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.

11.2.1 Water Potential

To comprehend plant-water relations, an understanding of certain standard terms is necessary. **Water potential (Ψ_w)** is a concept fundamental to understanding water movement. **Solute potential (Ψ_s)** and **pressure potential (Ψ_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 Ψ 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 Ψ_s. Ψ_s is always negative. The more the solute molecules, the lower (more negative) is the Ψ_s. For a solution at atmospheric pressure (water potential) Ψ_w = (solute potential) Ψ_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. Can you think of any system in our body where pressure is built up? 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** (see section 11.2.2);

The bulk movement of substances through the conducting or vascular tissues of plants is called **translocation.**

Do you remember studying cross sections of roots, stems and leaves of higher plants and studying the vascular system? 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.

11.3.1 How do Plants Absorb Water?

We know that the roots absorb most of the water that goes into plants; obviously that is why we apply water to the soil and not on the leaves. The responsibility of absorption of water and minerals is more specifically the function of the root hairs that are present in millions at the tips of the roots. 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

The **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 (Figure 11.6). 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

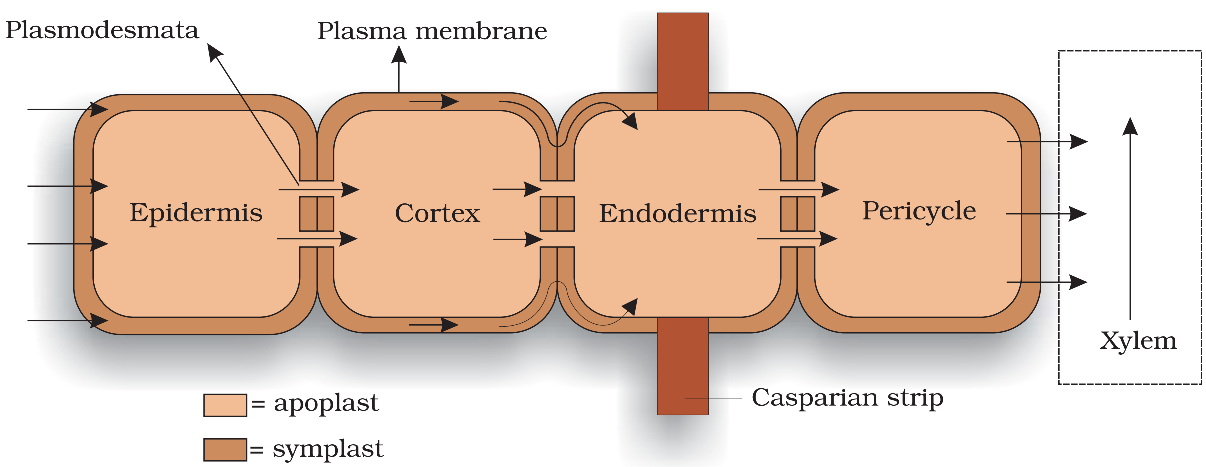

Figure 11.6 Pathway of water movement in the root

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.** 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. You may have observed cytoplasmic streaming in cells of the *Hydrilla* leaf; the movement of chloroplast due to streaming is easily visible.

Most of the water flow in the roots 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. The path of water and mineral ions into the root vascular system is summarised in Figure 11.7.

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

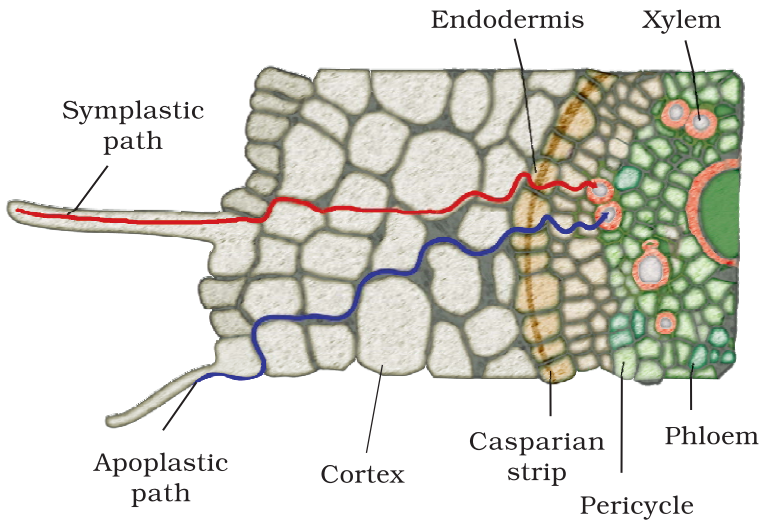

Figure 11.7 Symplastic and apoplastic pathways of water and ion absorption and movement in roots