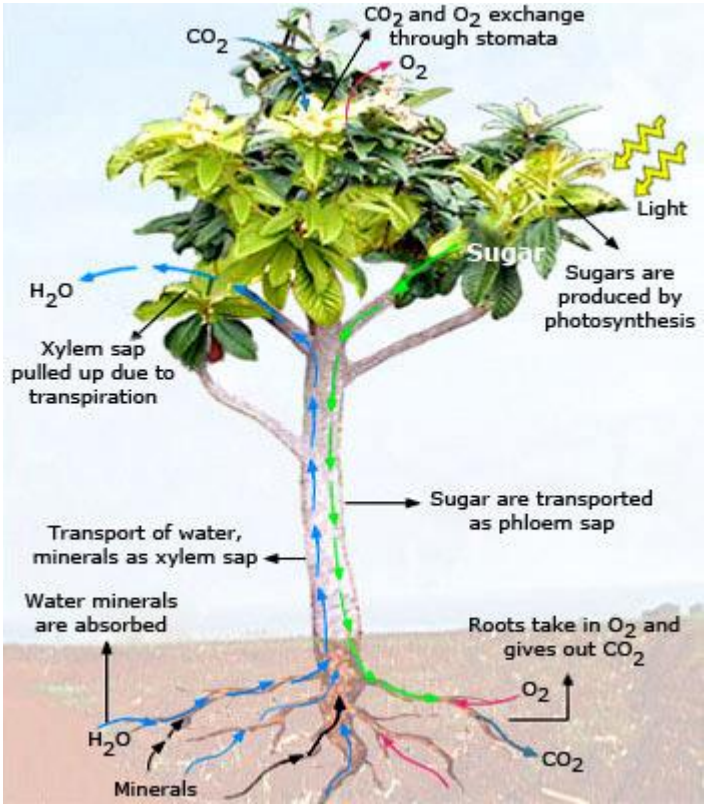
CASE STUDY

WATER ABSORPTION AND TRANSPORT IN PLANTS

Presentation of the problem: We need a pump to uplift water to a tank. The requirement of a pump is to pull water against the gravity. Look at the human body. We do also have a pump (heart) to circulate blood. Now imagine tall tree. In plants, there are no standing tanks, pumps (hearts), or valves that can move water up trees. The leaves at the tip of the tree must get water to survive and for preparation of food. Do a tree have a pump to pull water against the gravitational force? How much water can a tree process? How do they prevent loss of water? Today we know that a big tree can process around 3000 liters of water a day. What are the motive forces of water movement in plants? What will be the speed of transport?

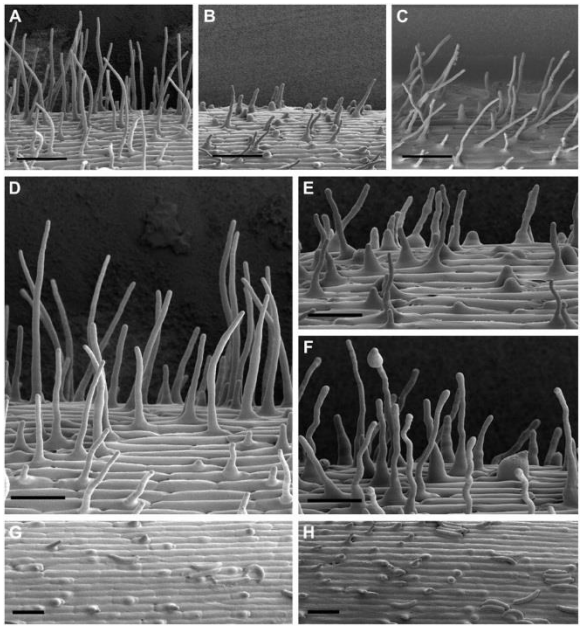
The route map of water transport in plants

Root Hair→Cortex cells-→Xylem vessels of root→Xylem vessels of stem→Xylem vessels of leaf→Stomata (Escapes in the form of water vapor—Transpiration)

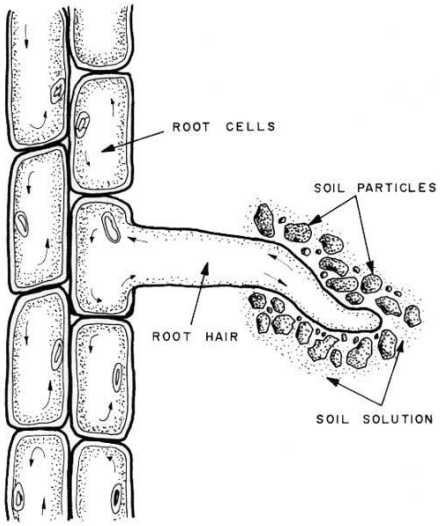


The hurdles of water relations in plants: (a) Water absorption (b) Water transport in xylem upwards against gravitational pull (c) Transport of sap in Phloem

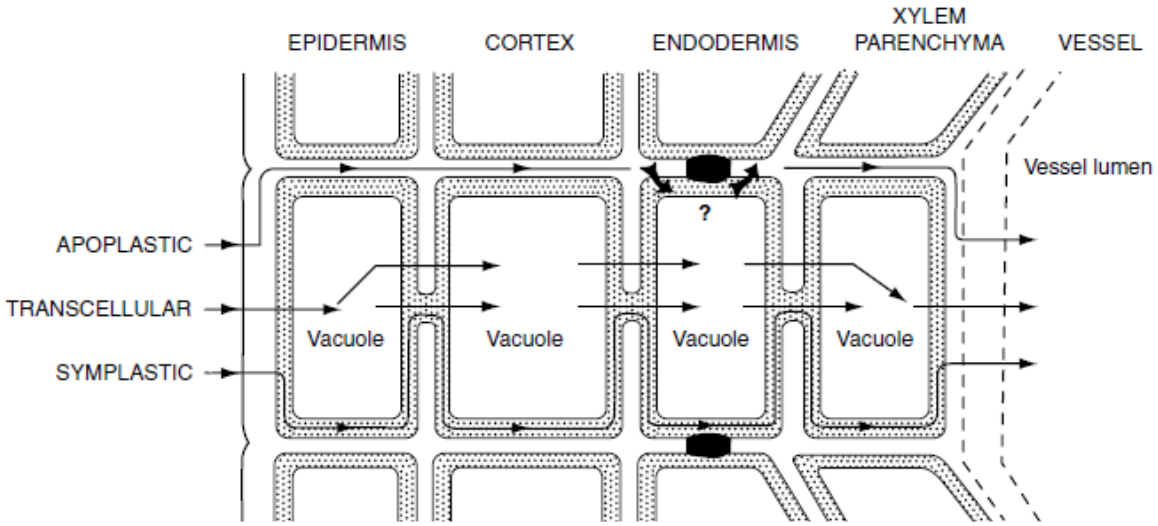
Water absorption: The water absorbing cell of the root is the root hair. Root hair cell is a root epidermal cell with a hair like projection. This is an adaptation to increase the water absorbing area. Another advantage of this **root hair architecture** is to maintain contact with the soil by bending into the soil particle and penetrating into the crevices. If you take a root, you will find a root hair zone where the frequency of the root hairs are high. This is towards the root tip. Hence all part of the root are not absorbing water. Because root is an organ which is **multifunctional**: (i)To absorb water and mineral ions (ii) To support the plant



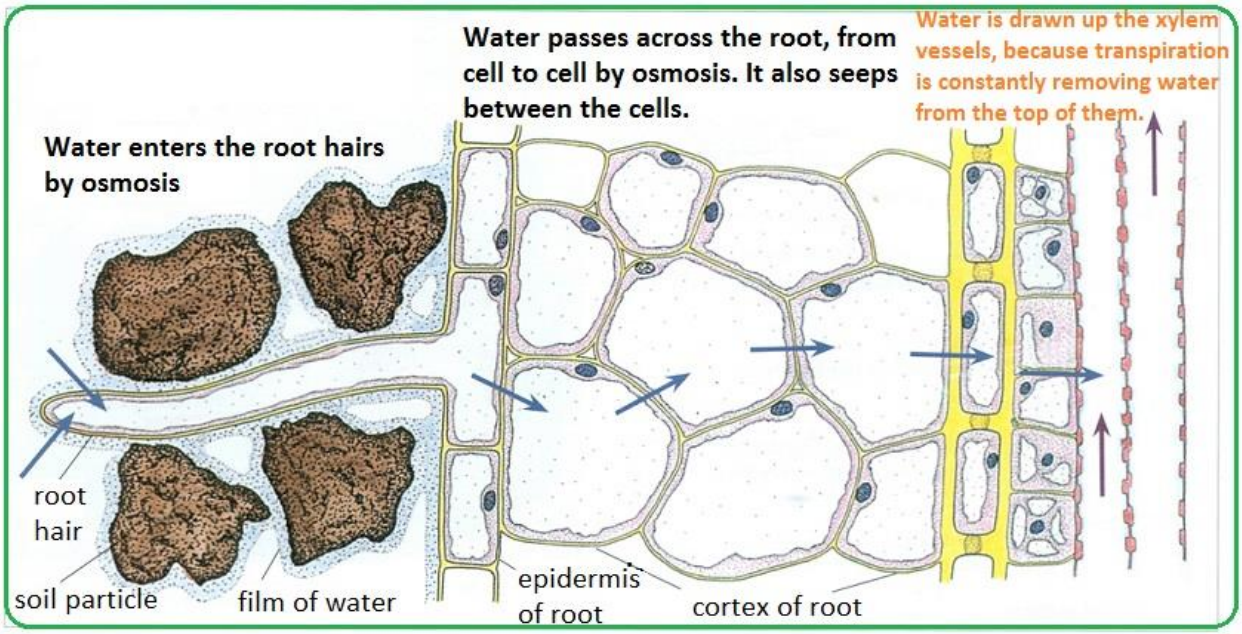
SEM pictures of root hairs in Rice



The cell wall is made up of cellulose. It is hydrophilic in nature. Root hair cell imbibe water. From here water enters the cell sap through osmosis. The water movement till the xylem cell is through osmosis. Then it enters xylem cell by the **transpiration pull**. So the water absorbed by the root has to move **radially** to reach the xylem. Here is the three possible ways of radial transport till the xylem vessel.



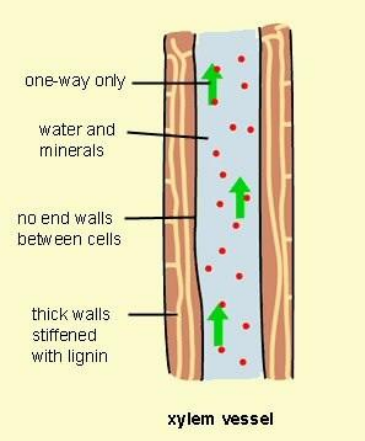
The figure showing the radial conduction of water in three different ways Apoplastic (through the non-living cell wall), symplastic (through the living parts ie cytoplasm) and transcellular (water crosses the cell wall and cell membrane and also through the vacule)



Now the question is **xylem is a dead tissue**. How it is enabled with features of water transport?

The root of water movement in the plant is through xylem vessels. It is the longest pathway of water transport. In a plant 1 m tall, more than 99.5% of the water transport pathway through the plant is within the xylem, and in tall trees the xylem represents an even greater fraction of the pathway. **Why the plant evolved with a dead tissue for water conduction?**

Xylem is dead. It means it has no membranes and no organelles. Its cross walls and contents will break down. Hence it is a **continuous system** (the lumina) from root till the leaf end. Its walls are **deposited with lignin**. This makes it **rigid**. It is **more hydrophobic**. The another advantages are (i) Being dead it can transport toxic substances (ii) Chilling does not stop water movement.



The motive forces of water movement: Capillary force, Transpiration pull (cohesion tension) and root pressure

(A) Capillary force

We know the from the school days that roots absorb water and minerals from the soil. The water is transported to the leaves and is necessary for the preparation of food through photosynthesis. Look at the following figure and find the analogy. What is the force behind?

Xylem vessels are narrow and dead without cross walls making it an ideal system to develop capillary force. This facilitates the water movement upward.

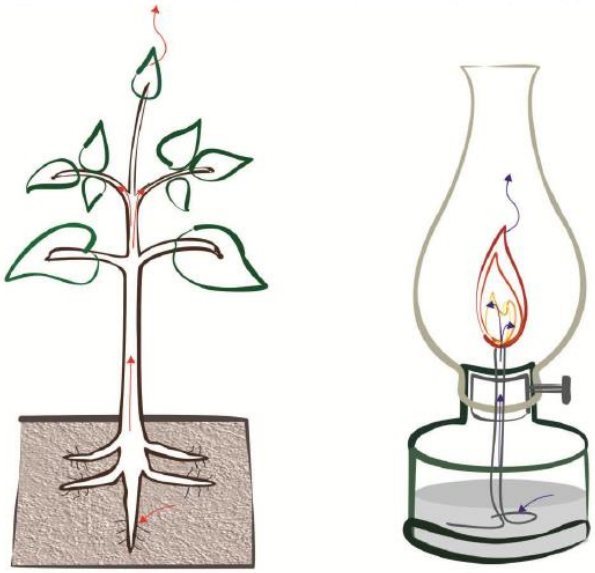
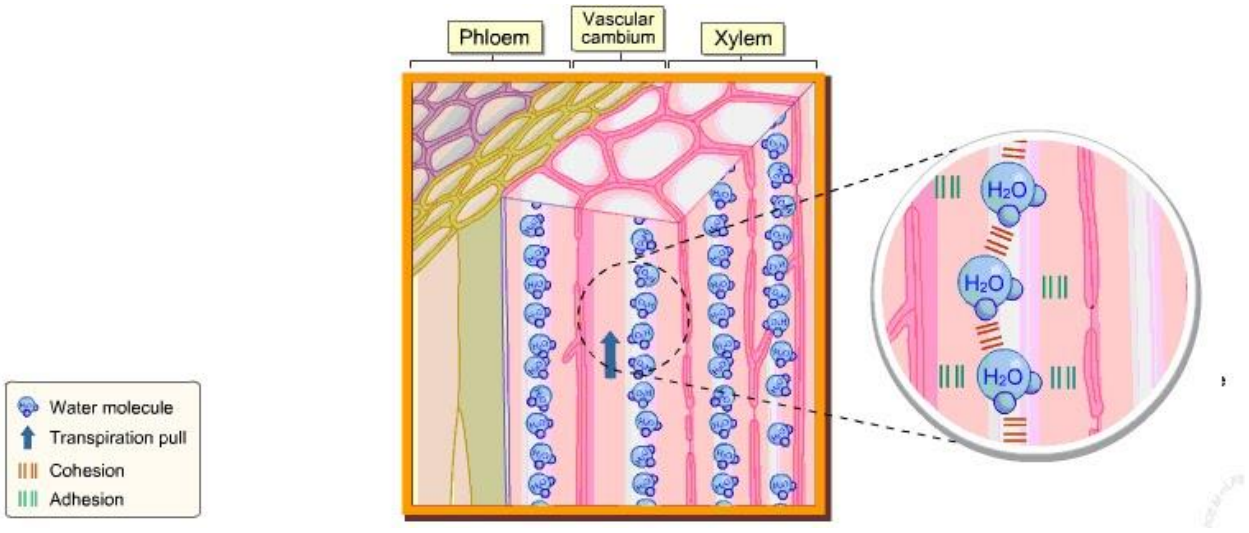


Fig. 1. Schematic representation of water flow through the plant (arrows), by analogy with the oil flow through the wick of an old fashion lampion.

The capillary force is very minimal and it is unable to lift water to very high levels as in the case of a tree. People use paper towels (and thus, capillary action) to wipe up liquid spills.

(B) Transpiration Pull (The cohesion Tension)

During transpiration water evaporates from the leaf and escape through the stomata. The water column is continuous from root hair till the stomata. As one molecule escapes, another one is pulled into the xylem. This is because of cohesive forces.



(C) Root pressure

A pressure is developed in xylem vessels when water is absorbed by root hair cells. This is the root pressure. Roots generate positive hydrostatic pressure by absorbing

ions from the soil. The absorption of ion requires energy ie ATP. Hence there is a **metabolic pump**. Ie the energy through the respiration of root hair cells itself.

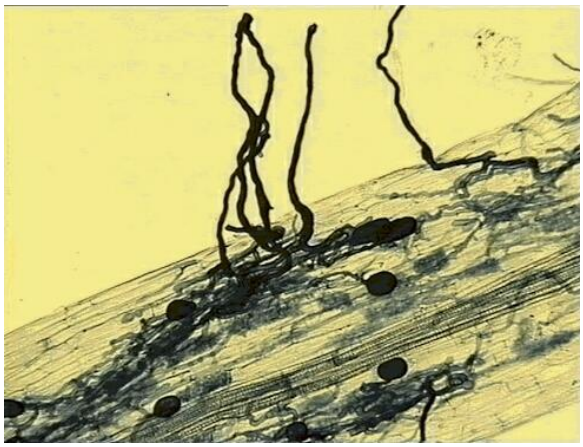
Now do you think that the from capillary water is in soil till the stomatal end is a continuous column? This is the Concept of the Soil-Plant-Atmosphere Continuum. Now look at the speed

Plant type	Speed ($m\ h^{-1}$)
Evergreen conifers	1.2
Mediterranean sclerophylls	0.4–1.5
Deciduous diffuse-porous trees	1–6
Deciduous ring-porous trees	4–44
Herbaceous plants	10–60
Lianas	150

In plants all cells are not living. It is a system or combination both dead and living cells emerged as an efficient mechanism of water transport!

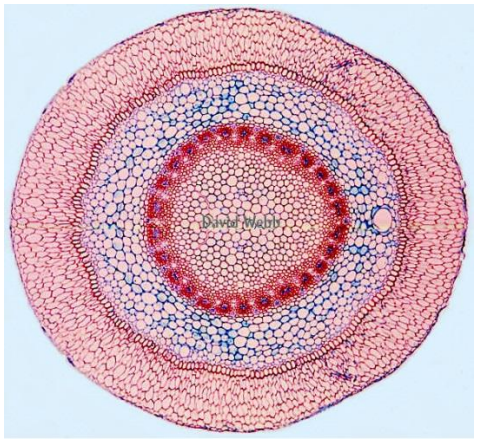
Mechanisms of enhancing efficiency of water absorption in plants

Mycorrhizae: This is a symbiotic relationship formed between root cells and fungus. The fungus helps in water absorption and mineral absorption. The fungal filaments are much finer than root hairs. Hence they can reach further areas of soil where root hair is unable to reach. In return plant cells provide food and shelter for fungus. This association can be found in most of the plants.



Velamen tissue: Many orchids are epiphytes. How do they absorb water? Orchids are equipped with special roots known as velamen roots. The outer layer of these roots are made up of **velamen tissue**. This is a dead tissue like xylem. Velamen tissue directly absorbs moisture from the atmosphere by imbibition. Now the nearby living cells absorb water from the velamen tissue.

Water absorption in hydrophytes: In these plants the function of root is merely restricted for anchorage. They do not have root hairs. Xylem is poorly developed in Hydrophytes as the water absorption takes place all over the body. In these plants stomata are inactive.

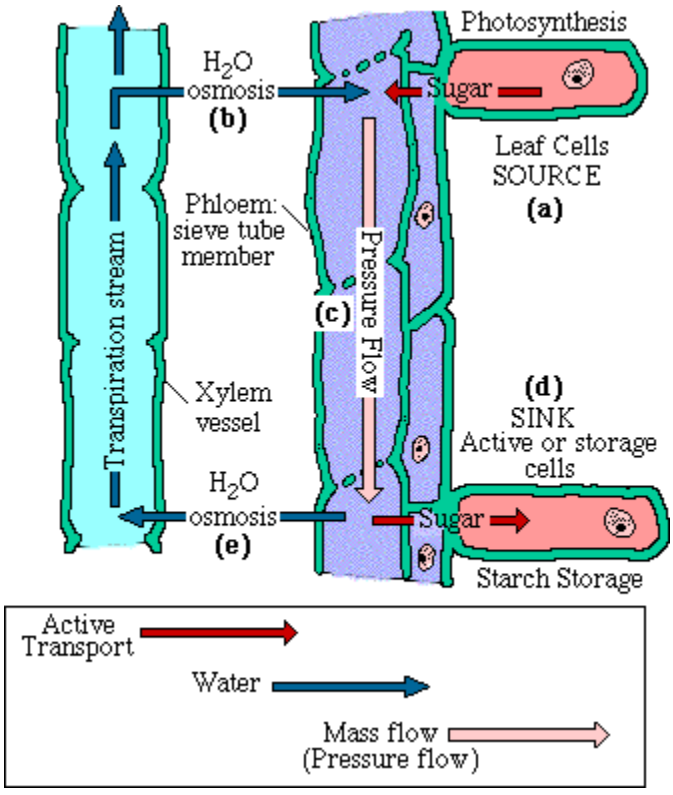


Mechanisms of phloem transport

In contrast to xylem phloem is a living tissue. It has cross walls. It transport the sap which contains mainly sugar apart from hormones. In phloem sap can be transported in both directions. How?

This can be explained on the basis of “Source sink” relationship. The leaves are the source of sugar. The sink is the consuming end may be a root which store it. Phloem sap can be transported in any direction needed so long as there is a source of sugar and a sink able to use. The source and sink may be reversed depending on the season, or the plant's needs. Sugar stored in roots may be mobilized to become a source of food in the early spring when the buds of trees, the sink, need energy for growth and development of the photosynthetic apparatus.

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



The movement of sugars in the phloem begins at the source, where (a) sugars are loaded (actively transported) into a sieve tube. Loading of the phloem sets up a water potential gradient that facilitates the movement of water into the dense

phloem sap from the neighboring xylem (b). As hydrostatic pressure in the phloem sieve tube increases, pressure flow begins (c), and the sap moves through the phloem. Meanwhile, at the sink (d), 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 (e), returning eventually to the xylem.

Can xylem and phloem gets blocked? Whether air bubbles are forming there?

Xylem and phloem can be blocked due to physical blockages with secondary metabolites such as phenolics. Blockages can also be possible with viral particles or phytoplasma. This can lead to wilt of the plant and death.

Water moving up in the xylem or up and down in phloem has to be continuous channel. If any air bubbles are formed, water fails to move.