Transport in Plants

CONTENTS

1. TRANSPORT OF SOLUTES AND WATER IN PLANTS

1.1 Introduction

- Transport in plants is molecular and ionic movement from one location to another of water, sugars, minerals, gases, and other molecules: proteins, RNA, hormones etc
- To get onto land, plants evolved way to keep from drying out, to stand upright. and transport nutrients and water both over long distance and short distances
- The algal ancestors of plants obtained water, minerals and CO_2 from the water in which they were completely immersed.
- However for vascular plants, the evolutionary journey onto land involved the differentiation of the plant body into roots, which absorb water and minerals from the soil, and shoots, which absorb light and atmospheric CO_2 for photosynthesis. This created the need to transport materials two ways between roots and shoots.
- Xylem transports water and minerals from the roots to the shoots.
- Phloem transports sugars from the site of production to the regions that need them for growth and metabolism.

1.2 Definition

"The movement of organic solutes occurs mainly in the phloem, where it is also known as translocation and where the direction of transport is from places of production, such as mature leaves, to places of utilization or storage, such as the shoot apex or developing storage roots."

- Organic materials translocated in the phloem include the direct products of photosynthesis (sugars) as well as compounds derived from them.
- Some movement of organic solutes does occur in the xylem of certain species.
- Inorganic solutes or mineral elements, however, generally move with water in the xylem from sites of uptake in the roots to sites where water is lost from the plant, primarily the leaves.
- Some redistribution of the ions throughout the plant may then occur in the phloem.

1.3 Means of Transport

- Physical forces drive the transport of materials in plants over a range of distances
- Transport in plants occurs on three levels:
  - The uptake and loss of water and solutes by individual cells, such as root hairs.
  - Short-distance transport of substances from cell to cell at the level of tissues or organs, such as the loading of sugar from photosynthetic leaf cells into the sieve tubes of phloem.
  - Long-distance transport of sap within xylem and phloem at the level of the whole plant.

1.3.1 Diffusion

"The movement of the molecules of gases, liquids and solutes from the region of higher concentration to the region of lower concentration is known as diffusion."

Or

"Diffusion is the net movement of molecules or ions of a given substances from a region of higher concentration to lower one by virtue of their kinetic energy."

Or

"It is the movement of molecules from high diffusion pressure to low diffusion pressure."

- The movement of substances from an area of high concentration to an area of low concentration.
- Diffusion by molecular motion good only at short distances.

1.3.1.1 Diffusion through membranes

- Cell membranes are bilayered, dynamic structures that regulate movement of molecules into and out of cells. Lipids, proteins, and carbohydrates in various combinations make these tasks possible
- A biological membrane may be permeable to some molecules and impermeable to others. Unsaturated phospholipids have higher permeability compared to saturated phospholipids
- Diffusion across a membrane is called passive transport and occurs without the direct expenditure of metabolic energy by the cell.
- Small molecules can move across the lipid bilayer by simple diffusion. (i.e. H_2O, O_2, CO_2).
- The more lipid-soluble the molecule, the more rapidly it diffuses. An exception to this is water.
- Polar and charged molecules such as amino acids, sugars, and ions do not pass readily across the lipid bilayer. These are essential for cell function – must be actively transported.
- The greater the lipid solubility – the faster the rate of diffusion.
- Diffusion is very important to plants since it the only means for gaseous movement within the plant body.

1.3.1.2 Diffusion of Water

- Water moves much more rapidly through the membrane than solutes. Movement of water is termed osmosis
- A compartment with high solute concentration – hypertonic. A compartment with low solute concentration – hypotonic

1.3.2 Facilitated Diffusion

- Facilitated Diffusion is a process of diffusion, facilitated by transport proteins.
    - Non-polar molecules, such as oxygen can diffuse easily across the membrane.
    - However polar molecules having hydrophobic moiety and charged ions cannot diffuse freely across cell membranes due to the hydrophobic nature of the phospholipids that make up the lipid bilayers.
    - All polar molecules are transported across membranes by proteins that form transmembrane channels.
    - These channels are gated so they can open and close, thus regulating the flow of ions or small polar molecules.
    - Larger molecules are transported by transmembrane carrier proteins, such as permeases that change their conformation as the molecules are carried through, for example glucose or amino acids.
- Membrane proteins provide sites at which such molecules cross the membrane.
- They do not set up a concentration gradient but a concentration gradient must already be present for molecules to diffuse even if facilitated by the proteins and as such cannot cause net transport of molecules from a low to a high concentration as this would require input of energy.
- Special proteins help move substances across membranes without expenditure of ATP energy.
- The proteins form channels in the membrane for molecules to pass through.
- The porins are proteins that form huge pores in the outer membranes of the plastids, mitochondria and some bacteria allowing molecules up to the size of small proteins to pass through
- Some transport proteins bind selectively to a solute on one side of the membrane and release it on the opposite side.

- Others act as selective channels, providing a selective passageway across the membrane.
- For example, the membranes of most plant cells have potassium channels that allow potassium ions (K^+) to pass, but not similar ions, such as sodium (Na^+).

1.3.2.1 Passive symports and antiports

- Some carrier or transport proteins allow diffusion only if two types of molecules move together.
  - Symport : Coupled Transport - transports two substances simultaneously in the same direction and the flow of the two ligands is coupled.
  - Antiport: Coupled Transport - transports two substances in opposite directions the flow of the two ligands is coupled.
  - Uniport – Not coupled - molecule moves across a membrane independent of other molecules.

1.3.3 Active Transport

- Active transport is the pumping of solutes across membranes against their electrochemical gradients, and requires expenditure of energy by the cell usually in the form of ATP, to transport solutes "uphill." i.e. from low concentration gradient to high concentration gradient.
- If ATP is used directly for the pumping system, as in the sodium–potassium pump, the system is a primary active transport system.
- Only cations, such as sodium, potassium, and calcium, are transported directly by pumps that use a primary active transport system.
- Secondary active transport systems use established gradients to move substances.
- This form of transport uses ATP indirectly. The ATP molecules are consumed to establish the ion gradient.
- The gradient is then used to move a substance as described for the symport and antiport systems-
  - Active transport is carried out by membrane-proteins. Pumps are proteins that use energy to carry substances across the cell membrane.
  - The most important active transport protein in the plasma membrane of plant cells is the proton pump.
    - It hydrolyzes ATP and uses the released energy to pump hydrogen ions (H^+) out of the cell.
    - This creates a proton gradient because the H^+ concentration is higher outside the cell than inside.
    - It also creates a membrane potential or voltage, a separation of opposite charges across a membrane.
  - Both the concentration gradient and the membrane potential are forms of potential (stored) energy that can be harnessed to perform cellular work. This potential energy is used to drive the transport of many different solutes. For example, the membrane potential generated by proton pumps contributes to the uptake of potassium ions (K^+) by root cells.
  - The proton gradient also functions in co-transport, in which the downhill passage of one solute (H^+) is coupled with the uphill passage of another, such as NO_3^- or sucrose.
  - The role of proton pumps in transport is a specific application of the general mechanism called chemiosmosis, a unifying process in cellular energetics.
    - In chemiosmosis, a trans-membrane proton gradient links energy-releasing processes to energy-consuming processes. The ATP synthases that couple H^+ diffusion to ATP synthesis during cellular respiration and photosynthesis

function somewhat like proton pumps. However, proton pumps normally run in reverse, using ATP energy to pump H^+ against its gradient.

1.3.4 Comparison of Different Transport Processes

- Proteins in the membrane are responsible for facilitated diffusion and active transport and hence show common characteristics of being highly selective; they are liable to saturate, respond to inhibitors and are under hormonal regulation.
- But diffusion whether facilitated or not – take place only along a gradient and does not use energy.

1.4 Plant-Water Relations

- Water is the most abundant constituent of all physiologically active plant cells.
- The survival of plant cells depends on their ability to balance water uptake and loss.
- It provides the medium in which most substances are dissolved.
- Water is often the limiting factor for plant growth and productivity in both agricultural and natural environments.

1.4.1 Water Potential

- In the case of a plant cell, the direction of water movement depends on solute concentration and physical pressure.
- The combined effects of solute concentration and pressure are called water potential, represented by the Greek letter "psi".
- Water will move across a membrane from the solution with the higher water potential to the solution with the lower water potential.
- For example, if a plant cell is immersed in a solution with a higher water potential than the cell, osmotic uptake of water will cause the cell to swell. By moving, water can perform work, such as expanding the cell.
- Therefore the potential in water potential refers to the potential energy that can be released to do work when water moves from a region with higher psi to lower psi.
- The greater the concentration of water in a system, the greater is its energy or 'water potential'. In other words, 'water potential' is the energy of water relative to pure free water (example- de-ionized water) in reference conditions.
- As such pure water will have the greatest water potential.
- Typically, pure water with standard temperature and pressure (or other suitable reference condition) is defined as having a water potential of 0.
- The addition of solutes lowers the water potential because the solutes bind water molecules, which have less freedom to move than they do in pure water, reducing its water potential or lowers its potential (makes it more negative).
- The magnitude of this lowering due to dissolution of a solute is called solute potential or Ψs.
- The solute potential (or osmotic potential) of a solution is proportional to the number of dissolved solute molecules.
- By definition, the solute potential of pure water is 0 and as such Ψs is always zero or negative.
- Similarly the increase in pressure increases its potential (makes it more positive).
- If possible, water will move from an area of higher water potential to an area that has a lower water potential.
- Pressure can build up in a plant system when water enters a plant cell due to diffusion causing a pressure built up against the cell wall.
- Pressure potential is denoted as Ψp. Pressure potential is the physical pressure on a solution and can be positive or negative.
- The relationship between water, solute and pressure potential is $\Psi w = \Psi s + \Psi p$.

- Water potential measured in megapascals (MPa), where one MPa is equal to about 10 atmospheres of pressure.

1.4.2 Osmosis

- Osmosis is the diffusion of water across a selectively permeable membrane. (Semi-permeable: permeable to solvents (Water), but not to large molecules).
- The net direction and rate of osmosis depends on both the pressure gradient and concentration gradient.
- Water moves from a high concentration of water (less salt or sugar dissolved in it) to a low concentration of water (more salt or sugar dissolved in it).
- This means that water would cross a selectively permeable membrane from a dilute solution (less dissolved in it) to a concentrated solution (more dissolved in it).

1.4.3 Plasmolysis

- Plasmolysis is the loss of water from the cell by osmosis, and this is evident when plasma membrane including the cell contents pulls away from the rigid cell wall as the water moves out.
- The reverse process, cytolysis, occurs if the cell is in a hypotonic solution resulting in a higher external osmotic pressure and net flow of water into the cell.
- Through observation of plasmolysis and cytolysis, it is possible to determine the tonicity of the cell's environment as well as the rate solute molecules cross the cellular membrane.

1.4.4 Imbibition

- Imbibition is defined as the displacement of one fluid by another immiscible fluid.
- It is a special type of diffusion when water is absorbed by solids such as absorption of water by hydrophilic colloids.
- Examples of plant material which exhibit imbibition are dry seeds before germination.
- The seeds have almost no water hence they absorb water easily.
- Different types of organic substances have different imbibing capacities.
- Proteins have a very high imbibing capacity, starch less and cellulose least.
- That is why proteinaceous pea seeds swell more on imbibition than starchy wheat seeds.
- Imbibition of water increases the volume of the imbibant which results in imbibitional pressure.
- This pressure can be of tremendous magnitude.
- This fact can be demonstrated by the splitting of rocks by inserting dry wooden stalks in the crevices of rocks and soaking them in water.

1.5. Long Distance Transport of Water

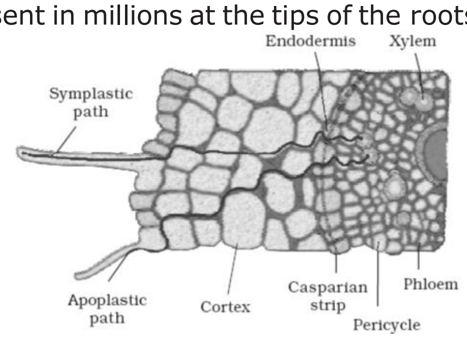
- When we carry out an experiment where we place a twig bearing white flowers in coloured water and watch it then we see that its colour changes. On examining the cut end of the twig after a few hours you had noted the region through which the coloured water moved. That experiment very easily demonstrates that the path of water movement is through the vascular bundles, more specifically, the xylem. Now we have to go further and try and understand the mechanism of movement of water and other substances up a plant.
- Long distance transport of substances within a plant cannot be by diffusion alone. Diffusion is a slow process. It can account for only short distance movement of molecules. For example, the movement of a molecule across atypical plant cell (about 50 μm) takes approximately 2.5s. At this rate, it will take many years it

would take for the movement of molecules over a distance of 1 m within a plant by diffusion alone.

- In large and complex organisms, often substances have to be moved across very large distances.
- Sometimes the sites of production or absorption and sites of storage are too far from each other; diffusion or active transport would not suffice.
- Special long distance transport systems become necessary so as to move substances across long distances and at a much faster rate.
- Water and minerals, and food are generally moved by a mass or bulk flow system. Mass flow is the movement of substances in bulk or *en masse* from one point to another as a result of pressure differences between the two points.
- It is a characteristic of mass flow that substances, whether in solution or in suspension, are swept along at the same pace, as in a flowing river. This is unlike diffusion where different substances move independently depending on their concentration gradients.
- Bulk flow can be achieved either through a positive hydrostatic pressure gradient (examples- a garden hose) or a negative hydrostatic pressure gradient (example-suction through a straw).The bulk movement of substances through the conducting or vascular tissues of plants is called translocation.
- The higher plants have highly specialised vascular tissues-xylem and phloem. Xylem is associated with translocation of mainly water, mineral salts, some organic translocates a variety of organic and inorganic solutes, mainly from the leaves to other parts of the plants.

1.5.1 How do Plants Absorb Water

- The responsibility of absorption of water and minerals is more specifically the function of the root hairs that are present in millions at the tips of the roots.



Symplastic and apoplastic pathways of water and ion absorption and movement in roots

Water Absorption by roots

- Water absorption is mostly carried out by root hair.
- Root hairs are thin-walled slender extensions of root epidermal cells that greatly increase the surface area for absorption.
- Water is absorbed along with mineral solutes, by the root hairs, purely by diffusion.
- There are two pathways for movement of water in plants-

1.5.1.1 Apoplast

- This movement of water occurs through the cell wall. This movement of water doesn't cross the walls.
- The apoplastic movement of water occurs exclusively through the intercellular spaces and the walls of the cells.
- This movement is dependent on the gradient. The apoplast does not provide any barrier to water movement and water movement is through mass flow.
- As water evaporates into the intercellular spaces or the atmosphere, tension develop in the continuous stream of water in the apoplast, hence mass flow of water occurs due to the adhesive and cohesive properties of water.
- Most of the water flow in the roots occurs via the apoplast since the cortical cells are loosely packed, and hence offer no resistance to water movement.

1.5.1.2 Symplast

- This is movement of water from a cell to another. It takes place through plasmodesmata.
- All cytoplasms are connected to each other by plasmodesmata.
- Water has to enter the cells through the cell membrane; hence the movement is relatively slower. Movement is again down a potential gradient.
- Symplastic movement may be aided by cytoplasmic streaming.
- It is observed cytoplasmic streaming in cells of the *Hydrilla* leaf; the movement of chloroplast due to streaming is easily visible.
- The movement of water through the root layers is ultimately symplastic in the endodermis.

1.5.2 Water Movement up a Plant

- Upward conduction of water from roots to leaves is called ascent of sap.
- Xylem is responsible for ascent of sap.

1.5.2.1 Root Pressure

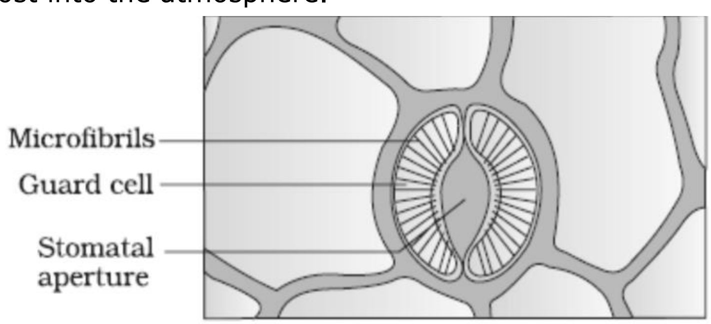
- Various ions from the soil are actively transported into the vascular tissues of the roots; water follows (its potential gradient) and increases the pressure inside the xylem. " This positive pressure is called root pressure", and can be responsible for pushing up water to small heights in the stem.
- When we choose a small soft-stemmed plant and on a day, when there is plenty of atmospheric moisture & cut the stem horizontally near the base with a sharp blade, early in the morning. We soon see drops of solution ooze out of the cut stem; this comes out due to the positive root pressure.
- If we fix a rubber tube to the cut stem as a sleeve we can actually collect and measure the rate of exudation, and also determine the composition of the exudates.
- Effects of root pressure is also observable at night and early morning when evaporation is low, and excess water collects in the form of droplets around special openings of veins near the tip of grass blades, and leaves of many herbaceous parts.
- Such water loss in its liquid phase is known as **guttation**.
- Root pressure; only provide a modest push in the overall process of water transport. They do not play a major role in water movement up tall trees.
- The greatest contribution of root pressure may be to re-establish the continuous chains of water molecules in the xylem which often break under the enormous tensions created by transpiration.

1.5.2.2 Transpiration Pull

- Despite the absence of a heart or a circulatory system in plants, the flow of water upward through the xylem in plants can achieve fairly high rates up to 15 metres per hour.
- The water is mainly 'pulled' through the plant, and that the driving force for this process is transpiration from the leaves. This is referred to as the cohesion-tension–transpiration pull model of water transport.
- Water is transient in plants. Less than 1 per cent of the water reaching the leaves is used in photosynthesis and plant growth. Most of it is lost through the stomata in the leaves. This water loss is known as transpiration.
- Water is pulled up once it enters the xylem through the stem to leaves. The **transpirational** pull and root pressure helps in moving water from roots to stem and then leaves. The surface tension created in xylem pulls out the water from roots and from the soil. Capillary action which is the movement of liquid along the surface of solid helps the water from the roots to move up.

1.6 Transpiration

- Transpiration is loss of water in the form of water vapours from the aerial parts of the plant.
- The loss of water is so great that it reduces water level in the soil but transpiration is said to be necessary for water and mineral absorption, ascent of sap and lowering the temperature.
- So, transpiration is known as necessary evil.
- About 98% of water absorbed by land plants evaporates from the aerial parts of the plants and is lost into the atmosphere.



A Stomatal aperture with guard cells

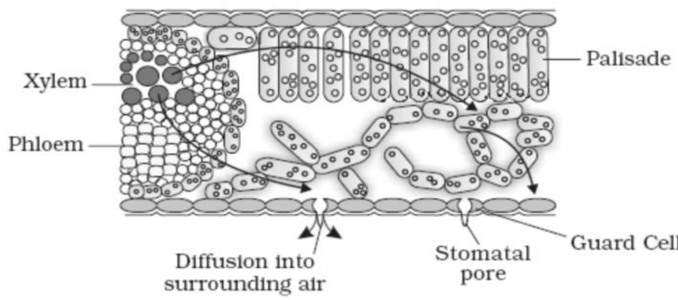
1.6.1 Definition

"The evaporation of water from the surface of plants is known as **transpiration**."

- It mainly occurs on the leaf surface. The leaf surface has openings or pores called as stomata. Stomata have guard cells which enable them to open and close.
- Leaf **transpiration** occurs through these small pores called as stomata.
- Temperature can affect stomatal openings and thus affects the rate of **transpiration**. The structure of stomata is given below:
- Guard cells control the stomatal opening and closure in the epidermis of leaves in plants. They also regulate the rate of **transpiration** in leaves.

1.6.2 Factors Affecting Transpiration

- Transpiration is affected by several external factors: temperature, light, humidity, wind speed.
- Plant factors that affect transpiration include number and distribution of stomata, number of stomata open, percent, water status of the plant, canopy structure etc.
- The transpiration driven ascent of xylem sap depends mainly on the following physical properties of water-
  - Cohesion – mutual attraction between water molecules.
  - Adhesion – attraction of water molecules to polar surfaces (such as the surface of tracheary elements).
  - Surface Tension – water molecules are attracted to each other in the liquid phase more than to water in the gas phase.



Water Movement in the leaf

1.6.3 Transpiration and Photosynthesis – a Compromise

- Transpiration has more than one purpose; it
  - creates transpiration pull for absorption and transport of plants supplies water for photosynthesis
  - transports minerals from the soil to all parts of the plant cools leaf surfaces, sometimes 10 to 15 degrees, by evaporative cooling maintains the shape and structure of the plants by keeping cells turgid.
  - An actively photosynthesizing plant has an insatiable need for water.
  - Photosynthesis is limited by available water which can be swiftly depleted by transpiration.
  - The humidity of rainforests is largely due to this vast cycling of water from root to leaf to atmosphere and back to the soil.
  - The evolution of the C_4 photosynthetic system is one of the strategies for maximising the availability of CO_2 while minimising water loss.
  - C_4 plants are twice as efficient as C_3 plants in terms of fixing carbon. However; a C_4 plant loses only half as much water as a C_3 plant for the same amount of CO_2 fixed.

1.6.4 Antitranspirants

- Antitranspirants are the chemical substances, which reduce the rate of transpiration without affecting other physiological processes.
- Initially colourless plastics, silica oils, low-density waxes etc. were used as Antitranspirants.
- Phenyl mercuric acetate (PMA), abscisic Acid (ABA), Aspirin, salicylic acid, is nowadays being used as Antitranspirants.
- A good Antitranspirants increases leaf resistance but does not affect mesophyll resistance.

1.6.5 Guttation

"Some vascular plants give out drops of xylem sap on the tips or edges of leaves. This is known as guttation."

- It is not dew. The root pressure in a plant gives out this fluid or drops of water on the edges of leaves through special pores called as Hydathodes.
- Guttation occurs when transpiration rate is very low as compared to rate of water absorption. Due to this root pressure is developed and water is pushed out through Hydathodes.
- Water loss in guttation per plant per night is generally up to 100ml, but in *Colocasia antiquoum*, it is maximum 200ml.
- Guttation can be observed in *Tropaeolum, Colocasia, Lycopersicium*, grasses, etc.

1.7 Uptake and Transport of Mineral Nutrients

- Plants obtain their carbon and most of their oxygen from CO_2 in the atmosphere.
- The remaining nutritional requirements are obtained from minerals and water for hydrogen in the soil.

1.7.1 Uptake of Mineral Ions

- All minerals cannot be passively absorbed by the roots.
- Two factors account for this-
  - minerals are present in the soil as charged particles (ions) which cannot move across cell membranes and
  - the concentration of minerals in the soil is usually lower than the concentration of minerals in the root.
- Therefore, most minerals must enter the root by active absorption into the cytoplasm of epidermal cells. This needs energy in the form of ATP.
- The active uptake of ions is partly responsible for the water potential gradient in roots, and therefore for the uptake of water by osmosis.
- Some ions also move into the epidermal cells passively.
- There are two types of **active transport**-

1.7.1.1 Primary active transport

- This **active transport** involves the use of ATP to move the molecules through a membrane.

1.7.1.2 Secondary active transport

- An electrochemical gradient is used for moving solute particles across membrane. It can be a direct result of diffusion of other substances.

1.7.1.3 Membrane potential

- All plant cells maintain ion distribution across the plasma membrane. This results in an electrical potential across the membrane which is known as **membrane potential**.

1.7.1.3.1 Nernst equation

- Magnitude of diffusion depends on ratio of concentrations of extracellular or outer space and between the spaces inside the cell (intracellular).
- **Nernst equation** is an equation to calculate this potential.

$$\mathbf{E = RT/ZF\ Ln\ [ion\ outside\ cell/ion\ inside\ cell]}$$

Or in simple words it is simplified as:

$$\mathbf{Ex = 61/Z\ \log [X_o]/[X_i]}$$

In this equation,

Z=valence of ions

Ex=electron potential in mV (millivolts) of ion x

X_0=concentration of ion outside cell

X_i=concentration of ion inside cell.

1.7.1.4 Membrane transport protein

- It's a protein which can move ions, small molecules or macromolecules across the cell membrane.
- They are found in membranes and they transport even macromolecules. These proteins help in movement through active transport and facilitated diffusion.

1.7.1.5 Solute Transport

- Plants have xylem and phloem cells for transport.
- Xylem tissue helps in moving water and minerals upwards from roots to the leaves.
- Sugars are produced in leaves and from leaves they are transported throughout the plant by phloem tissue. Some solute particles are transported to xylem.
- Vessels or tracheids in plants mainly consist of ions and water.

1.7.1.6 Passive transport

- Passive transport of solute doesn't involve chemical energy. In this process molecules and solute particles move across the membrane. It has 4 types:
    - **Diffusion**- This is movement of material from a region of higher concentration to the region of lower concentration.
    - **Facilitated diffusion**-This is the transport of bigger molecules through membrane using the transport proteins which are embedded in membrane.
    - **Osmosis**-Osmosis is also a passive transport. Here, there is diffusion of water through membrane to a region of lower concentration.
    - **Filtration**-It is the process of movement of water and solute particles across a membrane due to pressure.

1.7.2 Translocation of Mineral Ions

- After the ions have reached xylem through active or passive uptake, or a combination of the two, their further transport up the stem to all parts of the plant is through the transpiration stream.
- The chief sinks for the mineral elements are the growing regions of the plant, such as the apical and lateral meristems, young leaves, developing flowers, fruits and seeds, and the storage organs.
- Unloading of mineral ions occurs at the fine vein endings through diffusion and active uptake by these cells.
- Mineral ions are remobilized, particularly from older, senescing parts. Older dying leaves export much of their mineral content to younger leaves.
- Similarly, before leaf fall in deciduous plants, minerals are removed to other parts.
- Elements most readily mobilised are phosphorus, sulphur, nitrogen and potassium. Some elements that are structural components like calcium are not remobilized.
- An analysis of the xylem exudates shows that though some of the nitrogen travels as inorganic ions, much of it is carried in the organic form as amino acids and related compounds.
- Similarly, small amounts of P and S are carried as organic compounds.
- In addition, small amount of exchange of materials does take place between xylem and phloem.
- Hence, it is not that we can clearly make a distinction and say categorically that xylem transports only inorganic nutrients while phloem transports only organic materials, as was traditionally believed.

1.8 Phloem Transport: Flow from Source to Sink

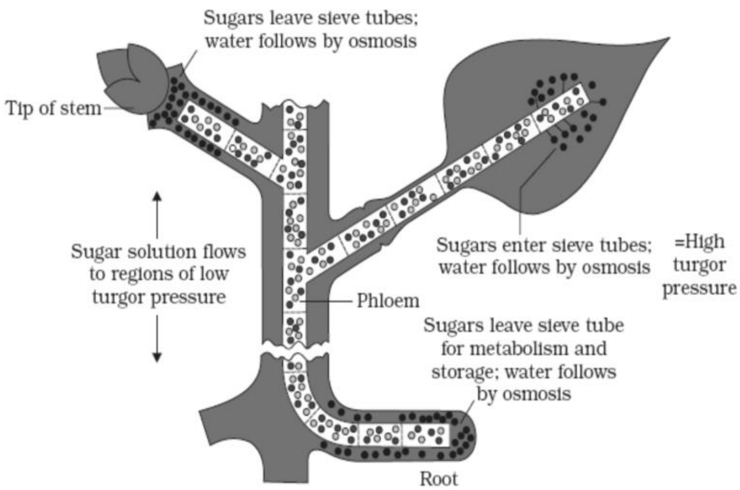
- Food, primarily sucrose, is transported by the vascular tissue phloem from a source to a sink.
- Usually the source is understood to be that part of the plant which synthesises the food, i.e., the leaf, and sink, the part that needs or stores the food. But, the source and sink may be reversed depending on the season, or the plant's needs.
- Sugar stored in roots may be mobilised to become a source of food in the early spring when the buds of trees, act as sink; they need energy for growth and development of the photosynthetic apparatus.
- Since the source-sink relationship is variable, the direction of movement in the phloem can be upwards or downwards, i.e., bi-directional.
- This contrasts with that of the xylem where the movement is always unidirectional, i.e., upwards.
- Hence, unlike one-way flow of water in transpiration, food in phloem sap can be transported in any required direction so long as there is a source of sugar and a sink able to use, store or remove the sugar.
- Phloem sap is mainly water and sucrose, but other sugars, hormones and amino acids are also transported or translocated through phloem.

1.8.1 The Pressure Flow or Mass Flow Hypothesis

"The accepted mechanism used for the translocation of sugars from source to sink is called the pressure flow hypothesis."

- As glucose is prepared at the source (by photosynthesis) it is converted to sucrose.
- The sugar is then moved in the form of sucrose into the companion cells and then into the living phloem sieve tube cells by active transport.
- The process of loading at the source produces a hypertonic condition in the phloem.
- Water in the adjacent xylem moves into the phloem by osmosis.
- As osmotic pressure builds up the phloem sap will move to areas of lower pressure. At the sink osmotic pressure must be reduced.
- Active transport is must to move the sucrose out of the phloem sap and into the cells which will use the sugar – converting it into energy, starch, or cellulose. As sugars are removed, the osmotic pressure decreases and water moves out of the phloem.
- The movement of sugars in the phloem begins at the source, where sugars are loaded into a sieve tube. Loading of the phloem sets up a water potential gradient that provides the mass movement in the phloem.
- Phloem tissue is composed of sieve tube cells, which form long columns with holes in their end walls sieve plates. Cytoplasmic strands pass through the holes in the sieve plates so forming continuous filaments.
- As hydrostatic pressure in the phloem sieve tube increases, pressure flow begins, and the sap moves through the phloem. Meanwhile, at the sink, incoming sugars are actively transported out of the phloem and removed as complex carbohydrates.
- The loss of solute produces a high water potential in the phloem, and water passes out, returning eventually to xylem.
- A simple experiment, called 'girdling', was used to identify the tissues through which food is transported. On the trunk of a tree a ring of bark up to a depth of the phloem layer, can be

removed. In the absence of downward movement of food the portion of the bark above the ring on the stem becomes swollen after a few weeks. This simple experiment shows that phloem is the tissue responsible for translocation of food; and that transport takes place in one direction, i.e., towards the roots.



Mechanism of Translocation

1.9 Points to Remember

- Plants obtain a variety of inorganic elements (ions) and salts from their surroundings especially from water and soil.
- The movement of the nutrients from environment into the plant as well as from one plant cell to another plant cell essentially involves movement across a cell membrane.
- Transport across cell membrane can be through diffusion, facilitated transport or active transport.
- In passive transport, nutrients move across the membrane by diffusion, without any use of energy as it is always down the concentration gradient and hence entropy driven.
- This diffusion of substances depends on their size, solubility in water or organic solvents.
- Osmosis is the type of diffusion of water across a semi-permeable membrane which depends on pressure and concentration gradient.
- In active transport, energy in the form of ATP is utilised to pump molecules against a concentration gradient across membranes.
- Water potential is the potential energy of water which helps in the movement of water. It is determined by solute and pressure potential.
- The behaviour of the cells depends on the surrounding solution. If the surrounding solution of the cell is hypertonic, it gets plasmolysed.
- The absorption of water by seeds and dry wood takes place by a special type of diffusion called imbibition.
- In higher plants, there is a vascular system, xylem and phloem, responsible for translocation.
- Water minerals and food cannot be moved within the body of a plant by diffusion alone. They are therefore, transported by a mass flow system – movement of substance in bulk from one point to another as a result of pressure differences between the two points.
- Water absorbed by root hairs moves deeper into the root by two distinct pathways, i.e., apoplast and symplast.

- Various ions, and water from soil can be transported upto a small height in stems by root pressure.
- Transpiration pull model is the most acceptable to explain the transport of water.
- Transpiration is the loss of water in the form of vapours from the plant parts through stomata.
- Temperature, light, humidity, wind speed and number of stomata affect the rate of transpiration.
- Excess water is also removed through tips of leaves of plants by guttation.
- Phloem is responsible for transport of food (primarily) sucrose from the source to the sink.
- The translocation in phloem is explained by the pressure- flow hypothesis.
- The translocation in phloem is bi-directional; the source-sink relationship is variable.