Unit 1
Transport in plants

A knowledge of how plants take in and transport substances is vitally important to agriculture. Using this knowledge, scientists are able to develop more effective ways of applying fertilisers and weed killers to help farmers increase their crop yields.

Plants have a system of simple tubes, called xylem, which transport water and mineral salts from the roots to the leaves. Another set of tubes, called phloem sieve tubes, transport nutrients such as sucrose and amino acids from the leaves to the rest of the plant.

In this unit you will look at how water and mineral salts enter through the roots of the plant and reach the leaves. You will also find out how the substances made in the leaves by photosynthesis get to the rest of the plant.

This unit is divided into three sections:

A	Transport of water and mineral salts
B	Transpiration
C	Transport of sugars and amino acids

In this unit you will learn to:

- describe the structure of a dicotyledonous root and stem as seen under the light microscope
- describe the structure of the xylem vessels which carry water
- describe how the structure of the xylem is linked to its functions: the support and transport of water
- describe the pathway and mechanisms by which water moves from the soil through the plant to the air
- describe how plants lose water vapour, a process described as transpiration
- explain how environmental conditions, such as temperature, affect the rate of water loss and water uptake
- describe how plants that live in a dry environment, such as a desert, reduce their rate of water loss
- describe how roots take up mineral salts through the root hairs
- describe the structure of the phloem sieve tubes
- describe how the structure of phloem sieve tubes is linked to the translocation of sugars and amino acids.

A Transport of water and mineral salts

Hint
Living organisms cannot survive without water.

Why do plants need water? Water is an essential substance of all living organisms.

Water:

- acts as a **solvent**; many substances like food, gases, and waste products need to be dissolved in water before they can be transported
- keeps the plant cells **rigid** and **firm**; water gives **shape** to the soft parts of the plants like flowers and leaves
- helps to control the **temperature** of living things; when water evaporates from a surface, it cools down that surface
- is essential for all **reactions** that take place in the cells; water itself takes part in many reactions.

Glossary
DICOTYLEDONOUS – producing two seed leaves when it germinates

Water and mineral salts enter the plant through the **roots** and pass up through the **xylem tubes** in the stem to the leaves. Water is lost from the leaves as water vapour in a process known as **transpiration**.

Structure of a dicotyledonous root

To understand how water is transported in a plant, we need to look at the structure of the root of a flowering plant to see how water is taken in by the roots. We will look at **root hairs** and **xylem vessels** in detail. Water is taken into plants from the soil through root hairs. Figures 1a and 1b show the part of a root of a DICOTYLEDONOUS plant.

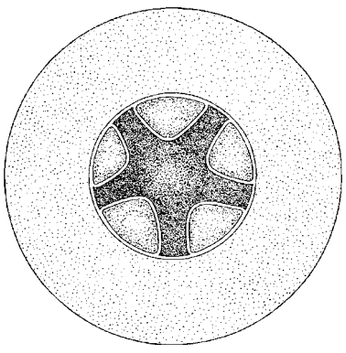

Figure 1a Transverse section of a root

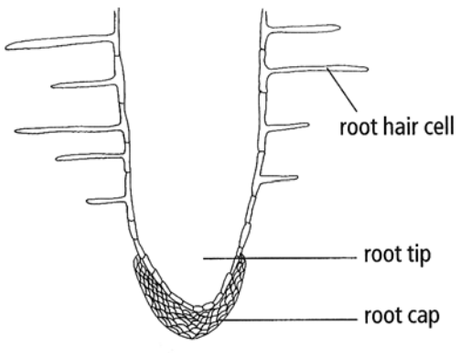

Figure 1b A section through the tip of a root showing root hairs

In Figure 1 you can see the **root hairs** just behind the tip of the root. There are millions of microscopic root hair cells in every root. The roots push in between the soil particles and absorb water by **osmosis**.

The root hairs are very delicate and easily damaged, so new hairs are being produced all the time. The root hairs grow out of the cells of the **epidermis**, the outer layer of the root. Figure 2 shows a root hair cell.

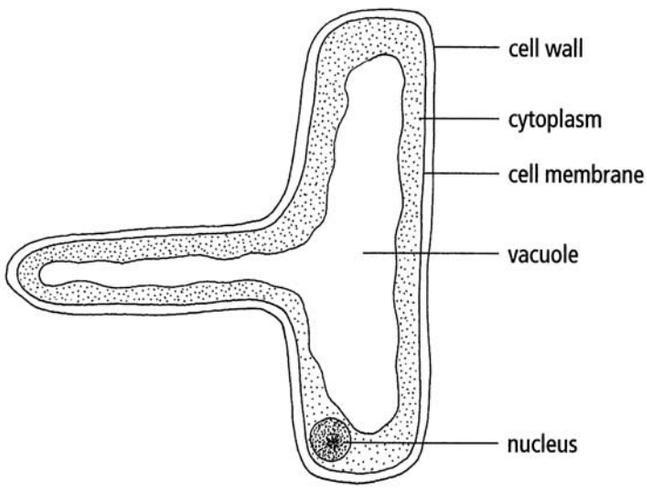

Figure 2 A section through a root hair cell

As shown in Figure 2, the root hair cell has a long, thin extension growing out into the soil. This gives each cell a **large surface area** for the absorption of water and mineral salts.

ACTIVITY 1

Spend about 5 to 10 minutes on this activity. Answer these questions in your notebook.

a Describe the function of the root hairs. In your explanation, use each of the following words:
absorb *soil particles* *water* *mineral salts* *surface area*

b How is a root hair cell adapted to carry out this function?

Xylem vessels run from the roots to the leaves and flowers. They contain a continuous column of water in which **inorganic salts** are dissolved. They form a continuous transport system inside a plant and are the main **water-conducting** cells in the plant. They have two functions:

- the movement of water and mineral salts
- the support of the plant.

Hint
We looked at the structure of xylem in detail in Module 1 Unit 4.

A xylem vessel is made up of many dead, hollow cells arranged end to end to form long tubes. The walls of the cells are strengthened with a complex organic compound called **lignin**. The lignin gives the xylem vessels great strength to support the plant. The stems of trees contain so many xylem vessels that the entire tree is used extensively for building and furniture.

Glossary
TRANSVERSE SECTION (T.S.) – cut across
LONGITUDINAL SECTION (L.S.) – cut along

Figure 3a shows a TRANSVERSE SECTION of a **stem**. It shows how these xylem vessels fit together to look like a mass of tubes for carrying water. Figure 3b is a LONGITUDINAL SECTION along the length of the xylem vessels. Figures 3a and 3b show how the dead xylem vessels are interspersed with other living cells.

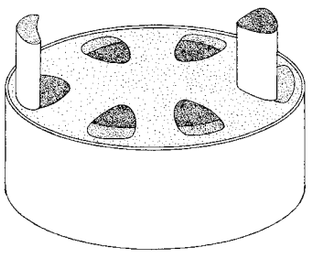

Figure 3a Transverse section of a stem

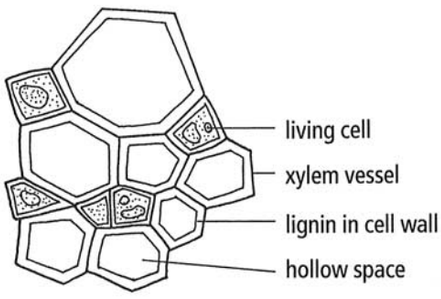

Figure 3b A transverse section of a plant stem showing xylem vessels

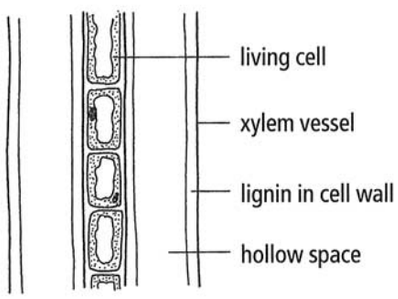

Figure 3c A longitudinal section of a plant stem showing xylem vessels

Figure 3d is a light micrograph of mature xylem vessels in a plant stem. You can clearly see the patterns of thickening produced by the lignin. This makes it strong enough to support the plant. The fact that xylem vessels are long hollow tubes make them adapted to carrying water, minerals and ions throughout the plant.

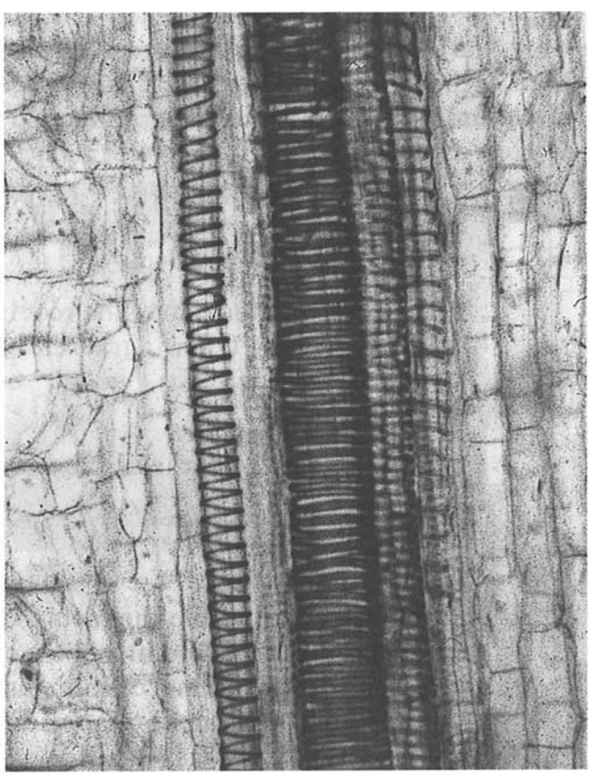

Figure 3d A light micrograph of xylem vessels

ACTIVITY 2

Spend about 5 to 10 minutes on this activity. Answer these questions in your notebook.

1 Where are xylem vessels found?

2 What are the two functions of xylem vessels?

3 What is the most unusual thing about xylem vessels?

4 Xylem vessels have a very tough, strong material called lignin in their cell walls. Suggest how lignin helps xylem vessels to perform their two functions.

How water is absorbed by a plant

Hint
The root hairs are on the edge the root and the xylem vessels are in the centre.

The **root hair** absorbs water and minerals from the soil. Water enters the root hair by osmosis. Water diffuses down its **concentration gradient**, into the root hair, through the partially permeable cell membrane. This happens because the water in the soil is a *dilute* solution; the cytoplasm and cell sap inside the cell are *concentrated* solutions. Once inside the root hair cell, water travels by osmosis across the cortex cells to the xylem vessels. The path taken by the water is shown as arrows in Figure 4. The arrows that show water movement via the cell walls indicate **apoplast** water movement, and the arrows that show water movement via cytoplasm or vacuoles, indicate **symplast** water movement.

1 Water enters root hairs by osmosis

2 Water passes across the root, from cell to cell, by osmosis (symplast). It also moves via cell walls (opoplast).

3 Water is drawn up the xylem vessels, because transpiration is constantly removing water from the top of them

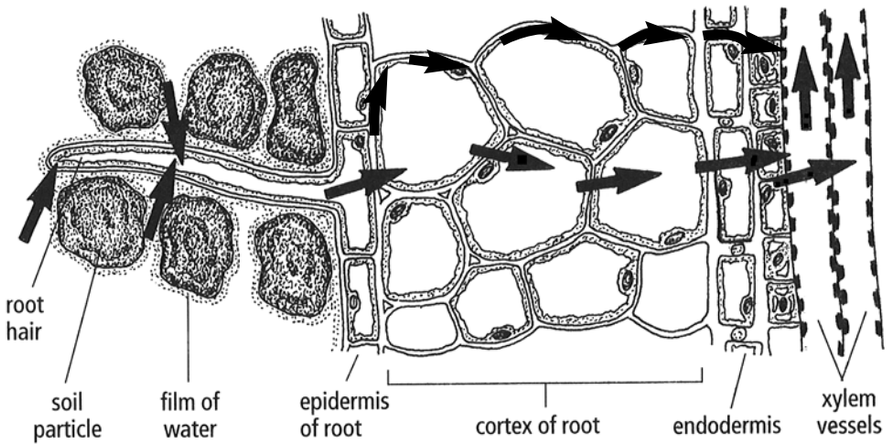

Figure 4 The path taken by water from the root hair cells to the xylem

These xylem vessels then transport the water through the **root** to the xylem in the **stem** from where the water passes to all other parts of the plant. As you saw in Figure 3, the xylem vessels are made up of dead, hollow cells that are placed end to end to form a continuous tube that runs up through the stem and into the leaves.

Why does water move up the xylem vessels? To answer this question, think about why water moves up a drinking straw when you suck the top of the straw. You *reduce* the pressure at the top of the straw when you suck the top of the straw.

The liquid in the glass is at a *higher* pressure so it flows up the straw into your mouth. In the same way, the pressure at the top of the xylem vessels is reduced by the loss of water through a type of evaporation known as **transpiration**. The pressure in the roots stays high so that water flows up the xylem.

ACTIVITY 3

Spend about 5 minutes on this activity. Answer this question your notebook.

Re-arrange these words in the correct order to describe the movement of water from the soil, across the root and into the xylem vessels in the centre of the root of the plant. Show the direction of the movement of water with arrows between the words.

xylem *cortex* *soil* *epidermis* *root hair*

Water potential and water uptake into root hairs

To understand the uptake and movement of water in plants you need to have an understanding of:

- diffusion and osmosis
- water potential and water potential gradients.

Water tends to move from a region where there is a *lot* of water to a region where there is *less* water; it moves from a *high* water potential to a *low* water potential. The symbol for water potential is **ψ**.

The reason why water moves from the soil into the root is as follows:

- the root hair is in close contact with the water and dissolved minerals in the soil
- there is more water in the soil than in the plant; we can say there is a *high* water potential in the soil and a *low* water potential in the plant
- water moves through the cell membrane of the root hair into the vacuole by **osmosis**; this means that water moves from the soil into the root hair *down* a **water potential gradient**.

ACTIVITY 4

Spend about 10 minutes on this activity. Answer these questions in your notebook.

Look at Figure 5 which shows the movement of water through the root.

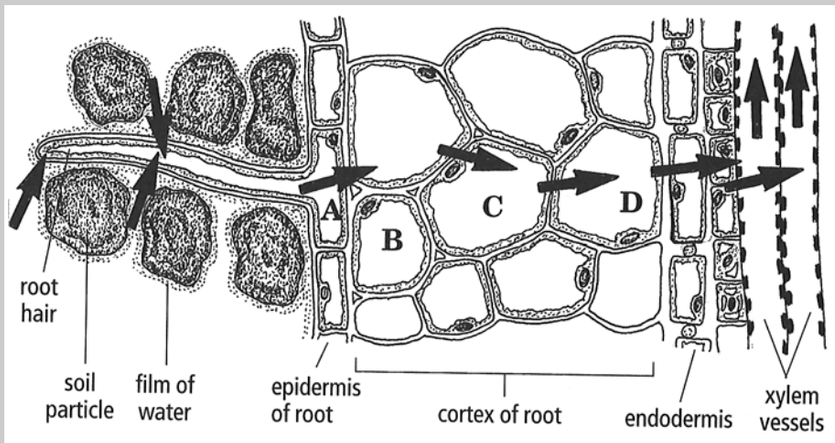

Figure 5 Movement of water from the soil into the root

a Explain, in terms of water potential gradient, why water moves from the soil to cell **A**.

b Explain, in terms of water potential gradient, why the water moves from cell **A** to cell **B**.

c Explain, in terms of water potential gradient, why water moves across the cortex of the root from cell **B** to cell **C** and into cell **D** and enters the xylem.

Water is constantly being taken from the top of the xylem vessels, to supply the cells in the leaves. This reduces the effective pressure at the top of the xylem vessels, so that water flows up them. In effect, the upward movement of water can be thought of as a 'pull' from above, which maintains a **water potential gradient** through the plant. This process is known as the **transpiration stream** which you will learn about in Section B.

ACTIVITY 5

Spend about 5 minutes on this activity. Read the following sentences carefully. For each statement, circle the words which are correct:

a The *more* / *less* solute there is in a solution the higher its water potential.

b Water moves from a higher to a *lower water potential* / *lower to a higher water potential*.

c Water moves *up* / *down* its concentration gradient.

d The *higher* / *lower* the water potential the greater the tendency of water to leave a system.

e Pure water has the *maximum / minimum* water potential.

f Water moves from a *dilute to a concentrated solution / concentrated to a dilute solution.*

B Transpiration

Hint
Evaporation is a change in state from a liquid to a gas and requires heat energy. The gaseous form of water is water vapour. Heat energy for transpiration is from the Sun. We will look at how transpiration is part of the water cycle in Unit 7 of Module 3.

Water moves out of the leaves through the stomatal pore, and **evaporates** into the air as **water vapour**. This loss of water vapour from a plant is described as **transpiration**. It occurs mainly from the leaves through tiny holes called **stomata**. Most leaves have *more* stomata on the lower surface than the upper surface to reduce the loss of water vapour. Some leaves have a waxy covering, called the **cuticle**, especially on the upper surface to reduce transpiration. Figure 6 shows stomata on the surface of a leaf.

Hint
Check back to Figure 5 in Unit 8 of Module 1 for the diagram of the stomata.

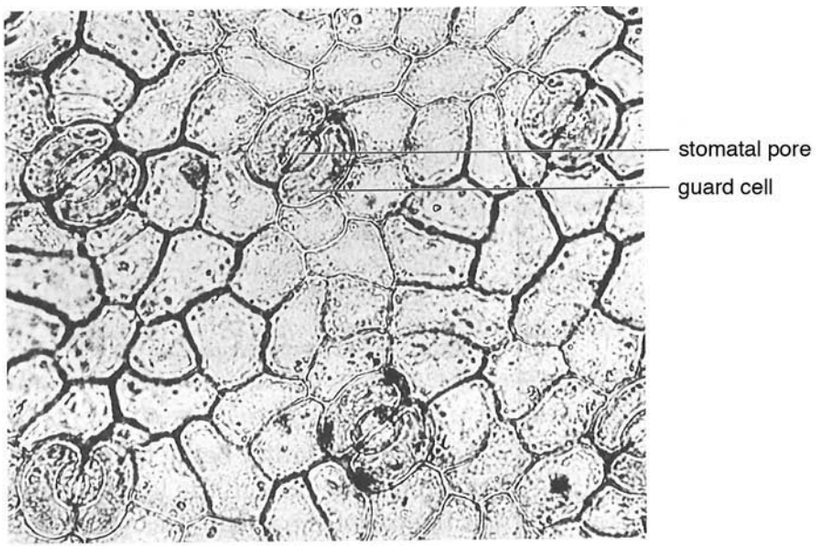

Figure 6 A photomicrograph of the lower surface of the leaf showing the closely fitting cells of the epidermis; the oval holes are the stomata

ACTIVITY 6

This practical activity will take about 20 to 30 minutes to set up and will need to be looked at over a few days.

Looking at transpiration

Hint
Carefully remove the leafy shoots from a tree or bush growing wild.

You will need:
- 2 leafy shoots, about 30 cm long
- 2 clear plastic bags, big enough to cover the shoots
- 2 transparent containers, such as plastic drink bottles
- some clean water.

1 Cut two leafy shoots from a tree or bush.

2 Fill the containers with clean water and put each shoot in a container.

3 Mark the containers **A** and **B**.

4 Tie a plastic bag around the leaves and stem of the plant in container **A** as shown in Figure 7.

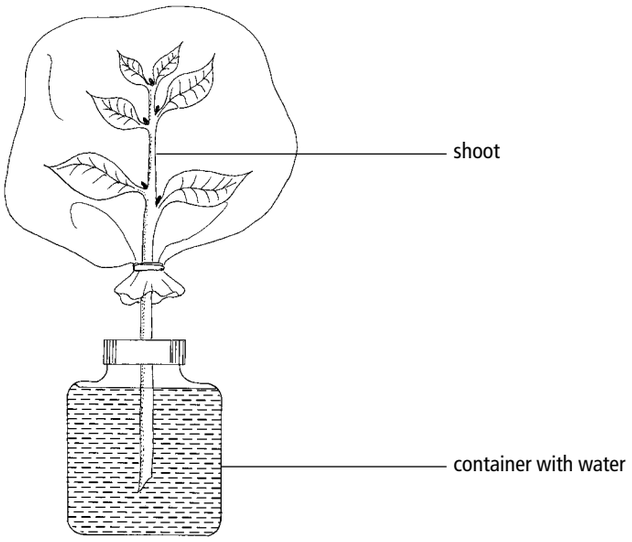

Figure 7 A leafy shoot in container A

5 Remove the leaves from the shoot in container **B**.

6 Tie the second plastic bag around the shoot just as you did for container **A**.

7 Place both containers side by side near a window.

8 Each day, look to see if there are any drops of liquid collecting on the inside of the plastic bags.

9 Write down what you see in your notebook and explain your results.

ACTIVITY 7

Spend about 10 minutes on this activity.

A special kind of paper, called cobalt chloride paper, is blue when dry but turns pink when wet. It can be used to show the presence of moisture.

In an experiment, some dry, blue cobalt chloride paper was attached to the upper and lower surfaces of a leaf on plants **A** and **B**.

Hint
The *y* axis is the vertical axis.

The graph in Figure 8 shows the results for the upper and lower surface of each plant, **A** and **B**. The *y* axis shows the time taken for the cobalt chloride paper to turn pink.

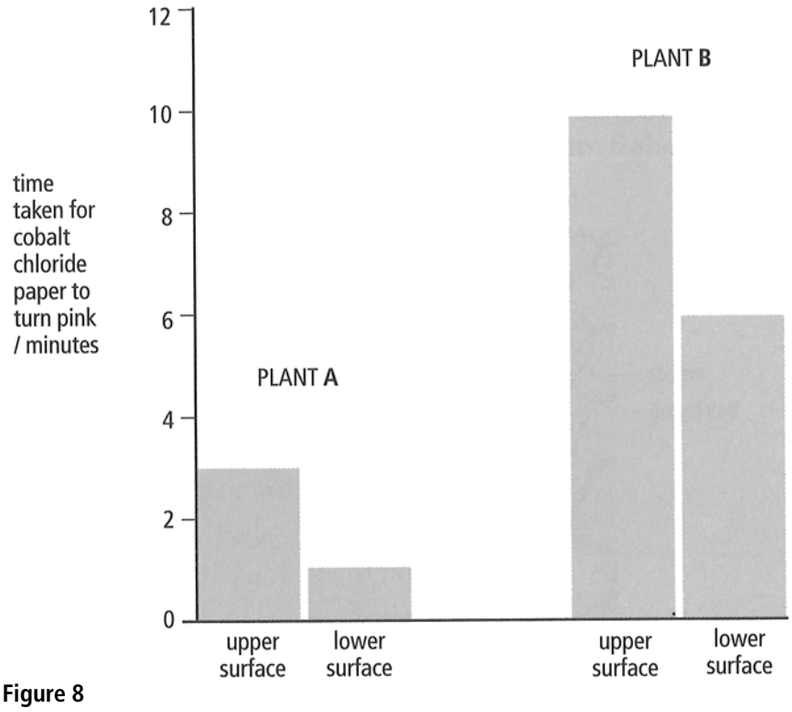

Figure 8

Look at the graph and answer these questions in your notebook:

a Which surface lost water faster – the upper surface or lower surface?

b Suggest a reason to explain this difference in water loss between the upper and lower leaf surfaces.

c Plant **A** loses water more quickly than plant **B**. Suggest **two** features of the leaves of plant **A** which would explain this difference.

Water movement in the leaves and transpiration

Transpiration sets up a **water potential** gradient in the leaves. This gradient is responsible for the movement of water out of the xylem by osmosis and into the leaf to replace the water lost through transpiration.