Topic: Ascent of Sap
B.Sc. Botany (Sub.) II
Group: C
Dr. Sanjeev Kumar Vidyarthi
Department of Botany
Dr. L.K.V.D. College, Tajpur

Ascent of Sap

Sap is water with dissolved ingredients (minerals). The upward movement of water from roots towards the tips of stem branches and their leaves is called ascent of sap. It occurs through the tracheary elements of xylem. That the ascent of sap occurs through xylem can be proved by stain test and ringing experiment.

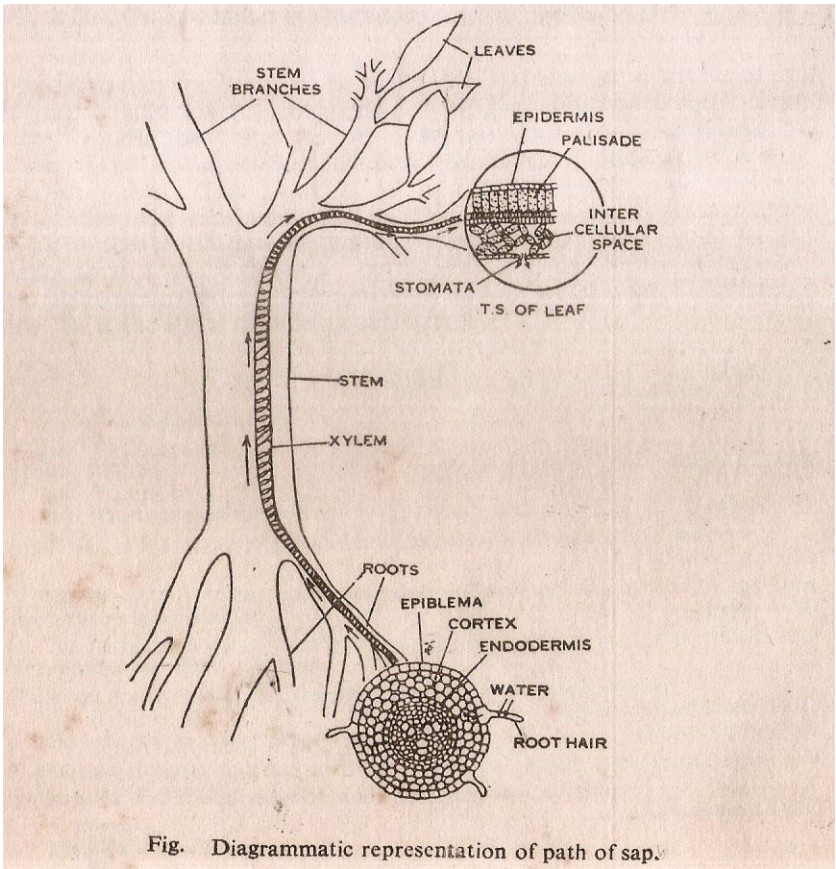


Fig. Diagrammatic representation of path of sap.

Theories of Ascent of Sap

Water or sap is lifted from near the root tip to the shoot tip against the force of gravity, sometimes to height of 100 meters. The rate of translocation is 25-75 cm/minute (15- 45 m/hr). Several theories have been put forward to explain the mechanism of ascent of sap.

The three main theories are vital force, root pressure and cohesion tension.

1. Vital Force Theory

A common vital force theory about the ascent of sap was put forward by J.C. Bose (1923). It is called pulsation theory. The theory believes that the innermost cortical cells of the root absorb water from the outer side and pump the same into xylem channels.

However, living cells do not seem to be involved in the ascent of sap as water continues to rise upward in the plant in which roots have been cut or the living cells of the stem are killed by poison and heat (Boucherie, 1840; Strasburger, 1891).

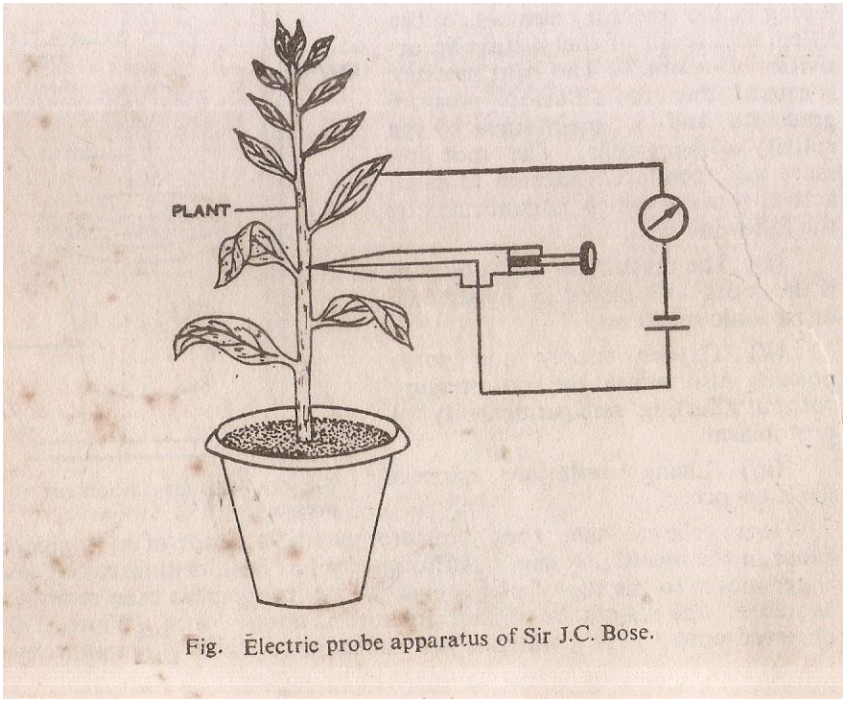


Fig. Electric probe apparatus of Sir J.C. Bose.

2. Root Pressure Theory

The theory was put forward by Priestley (1916). Root pressure is a positive pressure that develops in the xylem sap of the root of some plants. It is a manifestation of active water absorption. Root pressure is observed in certain seasons which favour optimum metabolic activity and reduce transpiration.

It is maximum during rainy season in the tropical countries and during spring in temperate habitats. The amount of root pressure commonly met in plants is 1-2 bars or atmospheres. Higher values (e.g., 5-10 atm.) are also observed occasionally. Root pressure is retarded or becomes absent under conditions of starvation, low temperature, drought and reduced availability of oxygen.

There are three viewpoints about the mechanism of root pressure development-

(i) Osmotic

Tracheary elements of xylem accumulate salts and sugars. High solute concentration causes withdrawal of water from the surrounding cells as well as from the normal pathway of water absorption. As a result a positive pressure develops in the sap of xylem.

(ii) Electro-osmotic

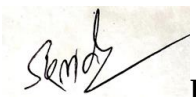
A bioelectric potential exists between the xylem channels and surrounding cells which favour the passage of water into them.

(iii) Nonosmotic

Differentiating xylem elements produce hormones that function as metabolic sinks and cause movement of water towards them. The living cells surrounding xylem can actively pump water into them.

Objections to Root Pressure Theory

- Root pressure has not been found in all plants. No or little root pressure has been seen in gymnosperms which have some of the tallest trees of the world.



- Root pressure is seen only during the most favourable periods of growth like spring or rainy season. At this time the xylem sap is strongly hypertonic to soil solution and transpiration rate is low. In summer when the water requirements are high, the root pressure is generally absent.
- The normally observed root pressure is generally low which is unable to raise the sap to the top of trees.
- Water continues to rise upwards even in the absence of roots.
- The rapidly transpiring plants do not show any root pressure. Instead a negative pressure is observed in most of the plants.
- Root pressure disappears in unfavorable environmental conditions while ascent of sap continues uninterrupted.
- Root pressure is generally observed at night when evapotranspiration is low. It may be helpful in re-establishing continuous water chains in xylem which often break under enormous tension created by transpiration.

3. Physical Force Theories

These theories consider dead cells of xylem responsible for ascent of sap. Capillary theory of Boehm 1863, Imbibition Theory of Unger 1868 and Cohesion-Tension Theory of Dixon and Joly 1894 are few physical theories. But cohesion-tension theory (also called cohesion-tension transpiration pull theory) of Dixon and Joly is most widely accepted one.

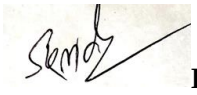
Cohesion Tension Theory (Cohesion-Tension and Transpiration Pull Theory)

The theory was put forward by Dixon and Joly in 1894. It was further improved by Dixon in 1914. Therefore, the theory is also named after him as Dixon's theory of ascent of sap. Today most of the workers believe in this theory.

The main features of the theory are-

(a) Continuous Water Column

There is a continuous column of water from root through the stem and into the leaves. The water column is present in tracheary elements. The latter do operate separately but form a continuous system through their unthickened areas.



Since there are a large number of tracheary elements running together, the blockage of one or a few of them does not cause any breakage in the continuity of water column (Scholander, 1957). The column of water does not fall down under the impact of gravity because forces of transpiration provide both energy and necessary pull. Cohesion, adhesion and surface tension keep the water in place.

(b) Cohesion or Tensile Strength

Water molecules remain attached to one another by a strong mutual force of attraction called cohesion force. The mutual attraction is due to hydrogen bonds formed amongst adjacent water molecules. On account of cohesion force, the water column can bear a tension or pull of up to 100 atm. (Mac Dougal, 1936). Therefore, the cohesion force is also called tensile strength.

Its theoretical value is about 15000 atm. but the measured value inside the tracheary elements ranges between 45 atm. to 207 atm. (Dixon and Joly, 1894). Water column does not further break its connection from the tracheary elements (vessels and tracheids) because of another force called adhesion force between their walls and water molecules. Water molecules are attracted to one another more than the water molecules in the gaseous state. It produces surface tension that accounts for high capillarity through tracheids and vessels.

(c) Development of Tension or Transpiration Pull

Intercellular spaces present amongst mesophyll cells of the leaves are always saturated with water vapours. The latter come from the wet walls of mesophyll cells. The intercellular spaces of mesophyll are connected to the outside air through stomata. Outside air is seldom saturated with water vapours.

It has a lower water potential than the moist air present inside the leaf. Therefore, water vapours diffuse out of the leaves. The mesophyll cells continue to lose water to the intercellular spaces. As a result curvature of meniscus holding water increases resulting in increase in surface tension and decrease in water potential, sometimes to -30 bars.

The mesophyll cells withdraw water from the deeper cells as its molecules are held together by hydrogen bonds. The deeper cells in turn obtain water from the tracheary elements. The water

in the tracheary elements would, therefore, come under tension. A similar tension is felt in millions of tracheary elements lying adjacent to the transpiring cells. It causes the whole water column of the plant to come under tension. As the tension develops due to transpiration, it is also called transpiration pull. On account of tension created by transpiration, the water column of the plant is pulled up passively from below to the top of the plant like a rope.

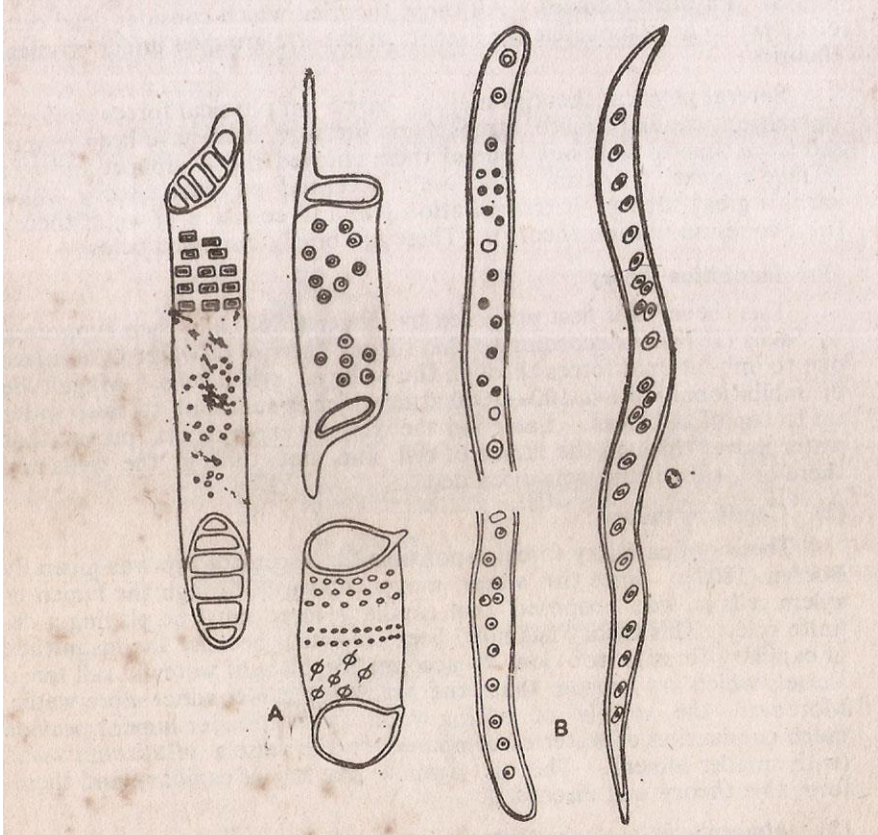


Fig. Xylem elements; A—vessels, and B—tracheids.

Evidences

- The rate of water absorption and hence ascent of sap closely follows the rate of transpiration. Shoot attached to a tube having water and dipping in a beaker having mercury can cause the movement of mercury into the tube showing transpiration pull.
- In a branch cut from a rapidly transpiring plant, water snaps away from the cut end showing that the water column is under tension.
- The maximum tension observed in water column is 10-20 atm. It is sufficient to pull the water to the top of the tallest trees of even more than 130 meters in height. The tension

cannot break the continuity of water column as cohesive force of xylem sap is 45 to 207 atm.

- Gymnosperms are at a disadvantage in the ascent of sap because of the presence of tracheids instead of vessels in angiosperms. However, tracheidal xylem is less prone to gravitation under tension. Therefore, most of the tall trees of the world are redwoods and conifers.

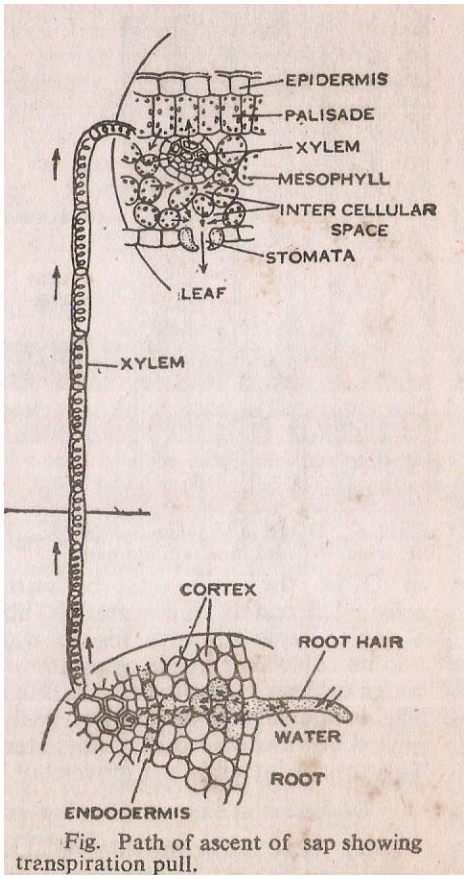


Fig. Path of ascent of sap showing transpiration pull.

Objections

- The gases dissolved in sap shall form air bubbles under tension and high temperature. Air bubbles would break the continuity of water column and stop ascent of sap due to transpiration pull.
- A tension of up to 100 atm. has been reported in the xylem sap by Mac Dougal (1936) while the cohesive force of sap can be as low as 45 atm.

- Overlapping cuts do not stop ascent of sap though they break the continuity of water column.

Mineral Uptake by Roots

Plants obtain their supply of carbon and most of their oxygen from CO_2 of atmosphere, hydrogen from water while the rest are minerals which are picked up individually from the soil. Minerals exist in the soil as ions which cannot directly cross the cell membranes.

The concentration of ions is some 100 times more in root interior than in the soil. Therefore, all minerals cannot be passively absorbed. The movement of ions from soil to interior of root is against concentration gradient and requires an active transport. Specific ion pumps occur in the membrane of root hairs.

They pump mineral ions from soil to cytoplasm of epidermal cells of root hairs. Energy is provided by ATP. Respiratory inhibitors like cyanide which inhibit ATP synthesis, generally reduce the ion uptake. The small amount which passes into the root even without ATP, must be through a passive technique.

For active transport, ATPases are present over the plasma membranes of root epidermal cells. They establish an electrochemical proton gradient for supplying energy for movement of ions. The ions are again checked and transported inwardly by transport proteins present over the endodermal cells.

Endodermis allows the passage of ions inwardly but not outwardly. It also controls the quantity and type of ions to be passed into xylem. Inward flow of ions from epiblema to xylem is along the concentration gradient. The collection of ions in the xylem is responsible for water potential gradient in the root that helps in osmotic entry of water as well as its passage to xylem. In the xylem, minerals are carried up along-with the flow of xylem solution. In leaves, the cells absorb the minerals selectively through membrane pumps.

Translocation of Mineral Ions in the Plant

Though it is generally considered that xylem transports inorganic nutrients while phloem transports organic nutrients, the same is not exactly true. In xylem sap, nitrogen travels as inorganic ions, as well as organic form of amino acids and related compounds.

Small amounts of P and S are passed in xylem as organic compounds. There is also exchange of materials between xylem and phloem. Therefore, mineral elements pass up xylem in both inorganic and organic form.

They reach the area of their sink, namely young leaves, developing flowers, fruits and seeds, apical and lateral meristems and individual cells for storage. Minerals are unloaded at fine vein endings through diffusion. They are picked up by cells through active uptake.

There is remobilization of minerals from older senescing parts. Nickel has a prominent role in this activity. The senescing leaves send out many minerals like nitrogen, sulphur, phosphorous and potassium. Elements incorporated in structural components are, however, not remobilised, e.g., calcium. The remobilised minerals become available to young growing leaves and other sinks.

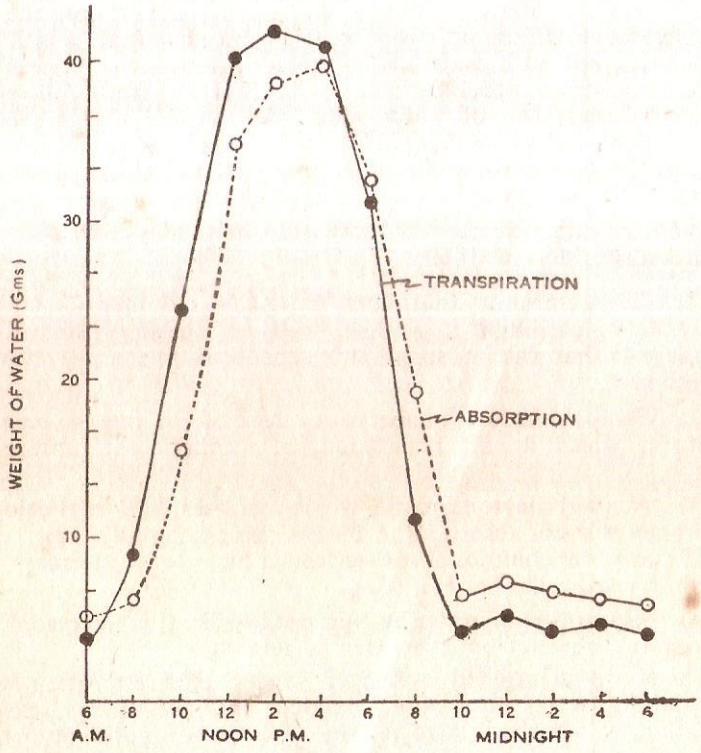


Fig. A graph showing parallel relationship between passive absorption of water and transpiration.