Transport of materials in plants

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CHAPTER NINE

Transport Of Materials In Plants

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INTRODUCTION:

Plants need an adequate supply of water, oxygen, carbon dioxide and mineral elements in order to satisfy their requirements for metabolism and growth. These materials together with the products of photosynthesis are transported through the entire body of the plant. The transport of soluble products of photosynthesis and other materials in plants is called **translocation** and this takes place in specialized conducting vessels which are located in groups known as vascular bundles.

In higher plants there is very little transport of gases from one part of the plant to another. The elaborate liquid transport system which exists in these species does not take part in gas transport. Movement of gases is by diffusion through the lenticels, stomata and air spaces, while food materials, water and mineral salts are transported in the xylem and phloem tissues. In order to carry on photosynthesis, plants expose a broad chlorophyll-containing surface to solar radiation. This means an exposure of a large surface area to the drying effect of the air. At the same time these plants must secure water in order to remain photosynthesizing and replace the water lost through transpiration with fresh supplies from the soil. The roots responsible for water and mineral uptake need food in order to remain alive. The phloem transports such food materials. The vascular bundles in stems are continuous with those in the roots and leaves, and extend through all the organs, thereby creating an extensive network of vessels necessary for rapid and efficient transport between the organs.

The movement of food materials and other substances in lower plants can take place by both diffusion and active transport, and does not require specialized conducting tissues.

GAS EXCHANGE AND TRANSPORT.

Most plants have no specialized organs for gas exchange, instead each part of the plant takes care of its gas-exchange needs. As already stated above, there is very limited transport of the respiratory/photosynthetic gases from one part of the plant to another. Although the roots, stems and leaves do respire, they do so at rates which do not present great demands for gas exchange. Each leaf is well adapted through the numerous stomata to take care of its own gas needs especially during photosynthesis when large volumes are exchanged. The distance that gases diffuse in even a large, bulky plant is not great because the active cells in the plant are located in thin layers quite close to the surface. The only living cells in both stems and roots are organized in such thin layers just beneath the bark, while the cells in the interior of woody stems are dead and serve as mechanical support mainly. Also, the plant cells have at least part of their surface in contact with air as a result of the loose packing of the cells which provide the interconnecting air spaces. Finally in corky stems and roots the lenticels provide pore through which oxygen and carbon dioxide reach the intercellular spaces for exchange with the outside environment.

sloping end walls which are not open-ended but perforated with numerous pits. Xylem vessels together with the tracheids are largely responsible for the upward transport of water and mineral salts in vascular plants.

THE PHLOEM TISSUE.

The phloem is responsible for the translocation of photosynthetic products. The sieve tubes are the major transport vessels in the phloem system. They are also cylindrical tubes with perforations at the end walls through which strands of cytoplasm pass across and connect adjacent cells. The sieve elements are placed end to end to form long continuous ducts (the sieve tubes) which run parallel with the long axis of the plant from the base to the top. The sieve elements have perforated end walls (the sieve plates) and through these pores, fine strands of cytoplasm connect the cells. Unlike the xylem vessels and tracheids, the sieve tubes, although they lose their nucleus at maturity, retain their cytoplasm. In many plants they lie adjacent to companion cells which still possess their nucleus. One or more of these companion cells are closely applied to the side of each sieve element and have cytoplasmic connections (plasmodesmata) with them (fig. 9.2). The companion cells are the site of intense metabolic activity and are believed to provide the more innert sieve elements with their metabolic needs, especially in providing the energy for active translocation of food materials.

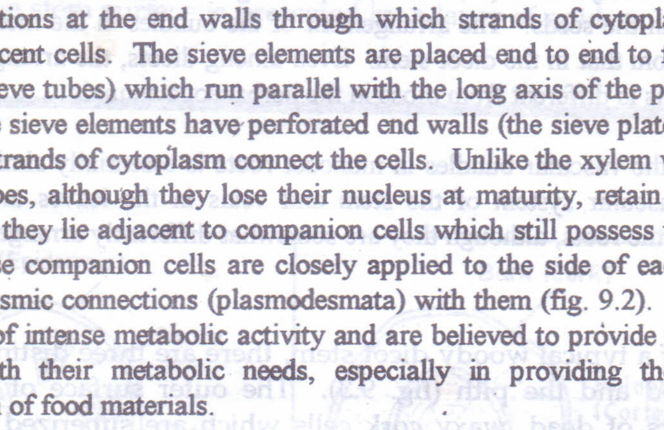


Fig. 9.2 PHLOEM SIEVE ELEMENTS.

The xylem and phloem tissues play a crucial role in the successful absorption and translocation of water and food materials in vascular plants.

The Organization of Vascular Bundles in Plants.

The vascular tissues in plants are differently arranged in the root, the stem and veins in leaves. The pattern of organization of these tissues also depends on which of the two major groups of flowering plants the plant belongs. The two groups are the dicotyledons (Dicots) and the monocotyledons (Monocots) depending on the number of food storage organs (cotyledons) in the seeds. The arrangement of the bundles in the monocot stem is markedly different from that in the dicot stem. Even among dicots, the arrangement in the woody perennial stems is different from those in the herbaceous annuals.

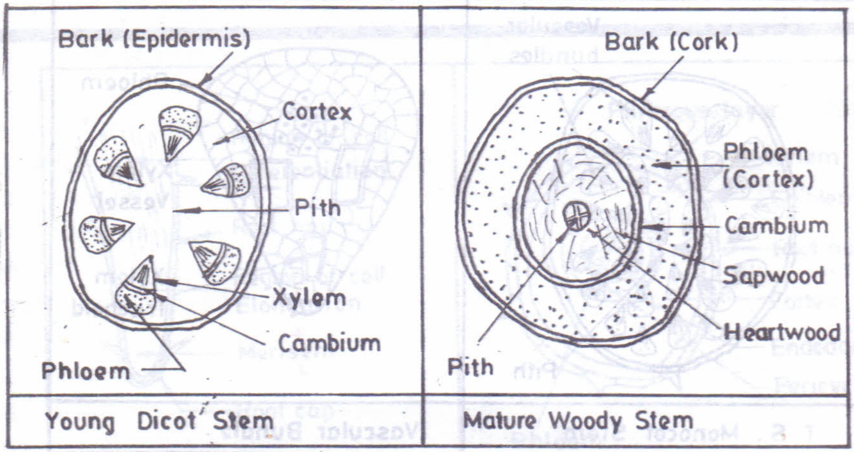
The arrangement of the vascular bundles in monocot roots is essentially similar to that in dicot roots. The vascular system of the stem and veins in the leaves are simply the extension of those in the roots, although they are somewhat differently arranged.

THE STEM.

In a young twig of a typical woody dicot stem, there are three distinct regions - the bark, the wood and the pith (fig. 9.3). The outer surface of the bark is protected by layers of dead, waxy cork cells which are suberized and which greatly reduce water loss from the plant. A large number of lenticels (non-suberized areas)permit exchange of oxygen and carbon dioxide between the stem tissues and the atmosphere. The cortex is found just beneath the cork.

In older plants the inner portion of the bark has alternating areas of phloem tissue and parenchyma. The parenchyma forms the horizontal rays that run between the pith and the bark and they carry on lateral transport of materials between the two regions. The phloem tissue consists of bundles of sieve tubes surrounded and supported by sclerenchyma cells.

A meristem, the cambium, marks the inner boundary of the bark and continually produces new phloem to the outside and new xylem towards the interior. The xylem makes up the wood region and serves a dual function of support and transport. In much older plants, only the most recent xylem tissue participate in the transport of materials. The older inner xylem ring tissue (heartwood) cease to function in transport but provide ever-increasing support for the weight of the tree (fig. 9.3). In the very young twig the arrangement is similar , but the stem surface is protected by a layer of epidermis rather than by cork.

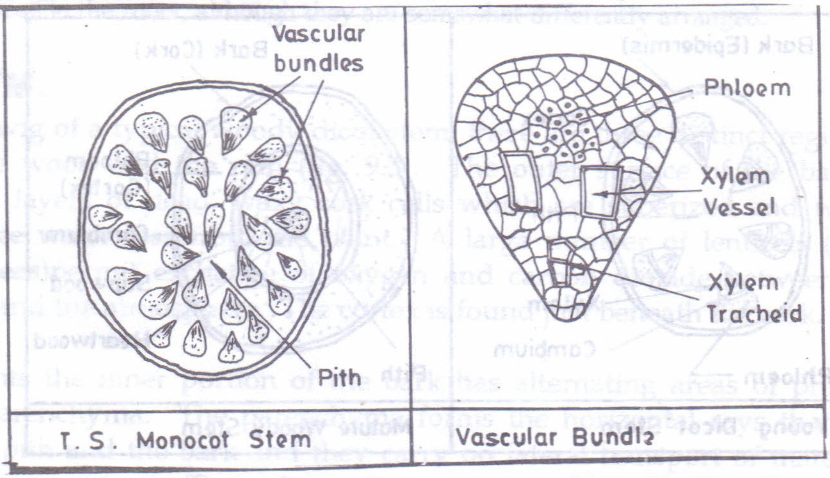


Young Dicot Stem **Mature Woody Stem**

Fig. 9.3: DICOT STEM.

The interior is packed with parenchyma, the pith and this disappears in the older woody stem. The outer portions of the vascular bundles contain the phloem tissue and on the inner side is the xylem, while both are separated by the cambium. Very young stems of both herbaceous and woody dicots have epidermis which may contain chloroplasts for carrying on photosynthesis. Stomata are also present and these take part in gas exchange.

The arrangement of the vascular bundles in the monocot stem is quite different from that of the dicot. The bundles are very much scattered at random through the pith and each bundle contains four xylem vessels which depict a caricature of the human face: two **"eyes"**, a **"nose"** and a **"mouth"** and the phloem on the **"forehead"** (fig. 9.4).



T.S. Monocot Stem **Vascular Bundle**

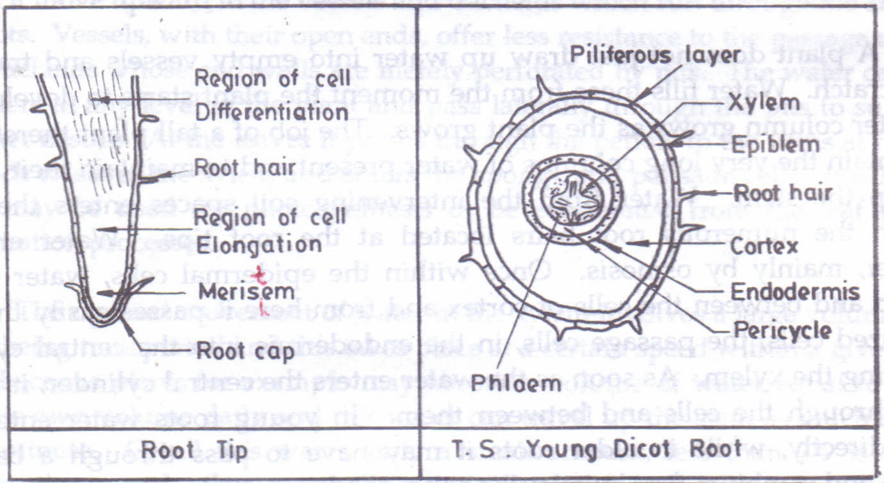
FIG. 9.4: MONOCOT STEM.

THE LEAF

The leaf veins are direct extensions of the vascular bundles of the stem. The bundles pass from the stem into the leaf petiole and then into the various veins in the leaves, branching into finer veins. The veins lend support to the soft tissues of the leaf blade.

THE ROOT.

In a typical young dicot root, the tip consists of the meristem which produces cells that develop into primary root structures. The meristem is protected by the root cap (fig. 9.5). Soon after full elongation of the root cell, differentiation into specialized structure follows. The cells at the surface form the epidermal cells most of which form the root hairs (the piliferous layer). These greatly increase the absorptive surface of the root and serve as the main avenue for water and mineral salt uptake.



Root Tip

T. S. Young Dicot Root

FIG. 9.5: THE ROOT.

In the endodermis (starch sheath) is located the central cylinder containing the vascular bundles. The vascular bundle is surrounded by the pericycle from which secondary or branch roots arise and within which are located the xylem and phloem tissues and the pith. The xylem tissue is arranged in bundles in a radial or spokelike fashion and they alternate with the phloem tissue. In older roots, the arrangement is the same, the cambium produces new xylem tissue to the inside and new phloem to the outside. We have stated earlier that the arrangement of the vascular bundles in monocot and dicot roots is essentially the same.

THE XYLEM TRANSPORT.

The part of the vascular bundles responsible for transport of water and mineral elements is the xylem. There is an unimpeded movement of water through the hollow lumina of the dead xylem vessels and tracheids, while their perforated pits allow horizontal movement of water in and out of them.

A plant does not just draw up water into empty vessels and tracheids from scratch. Water fills these from the moment the plant starts to develop and the water column grows as the plant grows. The job of a tall plant therefore, is to maintain the very long columns of water present and to maintain their steady flow up the stem. Water from the intervening soil spaces enters the plant through the numerous root hairs located at the root tips. Water entry is however, mainly by osmosis. Once within the epidermal cells, water passes through and between the cells of cortex and from here it passes easily through specialized cells, the passage cells, in the endodermis into the central cylinder containing the xylem. As soon as the water enters the central cylinder, it moves freely through the cells and between them. In young roots water enters the xylem directly, while in older roots it may have to pass through a band of phloem and cambium first by travelling through horizontal xylem rays.

It should be noted that while water and mineral elements do share the same final pathway in the xylem, the uptake and movement of minerals by the root is not simply as dissolved in water. The absorption of minerals has some special features that even when water is not being absorbed by the roots, mineral salts do enter freely and can take place against a concentration gradient (that is, from a region of low concentration in the soil to a region of high concentration in root cells). This is an active process and it is known that any interference with this process generally, impedes mineral uptake. All the elements taken up by plants for example Nitrogen, Phosphorus, Potassium, etc. are in inorganic mineral forms such as NO_3^-, NH_4^+, PO_4^+, K^+, Ca^{++} etc. The ions are selectively absorbed by active transport involving expenditure of energy. As soon as the inorganic ions are within the epidermal cells of the roots, they pass inward from cell to cell probably through the plasmodesmata and finally to the xylem.

Inside the xylem, both water and mineral ions that have been deposited within it move upward in the vessels and tracheids which run through the stem and the roots. Vessels, with their open ends, offer less resistance to the passage of water than tracheids whose end walls are merely perforated by pits. The water can leave the xylem at any level in the plant and pass laterally through the pits to supply all the other tissues. At the leaves it passes through the petiole to the veins at the ends of which it leaves the xylem and enters the spongy and palisade cells. It is here the water may be used for photosynthesis or be evaporated from the leaf through transpiration processes.

The upward movement of water in the xylem involves a large volume of the liquid being transported and this takes place at a certain speed within a given plant. A herbaceous plant, for example may absorb a volume of water equal to several times its own volume daily and this water can travel up the stem as much as 75cm every minute. Of all this water, only a small amount, less than 2% is used in photosynthesis and other metabolic activities of the leaf cells. The remainder evaporates from the leaf through transpiration across the open stomata. For the leaves to continue functioning therefore, fresh supplies of water must be received by them in order to replace the losses through transpiration.

Factors Affecting Xylem Transport.

A number of physical factors of the environment are known to affect the movement of water in the xylem, hence its uptake from the soil. These include:

(i) *LIGHT: When plants are exposed to light they transpire more rapidly than in the dark. This is mainly because light stimulates stomatal opening and at the same time warms the leaf.*

(ii) *TEMPERATURE: Increase in environmental temperature leads to increased transpiration compared to low temperatures.*

(iii) *RELATIVE HUMIDITY: The humidity immediately surrounding a plant affects its rate of transpiration. High relative humidity reduces the rate of water loss from the leaves and the reverse is the case if the surrounding air is dry.*

(iv) *WIND: The air currents around the leaves increase water loss from the leaves. As humid air is carried away by the wind, it is replaced by fresh dry air. When there is no air current passing, the air around a transpiring leaf becomes more humid and decreases water loss.*

(v) *SOIL WATER: The rapid loss of water in plants is compensated by absorption of fresh supplies from the soil. If the uptake by roots does not keep pace with the rate of transpiration, the plant experiences loss of turgor and the stomata close, and if this extends to the other parts of the plant wilting will occur. The quantity of water absorbed and the height it travels up the plant may be affected to a certain extent by root pressure. This is an active process and plays a significant role in water transport of some perennial woody plants.*

The water potential of the xylem sap is lower than that of the surrounding soil water, that means the xylem sap may be hypertonic to soil water due to the presence of dissolved sugars and other metabolites taken up by active transport. Water would then flow through the sap vacuole by osmosis (vacuolar pathway) or through the cytoplasm via plasmodesmata (symplastic pathway) in the endodermis or along the cell walls, between cells and inter-cellular spaces (apoplastic pathway) to the xylem ducts, thus creating a pressure in the root, which would be relieved by movement of the sap up the ducts. This however, cannot account completely for the upward movement of water in the xylem.

The transportation of water from the roots to the leaves through the stem is chiefly by transpiration stream. Water instead of being pushed up by root pressure from below is pulled up by tension and pressure from above. The use of water in the leaf exerts a pull on the water in the xylem ducts and more water is drawn into the leaf. The pull is further transmitted to the roots and finally draws more water from the soil into the xylem ducts. Water then moves up high in the plant being aided by forces of attraction (cohesion and tension). Cohesion is a force of attraction between like molecules and by this, water molecules cling together to each other without breaking. The force of tension attracts the water molecules to the molecules making up the walls of the xylem vessels. The cohesive strength of the water filament in the duct coupled with the adhesive force of the molecules to the walls of the duct, enables the water column to be pulled up to the top of the plant without breaking or pulling away from the walls of the xylem duct.

Further more, the use of water in the leaves creates a gradient of water potential through the whole plant and this is highest in the soil surrounding the roots but lowest in the atmosphere outside the leaves. The gradient induces a continuous mass flow of water through the plant and this is being facilitated by evaporation from leaf cells which lowers the turgor pressure of the cells.

THE PHLOEM TRANSPORT.

Foods and other substances such as hormones manufactured by the plant are transported in the phloem system of the vascular bundles. Sugars, amino acids and other organic molecules manufactured in the leaves enter the phloem cells by way of plasmodesmata. These substances once within the phloem may be transported up or down to any region of the plant. Sugars destined to the roots pass in solution through the phloem of the stem and root. In the root they pass out of the phloem into the cells of the cortex where they may be converted to starch and stored as food reserve.

The transport of food materials through the phloem proceeds quite efficiently, and because the food is being transported in a fairly dilute water solution, an appreciable flow occurs.

The mechanism by which sugars and other molecules are translocated through the phloem is not clearly understood. However, the mechanism includes passive mass flow of substances, electro-osmosis, surface spreading and cytoplasmic streaming. This also appears to be largely dependent on the metabolic activities of the phloem cells (that is an active energy-requiring process). Metabolic energy is needed at the ends of the phloem system for despositing sugars in the phloem of the leaves and withdrawing them again from the phloem of the storage roots and growing shoots. Any condition that inhibits or slows down the metabolism of the phloem also slows down the rate of translocation of these substances. For example, low temperature and oxygen deficiency depress the rate of food translocation, and anything that kills the phloem cells puts an end to the process.

The translocation of food materials through the phloem occurs as a result of the fact that water containing the food molecules in solution flows under pressure through the phloem. The pressure arises from differences in water concentration of the phloem solution and the relatively pure water in nearby xylem ducts. With the accumulation of sugars and other photosynthetic products in the phloem, the contents of the sieve tubes are under pressure, water enters by osmosis. The pressure building up in these cells resembles the root pressure in reverse. As the sap is pushed down and up the phloem, sugars are removed by the cortex of both stem and roots, and either consumed in respiratory processes or converted into starch. Consequently, the osmotic pressure of the phloem contents decreases. Finally relatively pure water is left in the phloem and this may leave by osmosis and/or be drawn back into nearby xylem vessels by the suction of transpiration pull.

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