Plant water relations
Unit I B.Sc III Year

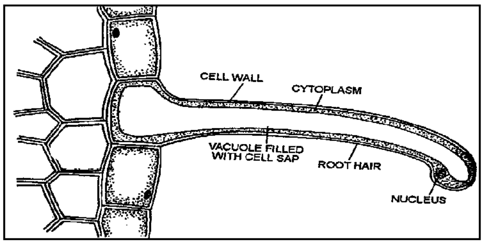
Water absorbing organs

Underground roots are specialized to absorb water from the soil. Roots are often extensive and grow rapidly in soil. Ditmer 1937 has found the total length of root system of a 4 month old *Rhye* plant to be 620 km. with a daily increase of 5 km. The surface area was calculated to be 255 square meters. Root ends of *Maize* grow by 6 % of their volume every 10 minutes. Such a spreading and growing root system allows the plant to absorb water efficiently from a restricted are in which it occurs.

In roots the most efficient region of water absorption is the root hair zone. Each root hair zone has thousands of root hairs. Ditmer has estimated that a four month old *Rhye* plant bears as many as 14 billion root hairs with a length of over 10,000 Km. and surface area of 900 Square meters.

Root hairs are tubular extensions of epiblema cells which are 0.05 – 1.5 mm. in length and 10 µ in diameter. Each root hair has central vacuole filled with osmotically active vacuolar sap. The cytoplasm of the root hair is pushed to periphery the nucleus lies towards the tip of the root hair. The wall of root hair is thin and permeable. The outer part of the wall is mainly made of pectic compounds while the inner part of the wall contains mainly cellulose. The pectic compounds function as the cement between the root and the soil particles. They also help in retaining water on the surface of the root.

The rate of absorption of water by the root hairs varies from 0.2 to 4.4μ^3 per μ^2 of the surface per minute. So the total absorption potential of root system of rye plant is 125 liters per day.



Root hair

Mechanism of water absorption

The absorption of water is also called as water uptake. Renner1912 – 1915 recognized two mechanisms of water absorption.

1. Active absorption.

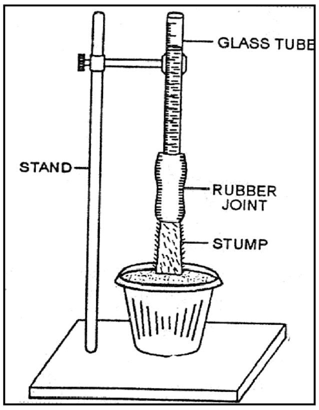
2. Passive absorption

1.Active absorption:- When roots are actively involved in water absorption and the water absorbing forces are developed in root, such type of water absorption is called active absorption. It is found in those plants where transpiration is less and water is present in sufficient amounts. Active absorption can be manifested by root pressure, guttation and bleeding.

Root pressure:- Plants sometimes exhibit a phenomenon referred to as root pressure. Roots generate positive hydrostatic pressure by absorbing ions from the dilute soil solution and transporting them into the xylem. The built up of solutes in the xylem sap leads to decrease in the xylem water potential. This lowering of the xylem water potential provides a driving force for water absorption which in turn leads to positive hydrostatic pressure in the xylem.

Root pressure is mostly likely to occur when soil water potentials are high and transpiration rates low. When transpiration rates are high, water is taken up so rapidly into the leaves and lost to atmosphere that a positive pressure never develops in xylem.

Stephen Hales (1727) observed that the liquid could rise to a height of 21 feet from the cut end of vine connected to a tube of ¼ // diameter. Hence root pressure is often described as exudation pressure.



Demonstration of root pressure:- Root pressure can be demonstrated experimentally by cutting the stem of a well watered herbaceous potted plant eg. *Tomato, Zennia* near its base. Attach the cut end of the stump to a narrow glass tube by means of rubber tubing. A little coloured water is poured into the tube and its level is marked **A.** Put a drop of non drying oil into the tube to prevent evaporation. After a few hours of keeping the apparatus in the moist and shady place water in the glass tube come from the root system which must have absorbed the same from the soil by forces present in the root (active water absorption). The rise of water also indicates the rate of pressure with which water enters the xylem of root.

Types of active absorption

(a). Osmotic active absorption

(b). Electro osmotic active absorption

(c). Non osmotic active absorption.

(a). Osmotic active absorption:- This method of active water absorption does not require a direct supply of energy for its operation. Water move from soil to the inside of the root along a gradient of diffusion pressure deficit. DPD is maximum in the xylem on account of the presence of salts. The solute concentration in the xylem is maintained by any of the following methods.

1. Sugar diffuses into the xylem vessels from the surrounding parenchyma cells.

2. Salts present in the xylem channels are partly derived from solute present in their mother cells and remaining are poured from surrounding cells.

3. All the living cells of root accumulate salts against a concentration gradient due to higher metabolic activity. However there is a progressive decrease in metabolic activity towards the interior of root on account of decreased availability of O_2 and increased concentration of CO_2. Therefore the xylem parenchyma cells can not retain excessive salts and loose the same to the xylem vessels.

(b). Electro osmotic active absorption :- Keller (1930) thinks that xylem vessels in contact with water are negatively charged. Water automatically moves towards the negatively charged part present in the root interior.

(c). Non osmotic active absorption :- Water flow is passive process that is water moves in response to physical process towards region of low water potential or low free energy. There are no metabolic pumps (reaction driven by ATP hydrolysis) that pushes water from one place to another.

This rule is valid as long as water is the only substance being transported. When solutes are transported water transport may be coupled to solute transport. And this coupling may move water against a water potential gradient e.g. the transport of Sugars, amino acids and other small molecules by various membrane proteins can drag up to 260 water molecules across the membranes per molecule of solute transported (Loo et. al 1996). Such transport of water can occur even when the movement is against the usual water potential gradient (i.e. towards a larger water potential.The theory of non osmotic active absorption is supported by the following facts

(a). Correlation between water absorption and rate of respiration:- Usually in presence of respiration reducing factors the rate of water absorption is also reduced. Thus both the processes are interrelated.

(b). Reduction of water absorption in presence of respiratory inhibitors:- It has been observed when a plant is placed in the solution of respiratory inhibitors like KCN the rate of water absorption is reduced. This indicates that respiration and water absorption are interrelated. KCN directly affects the coenzymes of respiratory chain like NAD, FAD, and cytochromes and thus effects respiration and other metabolic activities.

(c). Wilting of plants in O_2 deficient soil :- In O_2 deficient soil the plants do not get sufficient O_2 for respiration and wilt.

(d). Effect of auxins :- In presence of auxins the rate of metabolism along with water absorption is increased.

(e). The occurrence of water absorption and respiration is found only in living cells.

2.Passive absorption :- It takes place mainly due to transpiration . In passive absorption the roots remain inactive and the water absorbing forces are first produced in the cells of leaves. When DPD is increased in the cells of leaves due to transpiration the water diffuses from the xylem cells to mesophyll cells of the leaves. When the rate of transpiration is high a tension is created in the water column of xylem which increases the DPD of water. This is like negative pressure and it moves from leaves to roots. At this stage the DPD in peripheral cells of young root hairs become high and water gets absorbed from the soil having low DPD.

Evidances of passive water absorption:

1. Water can be absorbed by the plant in the absence of its root system.

2. A negative pressure is seen in the xylem sap of the shoot during periods of rapid transpiration.

3. Normally the rate of water absorption is approximately equal to the rate of water lost through transpiration.

Pathway of water in plants:- From the epidermis to the endodermis of the root there are three pathways through which water can flow. The apoplast, Transmembrane and symplast pathways.

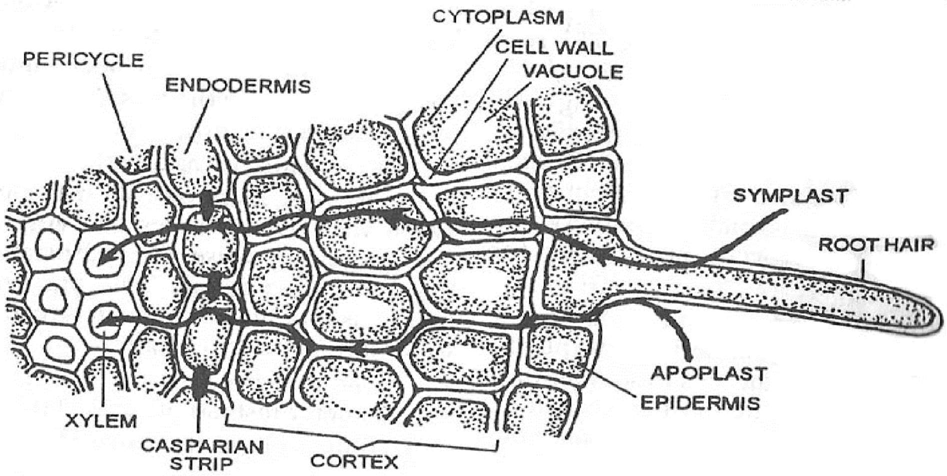
1. Apoplast:- In the apoplast pathway water moves exclusively through the cell walls without crossing any membrane. The apoplast is the continuous system of the cell walls and intercellular air spaces in the plant tissue.

2. Transmembrane pathway:- The transmembrane pathway is the route followed by water that sequentially enters a cell on one side, exits the cell on the other side, enters the next in the series and so on. In this pathway water crosses at least two membranes or each cell in the path. The plasma membrane on entering and on exiting .Transport across tonoplat may also be involved.

3. Symplast:-In the symplast pathway water moves from one cell to next via the plasmodesmata. The symplast consists of the entire net work of the cell cytoplasm interconnected by the plasmodesmata.

At the endodermis water movement through the apoplast pathway is obstructed by the casparian strips. The casparian strip is a band of radial cell walls in the endodermis that is impregnated with the wax like hydrophobic substance suberin. Suberin acts as a barrier to water and solute movement. The casparian strips breaks the continuity of the apoplast pathway and forces water and solutes to cross the endodermis through symplast pathway.

The apical region of the root is most permeable to water, beyond this point the



exodermis becomes suberized limiting water uptake however some water absorption may take place through older roots perhaps through breaks in the cortex associated with the outgrowth of secondary roots.

Apoplast and symplast pathway of water movement

Factors affecting the rate of water absorption

The various factors affecting the process of water absorption in plants are.

1. Available soil water:- The rate of water absorption of water is always constant, however if the amount of water is increased beyond field capacity it creates a bad effect on soil aeration and reduces the rate of water absorption. Similarly on the shortage of soil water the rate of water absorption is also reduced.

2. Soil aeration:- When the soil aeration is high it increases the water absorption. When it is low it decreases the rate of water absorption.

3.Concentration of soil solution:- The osmotic pressure of any solution is directly proportional to its concentration. If the soil water contains more salts its osmotic pressure and concentration will be more, so rate of water absorption is reduced. Due to this reason the plants growing in alkaline and marshy soils show a very little or no water absorption.

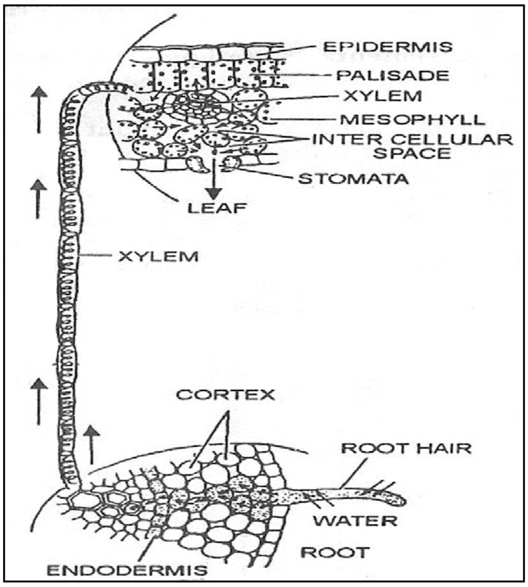
4. Soil temperature:- Maximum water absorption is between 20^o to 30^o C. It decreases below 20^o C. and also decreases above 30^o C and stops at 0^o C.

5. Root system:- Well developed root system shows higher rate of water absorption in comparison to those which possess very small roots and less number of root hairs.

Ascent of Sap (water transport through xylem)

Ascent of sap means the movement of the water and dissolved minerals from the root xylem up to the top of the plants i.e. leaves. In most plants the xylem constitutes the longest part of the pathway of water transport. The conducting cells in the xylem have a specialized anatomy that enables them to transport large quantities of water with great efficiency. The two types of tracheary elements in the xylem are tracheids and vessels. Vessels are found only in angiosperms, a small group of gymnosperms called the Gnetales and perhaps some Ferns. Tracheids are present in both angiosperms and gymnosperms as well as in ferns. The maturation of both tracheids and vessel elements involves the death of the cell. Thus functional water conducting cells have no membrane and no cell organelles what remains are the thick lignified cell walls which form hollow tubes through which water can flow with relatively little resistance.

Cohesion tension theory of ascent of sap:- This theory best explains the water transport in the xylem given by Dixon and Jolly in 1894.



In theory the pressure gradients needed to move water through the xylem could result from the generation of positive pressure at the base of the plant or negative pressures at the top of the plant. Some roots can develop positive hydrostatic pressure in their xylem the so called root pressure; however root pressure is typically less than 0.1 MPas. Which can lift the water to the maximum of 20M? But what about the tallest trees like *Sequoia semipervirens* of North America and *Eucalptus regnans* of Australia the tallest tree exceeds more than 100 M. in height so it is clearly inadequate to move water up a tall tree by the root pressure.

Instead the water at the top of the tree develops a large tension (a negative hydrostatic pressure) and this tension pulls water through the xylem. This mechanism first proposed is called the cohesion tension theory of ascent of sap given by Dixon and Jolly 1894. Because it requires the cohesive properties of water to sustain large tensions in the xylem water column.

A pressure difference of roughly 3 Mega pascals is developed due to tension from the base to the top, which can carry water to tallest trees

The tension needed to pull water through the xylem are the result of evaporation of water from leaves through the stomata. The water evaporates continuously from the leaves due to transpiration. The mesophyll cells of the leaves possess intercellular space filled with water vapours which go out in the atmosphere through stomata. To overcome this deficiency the water diffuse from the neighbouring mesophyll cells into intercellular spaces. Due to loss of water vapours the cytoplasm of mesophyll cells becomes concentrated and their osmotic pressure is increased resulting in absorption of water from the adjacent cells. This process continues slowly and slowly up to cells of xylem vessels. The attraction of water molecules from xylem vessels towards mesophyll cells also start. The xylem vessels of root stem and leaves are connected with each other due to which the water absorbed through root hairs forms a water column. Due to cohesive force the water ascends to a very height. This pulling force is called transpiration pull. And the water column rises due to transpiration stream because the force is created due to transpiration. So according to cohesion theory the suction force is created in the leaves due to transpiration which pushes the water column of xylem vessels towards leaves. The continuity of water column does not break due to cohesive force among water molecules. Due to both these forces the water column reaches to the upper apical leaves of very tall plants.

Xylem transport of water in trees faces physical challenges which are.

The large tension that develops in xylem of trees and other plants can create some problems.

(a). First the water under tension transmits an inward force to the walls of the xylem. The secondary wall thickenings and lignification of tracheids and vessels are adaptations that offset this inward pulling of walls of the xylem vessels or tracheids.

(b). When tension in the water increases, there is an increased tendency for air to be pulled through microscopic pores in the xylem cell walls. This is called air seeding. Second gas bubbles are formed due to reduced solubility of gases. These bubbles expand because these can not resist the tensile forces. This phenomenon of bubble formation is known as cavitation or embolism. Cavitation breaks the continuity of water column and prevents water transport in the xylem.

The impact of xylem cavitation on the plant is minimized by several means. Since the capillaries in the xylem are interconnected, one gas bubble does not completely stop water flow, instead water can detour around the blocked point by traveling through neighbouring connected capillaries.

Gas bubbles can also be eliminated during night when transpiration is low. Xylem μ_P increases and the water vapour and gases may simply dissolve back into the solution of xylem.

Finally many plants have secondary growth in which new xylem is formed each year. The new xylem becomes functional before the old xylem ceases to function.

Evidences in Support of Cohesion theory

●That 1932 demonstrated that a leaf twig when cut under water and the cut end of the twig is sealed to a top of mercury monometer the mercury level ascends.

●Mc. Dermot 1914 observed that if a vessel with water under tension was punctured water snapsed apart from the punctured portion.

●Krammer and Kozlawski 1960 demonstrated that the diameter of the stem decreases during the day when transpiration is high. . The decrease in diameter is obviously due to strain caused on the water column by tension.

●The amount of water transpired is equal to the amount of water absorbed.

Transpiration

The loss of water in the vapour form, from the exposed aerial parts of the plants is termed as transpiration. Only 2 % of the absorbed water is retained in the plants and remaining 98 % is lost through aerial parts. It has been calculated in the Maize plant that over 99 % of water absorbed by the maize plant during its entire growth period is lost in transpiration.

Kinds of transpiration:- Transpiration is of three types.

1. Cuticular transpiration:- Transpiration directly takes place through epidermal cells which are cuticularised. This layer is impervious to water but some water loss takes place through the layer of cutin. It constitutes up to 5- 10 % of the total water loss from the plants through transpiration. The plants growing in shady places transpire through cuticle upto 15% of the total water transpired. The amount of water loss in xerophytic plants through cuticle is quite little or negligible. In flowers, stems and fruits mainly cuticular transpiration is found.

2. Lenticular transpiration:- The loss of water in the form of vapours through lenticels is called lenticular transpiration. Lenticels are the small pores present below the bark of old trees. This is the main source of water loss from decidous trees after leaf fall. It constitutes about 1-2 % of total water loss through transpiration.

3. Stomatal transpiration:- The loss of water in the form of vapours through the stomata of leaves is called stomatal transpiration. The maximum amount of water (80-90 %) of the total water absorbed is lost through stomata.

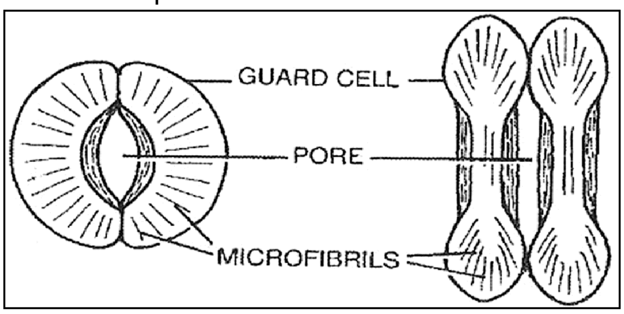
Structure of stomata:- The epidermis of leaves and green stems possess many small pores called stomata. The length of open stomata is 10-40µ and breadth is 3-10µ. These pores are surrounded by specialized epidermal cells called guard cells. Guard cells show considerable morphological diversity. One is typical of grasses and few other monocots such as palms. The other is found in all dicots, in many monocots and in mosses, ferns and gymnosperms.

In grasses guard cells have a characteristic dumbbell shape, with bulbous ends. The pore proper is a long slit located between the two dumbbells. These guard cells are always flanked by a pair of differentiated epidermal cells called subsidiary cells. The guard cells, subsidiary cells and pores are collectively called the stomatal complex.

In dicot plants and non grass monocots guard cells are kidney shaped with elliptical contour, with pores at its centre. Subsidiary cells are exceptional, often absent when the guard cells are surrounded by the ordinary epidermal cells.

A distinctive feature of the guard cells is the specialisd structure of their walls. kidney shaped guard cells have thick inner and outer lateral walls and thin dorsal walls (the wall in contact with epidermal cells) and somewhat thickened ventral (pore) wall. The portion of the wall that faces the atmosphere extend into well developed ledges which form the pore proper..

In guard cells the microfibrill organization is different. Kidney shaped guard cells have cellulose microfibrills fanning out radially from the pore. In grasses the dumbbell shaped guard cells function like beams with inflated ends. As the bulbous ends of the cell increase in volume and swell. The beams are separated from each other and the slit in between them widens.



Arrangement of microfibrills in the kidney shaped and dumbbell shaped guard cells

Distribution of stomata on leaf:- The stomata are found distributed on the upper and lower surfaces of the leaves. In dicot leaves their number is more on the lower surface as compared to upper surface In monocot leaves their number is equal on both the surfaces. In submerged leaves of the water plants like *Potomogeton* and *Hydrilla* non functional stomata are found. In xerophytes sunken stomata are found. In dicot leaves usually the stomata are found scattered where as in monocot leaves they are arranged in parallel rows. The number of stomata in a leaf varies from 1000 – 6000 per square centimeter. All the stomata of a leaf cover about 1-2 % of the total area of leaf.

Mechanism of opening and closing of stomata

Stomata open because the guard cells take up water and swell. The cellulose microfibrils or micelles that make up the plant cell walls are arranged around the circumference of the elongated guard cells .The result of this arrangement of microfibrils is that when a guard cell expands by taking up water it can not increase much in diameter, because the microfibrils do not stretch much along their length. But the guard cells can increase in length, therefore because two guard cells are attached to each other at both ends they bend outward when they swell which opens the stomata. So opening of stomata is due to differential thickening of the cell walls of the guard cells. When the turgidity of guard cells start decreasing both the walls start regaining their original state and the stomata start closing.

Different theories were proposed by various physiologists to explain the reasons of change in turgidity of guard cells. The important and valid one is.