PHYSIOLOGY

[SEM-V, PAPER-III, UNIT-II]

WATER POTENTIAL (W.P.)

It is called as "Chemical potential of water". Chemical potential is the free energy per mole of water present in a system of constant pressure and temperature; free energy being the energy available for doing work (kinetic energy). they are the Collision between particles. Under constant temperature & pressure, the chemical potential depends upon the number of moles of substance present in system.

Term 'water potential' was coined by Ralph Slayter and Sterling Taylor. Water potential is defined as "Difference between chemical potential of water in the system and chemical potential of pure water at same temperature and pressure". It cannot be directly measured; absolute values not possible, only comparative values can be estimated considering C.P of pure water as zero (maximum W.P). Accordingly, W.P becomes negative or positive. It is measured in the unit of pressure – 'bars' or 'mega pascal'. [1 mega pascal = 10 bars]. It is denoted by Greek letter Ψ (psi). W.P can be written as Ψw.

SIGNIFICANCE OF WATER POTENTIAL (W.P.):

It is a diagnostic tool to know the water status of plant. It gives information regarding water status of the plant, cell and tissue. Lower the W.P., greater is the ability to absorb water. Besides, higher the W.P., greater is the ability of plant to supply water to other cells. W.P thus an indicator of water stress in a plant. It is a tool to explain osmosis and turgor pressure, which is an important mechanism to explain water movements in plants. Difference in C.P of water across the cell membrane is a major factor in movement of ions from soil into the plants and transport of ions in and out of plant cell.

COMPONENTS OF WATER POTENTIAL (W.P.):

W.P.:- Solute Potential Ψs, Pressure Potential Ψp, Matric Potential Ψm.

These three factors operate together and contribute to W.P.

W.P of a cell or tissue is an algebraic sum of these three components, so written as $\Psi w = (- \Psi s + \Psi p + \Psi m)$.

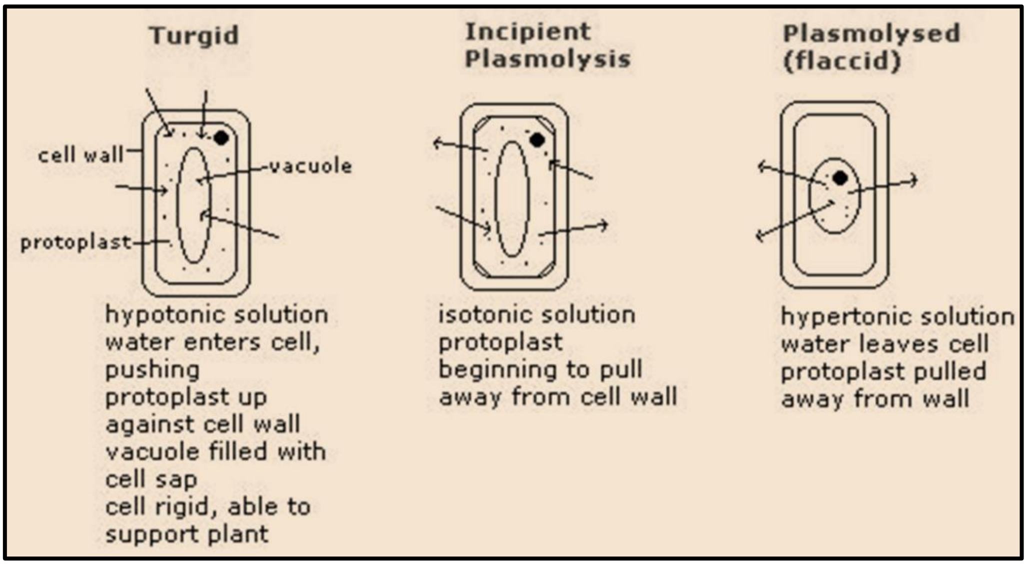
1. SOLUTE POTENTIAL (ΨS):

Potential of pure water by definition is zero, but the presence of solutes in it lowers its W.P. due to collision of water molecules with the solute molecules. "Decrease in W.P. brought about by substances either ionic or non-ionic in solution is referred to as solute potential". Mixing of solutes increases the disorder or entropy of system, thereby reducing its free energy. If solution contains many solutes, then Ψs is equal to the sum of individual solute potentials of each solute. Value of Ψs varies from species to species. Eg., In cold regions, it is -1 Mpa to -2 MPa; for thallophytes, -5 to -8 Mpa; xerophytes -10 MPa. Small variations can occur on daily basis. According to earlier literature, Solute potential is same as osmotic potential, O.P being positive, while S.P. being negative.

2. PRESSURE POTENTIAL / TURGOR PRESSURE (ΨP):

Plant cells have rigid inelastic cell wall and differentially permeable cell membrane, allowing plants to survive in wide osmotic ranges. When cell placed in pure water, water will move into the cell due to hypertonicity of cell sap, causing plasma membrane to be pressed against the cell wall. Pressure required for this is actually called 'pressure potential' or 'turgor pressure'. Cell wall being rigid exerts an equal and opposite force, called as 'wall pressure'. As a result of the interplay of these two forces, plant cell under these conditions is said to be turgid, thus pressure potential is taken as a component of water potential. For normal cell it can be written as, Ψw = - Ψs + Ψp. Water movement continuous till equilibrium, when cell is said to be turgid Ψw = 0; hence – Ψs = Ψp. When cell is placed in hypertonic solution with high solute potential, exosmosis will occur, cell membrane starts separating from cell wall, this stage called as 'incipient plasmolysis. Cell wall being rigid stops exerting pressure on membrane at one point and at plasmolysed stage, Ψp = 0. Thus, Ψw = - Ψs.

If cell is kept in hypertonic solution for longer periods, the protoplasm shrinks and cell is said to be fully plasmolysed. If plasmolysed cell is placed back in hypotonic solution, endosmosis will occur, effect of plasmolysis is nullified and cell is said to be deplasmolysed.



SIGNIFICANCE OF TURGOR PRESSURE:

It maintains turgidity and rigidity in plant cell. It also maintains structural integrity of cell and cellular organelles. Cell enlargement during cell growth is controlled by turgor pressure, causing irreversible stretching of primary cell walls. Phenomena like stomatal opening and closing, folding and unfolding of leaves, drooping of leaves of *Mimosa pudica* in response to stimulus, etc. are controlled by turgor pressure.

3. MATRIC POTENTIAL (ΨM):

Cell wall in plants composed of network of cellulose microfibrils 10 – 30 nm in diameter, with interfibrillar space of 1 – 100 nm between them. Cell wall also consists of pectic substances, proteins and a variety of other constituents with many hydroxyl and carboxyl groups, held together by hydrogen bonding. Water also held by surface tension in the interfibrillar space. The W.P lowered by these matric forces is called matric potential represented by Ψm. Up to 50% of cell wall volume occupied by water held by matric forces. Presence of proteins and other colloids in cytoplasm results in Ψm in addition to Ψs due to dissolved salts. Thus in entire cells and tissues, various forces interact continuously and therefore water potential can be defined as "difference in free energy per unit volume between matrically bound pressurized and osmotically held water and pure water".

W.P can thus be partitioned into three components:

- Solute components due to dissolved salts, most of which is within the vacuoles.
- Pressure potential due to pressure developed in the cell.
- Matric potential due to binding of water molecules to cell wall constituents and protoplasm.

OSMOSIS

"The movement of water molecules from a solution of lower concentration to a solution of higher concentration through a semipermeable membrane is known as osmosis". The net direction and rate of osmosis is determined by pressure and concentration gradient.

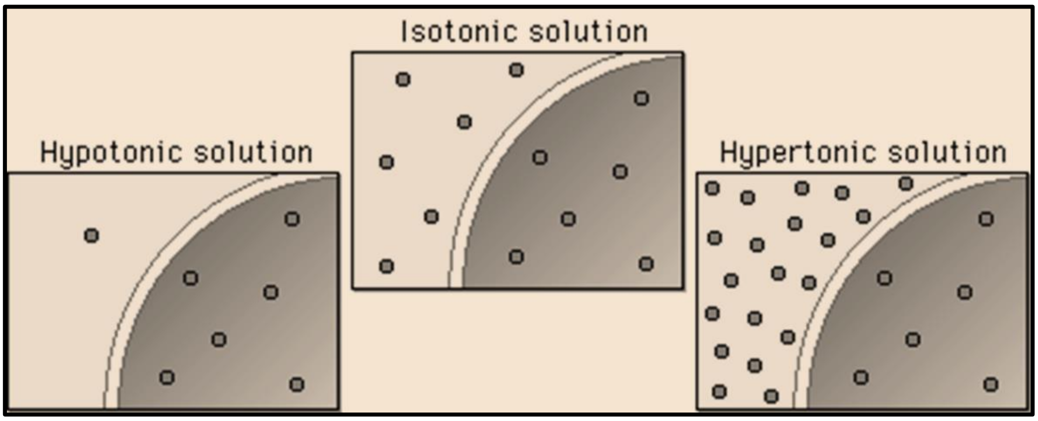
Osmosis is important for plants. They gain water by osmosis through their roots. Water moves into plant cells by osmosis, making them turgid or stiff so that they are able to hold the plant upright.

OSMOTIC PRESSURE (O.P):

O.P of a solution is equal to a pressure required to prevent the passage of solvent into it through a semi-permeable membrane. Symbolically represented as π (pi). O.P of pure water = zero. O.P is directly proportional to number of solute molecules in a given solvent. So, more is the solute concentration, greater will be the O.P. Numerically, O.P is equivalent to osmotic potential (solute potential), but the sign is opposite. O.P is the positive pressure applied, while osmotic potential is negative.

Depending on osmotic pressure, solutions classified as:

Solutions: - 1. Hypotonic 2. Isotonic 3. Hypertonic



HYPOTONIC:

If the external solution is more diluted than the cytoplasm, it is said to be hypotonic. The solute concentration of cell is greater than that of solvent. When plant cell is placed in a hypotonic solution, water diffuses into the cells due to which it becomes turgid. It is called as endosmosis. Turgor pressure is the pressure developed inside the cell when it is placed in a hypotonic solution.

ISOTONIC:

It is responsible for enlargement and extension growth of the cells. If the external solution balances the osmotic pressure of the cytoplasm, it is said to be isotonic. The solute concentration of cell is equivalent to that of the solvent. When a plant cell is kept in an isotonic solution, concentration of external solution = concentration inside the cell. The system is said to be in equilibrium. There is no net flow of water in and out, the cell in such case is said to be flaccid. Net osmosis is balanced in such a cell. In flaccid cell, $\Psi p = 0$.

HYPERTONIC:

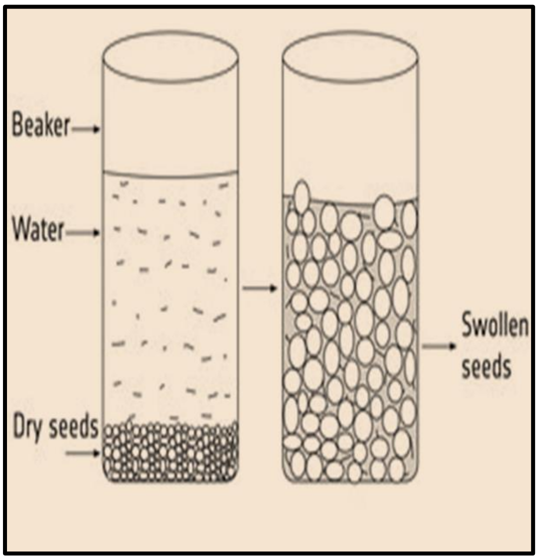
If the external solution is more concentrated than the cytoplasm, it is said to be hypertonic. The solute concentration of cell is less than that of the solvent. When a plant cell is kept in hypertonic solution, water diffuses out of the cytoplasm into the surrounding medium. It is called as exosmosis. The protoplast shrinks away from the cell wall and this phenomenon called as plasmolysis. Process of plasmolysis is usually reversible when plasmolysed cell is placed in hypotonic solution.

Importance of osmosis in plants:

- For water absorption – water potential of root epidermal cells is lower than that of sol water.
  -water moves from the soil (higher water potential) into the root epidermal cells (lower water potential).
- For support – young, non woody plants depend entirely on turgidity for support.
  -if water loss is significant, plant tissue will become flaccid and the plant will wilt.

IMBIBITION

“ Process of temporary increase in volume of cell due to absorption of water by solid – colloidal substances without forming solution is called imbibition”.



The substance that imbibes (absorbs) water is called as imbibant. For example, cell protoplasm, seed coat. Different types of organic substances have different imbibing capacities. Very high imbibing capacity in proteins, less in starch and least in cellulose. Proteinaceous pea seeds swell more as compared to starchy wheat seeds. The liquid substance that is absorbed or imbibed is called imbibate. Mostly the imbibate is water.

CONDITIONS REQUIRED FOR IMBIBITION:

A water potential gradient should occur between the imbibant and the liquid imbibate. There should be some force of attraction between imbibant and imbibed liquid. Increase in temperature brings about increased imbibition.

CHARACTERISTICS OF IMBIBTION:

- Adsorption:

Imbibant substance is an adsorbent. Imbibant holds imbibate (water) by adsorption due to the great force of attraction between the two.

- Water Potential:

Imbibants have a very high negative water potential. It is called matric potential. Water has (the highest) maximum water potential (maximum being zero).

- Water Potential Gradient:

When dry imbibant (with high negative water potential) comes in contact with water (maximum water potential), a steep gradient of water potential is created and water diffuses rapidly from its higher potential into the imbibant.

- Heat of Wetting:

Energy in the form of heat is released during imbibition. It is called heat of wetting.

- Increase in Volume:

Volume of the imbibant increases during imbibition e.g. swelling of soaked seeds, swelling of wooden frames during rainy season, etc.

IMBIBITION PRESSURE:

When the imbibing substance is kept in a confined space, pressure is developed due to the increase in the volume of the imbibant. This is called imbibition pressure. It develops due to the matric potential of the imbibant, hence called matric potential and is denoted as Ψm (= psi). Ψm measured in bars or mega pascals (MPa). Now a days, the term imbibition pressure is replaced by the new term matric potential.

FACTORS INFLUENCING IMBIBITION:

Capacity as well as the degree of imbibition vary in different imbibing substances and depend up on following factors:

(a) Texture of the imbibant

(b) Affinity of the imbibant for the imbibate

(c) Temperature

(d) Pressure

(e) pH of the medium

ROLE OF IMBIBITION IN PLANTS:

Imbibition is the first step in the absorption of water by the roots and cells. Imbibition of water by cell walls helps to keep the cells moist, and. Imbibition pressure is helpful in seed germination, growth of seedling through the soil, ascent of sap in plants, etc.

SIGNIFICANCE OF IMBIBITION:

It is the dominant and first step of water absorption. Imbibition is the first step of seed germination. Seedling is able to come out of soil due to development of imbibitional pressure.

IMBIBITION	DIFFUSION
It involves the absorption of solvent or water by a solid substance (adsorption occurs).	It is the movement of all types of substances from the area of their higher free energy to the area of their lower free energy.
It produces heat.	It does not produce heat.
It can develop a very high pressure (upto 100 atm) called imbibition pressure.	It cannot develop a high pressure.

Extent of absorption of water in plants – An interesting example: A botanist H. J. Dittmer (1937) worked out that a four-month old rye plant had an aggregate root length of about 600 km! The number of root hairs in it exceeded 14 billion and their estimated total length would even exceed 10,000 km!

TRANSPIRATION

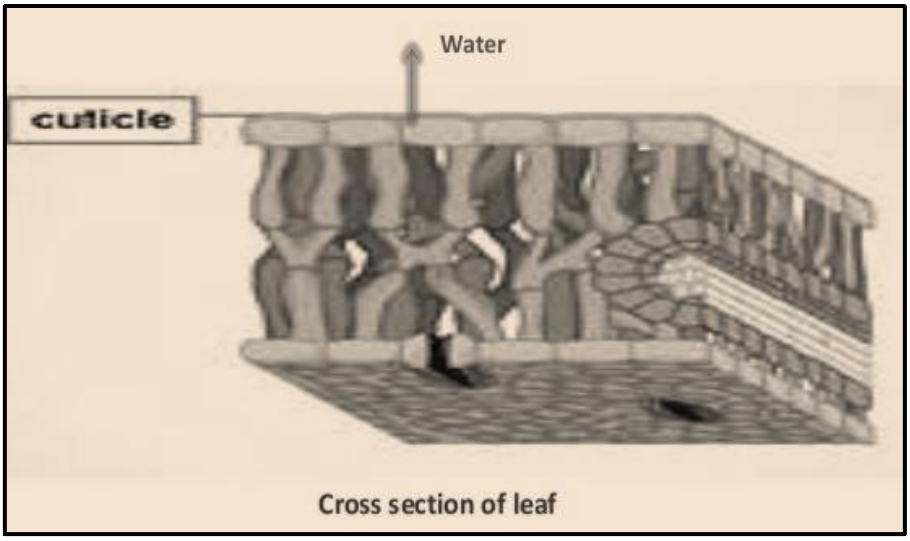
“The loss of water in the form of water vapour from the aerial parts of the plants is known as transpiration”. Plants absorb sufficient quantity of water from soil with their root hair. Most of the water absorbed is ultimately lost through stem and leaves. Only a very small fraction is utilized in plant development and metabolic processes. Basically, transpiration is an evaporation phenomenon but which differs from the general process of evaporation. Evaporation is referred to as loss of water from a free surface, whereas in case of transpiration, the water passes through the epidermis which is with cuticle or through the stomata.

TRANSPIRATION	**EVAPORATION**
Transpiration is a physiological process.	Evaporation is a physical process.
Transpiration occurs only in living plants.	Evaporation occurs both living and non-living bodies.
It is loss of water from the free surface of cell.	It is loss of water from the free surface of water.
This process is influenced by both external and internal condition.	This process is only influenced by external condition
It is comparatively slow process.	It is faster than transpiration.

DIFFERENT TYPES OF TRANSPIRATION:

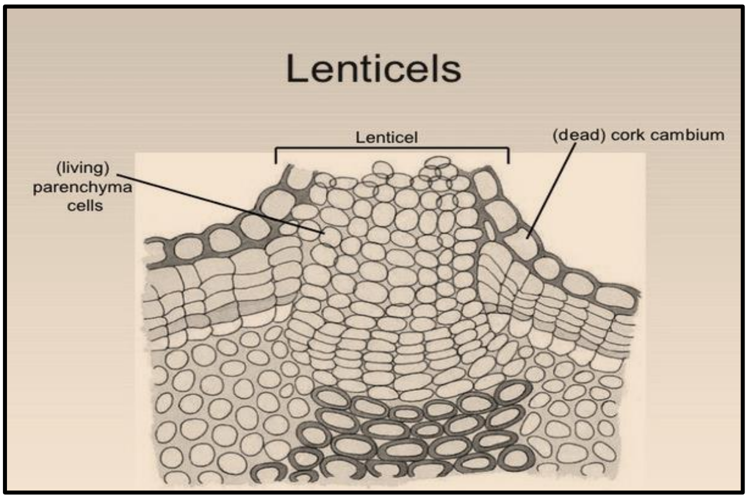
- Cuticular
- Lenticular
- Stomatal

CUTICULAR TRANSPIRATION:



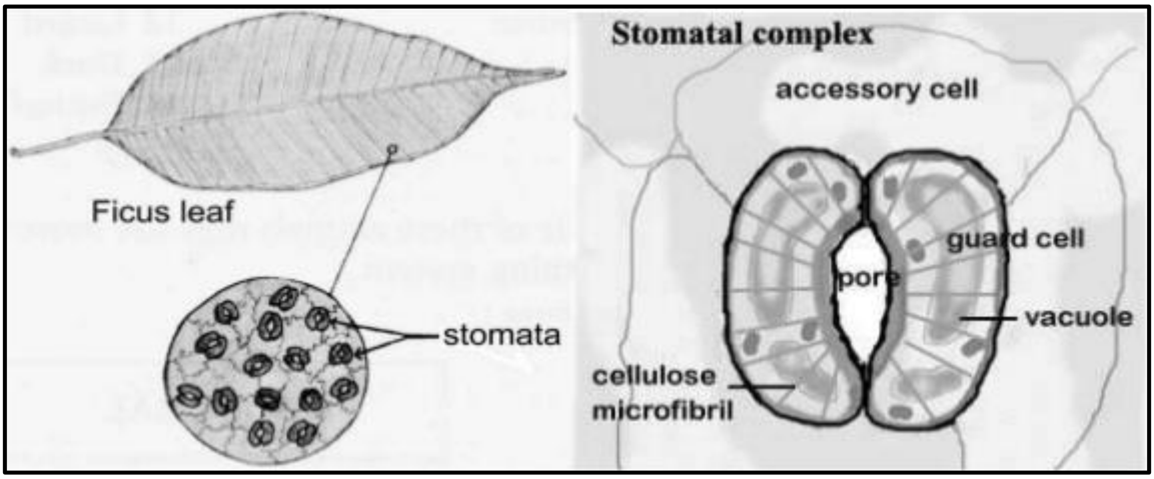
It takes place through cuticle found on the surface of stem and leaves. Cuticle is a non-cellular covering of cutin and wax that lies on the exposed surface of epidermal cells. It reduces loss of water but is not strictly impervious to it. This type of transpiration depends on the thickness of cuticle. Thicker the cuticle, less will be the rate of transpiration. About 8 – 10% water loss occurs through cuticle by simple diffusion. If cuticle is thin, up to 20% of transpiration may take place through it. This mode of transpiration takes place throughout day and night.

LENTICULAR TRANSPIRATION:



This occurs through the lenticels. They are fine pores present on older parts of plants like bark of old stems and pericarps of woody fruits. They bear small loosely arranged complementary cells. Negligible water loss (0.1 – 1%) through lenticels takes place by transpiration. This also occurs throughout day and night.

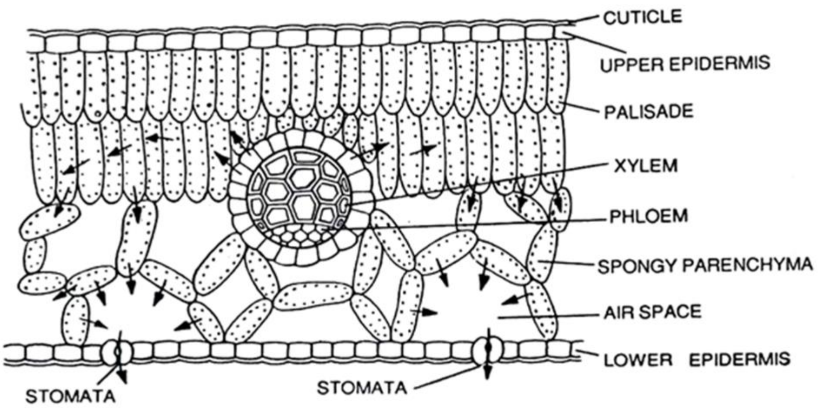
STOMATAL TRANSPIRATION:



It is the most important mode of transpiration. Occurs through stomata present on the aerial parts of plants, mostly the leaves and young stems. Small openings usually confined to the epidermis of leaves. Number of stomata is usually greater on lower side of leaf. About 90 – 97% of transpiration takes place through stomata. Takes place only during the day when stomata are open. This type of transpiration is controlled by guard cells of stomata.

MECHANISM OF STOMATAL TRANSPIRATION:

Water rises up in the stems of plants through xylem vessels. From the xylem vessels of leaf veins, water diffuses to mesophyll tissue gradually making the assimilatory cells fully turgid. Moist cellular walls release water in the form of vapor which reaches intercellular spaces. Intercellular spaces become more saturated than outer atmosphere. As intercellular spaces are connected with substomatal chambers, they get saturated with water vapor. Outer atmosphere is comparatively drier than inner tissues and therefore, water vapor diffuses from substomatal chambers to outside through stomata. Outer air remains in close contact with the leaves, evaporating water from their surfaces. This process goes on continuously.



Mechanism of Stomatal transpiration in V.S. of typical dicot leaf. The arrows show the movement of air

OPENING AND CLOSING OF STOMATA:

Levitt (1974) proposed proton transport concept to explain mechanism of opening and closing of stomata. According to this, opening and closing of stomata takes place as a result of an active transport of potassium ions into guard cells and out of them. The adjacent epidermal cells act as storage cells for guard cells. During daytime, starch is converted into malic acid in cytoplasm of guard cells. Malic acid dissociates into H+ ions and malate ions. H+ ions given out of guard cells and K+ ions from subsidiary cells enter guard cells. Intake of K+ is balanced by intake of Cl- ions. During night time, photosynthesis ceases. CO2 concentration in guard cells increases and pH becomes acidic (5.0). In presence of CO2, an inhibitor ABA functions and inhibits uptake of K+ and Cl- ions by changing the diffusion and permeability of guard cells. K+ and Cl- move out to the subsidiary cells.

During day light – accumulation of K^+ ions by the guard cells – increased solute concentration – decreased water potential – endosmosis of water – increased turgidity – stoma open

During night / dark – loss of K^+ ions by the guard cells – decreased solute concentration – increased water potential – exosmosis of water – decreased turgidity – stoma close

DIURNAL (DAILY) VARIATION IN TRANSPIRATION:

Transpiration Ratio: “The ratio of transpirational loss of water to its dry matter production”. Photosynthesis productivity, water loss gives an idea about efficiency of plants’ utilization of water. Smaller the ratio, more is the efficiency of water utilization.

Transpiration Flux: “The quantity of water vapor transpired by unit area of leaf surface in unit time”.

It has been shown experimentally that plants give out large quantities of water during transpiration.

- A full grown single sunflower plant is estimated to lose about half a litre of water per day by transpiration.
- A single maize plant loses about 2 litres of water per day.
- A large apple tree may lose about 30 litres of water per day.

These figures give an idea about huge quantities of water released into atmosphere by vast stretches of fields and particularly forests. Thus, transpiration increases moisture in atmosphere and brings rain. “Forests contribute in bringing rain. Transpiration is the secret.”

FACTORS AFFECTING TRANSPIRATION:

External factors:

- Intensity of sunlight: More transpiration occurs during the day when stomata are open to facilitate inward diffusion of carbon dioxide.
- Temperature: Increase in temperature allows more water to evaporate from aerial parts of plants.
- Velocity of wind: Transpiration directly proportional to wind velocity.
- Humidity: Inversely proportional to transpiration.
- Carbon dioxide: Increase in CO2 level in the outside air over normal 0.03% causes stomatal closure and results in decrease in transpiration.
- Atmospheric pressure: Rate of transpiration decreases with increase in atmospheric pressure.

Internal factors:

Water content of leaves: If water content of leaves decreases due to insufficient absorption of water by roots, the leaves wilt and transpiration is reduced. Such reduction in transpiration is indirectly due to closure of stomata.

SIGNIFICANCE OF TRANSPIRATION:

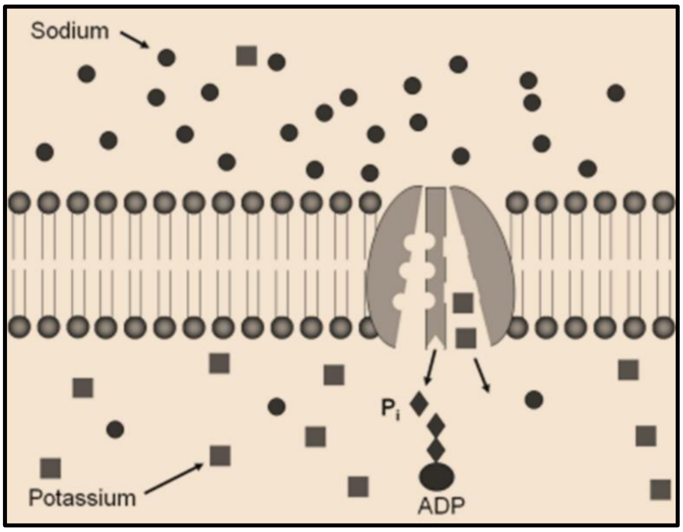
Beneficial Effects:

Continuous water stream maintained due to transpiration pull throughout plant body. Due to transpiration there is mass flow of water from soil to roots. When rate of transpiration is high, rate of water translocation through xylem elements is also rapid. Minerals dissolved in water are passively absorbed under the influence of transpiration and minerals actively absorbed are translocated up to top of plant due to transpiration pull (ascent of sap). Helps in reducing temperature of leaf and avoids plant being overheated. Thus, gives cooling effect and protects the plant. Maintains optimum degree of turgidity in plant cells at which they function efficiently. Under favorable conditions, plant absorbs excess amount of water which is given off by transpiration to maintain optimum turgidity for better growth and development. Helps in the formation of mechanical tissue in plants.

Harmful Effects:

A large amount of water absorbed is lost, thus it is an energy sapping process. It causes water deficit and plants can suffer injury due to dessication. Deciduous trees have to shed their leaves to check transpiration. Mesophyll tissue is made up of thin walled cells with intercellular spaces and stomata are for gaseous exchange required for photosynthesis and respiration. Due to this, transpiration is unavoidable. Steward (1959) called it as ‘unavoidable evil’. Though it is energy sapping, transpiration helps in absorption and translocation process. So, according to Curtis (1926), transpiration is ‘necessary evil’.

TRANSPORT OF IONS ACROSS CELL MEMBRANE



Mineral elements are distributed in soil either in dissolved form or in an adsorbed form. Dissolved salts form soil solutions while adsorbed minerals are held on to soil to form colloids or micelles. They are adsorbed in ionic form either as cations or anions. Eg. Nitrogen can be in the form of cations (NH4+) and anions (NO3-, NO2-). K+, Mg++, Ca++, Fe++, Zn++ exist in cationic form while P-, S-2, Bo-, Mo-, Cl- exist as anions. Minerals held in salt solution or adsorbed on soil particles are taken through root cells which are in association with soil solution. Cell wall is freely permeable to these ions while the cell membrane acts as barriers for the transport of ions across them.

MECHANISMS OF ION TRANSPORT ACROSS MEMBRANE:

Mechanisms of ion transport:-

Non – mediated - It is always passive

Mediated - It can be either passive or active

a) NON – MEDIATED PASSIVE TRANSPORT:

Characteristics of passive transport:

It possess spontaneous process. Physical driving forces are involved and always proceed towards equilibrium. No metabolic energy are involved.

Types of non-mediated transport:

a) Diffusion
b) Ion exchange
c) Mass flow
d) Donnan effect and equilibrium

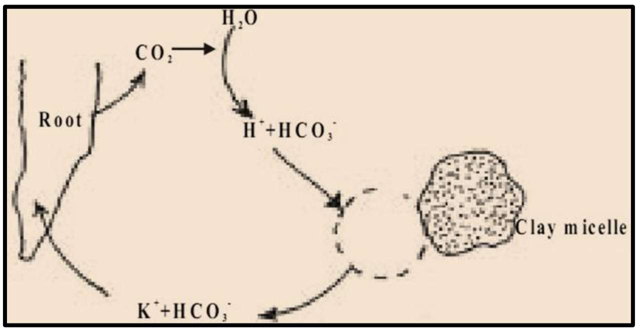
a) Diffusion:

Minerals from soil are absorbed through roots of plants by simple diffusion process. A physical phenomenon where there is movement of ions against concentration gradient till it reaches an equilibrium point. Physical driving force here is concentration gradient between root cells and soil solution. This gradient can be created by transpiration, rapid assimilation and compartmentalization of these ions into the vacuoles which creates an ion deficit in root cells and hence the concentration gradient, thereby facilitating transport of ions. It is very significant process for plants as it is an effective means of transport of ions over short distances.

b) Ion exchange:

Carbonic acid exchange mechanism:

Cells of roots release CO2 during respiration. CO2 combines with water to form carbonic acid in the soil surrounding the roots. Carbonic acid dissociates to release hydrogen ions and bicarbonate ions. The hydrogen ions released near roots are exchanged with K+ ions in the soil, which then enter the root cells. Physical driving force is transpiration pull.



c) Mass flow:

Ions can move from plant root along with mass flow of water rapidly. Transpiration causes rapid absorption of ions dissolved in water. In other words, transpiration pull helps in mass flow. Increase in water uptake with dissolved ions can also occur due to increase in the hydrostatic pressure in the xylem tissue.

d) Donnan effect and equilibrium:

In general, donnan equilibrium may be expressed in the following equation:

$$\frac{\text{Concentration of positive ions (inside)}}{\text{Concentration of negative ions (outside)}} = \frac{\text{concentration of positive ion (outside)}}{\text{concentration of negative ion (inside)}}$$

This theory takes into account the effect of fixed or non-diffusable ions which includes proteins, polymers like DNA, RNA along with carboxide and phosphate groups. These fixed ions are negatively charged and are balanced by additional absorption of cations from outer solution. Thus, cations absorbed more in respect to anions. Membrane is freely permeable to most cations and anions in soil solution. Therefore equal no of cations and anions diffuse across the membrane until an equilibrium is attained. The equilibrium is electrically balanced. However, additional cations will be needed to balance negative charges of fixed ions on inner side of membrane. Thus, cation concentration will be more in internal solution than it is in external solution.

Donnan phase is a region which contains indiffusable or fixed ions. At equilibrium point, the ratio of anions and cations in internal solution is equal to the ratio in external solution. In other words, Donnan equation is attained according to following equation: [Ci+] / [Ai-] = [Co+] / [Ao-]

This accumulation of ions against concentration gradient occurs without participation of metabolic energy. But there is no selectivity of ions that are allowed. In Donnan effect the equation results in the accumulation of anions in much greater concentration with in the cell than external medium. For instance, accumulation and absorption of Zn++ by roots have been found to be due to Donnan effect. It is estimated that absorption and accumulation of substances in cell sap due to Donnan equation is approximately up to 30 times more than normal absorption.

b) MEDIATED TRANSPORT:

Types of mediated transport depending on thermodynamics of system:

a) Passive mediated transport - Also called facilitated diffusion. Eg. Carriers and ion channels. Here, a specific molecule moves from higher to lower concentration with the help of mediator molecule but not metabolic energy.
b) Active mediated transport - Eg. Ionic pumps. Here, a specific molecule is transported from lower concentration to higher concentration against concentration gradient. An endergonic process. So, coupled with an exergonic (energy generating) means to make process favorable.

MEMBRANE TRANSPORT PROTEIN:

Carriers and ion channels are passive mechanisms while ionic pumps are active mechanisms. These protein transporters have specific geometric configuration for binding to specific ion site with the help of multiple weak non-covalent interactions. These trans-membrane proteins have hydrophilic amino acid chain that forms channels to increase the rate of diffusion.

a) ION CHANNELS:

Trans-membrane protein which functions as selective pore through which ions can easily diffuse across the membrane. Present in the plant cell membranes. Ion fluxes through channels are driven by electrochemical potential difference. Ion flow through channel is always positive. Direction of flow of particular ion is decided by electrochemical potential gradient for that particular ion. Two types – cation channels (K+, Ca++) and anion channels (Cl-, NO3-, organic acid, etc).

Aqua pores or aquaporines appear in membrane due to pairing of intrinsic protein which act as open channel. These channels allow passage of water and small sized ions. The specificity is determined by specific binding site within channel pores. The channel regulates the passage of ions through voltage gate; they open and close depending on membrane voltage. Selectively filters are located at inner side of two channels to decide specificity of diffusing ions. Channels are controlled by conformational (structural) shifts; open means permeable and closed means non-permeable stage; it is called ‘gating’.

Channels are not opened all the time. The gate opens and closes in response to voltage changes of membrane. The channel may be inward or outward channels. For eg. Ca++ channels are inwards (exterior to interior) whereas anions are from interior to exterior. K+ is an exception because it can move in and out depending on membrane potential.

b) CARRIERS:

Van Hobert (1937) was first one to propose role of carrier in transport of ions across membranes. This type of transport protein doesn’t involve any chemical modification of any compound being carried from exterior to interior of membrane. They catalyze only vectored movement of inorganic and simple organic molecules across the membrane.

Principle inorganic nutrients include NH4+, K+, NO3-, SO4--, Cl-, etc are all translocated into the cells by plasma membrane carriers. Organic molecules like sugar, purines, pyrimidine bases are all translocated in to the cell by carriers. Plasma membrane carriers not only important for nutrient absorption from soil but also plays fundamental role in modification of storage metabolites like enzymes. Carriers are also specific for the ions they carry. So far, all the plant carriers identified are hydrophobic.

Step By Step Sequence Of Transport Of Ions Using Carriers:

Activation of carrier precursor - Brings about conformational changes in it to complement with the ion - Binding of substance undergoing transport to the absorption site of carrier - Ions moved across the membrane - Movement occurs due to conformational changes of carrier when bound to the ion forming a carrier ion complex

c) PUMPS:

Active transport of ions across membranes is a key feature, which takes place at the expense of free energy liberated in chemical reactions. Membrane transport proteins involved in primary active transport are called as pumps. Most of the pumps transport ions such as protons, Ca++, K+, Na+, etc and they are called ionic pumps. Some solutes are co-transported out and the process is called as secondary active transport.

TYPES OF IONIC PUMPS:

Electroneutral pump - Those which are associated with transport of ions with no net movement of charge across the membrane. For eg. Proton – K+ ATPase pump (H+-K+) which pumps out one proton for each potassium ion taken in with no net movement of charge.

Electrogenic pump - Transport ions involving net movement of charge across the membrane. Eg. Na+-K+ ATPase pumps because it expels three Na+ for every two K+ taken in resulting in net outward movement of one positive ion.

Plasma Membrane ATPases Pumps:

It is also called proton ATPases. One of the most important electrogenic pumps. In this, hydrogen ions are actively transported to the outside across the plasma membrane. This creates a gradient of pH and electric potential which helps in transport of several molecules and ions.

Enzyme ATPase regulates pumping of substances by binding with ions as well as ATP on the inner side. After this there is transfer of phosphate group of ATP to the phosphorylate aspartic acid component of the protein of the enzyme ATPase system. This brings about change in protein in such a manner that the proteins open up on the outer side to allow the exit of ions to the outer side; such pumps are called Proton-type ATPases. Na+-proton ATPases of plasma membrane and Ca++ transporter of ER are examples of P-type ATPases.

Vacuolar Proton ATPases Pumps:

It is another example of electrogenic pump. Is responsible for pumping protons from cytosol into the vacuole. Cation transport generally occurs through the agency of enzyme ATPases.

Active transport:-

- Uniport - Where one ion or molecule crosses plasma membrane at one side.
- Symport / Co-transport - When two or more ions or molecules cross at same side in same direction.
- Co-transport - When two or more ions or molecules cross at same side in opposite direction.

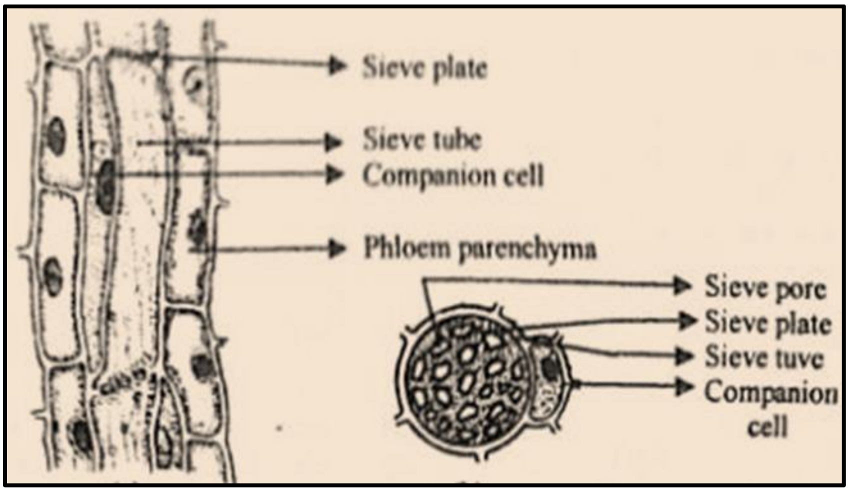
TRANSLOCATION OF SOLUTES

“Transport of soluble products of photosynthesis or organic solutes from leaves to different parts of the plant through the phloem tissue is called Translocation of solutes”.

Growing parts of plants require more food in spring and summer seasons when the growth is prolific. The transport of food through perennating organs takes place later. Translocation of soluble products of photosynthesis occurs through vascular tissue called phloem. It has four different components but only sieve tubes are modified for massive longitudinal translocation of sucrose and other soluble products.

COMPONENTS OF PHLOEM:

a) Sieve tubes: Phloem tissue in flowering plants mainly consist of no. of sieve tube elements joined end to end forming continuous system throughout length of plant. End walls of separating two sieve tubes are specialized plates called sieve plates which are perforated. Protoplasmic strands extend throughout one element to another maintaining continuity of conduction.
b) Companion cells: Sieve tube elements always associated with thin walled parenchymatous cells called companion cells in angiosperms and albuminous cells in gymnosperms. Possess nucleus, dense cytoplasm, ER, ribosomes, many mitochondria indicating intense metabolic activity. Plasmodesmatal connections between companion cells and associated sieve tube elements.
c) Phloem fibers: They only provide mechanical support and has no role in translocation.
d) Phloem parenchyma: Thin – walled parenchymatous cells which help in the lateral transport of organic solutes and water. They also store food.

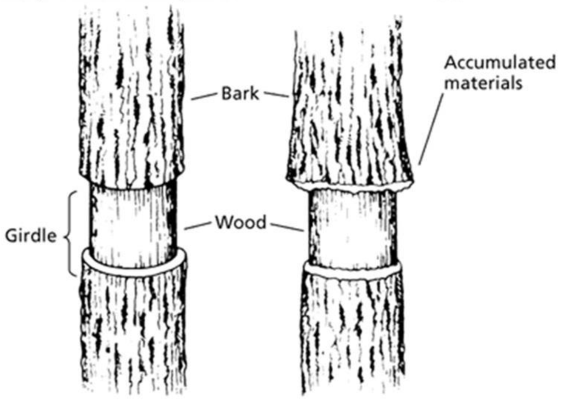


Experimental Evidence to Show That Translocation Takes Place Through Sieve Tube of Phloem:

It is called as girdling or ringing technique. Broad band of bark completely encircling the stem is removed. Bark consists of all tissues external to the cambium, thus its removal results in complete removal of phloem but xylem remains intact. Girdling intercepts transport in phloem but has no effect on transport through xylem. Due to severing of phloem the organic food translocating downwards from leaves will accumulate in phloem tissue above girdles often seen as visible swelling in bark immediately above girdles in few days.

When girdle is made on main stem of small plants the parts below the girdles including root system will starve and die prematurely.

"Girdling" a woody plant causes swelling of stem above the point of damage, indicating a blockage of phloem transport.

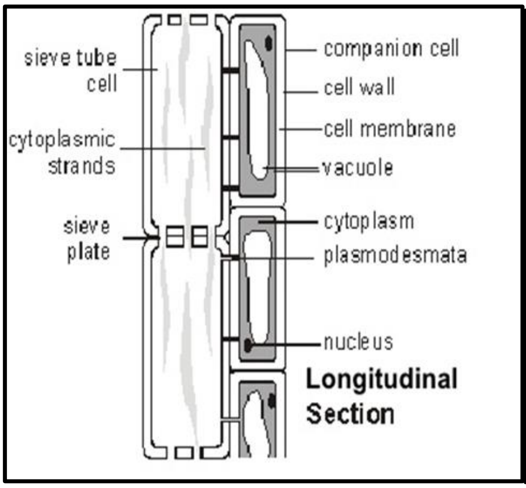


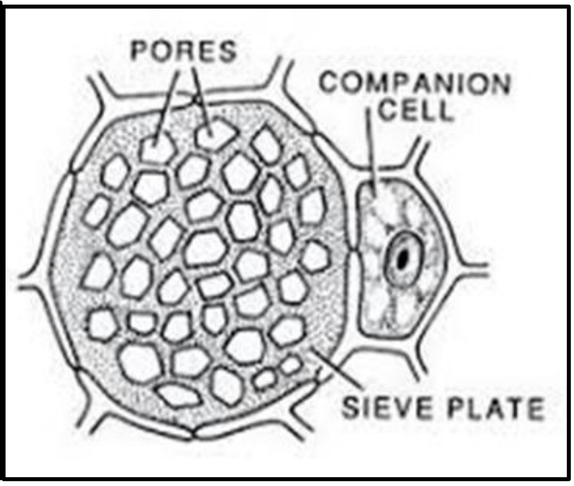
COMPOSITION OF PHLOEM SAP:

- Phloem sap contains food translocated through the phloem.
- More than 90% of dry weight of sieve tube sap consists of sugars.
- Sucrose is the predominant form in which organic material is translocated from the source to the sink through phloem sieve tubes. Glucose and its phosphorylated derivatives are completely absent in phloem sap. In addition to sucrose three other sugars have been found in sieve tubes of some plants – raffinose (trisachharide), stachyose (tetrasachharide) and verbascose (pentasachharide). Stachyose has a sucrose residue in its structure.
- Sieve tube sap also contains small amounts of other organic substances like amides, organic acids, sugar alcohol like mannitol, sorbitol, etc., plant growth substances like auxins, gibberellins, abscisic acid, etc.
- Concentration of sugar (sucrose) in sieve tube is very high. Variation in sugar concentration occurs from season to season and also on a daily basis depending upon the rate of photosynthesis.

ANATOMY OF SIEVE TUBES:

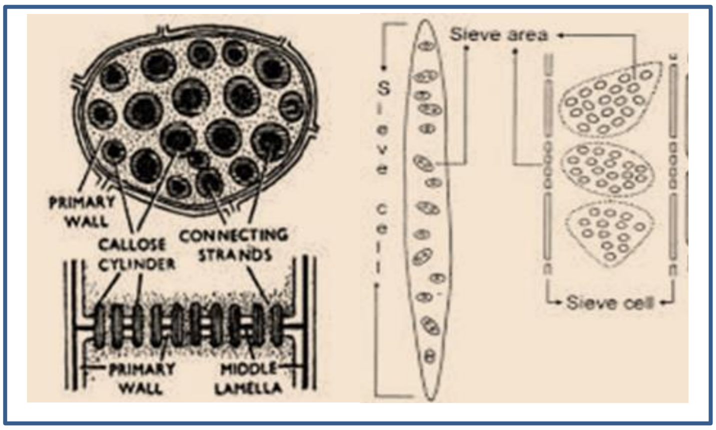
Elongated tubes made up of sieve tube elements connected end to end forming continuous structure throughout length of plant. End walls separating two vertically adjacent sieve tube elements are specialized as sieve plates. Pores of sieve plates are 1 – 2 mµ in diameter. Adjacent sieve tube elements connected by cytoplasmic strands extending from one element to another called plasmodesmata which increases the continuity of conducting system. Phloem fibres support the system but not involved in translocation. Parenchyma cells associated with sieve tube elements helping in transport of organic solvents. In gymnosperms they occur as sieve cells, which are provided with pores on lateral walls and end walls.





Sieve tubes:

Made up of cell wall consisting of cellulose and pectin. Walls are initially thin but become thicker during maturation. In young cells sieve cells contain large nucleus, dense cytoplasm in constant streaming motion and vacuoles. With maturity marked changes take place in anatomical structure of sieve tubes – most remarkable being development of sieve areas in the walls and gradual disappearance of nucleus from protoplast. Sieve areas appear as depressions in the walls and in which the groups of pores are distributed. Connecting strands appear in the pores which connect elements of protoplast of neighbouring sieve elements. These are much thicker in sieve areas than plasmodesmata. When phloem is injured, more callose is formed and deposited rapidly in the pores plugging the pores thus preventing exudation of sap from sieve tubes.



Part of cell wall bearing specialized sieve areas are called sieve plates, present on end walls of sieve tube elements. Those sieve elements that have specialized sieve areas which are similar throughout are called sieve cells, which do not have sieve plates. These cells are usually elongated with tapering ends, found in gymnosperms and vascular cryptogams.

Changes Taking Place During Maturation In Sieve Tube Elements:

There is presence of more or less viscous substance in sieve tube elements, appearing as discrete bodies which are slimy in texture. They are known as slimy bodies. These bodies are made up of special kinds of proteins called phloem proteins. Electron microscopy studies reveal that phloem protein structures vary from species to species and appear in many morphological forms. They may be filamentous, granular or crystalline. Changes in the structure of phloem proteins from one type to other occurs during differentiation of sieve tube elements. They are 8-10 μm in diameter and found in all the dicots. Slime bodies spread out in cytoplasm and with disintegration of nucleus, gradually they assume parietal position in cytoplasm. Slime bodies occurring near sieve plates are called sieve plugs.

During maturation of sieve tube elements, all components become disorganized and disappear except plasma membrane, mitochondria, plastids and ER. In mature active sieve elements, cytoplasm becomes less dense and appear as a thin lining layer on inner surface of cell wall. There is large vacuole present at centre of cell but the membrane lining called tonoplast disappears or disintegrates. Inner materials of cells lose its gel like property and gets consistency of a fluid. Marked change that takes place during maturation is that the sieve cells gets filled with p-protein filaments. P-protein accumulates near the filaments which are due to cut areas. Lumen gets transversed by p-protein elements. P-protein is contractile protein and plays an important role in transport of photosynthetic products. Walls of mature sieve elements remain non-lignified but thick due to deposition of cellulose.

Companion cells:

Densely nucleated cells associated with sieve tubes with which it has common origin. Plays a very important role in the functioning of sieve tubes. These are elongated cells, maybe as long as the associated sieve tube elements or shorter. Strongly attached to sieve tube elements and cannot be separated even by maceration. Walls between sieve tube elements and companion cells are thin with sieve areas or sides of sieve tube elements and primary pits on the side of c.c. Two cells are connected by plasmodesmata which extend to these openings.

In small leaves, the leaf veins of many herbaceous dicots, the sieve elements are shorter than associated parenchyma cells. These parenchyma cells develop certain infoldings on their walls and help in transfer of solutes from mesophyll cells to sieve tube elements, therefore called as transfer cells. In contrast to sieve tube elements, c.c. have prominent nuclei. At maturity, cytoplasm is very dense due to presence of dictyosomes, ER, mitochondria, plastid, etc. C.c. counterpart in gymnosperms are called albuminous cells, associated with sieve cells in them. They are densely cytoplasmic, nucleated parenchyma cells.

Functions of Companion cells:

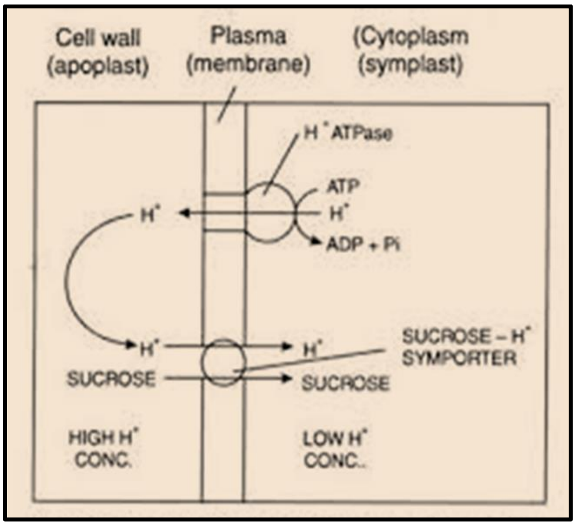
C.C and sieve tube elements are ontogenetically related. They also have physiological and functional relations. This is proved from the fact that in non-functional sieve tubes, the associated c.c. dies. They are active sites for protein synthesis. The ER, plastids and plasmodesmata form a route through which photosynthetic products are transferred to neighbouring cells. C.c. maintains a pressure gradient in sieve tubes.

TRANSLOCATION THROUGH THE PHLOEM:

Translocation of organic solutes like sucrose takes place through sieve tube elements of phloem from source to sink. Before this translocation of sugar could proceed the soluble sugar from the mesophyll cells should be transferred to the sieve tube elements of respective leaves. This transfer of sugar from mesophyll cells to sieve tube elements of leaves is called as phloem loading. On the other hand the transfer of sugars from the sieve tube elements to the receiving cells is called as phloem unloading. Phloem loading is an energy requiring process.

Phloem loading:

As a result of photosynthesis the sugars which are produced in mesophyll cells move to the sieve tube of smallest vein of the leaf. Transfer occurs against the concentration gradient because the concentration of sugar in sieve tube is 1.5 – 2 times higher than in mesophyll cells, therefore it requires energy and hence an active process. This movement may occur through symplast or apoplast. In this case sugars are actively loaded from the apoplast to the sieve tube elements by energy driven transport located in plasma membrane of these cells. The mechanism of phloem loading in such cells has been called sucrose – proton symport / co-transport. According to this mechanism, protons are pumped out through plasma membrane using energy from ATP and ATPase system. As the concentration of protons become higher outside than inside the cell, spontaneous tendency towards equilibrium causes proton to diffuse back into cytoplasm through plasma membrane. This movement of proton is coupled with the transport of sucrose from apoplast to the cytoplasm through the sucrose – H^+ symporter located in plasma membrane.



Apoplastic and symplastic loading:

Four steps of phloem loading occurs generally:

Step 1 – Diffusion of photosynthetic product from matrix of chloroplast to cytoplasm of mesophyll cell and its conversion to sucrose.

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Step 2 – Sucrose travels a few cells from mesophyll cell to the nearby sieve elements (short distance transport).

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Step 3 – Sugar enters the sieve elements – companion cells complex.

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Step 4 – Sugar transported to the root (sink) (long distance transport).

Phloem unloading:

Transport of sugar from sieve elements to the sink or to the consuming cells is called as phloem unloading. This is mainly symplastic and to a very small extent apoplastic. This symplastic unloading is along the concentration gradient and is passive. Apoplastic unloading may be active.

Step 1 – Transport of sugar out of the sieve tube.

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Step 2 –Sugar diffuses into the storage tissue or sink.

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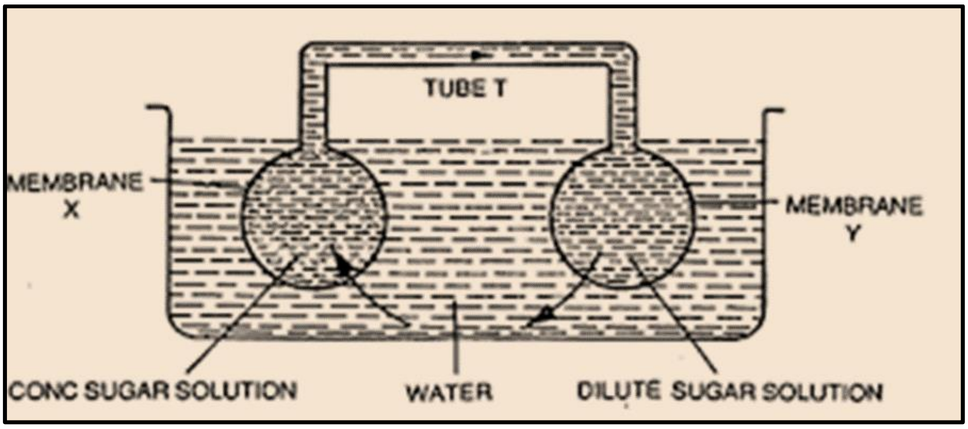
Step 3 –It is either consumed and remaining converted to starch for storage.

MECHANISM OF TRANSLOCATION:

1. MUNCH PRESSURE / MASS FLOW HYPOTHESIS:

   It is either active or passive. It is the most accepted theory of translocation of food through phloem. It was put forward by F. F. Munch (1930). According to him, there are purely physical forces that causes translocation and are classified as passive forces. Physical driving force is the turgor pressure gradient between the source cells and sink cells in a plant which is the driving force for organic translocation. According to him, water along with solutes move ‘en masse’ (bulk) along the sieve tubes through the length of the plant. This process of translocation suggested by Munch can be physically demonstrated.



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