CHAPTER 11
TRANSPORT IN PLANTS

- Plants need to move molecules over very long distances, much more than animals do; they also
do not have a circulatory system in place.
- Water taken up by the roots has to reach all parts of the plant, up to the very tip of the growing
stem. The photosynthates or food synthesised by the leaves have also to be moved to all parts
including the root tips embedded deep inside the soil.
- Movement across short distances, say within the cell, across the membranes and from cell to cell
within the tissue has also to take place.
- In a flowering plant the substances that would need to be transported are water, mineral
nutrients, organic nutrients and plant growth regulators.
- Small distance transport – by diffusion and by cytoplasmic streaming supplemented by active
transport.
- Long distance Transport – through the vascular system (the xylem and the phloem) and is
called translocation.
- In rooted plants, transport in xylem (of water and minerals) is essentially unidirectional, from
roots to the stems.
- Organic and mineral nutrients however, undergo multidirectional transport.
- Organic compounds synthesised in the photosynthetic leaves are exported to all other parts of the
plant including storage organs. From the storage organs they are later re-exported.
- The mineral nutrients are taken up by the roots and transported upwards into the stem, leaves and
the growing regions. When any plant part undergoes senescence, nutrients may be withdrawn
from such regions and moved to the growing parts.
- Hormones or plant growth regulators and other chemical stimuli are also transported, though in
very small amounts, sometimes in a strictly polarised or unidirectional manner from where they
are synthesised to other parts.

MEANS OF TRANSPORT

Diffusion
- Passive movement and may be from one part of the cell to the other, or from cell to cell, or
over short distances, say, from the intercellular spaces of the leaf to the outside.
- No energy expenditure takes place.
- Molecules move in a random fashion, the net result being substances moving from regions of
higher concentration to regions of lower concentration.
- Diffusion is a slow process and is not dependent on a 'living system'.
- Diffusion is obvious in gases and liquids, but diffusion in solids rather than of solids is more
likely.
- Diffusion is very important to plants since it is the only means for gaseous movement within
the plant body.
- Diffusion rates are affected by the gradient of concentration, the permeability of the
membrane separating them, size of the substances, temperature and pressure.

Facilitated Diffusion
- The diffusion of any substance across a membrane also depends on its solubility in lipids, the
major constituent of the membrane.
- Substances soluble in lipids diffuse through the membrane faster.
- Substances that have a hydrophilic moiety, find it difficult to pass through the membrane;
their movement has to be facilitated. Membrane proteins provide sites at which such
molecules cross the membrane.
They do not set up a concentration gradient: a concentration gradient must already be present for molecules to diffuse even if facilitated by the proteins. This process is called facilitated diffusion.

In facilitated diffusion, special proteins help move substances across membranes without expenditure of ATP energy.

- Facilitated diffusion cannot cause net transport of molecules from a low to a high concentration - this would require input of energy.
- Transport rate reaches a maximum when all of the protein transporters are being used (saturation).
- Facilitated diffusion is very specific: it allows cell to select substances for uptake.
- It is sensitive to inhibitors which react with protein side chains.
- The proteins form channels in the membrane for molecules to pass through. Some channels are always open; others can be controlled. Some are large, allowing a variety of molecules to cross.
- 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.
- When an extracellular molecule bound to the transport protein; the transport protein then rotates and releases the molecule inside the cell, e.g., water channels (made up of eight different types of aquaporins.)

Passive symports and antiports

- Some carrier or transport proteins allow diffusion only if two types of molecules move together.
- In a symport, both molecules cross the membrane in the same direction; in an antiport, they move in opposite directions.
- When a molecule moves across a membrane independent of other molecules, the process is called uniport.
Active Transport
- Active transport uses energy to pump molecules against a concentration gradient.
- Active transport is carried out by membrane-proteins. Hence different proteins in the membrane play a major role in both active as well as passive transport.
- Pumps are proteins that use energy to carry substances across the cell membrane. These pumps can transport substances from a low concentration to a high concentration ('uphill' transport).
- Transport rate reaches a maximum when all the protein transporters are being used or are saturated.
- Like enzymes the carrier protein is very specific in what it carries across the membrane.
- These proteins are sensitive to inhibitors that react with protein side chains.

Comparison of Different Transport Processes

<table>
<thead>
<tr>
<th>Property</th>
<th>Simple Diffusion</th>
<th>Facilitated Transport</th>
<th>Active Transport</th>
</tr>
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<tbody>
<tr>
<td>Requires special membrane proteins</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Highly selective</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Transport saturates</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Uphill transport</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Requires ATP energy</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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</tbody>
</table>

- 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 do not use energy.
PLANT-WATER RELATIONS

- Water is essential for all physiological activities of the plant and plays a very important role in all living organisms.
- It provides the medium in which most substances are dissolved. The protoplasm of the cells is nothing but water in which different molecules are dissolved and (several particles) suspended. A watermelon has over 92 per cent water; most herbaceous plants have only about 10 to 15 per cent of its fresh weight as dry matter.
- Of course, distribution of water within a plant varies - woody parts have relatively very little water, while soft parts mostly contain water. A seed may appear dry but it still has water - otherwise it would not be alive and respiring!
- Terrestrial plants take up huge amount water daily but most of it is lost to the air through evaporation from the leaves, i.e., transpiration. A mature corn plant absorbs almost three litres of water in a day, while a mustard plant absorbs water equal to its own weight in about 5 hours. Because of this high demand for water, it is not surprising that water is often the limiting factor for plant growth and productivity in both agricultural and natural environments.

Water Potential

- Water potential ($\psi_w$) is a concept fundamental to understanding water movement. Solute potential ($\psi_s$) and pressure potential ($\psi_p$) are the two main components that determine water potential.
- Water molecules possess kinetic energy. In liquid and gaseous form they are in random motion that is both rapid and constant. The greater the concentration of water in a system, the greater is its kinetic energy or 'water potential'. Hence, it is obvious that pure water will have the greatest water potential.
- If two systems containing water are in contact, random movement of water molecules will result in net movement of water molecules from the system with higher energy to the one with lower energy. Thus water will move from the system containing water at higher water potential to the one having low water potential.
- This process of movement of substances down a gradient of free energy is called diffusion.
- Water potential is denoted by the Greek symbol Psi or $\psi$ and is expressed in pressure units such as pascals (Pa).
- By convention, the water potential of pure water at standard temperatures, which is not under any pressure, is taken to be zero.
- If some solute is dissolved in pure water, the solution has fewer free water and the concentration of water decreases, reducing its water potential. Hence, all solutions have a lower water potential than pure water; the magnitude of this lowering due to dissolution of a solute is called solute potential or $\psi_s$. $\psi_s$ is always negative. The more the solute molecules, the lower (more negative) is the $\psi_s$.
- For a solution at atmospheric pressure (water potential) $\psi_w = (\text{solute potential}) \psi_s$.
- If a pressure greater than atmospheric pressure is applied to pure water or a solution, its water potential increases. It is equivalent to pumping water from one place to another.
- 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, it makes the cell turgid, this increases the pressure potential. Pressure potential is usually positive.
- Though in plants negative potential or tension in the water column in the xylem plays a major role in water transport up a stem. Pressure potential is denoted as $\psi_p$.
- Water potential of a cell is affected by both solute and pressure potential. The relationship between them is as follows:

$$\psi_w = \psi_s + \psi_p$$
Osmosis

- The plant cell is surrounded by a cell membrane and a cell wall. The cell wall is freely permeable to water and substances in solution hence is not a barrier to movement.
- In plants the cells usually contain a large central vacuole, whose contents, the vacuolar sap, contribute to the solute potential of the cell.
- In plant cells, the cell membrane and the membrane of the vacuole, the tonoplast together are important determinants of movement of molecules in or out of the cell.
- **Osmosis** is the term used to refer specifically to the diffusion of water across a differentially- or semi-permeable membrane. Osmosis occurs spontaneously in response to a driving force.
- The net direction and rate of osmosis depends on both the **pressure gradient** and **concentration gradient**.
- Water will move from its region of higher chemical potential (or concentration) to its region of lower chemical potential until equilibrium is reached. At equilibrium the two chambers should have the same water potential.

In above Fig two chambers, A and B, containing solutions are separated by a semi-permeable membrane.

(a) **Solution of which chamber has a lower water potential?** - B
(b) **Solution of which chamber has a lower solute potential?** - B
(c) **In which direction will osmosis occur?** - A→B
(d) **Which solution has a higher solute potential?** - A
(e) **At equilibrium which chamber will have lower water potential?** - Equal
(f) **If one chamber has a \( \phi \) of -2000 kPa, and the other -1000 kPa, which is the chamber that has the higher \( \phi \)?** - second with -1000 kPa.

**Experiment** – a solution of sucrose in water taken in a funnel is separated from pure water in a beaker through a semi-permeable membrane (Egg membrane – Can be obtained by removing the yolk and albumin through a small hole at one end of the egg, and placing the shell in dilute solution of hydrochloric acid for a few hours. The egg shell dissolves leaving the membrane intact). Water will move into the funnel, resulting in rise in the level of the solution in the funnel. This will continue till the equilibrium is reached.

External pressure can be applied from the upper part of the funnel such that no water diffuses into the funnel through the membrane. This pressure required to prevent water from diffusing is the **osmotic pressure**.

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*Fig :* A demonstration of osmosis. A thistle funnel is filled with sucrose solution and kept inverted in a beaker containing water. (a) Water will diffuse across the membrane (as shown by arrows) to raise the level of the solution in the funnel (b) Pressure can be applied as shown to stop the water movement into the funnel.
and this is the function of the solute concentration; more the solute concentration, greater will be the pressure required to prevent water from diffusing in. **Numerically osmotic pressure is equivalent to the osmotic potential, but the sign is opposite.** Osmotic pressure is the positive pressure applied, while osmotic potential is negative.

**Plasmolysis**
- The behaviour of the plant cells (or tissues) with regard to water movement depends on the surrounding solution.
  - If the external solution balances the osmotic pressure of the cytoplasm, it is said to be **isotonic**.
  - If the external solution is more dilute than the cytoplasm, it is **hypotonic** and if the external solution is more concentrated, it is **hypertonic**.
- Cells swell in hypotonic solutions and shrink in hypertonic ones.
- Plasmolysis occurs when water moves out of the cell and the cell membrane of a plant cell shrinks away from its cell wall. This occurs when the cell (or tissue) is placed in a solution that is hypertonic (has more solutes) to the protoplasm. Water moves out; it is first lost from the cytoplasm and then from the vacuole. The water when drawn out of the cell through diffusion into the extracellular (outside cell) fluid causes the protoplast to shrink away from the walls. The cell is said to be plasmolysed.
- The movement of water occurred across the membrane moving from an area of high water potential (i.e., the cell) to an area of lower water potential outside the cell.
- The process of plamolysis is usually reversible.
- When the cells are placed in a **hypotonic** solution (higher water potential or dilute solution as compared to the cytoplasm), water diffuses into the cell causing the cytoplasm to build up a pressure against the wall, that is called **turgor pressure**. The pressure exerted by the protoplasts due to entry of water against the rigid walls is called **pressure potential**. Because of the rigidity of the cell wall, the cell does not rupture.
- This turgor pressure is ultimately responsible for enlargement and extension growth of cells.

**Imbibition**
- **Imbibition** is a special type of diffusion when water is absorbed by solids - colloids - causing them to enormously increase in volume. e.g., absorption of water by seeds and dry wood.
- The pressure that is produced by the swelling of wood had been used by prehistoric man to split rocks and boulders.
- If it were not for the pressure due to imbibition, seedlings would not have been able to emerge out of the soil into the open.
- Imbibition is also **diffusion** since water movement is along a concentration gradient; the seeds and other such materials have almost no water hence they absorb water easily.
- Water potential gradient between the absorbent and the liquid imbibed is essential for imbibition.
In addition, for any substance to imbibe any liquid, affinity between the adsorbant and the liquid is also a pre-requisite.

**LONG DISTANCE TRANSPORT OF WATER**

- 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 a typical plant cell (about 50 µm) takes approximately 2.5 s.
- 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 (e.g., a garden hose) or a negative hydrostatic pressure gradient (e.g., 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 nitrogen and hormones, from roots to the aerial parts of the plants. The phloem translocates a variety of organic and inorganic solutes, mainly from the leaves to other parts of the plants.

**How do Plants Absorb Water?**

- The responsibility of absorption of water and minerals is of the root hairs.
- 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.
- Once water is absorbed by the root hairs, it can move deeper into root layers by two distinct pathways:
  - Apoplast pathway
  - Symplast pathway
- **Apoplast** is the system of adjacent cell walls that is continuous throughout the plant, except at the casparian strips of the endodermis in the roots. The apoplastic movement of water occurs exclusively through the intercellular spaces and the walls of the cells. Movement through the apoplast does not involve crossing the cell membrane. 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.
- The **symplastic** system is the system of interconnected protoplasts. Neighbouring cells are connected through cytoplasmic strands that extend through **plasmodesmata**.

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During symplastic movement, the water travels through the cells - their cytoplasm; intercellular movement is through the 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.

- Most of the water flow in the root occurs via the apoplast since the cortical cells are loosely packed, and hence offer no resistance to water movement. However, the inner boundary of the cortex, the endodermis, is impervious to water because of a band of suberised matrix called the casparian strip.
- Water molecules are unable to penetrate the layer, so they are directed to wall regions that are not suberised, into the cells proper through the membranes.
- The water then moves through the symplast and again crosses a membrane to reach the cells of the xylem.
- The movement of water through the root layers is ultimately symplastic in the endodermis. This is the only way water and other solutes can enter the vascular cylinder.
- Once inside the xylem, water is again free to move between cells as well as through them. In young roots, water enters directly into the xylem vessels and/or tracheids. These are non-living conduits and so are parts of the apoplast.

**Fig:** Pathway of water movement in the root. The cortical cells are loosely packed, and hence offer no resistance to water movement. However, the inner boundary of the cortex, the endodermis, is impervious to water because of a band of suberised matrix called the casparian strip.
Some plants have additional structures associated with them that help in water (and mineral) absorption. A mycorrhiza is a symbiotic association of a fungus with a root system. The fungal filaments form a network around the young root or they penetrate the root cells. The hyphae have a very large surface area that absorb mineral ions and water from the soil from a much larger volume of soil that perhaps a root cannot do. The fungus provides minerals and water to the roots, in turn the roots provide sugars and N-containing compounds to the mycorrhizae. Some plants have an obligate association with the mycorrhizae. e.g., Pinus seeds cannot germinate and establish without the presence of mycorrhizae.

**Water Movement up a Plant**

**Root Pressure**
- As 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.
- 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 can, at best, only provide a modest push in the overall process of water transport. They obviously 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.
- Root pressure does not account for the majority of water transport; most plants meet their need by transpiratory pull.

**Transpiration pull**
- The flow of water upward through the xylem in plants can achieve fairly high rates, up to 15 metres per hour.
- Most researchers agree that 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. But, what generates this transpirational pull?
- 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.
The opening of the stoma is also aided due to the orientation of the microfibrils in the cell walls of the guard cells. Cellulose microfibrils are oriented radially rather than longitudinally making it easier for the stoma to open.

When the guard cells lose turgor, due to water loss (or water stress) the elastic inner walls regain their original shape, the guard cells become flaccid and the stoma closes.

Usually the lower surface of a dorsiventral (often dicotyledonous) leaf has a greater number of stomata while in an isobilateral (often monocotyledonous) leaf they are about equal on both surfaces.

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, per cent, 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.

These properties give water high *tensile strength*, i.e., an ability to resist a pulling force, and high *capillarity*, i.e., the ability to rise in thin tubes. In plants capillarity is aided by the small diameter of the tracheary elements - the *tracheids* and *vessel elements*.

The process of photosynthesis requires water. The system of xylem vessels from the root to the leaf vein can supply the needed water.

As water evaporates through the stomata, since the thin film of water over the cells is continuous, it results in pulling of water, molecule by molecule, into the leaf from the xylem.

Also, because of lower concentration of water vapour in the atmosphere as compared to the substomatal cavity and intercellular spaces, water diffuses into the surrounding air. This creates a *pull*.

Measurements reveal that the forces generated by transpiration can create pressures sufficient to lift a xylem sized column of water over 130 metres high.

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**Fig:** A stomatal aperture with guard cells

**Fig:** Water movement in the leaf. Evaporation from the leaf sets up a pressure gradient between the outside air and the air spaces of the leaf. The gradient is transmitted into the photosynthetic cells and on the water-filled xylem in the leaf vein.
**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 photosynthesising 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 C₄ photosynthetic system is probably one of the strategies for maximising the availability of CO₂ while minimising water loss.
- C₄ plants are twice as efficient as C₃ plants in terms of fixing carbon (making sugar). However, a C₄ plant loses only half as much water as a C₃ plant for the same amount of CO₂ fixed.

**UPTAKE AND TRANSPORT OF MINERAL NUTRIENTS**

- Plants obtain their carbon and most of their oxygen from CO₂ in the atmosphere. However, their remaining nutritional requirements are obtained from minerals and water for hydrogen in the soil.

**Uptake of Mineral Ions**

- Unlike water, all minerals cannot be passively absorbed by the roots.
- Two factors account for this:
  (i) minerals are present in the soil as charged particles (ions) which cannot move across cell membranes and
  (ii) 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.
- Ions are absorbed from the soil by both passive and active transport.
- Specific proteins in the membranes of root hair cells actively pump ions from the soil into the cytoplasm of the epidermal cells.
- Like all cells, the endodermal cells have many transport proteins embedded in their plasma membrane; they let some solutes cross the membrane, but not others.
- **Transport proteins of endodermal cells are control points**, where a plant adjusts the quantity and types of solutes that reach the xylem.
- the root endodermis because of the layer of suberin has the ability to actively transport ions in one direction only.
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 frequently remobilised, 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 remobilised.
- 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.

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.

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 (a disaccharide). 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.
- This 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. Again **active transport** is necessary 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 (actively transported) into a sieve tube. Loading of the phloem sets up a water potential gradient that facilitates the mass movement in the phloem.

Phloem tissue is composed of sieve tube cells, which form long columns with holes in their end walls called 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 carefully 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.

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**Fig:** Diagrammatic presentation of mechanism of translocation