Transport in Plants - Part 2

Objectives

After going through this lesson, the learners will be able to understand the following:

- Role of xylem in transport of water
- Absorption of water by roots and short distance transport of water to the xylem
- Long distance movement of water in the xylem, concept of bulk flow
- Role of root pressure and transpiration pull in the ascent of sap
- Process of transpiration, Mechanism of opening and closing of stomata, factors affecting opening of stomata
- Importance of transpiration to the plant

Content Outline

- Introduction - evidence to show that water transport takes place in the xylem
- Transport of water from the root to the xylem - a short distance transport
- Long distance transport of water in the xylem - concept of bulk flow
- Ascent of sap - role of root pressure and transpiration pull
- Transpiration, structure and distribution of stomata
- Mechanism of opening and closing of stomata
- Role of transpiration
- Summary

Introduction

Water is absorbed by the roots and is transported to all parts of the plant, it reaches the top of the tallest trees. This long distance movement of water (also called **ascent of sap**) takes place through the xylem tissues. In this module we will try to understand the mechanism of transfer of water absorbed by the plant to all parts of the plant.

Role of xylem tissue: A simple experiment demonstrates that water is transported through the xylem.

i. A small twig of a herbaceous plant (e.g. twig of *Impatiens balsamina*, Hindi name – Gul-mehendi or stem of celery, as shown in image given below) is dipped in a beaker of coloured water. (100ml water to which 5 drops of 1% safranin is added)

ii. After two hours the movement of the water through the twig is observed.

Experiment to show that water is transported in the xylem

A T.S. of the twig reveals that xylem vessels are coloured demonstrating that water is transported through the xylem.

Transport of Water from the Root to the Xylem - A Short Distance Transport

Water absorbed by the roots must travel from the epidermis through the cortex and the endodermis to the xylem. Water and minerals are absorbed by the root hairs present in the root tips. Root hairs are thin walled unicellular extensions of the epidermal cells. They greatly increase the surface area for absorption. The root hairs of some plants have a symbiotic association with fungal hyphae which form a network around the root and thereby increase the surface area for absorption of water and minerals. This association is referred to as **mycorrhiza**. The fungus obtains shelter and nutrients from the plants. The mycorrhiza may be of two types –

1. **Ectomycorrhiza** – where the fungal hyphae form a sheath or mantle around the root tips but do not penetrate the root cells.
2. **Endomycorrhiza** – where the fungal hyphae penetrate the root cells.

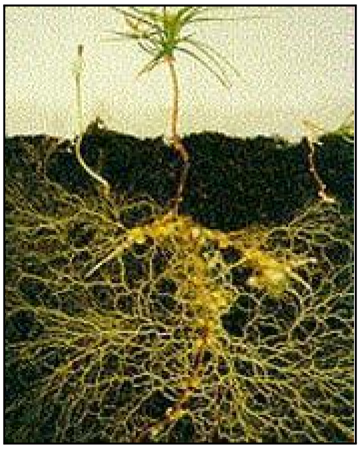


Figure: Image showing Ectomycorrhizae associated with *Pinus* roots

Source: https://www.blm.gov/nstc/soil/fung

Some plants have an obligate association with mycorrhiza e.g., *Pinus* seedlings cannot be established without the presence of mycorrhiza.

Water and some minerals are absorbed by the roots by diffusion. Some minerals that are present as ions or whose concentration in the soil is lower than that in the cell sap, enter the root by active absorption. Once water is absorbed by the root hairs it moves deeper into the root tissues travelling from the epidermis through the cortex to the endodermis through three different pathways-

i. Apoplast
ii. Transmembrane
iii. Symplast

i. **Apoplast** – The apoplast is the nonliving continuum in plants. It is made up of the continuous system of cell walls and intercellular air spaces in plants. Apoplastic movement is dependent on the concentration gradient.

ii. **Transmembrane pathway** – In this pathway water enters the cell on one side and exits at the other and enters the next cell. Water crosses the cell membrane twice for each cell in its path. Transport across the tonoplast i.e., the vacuolar membrane, may also be involved.

iii. **Symplast** – The symplast is the living continuum in plants. It is a network of protoplasts connected by plasmodesmata. During symplastic movement water travels from one cell to another and intercellular movement is through the plasmodesmata. Movement of water takes place down a potential gradient by diffusion.

Most of the water flow in the root occurs via the apoplast as the cortical cells are loosely packed. Water movement through the apoplast is obstructed at the endodermis. The radial walls of the endodermis are impregnated with a wax-like hydrophobic substance-suberin. The radial walls form a band of suberized matrix called the Casparian strip. Water molecules are unable to penetrate this layer and water movement across the endodermis occurs through the symplast. Once inside the xylem, a nonliving conduit, water moves from the roots to all parts of the plant.

Long Distance Transport in the Xylem- Bulk Flow Through the Xylem

Diffusion is an effective method of transport from one cell to another. However, diffusion is a very slow process. The movement of a molecule across a typical plant cell (about 50 microns) takes approximately 2.5 seconds. At this rate can you calculate the time it would take for water to travel by diffusion to the top of the tallest trees which are 100-120m in height?

Water and dissolved minerals travel a long distance from the root to the veins that branch throughout each leaf by bulk flow through the xylem. **Bulk flow** is the movement of liquid in response to a pressure gradient. The bulk flow of material always occurs from higher to lower pressure, is a passive process and unlike osmosis is independent of solute concentration.In **bulk flow** liquids and solutes are swept along passively at the same pace, as in a flowing river.

Long distance travel in both xylem and phloem occurs by bulk flow. Mature tracheids and vessel elements in the xylem are dead cells and lack cytoplasm. They provide very little resistance to the movement of water by bulk flow.

Bulk flow can take place due to a positive hydrostatic pressure gradient (as in a hose pump) or through a negative pressure gradient (as in suction through a straw).

Ascent of sap- role of turgor pressure and transpiration pull

We have looked at how plants absorb water from the soil and move it into the vascular tissue (xylem). Now, we will try to understand how this water moves up the stem, against gravity. Is it a passive process or does it require energy? How is the pressure gradient required for bulk flow established? These are the questions we will try to answer.

It is thought that the pressure required for bulk flow may be provided by –

- **i.** Root pressure
- **ii.** Transpiration pull

i. Root pressure: The roots absorb various ions along with water from the soil. Root cells actively pump these ions into the xylem. This high concentration of ions in the xylem cells lowers the water potential of the xylem. As a result water enters the xylem which in turn leads to the build up of positive hydrostatic pressure in the xylem. This pressure is called root pressure. Root pressure develops in well watered plants on humid days when the rate of transpiration is low. On bright sunny days when transpiration rates are high, the root pressure developed is negligible.

The existence of root pressure can be demonstrated by the following experiment which should be performed on a day with high relative humidity.

A well-watered soft stemmed plant is cut horizontally just near the base, early in the morning.

Cell sap will be seen to ooze out of the cut end for a long time. If a manometer is sealed over the stump, a positive pressure up to 0.5MPa in magnitude can be measured.

Root pressure occurs when soil water potentials are high and transpiration rates are low. When transpiration rates are high, water is so rapidly taken into the leaves and lost by transpiration that root pressure does not develop in the xylem. Root pressure plays a very small role in pushing the water column up the xylem as:

a. The pressure is too weak to overcome the gravitational force acting on the water column,

b. Many plants do not generate root pressure or do so only under certain conditions,

Root pressure is inadequate to pump water from the roots to the top of the plants. It provides only a modest push in the overall direction of water transport.

Plants that produce root pressure frequently produce liquid droplets of water on the edges of the leaves, at vein endings. The loss of water in the form of droplets through specialized structures called hydathodes is known as **guttation.**

Figure: Image Guttation in leaves of Nasturtium

Source: http://www.warrenphotographic.co.uk/33971-nasturtium-leaves-showing-guttatio

ii. **Transpiration pull - suction due to transpiration:** The flow of water upward through the xylem in plants can achieve a rate of 15m/hour. How is this movement accomplished? It is now established that the water column is 'pulled up' by a suction force rather than 'pushed' up by the positive root pressure acting like a pump. This idea was put forward by Dixon and Jolly in the cohesion – tension theory for the ascent of sap.

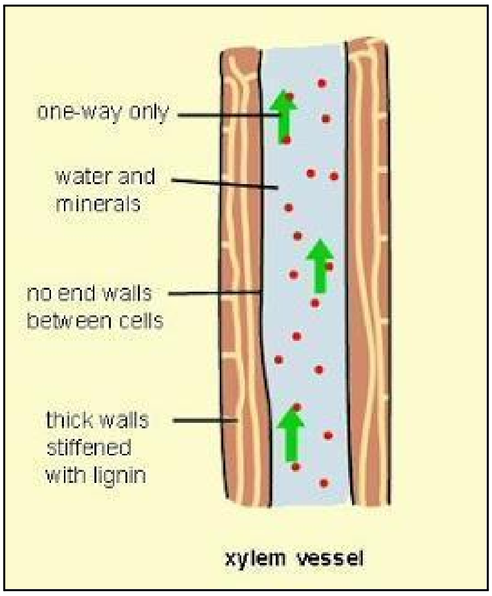
There are three basic elements of the cohesion-tension theory for the ascent of sap-driving force, adhesion, and the cohesion of water molecules. The driving force is the tension/suction force that develops at the top of a tree due to transpiration that takes place through the stomata. The cell wall acts like a capillary network. A thin film of water covers the walls of the mesophyll cells and as this film evaporates, the air-water interface retracts farther in the cell wall. Due to the high surface tension of water, the curvature of the interphase induces a tension or negative pressure potential in the water. This suction force can pull water through the xylem even to the top of tall trees more than 100 m in height. The water column is pulled up and does not break and air bubbles are also not formed because of two factors:

a. **Cohesion** is the attractive force between similar molecules. Cohesive forces between water molecules great tensile strength and capillarity i.e. the ability to be drawn out into thin films.

b. **Adhesion** is the attractive force between dissimilar molecules. The adhesion of water molecules with the wall of the xylem helps to offset the effect of gravity.

The transpirational pull is transmitted from the leaves to the roots and results in the ascent of sap.

Thus ascent of sap in the xylem takes place in response to a pressure gradient. The sap does not have to cross the plasma membrane but bulk flow in response to a pressure gradient, takes place through the vessels which are hollow dead cells. No energy is expended by the plant for the ascent of sap. However, as transpiration is the driving force, ascent of sap in the xylem can be said to be solar-powered.



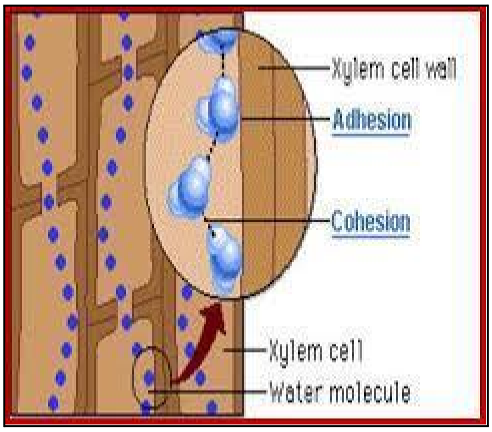


Figure: Image Bulk flow through xylem Google images

Source (left): https://www.youtube.com/watch?v=J5b-FO3FMQw

Source (Right):

http://igcse-biology-edexcel.blogspot.in/2015/12/252-describe-role-of-xylem-in.html#!/2015/12/252-describe-role-of-xylem-in.html

Transpiration, Structure and Distribution of Stomata

Transpiration is the loss of water in the form of vapour through the aerial parts of plants. More than 99% of the water absorbed by the roots is lost through transpiration, and less than 1% is used for photosynthesis. Transpiration can take place through stomata, cuticles or through lenticels.

Stomatal transpiration accounts for more than 90% of the water lost through transpiration. The stomata cover 1-2% of the leaf area yet bulk of the water absorbed is lost through the stomatal apertures. The stomatal density may be as high as 20,000 - 30,000 stomata/cm square. In the dorsiventral leaf of dicots stomata are more frequent on the lower epidermis. In isobilateral leaves usually found in monocots, stomata are equally distributed in the upper and lower epidermis.

Stomata are small openings in the leaf epidermis. **Stomatal aperture** is flanked on either side by a **guard cell** which may be kidney shaped (dicots) or dumb bell shaped (grasses). Adjacent to each guard cell is modified epidermal cells called subsidiary cells.

Guard cell walls are unevenly thickened – the region adjacent to the pore is thick while the outer wall is thin. The cellulose microfibrils on the walls are radially arranged.

Mechanism of Opening and Closing of Stomata

Generally stomata are open during the day and closed at night. However, in CAM plants stomata are closed during the day in order to reduce transpiration and remain open at night.

Stomata open when the guard cells are turgid. Guard cells actively accumulate K^+ ions from surrounding epidermal cells. As a result, the solute concentration of the guard cells rises and the water potential decreases. Water enters the guard cells by endosmosis making it turgid. The thin outer walls of the guard cells bulge out and pull the inner walls into a crescent shape, thereby opening the stomata. The radial micellation on the walls of the guard cells facilitates the opening of the stomata.

Loss of K^+ ions from the guard cells causes loss of water by exosmosis. This makes the guard cells flaccid and the stomata close.

Factors Affecting Rate of Transpiration

Plant factors: Stomatal density, percentage of open stomata, water status of the plant are factors that affect the rate of transpiration.

External factors: Light, wind, temperature, relative humidity are some external factors that affect the rate of transpiration.

Role of Transpiration

Transpiration has more than one purpose; it

- Creates transpiration pull for ascent of sap
- 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

Uptake and Transport of Minerals

Most minerals enter the root by active transport. This is because –

a. In the soil most minerals exist in the form of ions which cannot cross the cell membrane
b. The concentration of many minerals is lower in the soil as to their concentration within the root.

Specific transporter proteins are present in the membrane of the root hair cells which actively pump ions into the root. Active uptake of ions by the root increases the osmotic potential of the cell sap with a resultant decrease in its water potential. This leads to the absorption of water by the root through osmosis.

The ions travel from the epidermal cells of the root through the cortex but cannot cross the suberin layer in the endodermis. Transport proteins present in the cell membrane of the endodermis allow some proteins to cross the membrane but not others. Transport proteins of endodermal cells are control points that regulate the type and quantity of ions that reach the xylem.

Once in the xylem the ions travel along with the transpiration stream to all parts of the plant. The chief sinks for the ions are the meristems, young leaves, developing fruits and seeds and the storage organs. Minerals are frequently remobilized e.g., from old and senescing leaves to younger developing ones.

The water column in the xylem also carries amino acids, and organic compounds containing sulphur and phosphorus. Some plant hormones are also transported through the xylem.

Summary

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.