION

General introduction :

* All the terrestrial plant utilized absorbed water by the roots in various metabolic activities. Overhelmingly large amount of water is absorbed by the plants from the soil, but whole of water is not used by the plants for its growth and development. A small fraction of the total water is used up by the plants for its growth and developmet and remaining amount of water is lost from the aerial part in vapour form and goes into the external atmosphere.

* "Thus, loss of water in vapour forms from the aerial parts (organs) of living plants is known as **Transpiration**".

* Only few percentage [1%] of absorbed water is used by the plants while remaining [99%] of water lost into the atmosphere.

* The process of transipiration is alike as evaporation but it differs in few respects.

* The process of transpiration differs from the process of evaporation in following respects as $\rightarrow$

Difference between transpiration & evaporation

	Transpiration		Evaporation
1.	It is vital activity	1.	It is physical process
2.	It occurs only in living plants.	2.	It occurs in both living and nonliving.
3.	Loss of water vapours through the stomata, epidermis and lenticels	3.	Loss of water is only through the moistened surface.
4.	Usually it occurs through the stomata	4.	This process do not occur by any cell
5.	This process is controled by guard cells.	5.	It is not controlled by guard cells.
6.	The surface of cells is dry resulting by this process.	6.	The surface becomes dry by this process.
7.	It is affected by varous factors.	7.	It is affected only by temperature.

* The minimum transpiration is found in succelent xerophytes. and no transpiration occurs in submerged plants.

  Maximum transpiration is found in mesophytes. it is approximately 300 - 500 units.

  The ratio of transpiration in true xerophytes approximately 100 : 200 units.

TYPES OF TRANSPIRATION :

Transpiration is of the following three types :

(i) Cuticular Transpiration :

Loss of water takes place through the cuticle which present on the herbaceous stem and leaves as their cuticle is very thin. A cutinised wax like thin layer is present on epidermis. The function of this layer is to reduce or to stop the transpiration. But a fraction of water lost in vapour forms through the thin cuticle. Of the total amount of water is lost from the plant, approximately 9% is lost through cuticle.

(ii) Lenticular Transpiration :

* Minute pores like structure are found in the stem of some woody plants and epidermis of some fruits are called **lenticels**. Some amount of water is lost by lenticels is known as lenticular transpiration. However it is approximately 0.1% to 1% of the total water lost.

(iii) Stomatal Transpiration :

* Transpiration takes place through the stomata which are present on the leaves of the plant and green organs is called **stomatal transpiration**. The maximum amount of total water delicate is lost by this transpiration. Of the total amount of transpiration from the plants about 80% to 90% transpiration is through the stomata.
* Some amount of transpiration is also takes place through the bark of the plants. But this amount is negligible.
* Stomata are absent in algae, fungi and submerged aquatic plants.

STRUCTURE OF STOMATA :

* Stomata are found on the aerial delicate organs and outer surface (epidermis) of the leaves in the form of minute pores. This stomata is surrounded by two epidermal cells called guard cell. They are kidney shaped. The number of guard cell of a leaf stomata are two.

  The structure of guard cells in Graminae or grass family is dumbbell shaped.
* Guard cells are epidermal cells. But due to presence of chloroplast they are different from that of epidermal cells.
* The outer wall of the guard cells are thin and elastic while inner wall is thick and non elastic, Guard cells contain one nucleus, cytoplasm and indefinite chloroplast. These cells are always living and opening and closing of stomata is due their movement.

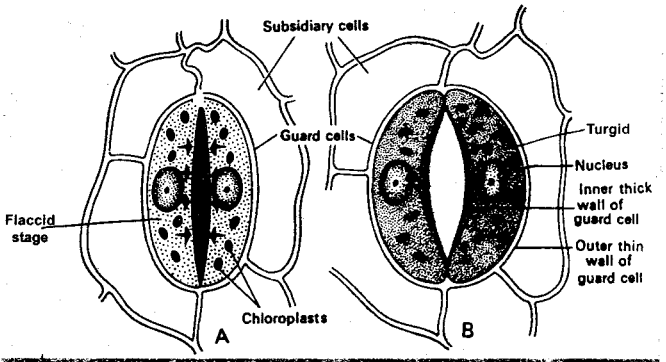


Fig. : The cell wall boardering the stomatal pore is thicker than that of next to the surrounding cells - (A) Aperture closed (B) Aperture open

* Guard cells are surrounded by some specialized epidermal cells are called **subsidiary cells or accessory**

cells.

* Stomata are found both upper and lower epidermis. Mesophyll cells lies between both the epidermis. Stomata are attached with air chambers and which forms a cavity which is called sub stomatal cavity.
* Accessory cells are located above the guard cells in xerophytic plants and due to this the position of stomata is below the surface of the leaf. Stomata present in this position are called sunken stomata.

TYPES OF STOMATA :

(A) Based on distribution :

(1) Apple and Mulberry type $\rightarrow$ When stomata present on the lower (dorsal/abaxial) surface of the leaf e.g. Oxalis, Peach, Nasturtium, Morus etc.

(2) Potato type $\rightarrow$ When stomata present mainly on the lower surface but some stomata are present on the upper surface (Adaxiay) also. e.g. - Tomato, Brinjal, Cabbage, Pea etc.

(3) Oat type $\rightarrow$ When stomata are almost equally distributed on both surfaces of the leaf. e.g. Monocots.

(4) Water lily type $\rightarrow$ When stomata present only on the upper surface of the leaf. e.g. Aquatic plants with floating leaves.

(5) Potamogeton type $\rightarrow$ The stomata in this type are either absent or rudimentary or functionless;e.g Submerged hydrophytes.

* Leaves
  - Hypostomatic $\rightarrow$ Stomata on lower surface
  - Epistomatic $\rightarrow$ Stomata on upper surface
  - Amphistomatic $\rightarrow$ Stomata on both surfaces

(B) Based on time of opening & closing $\rightarrow$ By Loftfield

(1) Alfalfa type $\rightarrow$ Stomata opens during the day and closes in night.
Ex. -Mesophytes as. Pea, Bean, Radish, Grapes, Apple etc.

(2) Potato type $\rightarrow$ Stomata always open except evening time.
Ex. - Onion, Potato, Cabbage, Banana etc.

(3) Equisetum type $\rightarrow$ Stomata always remains opened e.g. - Amphibious plants.

(4) Barley type $\rightarrow$ Stomata remain always closed except for a few hours in day time. Wheat, Maize etc.

(5) Scoto active opening $\rightarrow$ Stomata closes during the day and opens in the night. Ex - Succulents - *Opuntia*.

* Blue light is most effective for stomatal opening.
* Evapo - transpiration maintains Hydrological cycle in nature.
* Number of Stomata may be 1000 - 6000 / cm^2 (Acco. some workers 14 - 1038/mm^2).
* Transpiration is physical as well as a vital events in Plants.
* Area of stomata is 1 - 2% of the total leaf surface in Mesophytes
* Transpired water is always less than absorbed water by plants.

(C) Stomata Based on structure and Number of Acessory cells :

(1) Anomocytic $\rightarrow$ Subsidiary cells - 5 or 6 and are same in structure.
Eg**.** - Family - Ranunculaceae.

(2) Anisocytic $\rightarrow$ Subsidiary cells - 3 and one cell smallth than the other two.

Eg. - Cruciferae

(3) Paracytic → Subsidiary cells - 2 and are parallell to guard cells.
Eg. - Rubiaceae

(4) Diacytic → Longitudinally situated and 2 Accessory cells.
Eg. - Caryophyllaceae.

Stomata in Gymnosperms :

(i) Syndetochielic - When subsidiary cells & guard cells originate from single cell.

(ii) Haplochielic - Both cells arises from separate cells.

STOMATAL OR FOLIAR TRANSPIRATION :

* Water absorbed by root hairs, reaches in the xylem from the cortical passage (path) through the passage cells of endodermis.
* Water reaches up to the upper part of the plant from the xylem by the process of ascent of sap.
* All cells of mesophyll remain in turgid condition due to presence of water.
* Intercellular spaces are present in between the mesophyll cells.
* Water of moistened walls of mesophyll cells changing into vapour forms. This water vapour accumulates in the substomatal cavities from the intercellular spaces and diffuse into the atmosphere due to less water vapour present in the atmosphere. In this way stomatal transpiration is completed.

Opening of stomata in Succelent Plants :

* Stomata opens during the night in succulent plants and closes during the day. This nature of stomata in *Opuntia* is called **scoto active stomata**.

During the night :

$2C_6H_{12}O_6 + 3O_2 \rightarrow 3C_4H_6O_5 + 3H_2O$

(Carbohydrate) (Malic Acid)

During the day :

$C_4H_6O_5 + 3O_2 \rightarrow 4CO_2 + 3H_2O$

[Malic Acid]

MECHANISM OF OPENING AND CLOSING OF STOMATA :

* The opening and closing of stomata depend upon the osmotic pressure of guard cells. When the guard cells are in turgid state the stomatal aperture opens and when guard cells are in flaccid state the stomatal aperture closes.
* When the osmotic concentration of the guard cells increases then they absorb water from the accessory cells and becomes turgid by endosmosis. Thin wall of the guard cell is pushed out side due to this turgor pressure hence a tension is created on the inner thicker wall thus pulling the inner wall towards the periphery.
* This happens in both guard cells & stoma and a gap is formed between them and which leads to opening of stomata.

The mechanism of opening and closing of stomata is proposed by different scientist.

(1) Theory of Photosynthetic product :

* This theory was proposed by **Von Mohl** & **Swendener.**
* According to them chloroplast are present in guard cell by which photosynthetic process takes place.
* Photosynthetic products are formed during the day [Line in presence of Light].
* Guard cells becomes turgid due to the formation of photosynthetic products and their turgor pressure increases.
* Increase in turgor pressure, causes opening of stomata.
* On contrary, stomata closes, during the night in the absence of photosynthesis and in lowering of osmotic pressure.

Objections :

(a) Formation of photosynthetic product is not clear.

(b) All the guard cells do not have chloroplast.

(2) Starch sugar inter conversion theory :

* First of all indicated that concentration of sugars is higher in guard cells during day time. The theory was proposed by **Sayre (1923)**.
* **Sayre** explained that the inter change of starch - sugar is dependent upon the pH. This theory is appreciated by **Scarth**.
* CO_2 utilized by the process of photosynthesis during day time which increases the pH and stomata opens.
* pH of guard cells decreases in the absence of photosynthesis during the night and stomata become closed.
* Excluding of this **Hanes** discovered a enzyme - **Phosphorylase** and **Yin** and **Tung** shown the presence of this enzyme in the guard cells.
* At high pH [7 to 7.4] phosphorylase enzyme converts starch into sugar.

$$\text{Starch} + \text{iP} \xrightarrow[\text{pH=5 Night}]{\text{pH=7 Phosphorylase}} \text{Glucose - 1 - phosphate} \rightarrow \text{Stomata open}$$

Objections :

* If Glucose and inorganic phosphate do not separate from each other then appropriate osmotic pressure would not be developed.

Modification by Steward (1964) :

* Glucose monophosphate forms Glucose and phosphate during the day time or in the presence of light.
* Osmotic concentration is doubled due to separation of Glucose and phoaphate which increases the turgidity.
* Stomata opens by increasing the turgidity of guard cells.

$$\text{Starch} + \text{Phosphate} \xrightarrow[\text{Phosphorylase}]{\text{pH=7}} \text{Glucose - 1 - phosphate}$$

$$\text{Glucose - 1- phosphate} \xrightarrow[\downarrow]{\text{Phosphoglucomutase}} \text{Glucose 6 phosphate}$$

$$\text{Glucose 6 - phosphate} \xrightarrow[\text{Phosphatase}]{} \text{Glucose + Phosphate.}$$

* Glucose and phosphate combined together in the presence of Hexokinase enzyme to form glucose monophosphate during the night or dark.
* Glucose monophosphate changes into starch at low pH and stomata closes by decreasing osmotic pressure of guard cells.

$$\text{Glucose + IP + ATP} \xrightarrow[\text{hexokinase}]{} \text{Glucose - 1 - phosphate}$$

$$\text{Glucose - 1 - phosphate} \xrightarrow{pH=5} \text{Starch + iP}$$

According to the hypothesis of Steward closing of stomata is an active process.

Objections :

(a) Blue light is shows extra effectiveness in the opening of stomata.

(b) Accumulation of sugars is not found in such amount which can develop desired osmotic pressure in the guard cells.

(c) Interchange of starch - Sugar is a slow process, while opening of stomata is a fast reaction.

(d) Guard cells of monocotyledon plants lack starch. For example leaves of onion donot have any polysaccharides.

(e) Organic acid is found in the guard cells of most of the plants.

(3) Modern Theory or Ion - Transport theory or K^+ Exchange or Active

Proton Transport Theory :

* First of all Fujino stated that concentration of K^+ is increases during stomatal opening.
* This theory was given by Levitt 1974.
* According to him opening and closing of stomata by exchange of $K^{"+}$ ions with H^+.
* According to **Raschke,** K^+ is obtained from neighbouring epidermal cells of the guard cells.
* Maximum amount of ATP is present in the guard cells during the day time. Due to the presence of ATP, a 'pump' occurs in guard cells is known as "**Hydrogen Potassium**" [$H^+ - K^+$] pump"
* Carbohydrate changed into phospho enol - Pyruvic acid [PEP] by the process of Glycolysis.
* This Phosphoenol Pyruvic acid react with CO_2 in the presence of PEP - carboxylase enzyme and oxalo acetic acid is produced, which converts into malate.

$$\text{Carbohydrate} \xrightarrow[\text{Glycolysis}]{pH=5} \text{PEP}$$

$$\text{PEP + } CO_2 \xrightarrow[\text{PEP}-\text{carboxylase}]{} \text{Oxalo Acetic Acid}$$

$$\text{(OAA)} \rightarrow \text{Malate}$$

* This PEP - carboxylase enzyme is highly active in the presence of blue light. Therefore, blue light is highly active for opening of stomata.
* Those pigment which absorb light for the movement stomata are called "**Phytochrome**".
* K^+ ions react with malate ions to form Potassium malate. It is highly active in osmosis.

* The osmotic pressure of the guard cells increased due to formation of potassium malate. Endosmosis of water takes place in the guard cells by increasing the osmotic pressure and stomata opens as a result of turgidity of the cells.
* On contrary, formation of ATP is stopped in the chloroplast during the night and high amount of ATP is used of in the night and $H^+ - K^+$ pump stops their function. Stomata closes.
* The cytoplasm of guard cells has **glyoxysomes**.
* The Malic Acid may converted into carbohydrate by the Glyoxylic Acid cycle in the glyoxysomes.
* Stomata are closed at mid day or noon time for certain amount of time. Because rate of transpiration increases during the day due to which deficit of water occurs.
* Degeneration of carotenoids takes place in the deficiency of water and a growth inhibitor ABA is produced.
* ATP - enzyme becomes inactive by this ABA results which in the deficit of ATP molecules and stomata are closed due to ABA.

Factors Affecting stomatal opening and closing :

(1) Light :

In most of the plants stomata open during the day except succulent xerophytic plants and close during the dark. Opening and closing of stomata is completed in the presence of blue and red light. Blue light is most effective and causing stomatal opening.

(2) Temperature :

Loft Field has shown temperature quotient of opening of stomata to be $[Q_{10}] = -2$

Scarth explained that stomata do not open at 0 - 8ºC in **Zebrina pendula** in the presence of light, while stomata opens at 38º – 40ºC in the absence of light [provided water is not deficient].

(3) CO_2 concentration :

* Stomata are sensitive towards the internal CO_2 in the deficiency of water in the cells of leaves.
* Stomata opens at low concentration of CO_2 while it close at high concentration of CO_2.

(4) Water contents of Leaves :

* Water potential in leaves from – 7 to – 18 when ranging bars reduce the turgidity of guard cells which results closure of stomata.
* ABA is formed due to high water tension in the chloroplast of leaves.

(5) Mineral concentration :

* **Pleasant** and **Desai** described that movement of stomata decrease in the deficiency of N, P and K ions. Possibility is that, they may affect hydrolysis of starch.

(6) Growth Hormone :

Cytokinin Hormone :

* It increases the influx of K^+ ions and stimulate the stomata for opening.
* While ABA stimulate the stomata to close. This hormone oppose the **induction effect** of cytokinin.
* ABA affects the permeability of the guard cells. It prevents the out flux of H^+ ions and increase the out flux of K^+ ions. Because of this pH of the guard cells is decreased.

  Above mentioned effects also found in high amount of CO_2.

(7) Atmospheric Humidity :

Stomata opens for long duration and in the presence of humid atmosphere, while stomata remains closed in dry atmosphere.

Factors affecting the rate of Transpiration :

Factors effecting the rate of transpiration are divided into two types :

(A) External factors

(B) Internal Factors

(A) External factors :

They are related to the atmosphere.

(1) Light :

* It is affected the movement of stomata. Stomata opens in the presence of light and the phenomenon of transpiration occurs.
* Opening of stomata is less in dim light which decreases the rate of transpiration.
* Action spectrum of transpiration is blue and red.
* Rate of transpiration is faster in blue light than that of red light. Because stomata are completely opened in the blue light.

(2) Temperature :

* The value of Q_{10} of transpiration is – 2. It means by the of increase 10ºC temperature, the rate of transpiration is approximately doubled.
* Water vapour holding capacity is affected by temperature.
* Water vapour holding capaicty of air is increased at high temperature, resulting in the increased rate of transpiration increased.
* On contrary vapour holding capacity of air decreases at low temperature hence the rate of transpiration is decreased.

(3) Atmospheric humidity :

* This is the most important factor the rate of transpiration is higher in low atmospheric humidity while at higher atmospheric humidity, the atmosphere is moistened. Resulting in decreasing of the rate of transpiration.
* Therefore, the rate of transpiration increases during the summer and it decreases in rainy season.

(4) Wind velocity :

Transpiration is less in constant air but if wind velocity is high the rate of transpiration also increases. Because wind removes humid air (saturated air) around the stomata and is replaced by unsaturated air. So that transpiration increases.

Transpiration increases in the begining at high wind velocity [30 - 35 km/hour]. But later on it cause closure of stomata due to mechanical effect and transpiration is decreased.

(5) Atmospheric Pressure :

The speed of the air increases at low atmospheric pressure, due to this rate of the diffusion increase which is the term increases the rate of transpiration.

The rate of transpiration is maximum in the high intensity of light at high attitude. The rate of transpiration decreases at high atmospheric pressure.

(6) Available soil water :

The rate of transpiration depends upon the available soil water.

The rate of the transpiration decreased due to loss of available soil water.

(7) Anti transpirants :

Those substances which reduce the rate of transpiration are known as **antitranspirants**. Anti transpirants are as follows :

* Phenyl Mercuric Acetate [PMA]
* Aspirin.
* Abscissic Acid [ABA]
* Oxi - ethylene
* Silicon oil
* CO_2 and Wax

PMA closed the stomato for more than two weeks partially.

These antitranspirants are used in dry - farming.

(B) INTERNAL FACTORS :

These factors are concern is with the structure of plants. They are of following types :

(1) Transpiring areas :

* The surface of the leaf is most important. hence, more transpiration take place through the large surfaced leaf.
* The area of leaves of xerophytic plants is reduced due to transformation of leaves in various forms. So that rate of transpiration is decreased.
* The loss of water from per unit area, in per unit time by transpiration is called rate of transpiration.
* The rate of transpiration is higher in young leaves as compared to older ones.

(2) Anatomical characteristics of Leaf

Several structures of leaf effect the transpiration as follows :

(a) Cuticle :

Thick cuticle of the leaf reduce transpiration.

(b) Transpiration is decreased due to the presence of thick epidermal cells and multilayering of epidermal cells e.g. ***Nerium*, Banyan Tree** etc.

(c) The presence of number of hairs and dense hairs are decrease the rate of transpiration.

(3) Stomatal characteristics :

Transpiration is affected by the structure of stomata, position of stomata, distance between the stomata, number of stomata per unit area and activity of the stomata.

The rate of the transpiration is decrased due to sunken stomata, sunken epidermis, very close stomata, less no. of stomata per unit area, less no. of stomata opening for small duration.

(4) Leaf Orientation :

Heating effect is increased due to the surface area of the leaf being exposed to the right angle of the light. Hence rate of transpiration as increased.

(5) Water status of Leaves :

If the amount of water is less then that of normal amount it causes closure of stomata and reduce the transpiration.

(6) Root - Shoot Ratio :

* The rate of transpiration decreases with root - shoot ratio.
* The rate of transpiration increases with root - shoot ratio.
* The following characteristics are found in leaf to reduce the transpiration.

(i) Leaves modified into spines.
(ii) Leaves transformed into needle like structures e.g. **Pinus.**
(iii) Folding and unfolding of leaves e.g. **Amophilla, Poa** etc.
(iv) Small size of the leaves.
(v) Presence of waxy layer on the leaves.
e.g. **Banyan tree**.

(9) Significance of Transpiration :

* According to Curtis "Transpiration is a necesary evil"

Transpiration has immense significance in plants:

(1) Water Absorption :

* Maximum absorption of water occurs due to transpiration pull.

(2) Mineral absorption :

* Mass flow of water occurs during the passive absorption of water. Hence it is assumed that minerals enter into the roots through the water.

Objection :

* Absorption of water takes place from the root hair region and absorption of minerals from the meristematic region.

Excluding of this most of the minerals are absorbed by active absorption, while absorption of water is a passive process.

(3) Ascent of sap :

Suction pressure is developed due to of ascent of sap which helps in ascent of sap upward movement of water from roots to the topmost part of the plant.

(4) Regulation of Temperature :

Cooling effect on the surface of leaves is produced by the process of transpiration by which the

temperature remains constant for the plants.

The plants are protected from the heat due to transpiration. Evaporation of water produces cooling effect.

(5) Drainage of soil Water :

The amount of water is increased in soil due to rains and aertion is reduced therefore, removal of increase water from the soil by the process of transpiration by which aeration is increased in soil.

(6) Assimilatory products :

Rubber latex, resins, alkaloids and pigments etc. are synthesized by the in the plants transpiration. These substances are useful to human beings.

(7) Mechanical Tissues :

The mechanical tissues like collechyma, sclerenchyma xylem etc. are developed due to loss of water. This loss of water takes place by transpiration. Mechanical tissues provide mechanical support to the plant. Hence of xerophytic plants are strong and hydrophytic plants are soft.

(8) Root system :

A well developed root system is found in transpiring plants which is helps in the absorption of more minerals and protects the developed aerial system from wind.

(9) Quality of fruits :

Amount of sugar is increased by the process of transpiration. Hence fruits become comparatively becomes sweet in taste.

(10) Distribution of absorbed salts :

Absorption of minerals is an active process, But minerals distributed to the remaining part of the plants from the xylem through the process of ascent of sap and ascent of sap takes place due to transpiration.

(11) Increase in dry weight :

The dry weight of the plant increased by transpiration. The higher osmotic pressure [OP] is found in the cells of the plants.

(10) LOSSES FROM TRANSPITON :

(1) Loss in Photosynthesis :

Loss in photosynthesis occurs due to water deficit by two different ways :

(a) Stomatal effect :

Stomata are closed in the deficiency of water

(b) Non stomatal effect : The permeability of the root is decreased by water deficit. Light reaction reduced and respiration and photorespiration increases **RUDP** and other enzymes are synthesized.

Photosynthesis is decreased by above mentioned reasons.

According to "**Hall**" a harmful substance "**proline**" is synthesized due to transpiration.

(2) Reduced Growth :

Turgidity of the cells decreases due to deficit of water. It affects the elongation of cells. Growth of the

plant reduced by decreasing turgidiy.

(3) Formation of ABA [Abscisic acid] :

ABA is formed due to loss of water which causes closing of stomata and affects many other metabolic activities.

(4) Death of Plants :

The death of the plants takes place in the when it loses water :

(5) Effects on metabolism :

All the metabolic activities are going on appropraite humidity. These activities decreased by loss of water.

(6) Xerophytic plants utilize their 3/4 energy for development of adapatation to reduced transpiration. Hence xerophytic plants are small. Because of this trees are not found in desert. Only shrubs are present.

(i) Potometer :

The rate of the transpiration is measured by potometer.

(iii) Cobalt chloride test :

This method is used for the comparision of transpiration from the both surface of the leaves. It is first of all shown by Stall.

GUTTATION

* "Loss of water from the uninjured part or leaves of the plant in the form of water droplets is called **guttation.**"
* The term "**Guttation**" was coined by **Burgerstein.**
* The process of guttation is found both shrubs and woody type of plants. Exuded liquid of guttation excluding water also contains some organic and inorganic (dissolved) substances.
* Normally, guttation process is found in some plants like grasses, **Tomato, Balsam, Nasturtium, Colocasia, Saxifraga** and in some of the plants of **Cucurbitaceae** family.
* Guttation occurs from the margins of the leaves through the special pore, called "**Hydathodes**"

  Each hydathode is formed by colourless epidermal cells.
* Parenchymatous and loose tissue lies beneath the hydathode which is known as "**Epithem**". It is also known as "Transfer tissue".
* The cells of epithem are soft and without chloroplast.
* The cells of epithem are involved in absorption and secretion.
* In the anterior part of epithem, a cavity is present which is called **water cavity**. It opens out through the hydathode.
* Hydathodes always remains open.

  The process of guttation of takes place due to root pressure.
* The process of guttation occurs in the special circumstances when the higher rate of absorption and transpiration is low.
* Above condition is developed during the night.

  Guttation takes place before sun rise.

guttation may be takes place during day time in the rainy season. Guttation is found in well irrigated land.

According to **Haberlandt**, hydathodes are of two types :

(i) Active hydathode : Guttation occurs in these cells through the cells of themselves.

(ii) Epithem hydathode :

Guttation occurs in these cells through the root pressure.

BLEEDING

* Fast flowing of liquid from the injured or cutting parts of the plants is called "Bleeding".
* This process take place due to high root pressure.
* Saccharide is obtain from the Sugar maple by this process. (also - Rubber latex)
* The highest bleeding is found in *Caryota urens* (about 50 liter per day).
* The process of bleeding can be seen in ***Agave, Betula Vitis, Getonia*** and ***Tomato*** etc.

SPECIAL POINTS

(1) The main reason of osmotic pressure of the opened atomata is the potassium chloride or potassium mallate.

(2) **Porometer** is used to measure the area of the stomata on the leaf.

(3) The maximum weight of a plant is in the morning and minimum weight is in the evening.

(4) Transpiration measuring instrument is called **potometer**. The rate of absorption of water is measured through this instrument. Because rate of water absorption is proportional to the transpiration.

(6) Liquid which comes out through the stomata passively, contains higher amount of inorganic material. But liquid tranpired actively contains both organic and inorganic substances.

(7) Osmotic pressure of the guard cell at the time of opening of stomata is found about 30-45 atm.

(8) The photophosphorylation process in the guard cells is a energy metabolic process, not CO_2 - metabolic process.

(9) This is takes place through the cyclic method.

(10) Accumulation of Na^+ ions is found inthe epidermal cells which is present near the guard cells in some of the plants. This is found in those plants which grow in saline soils.

(11) Transpiration is completely absent in hydrophyte like emerged hydrophytes.

(12) The rate of transpiration of C_4 plants is comparatively less as compared to C_3 plants.

(13) The pH of normal fertile soil is about 6 to 7.

(14) If the tissues are removed from the stem up to the endodermis in a ring so that food is not reached to the root. Results, root dies earlier than others in the absence of food.

(15) Removal of bark of the plant causes great loss to them.

Calcium - ABA Second Messenger Model :

* Ca^{++} inhibits the stomatal opening if it applied to isolated epidermis (by Cowan & De silva 1985).
* Acc. to Manfield etc. all (1991) Ca^{++} inhibits opening and it can move rapidly from root to shoot.
* ABA induced increase in cytosolic free calcium ion (Ca^{++}) which trigger stomatal closure. Ca^{++} also inhibits K^+ induced swelling of guard cell protoplast.
* There is evidence that Ca-binding protein (Calamodulins) may also participate in action mediated by Ca^{++}.