Food making and growth in plants

Unit 4

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4.1 The leaf

By the end of this section you should be able to:

- Label the internal structures of leaves.
- Explain the functions of the internal structures of leaves.
- Use the microscope to study the internal structures of leaves.

The flowering plant is a complete organism with organs carrying out particular functions. There are four main organs of a flowering plant. Understanding them will help you understand how a plant makes food and grows.

- The **flowers** which contain the reproductive organs.
- The **leaves** which use light energy, carbon dioxide and water to make food by photosynthesis.
- The **stem** which provides support and a transport system for water and minerals to the leaves and flowers. It also transports food from the leaves to the roots and flowers.
- The **roots** which anchor the plant to the ground and absorb water and minerals.

In the following activity, you will examine the organs of a flowering plant.

Activity 4.1: Examining the external features of a flowering plant

You will need:

- a typical dicotyledonous plant with roots, e.g. bean plant, black jack
- a hand lens

Method

1. Identify the following parts on your flowering plant: shoot system, root system, terminal bud, axillary bud, node, internode, leaves, stem, flowers, fruits, lateral roots, tap root.
2. Note the distinguishing features of the stem and root.
3. With the help of a hand lens, examine the root hairs.
4. Make a large, well-labelled drawing of your specimen showing all the parts that you have identified.

Review question

1. How does the plant you have observed in the above activity differ from a maize plant?

A photosynthesising machine

Plants take the inorganic molecules carbon dioxide and water and use them to produce the organic molecule glucose along with inorganic oxygen in the presence of energy from light. This amazing process is the basis of all life on Earth – it provides the food we eat and the oxygen we breathe. And it all takes place in the leaves of plants. Plant leaves are perfectly adapted to allow the maximum possible amount of photosynthesis to take place whenever there is light available.

Adaptations of a leaf for photosynthesis

- The **leaf** is flat and wide, giving a large surface area to collect light and short distances for gases to diffuse. The veins bring water from the soil to the cells.
- The **waxy cuticle** is a waterproof layer found on the surface of many leaves to help prevent water loss.
- The **palisade mesophyll** is the main photosynthetic tissue of the plant. There are many cells, closely packed together near the surface of the leaf to get as much light as possible. Each cell has many chloroplasts – hundreds of them – which are spread out through the cytoplasm of the cell when light levels are high but which cluster at the top of the cell when light levels are low.
- The **spongy mesophyll** has fewer cells with fewer chloroplasts. However, there are lots of air spaces and a big surface area for gas exchange. Some photosynthesis takes place here but more importantly it is where the carbon dioxide needed for photosynthesis moves into the cells, and the oxygen moves out. The water lost in transpiration evaporates from the cells here as well.
- The **lower epidermis** has openings known as **stomata** which allow carbon dioxide to diffuse into the leaf and oxygen and water vapour to diffuse out. The **guard cells** open and close to control the entry of carbon dioxide into the leaf and also to control the loss of water by transpiration.

KEY WORDS

waxy cuticle *waterproof upper surface layer found in many types of leaf*

palisade mesophyll *the main photosynthetic tissue of a leaf*

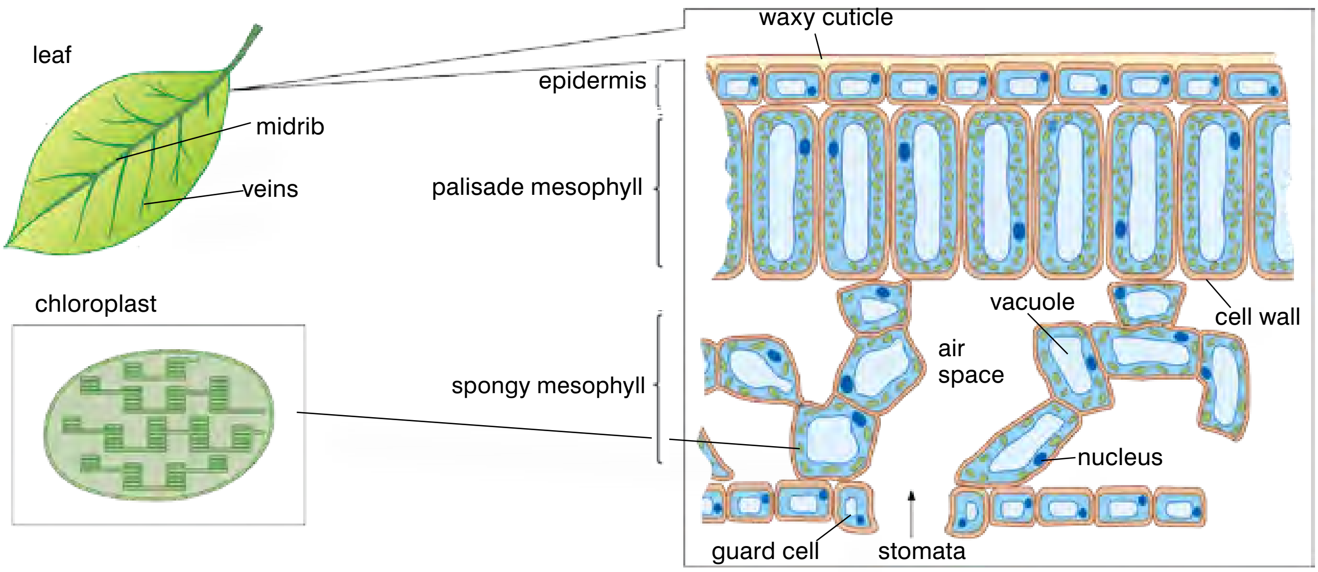
spongy mesophyll *the main gas exchange tissue of a leaf*

lower epidermis *surface layer of a leaf containing stomata*

stomata *pores mostly on the lower surface of leaves that can be opened or closed to control gas exchange and water loss*

guard cells *pairs of cells which surround and control the size of stomata by altering their shape*

Figure 4.1 *This cross section of a leaf shows that leaves of plants are perfectly adapted to make the best possible use of the light that falls on them.*



- The **vascular bundles** contain the **xylem**, dead tissue which brings water from the soil to the cells of the leaves, and the **phloem**, living tissue which carries the products of photosynthesis away from the leaves to all of the cells of the plant.
- Each **chloroplast** contains stacks of membranes and chlorophyll to give an increased surface area for photosynthesis to take place.

Activity 4.2: Investigating leaf structure

The diagram in figure 4.1 of the tissues inside a leaf is – as always – of an ideal piece of tissue. Your work with microscopes so far will have shown you that cells aren't always as easy to see and identify down a microscope as they are in the diagram of a textbook! Your task is to look at a living leaf and then at a prepared slide of a section through a leaf and identify as many of the regions listed as possible.

You will need:

- a light microscope
- a lamp
- a fresh leaf
- a piece of graph paper
- a prepared microscope slide of a section through a leaf

Method

1. First look carefully at your fresh leaf. Identify the midrib (the main vein) and the smaller veins running through the leaf tissue. Draw and label your leaf.
2. Work out the surface area of your leaf exposed to the sunlight using the graph paper. Draw the outline of your leaf on the paper and count the small squares it covers to reach a rough approximation of the area of your leaf in mm^2 or cm^2 (depending on the size of the leaf you have chosen).
3. Now estimate how many leaves there are on the whole plant – and work out a very rough estimation of the surface area available to the plant to capture light for photosynthesis. You may be surprised! Add your calculations to your drawing of the leaf.
4. Now use your microscope to look at a cross section of the leaf in more detail. Remember – microscopes are expensive and delicate pieces of equipment so always take care of them and handle them safely.
5. Observe your prepared slide carefully and identify as many of the different tissues listed on pages 143–144 as possible.
6. Make a plan of your section, showing where each of the different areas are but without putting in any cell details. Label the different layers. Show the magnification.
7. Now make a more detailed drawing of the section, showing just a few of each type of cell. Show the magnification. Give full annotations to explain how each tissue is adapted to carry out its function in the leaf.

Summary

In this section you have learnt that:

- The internal structures of leaves are adapted for photosynthesis to take place.
- Leaves have a number of different tissues including the waxy cuticle, the epidermis, the palisade mesophyll, the spongy mesophyll, the vascular bundles, the stomata and guard cells.
- The different tissues of the plant leaf have different functions, e.g. waxy cuticle prevents water loss, palisade mesophyll allows maximum photosynthesis, stomata allow the diffusion of gases into and out of the leaf.
- You can use the light microscope to study the internal structures of leaves.

KEY WORDS

vascular bundles *part of the transport system in vascular plants, containing xylem and phloem*

xylem *the hollow cells of a plant that transport water and minerals to plant cells*

phloem *the food-conducting living tissue of a plant*

chloroplast *the organelle in the cytoplasm of plant cells where chlorophyll is stored, and photosynthesis takes place*

Review questions

1. Which of the following is not an external feature of a leaf?

   A petiole

   B midrib

   C chloroplast

   D cuticle

2. Which of the following is the tissue where most photosynthesis takes place?

   A spongy mesophyll

   B palisade mesophyll

   C epidermis

   D stomata

3. Gases move in and out of a plant through:

   A the cuticle

   B the stomata

   C the epidermis

   D the roots

KEY WORDS

photosynthesis *a plant chemical process of making food (sugars) and oxygen, from carbon dioxide and water, in the presence of light*

heterotrophs *organisms that obtain their energy through consuming other organisms*

autotrophs *organisms that make their own food from inorganic substances, via photosynthesis*

4.2 Photosynthesis

By the end of this section you should be able to:

- Explain the importance of light, chlorophyll and carbon dioxide (CO_2) for photosynthesis.
- Demonstrate the importance of light, chlorophyll and carbon dioxide (CO_2) for photosynthesis with simple experiments.
- Explain how plants convert carbon dioxide and water into carbohydrate by describing the light and dark reactions.
- List the various food storage organs of plants with examples.
- Explain the importance of photosynthesis in agriculture.
- Explain that much photosynthesis takes place in water bodies and that people need to try and make use of this.
- Explain how photosynthesis helps to balance the concentrations of oxygen (O_2) and carbon dioxide (CO_2) in the atmosphere.
- Explain how deforestation may lead to a CO_2 build-up in the atmosphere and finally to global warming.

Like all living organisms plants need food to provide them with the energy for respiration, growth and reproduction. Many organisms, including all animals, eat food to get the energy they need to live. They are known as **heterotrophs** (feeding on others). In contrast, plants produce their own food in a process known as **photosynthesis**. They are known as **autotrophs** (feeding themselves). Photosynthesis takes place in the green parts of plants, especially the leaves, in the presence of light.

Figure 4.2 *Plants can make their own food by photosynthesis and they use it to grow in some spectacular ways. Oxygen is a by-product of photosynthesis and it is used for respiration by plants and animals alike.*

What is photosynthesis?

Photosynthesis can be summed up in the following equation:

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{light energy}]{\text{chlorophyll}} \text{glucose} + \text{oxygen}$$

The chemical equation for the same process is:

$$6CO_2 + 6H_2O \xrightarrow[\text{light energy}]{\text{chlorophyll}} C_6H_{12}O_6 + 6O_2$$

During photosynthesis light energy from the sun is absorbed by a green substance called chlorophyll that is found in the chloroplasts of some plant cells. The energy that is captured is used to convert carbon dioxide from the air and water from the soil into a simple sugar, glucose, with oxygen as a by-product.

Some of the glucose produced during photosynthesis is used immediately by the cells of the plant for respiration to provide energy for cell functions, growth and reproduction.

The energy released in respiration is used to build up smaller molecules into bigger molecules:

- Sugars like glucose are built into starch for storage.
- Sugars like glucose are built into molecules like fructose (fruit sugar) and sucrose (a double sugar unit) to be transported around the plant.
- Sugars like glucose are built up into more complex carbohydrates like cellulose to make new plant cell walls.
- Sugars, along with nitrates and other nutrients that the plant takes up from the soil, are used to make amino acids. These amino acids are then built up into proteins to act as enzymes and make up much of the cytoplasm of the cells.
- Sugars may be built up into fats and oils (lipids) for storage in seeds and to make up part of the cell membranes.
- Sugars may be used to build up important large molecules such as chlorophyll, using minerals such as magnesium taken up from the soil.

Some of the glucose produced by photosynthesis is always converted into starch for storage, at least as a first step. This is because glucose is soluble and so could affect the water balance within the plant. If the concentrations of glucose vary in different parts of the plant then osmosis takes place to correct this and this could upset the whole organism. Starch is insoluble, which means that it does not dissolve, so it has no effect on the concentration of solutions. This means that it can be stored in different places without having any effect on the water balance of the plant. Starch is also a very compact molecule, so it takes up relatively little room, and it is easily broken down again into glucose molecules when it is needed by the cells of the plant. Because so much starch is produced, we often use it to show us that photosynthesis has taken place in a plant.

DID YOU KNOW?

Plants synthesise around 35×10^{15} kg of NEW biological material and produce about 36.8×10^{13} kg of the invaluable waste product of oxygen each year. This is why plants are vitally important to the survival of all species on Earth.

What is needed for photosynthesis?

As you can see from the equation at the beginning of this chapter, for photosynthesis to occur successfully the inorganic molecules carbon dioxide and water are needed, along with a supply of light energy and the means to capture that energy in the form of the green pigment chlorophyll. But to show that certain factors are needed for photosynthesis, or to have an effect on its rate, we need a way of demonstrating that photosynthesis has actually taken place.

The simplest way to do this is to look at the end products of the process. We can use the presence of starch in the leaf of a plant to show that it has been photosynthesising. Iodine solution is reddish brown. In the presence of starch, iodine turns blue-black.

Unfortunately you can't just add a few drops of iodine solution to the leaves of a plant to see if it has made starch – the waxy cuticle forms a waterproof layer so the iodine cannot penetrate and the green colour could mask a slight colour change. However, there is a simple procedure to test a leaf successfully for the presence of starch that you can use in many different experiments to investigate photosynthesis.

Activity 4.3: Testing a leaf for starch

A common way of demonstrating that a plant has or has not carried out photosynthesis is to test a leaf for the presence of starch (see figure 4.3).

To see the effect of starch on iodine solution place a few drops of iodine solution onto a piece of bread or a cut piece of potato or even a piece of paper and observe the colour change.

To be able to see clearly that a leaf has been photosynthesising and that starch has indeed been produced, you need to remove the outer waxy layer. To do this you need to follow these steps:

You will need:

- potted plants, e.g. geraniums (pelargoniums) that have been kept in the light for several hours before the investigation
- a large beaker
- a Bunsen burner, a tripod, gauze and a heatproof mat
- ethanol (NB. Keep ethanol away from the naked flame.)
- a boiling tube
- forceps
- a white tile

Method

1. Set up your Bunsen burner on a heatproof tile with the tripod and gauze. Half fill the beaker with water and bring it to the boil.
2. Remove a leaf from the plant and, holding it in the forceps, plunge it into boiling water and continue to boil briefly (about 30 seconds). TAKE GREAT CARE. This serves two main purposes. It stops all the biochemical processes by killing the leaf, and it breaks open the cells making them more accessible to the iodine solution.
3. Turn off the Bunsen burner. Place the leaf in a boiling tube half filled with ethanol, so the ethanol covers the leaf. Place the boiling tube in the beaker of water that has just stopped boiling. The ethanol will boil and the green colour will be removed from the leaf. This MUST be carried out in a water bath and great care taken as ethanol is very flammable. NEVER heat ethanol directly with a Bunsen burner. The removal of the green pigment from the leaf means that any colour changes in the iodine solution will be more clearly seen.
4. Ethanol makes the leaf brittle so remove the white leaf from the boiling tube with the forceps and wash it in the hot water again to soften it.
5. Then spread the leaf out on a white tile – or a Petri dish on a piece of white paper – to make colour changes more obvious, and add a few drops of iodine solution.
6. Observe any colour changes – the parts of the leaf that contain starch will turn blue-black and this indicates that photosynthesis has taken place.

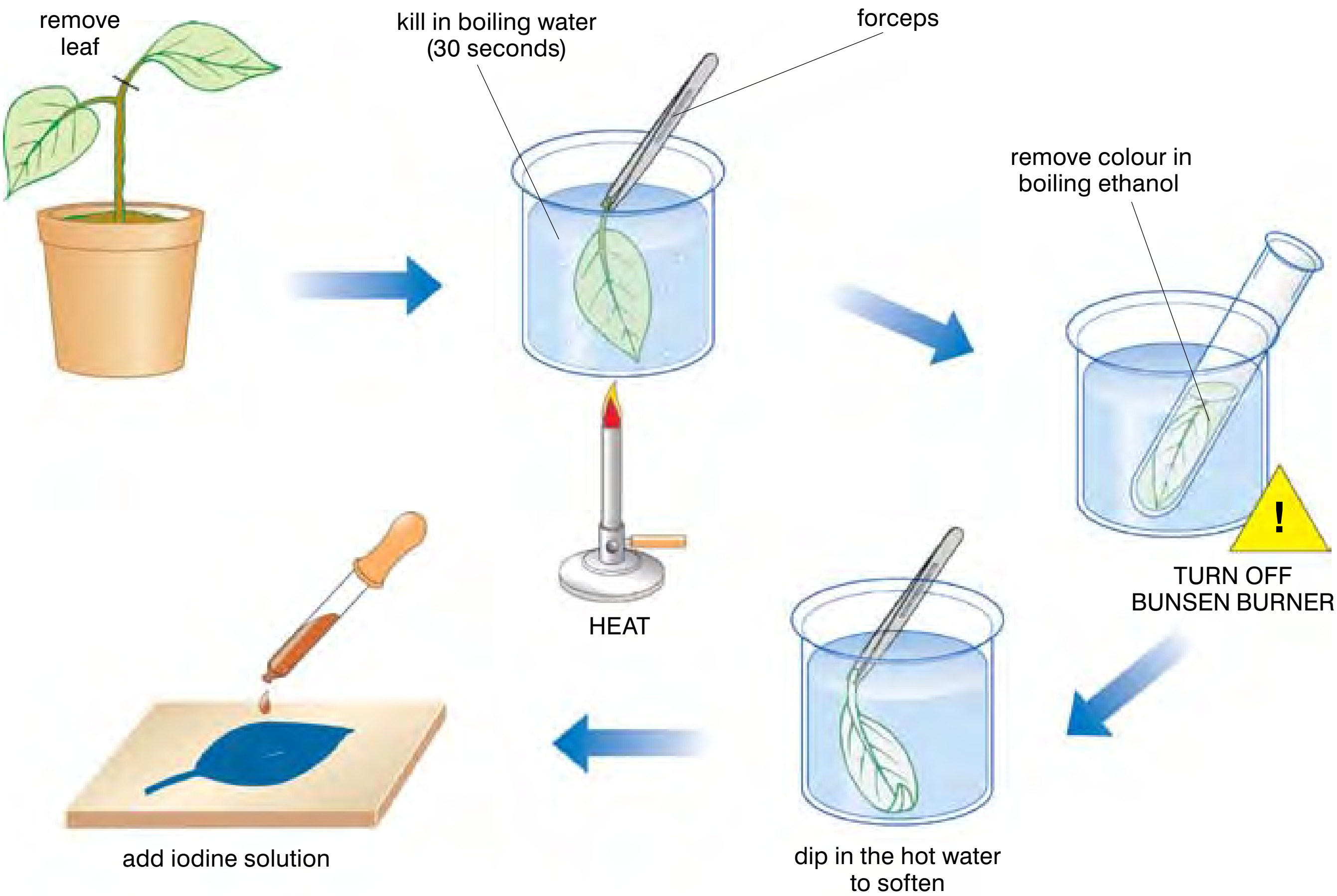


Figure 4.3 *We use the iodine test for the presence of starch to show us that photosynthesis has taken place. A blue-black colour indicates starch is present in the leaf and so photosynthesis has taken place.*

Review questions

1. Where does a plant get the carbon dioxide, water and light that it needs for photosynthesis?
2. Work out the path taken by a carbon molecule as it moves from being part of the carbon dioxide in the air to being part of a starch molecule in a plant.

The need for light

Everyone knows that plants need light for photosynthesis – but in fact that is not completely true. The simple equation we use for photosynthesis represents many different chemical reactions that go on in the chloroplasts of a plant to convert carbon dioxide and water into glucose and oxygen. And while light is absolutely necessary for some of those reactions, others can continue even if there is no light at all. The light-dependent reactions cannot take place without light energy. The light energy is absorbed by chlorophyll molecules through activation of their electrons and used to split water molecules into hydrogen and oxygen. Adenosine triphosphate (ATP) for energy is produced as well. The hydrogen is used in the rest of the process, and the oxygen is given off as a gas. It is a waste product of the light reactions of photosynthesis.

The hydrogen and ATP produced in the light reaction are then used in a series of reduction reactions that convert carbon dioxide into

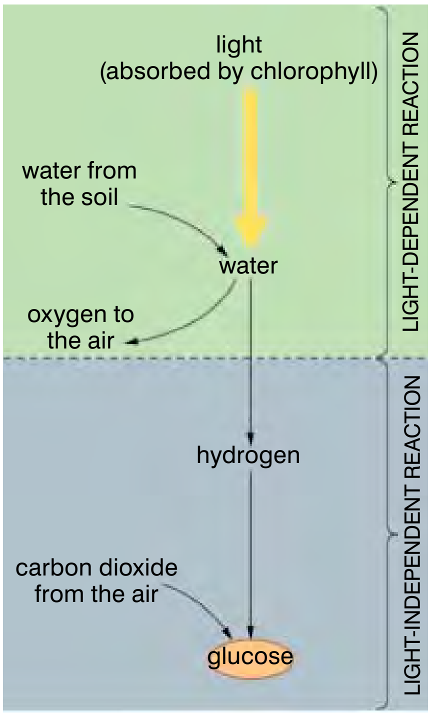


__Figure 4.4__ The light-dependent and -independent reactions of photosynthesis can be summarised like this. They both take place in the chloroplasts.

glucose. This stage of the process does not need light to take place and is known as the light-independent reaction.

However, for all practical purposes we can still say that plants need light for photosynthesis – because without the products of the light-dependent reaction the light-independent reactions can't take place at all! For most plants the source of light energy for photosynthesis is the sun, although in some cases people intervene and supply extra artificial light. If plants are deprived of light for any substantial amount of time they will die, because once the stores of starch have been used up they are not replaced and so there is no energy available for the metabolic reactions of the cells.

It is important to be able to show that plants need light for photosynthesis – how do you think it might be done? Make a list of your ideas and then read on.

The simplest way of demonstrating the need of a plant for light is to deprive it of light and see what happens. You can keep a whole plant in the dark for two to three days – this is called **destarching** the plant – and then compare the leaves with those from a plant kept in the light. Alternatively you can cover either a whole leaf or part of a leaf of a destarched plant with black paper or foil. This prevents light from reaching the covered area. If the plant is then left in the light for several hours and the covered leaf is tested for the presence of starch and compared to an uncovered leaf the difference is plainly visible (see figure 4.5).

__Figure 4.5__ The results of the iodine test for starch: leaf A is from a destarched plant which has been kept in the dark; leaf B is from a plant kept in the light.

However, starch is not the only end product of photosynthesis. Oxygen gas is produced as well. While we cannot easily observe the oxygen gas produced during photosynthesis in land plants, it is a useful way of showing that photosynthesis is taking place in water plants. They give off bubbles of oxygen-rich gas from their leaves and from any cut or broken stems when they are photosynthesising. You can use this to show that light is needed for photosynthesis to take place, simply by collecting the gas collected from a water plant kept in the dark and one kept in the light. The gas given off by the plant in the light will relight a glowing splint – showing that it is rich in oxygen. The much smaller amount of gas collected from the plant in the dark does not do this – in fact it will extinguish the splint as it is rich in carbon dioxide from respiration. You can also use this method to measure the rate at which photosynthesis takes place when you look at the limiting factors in photosynthesis.

KEY WORDS

destarching *the process of eliminating starch reserves from a plant by depriving it of light*

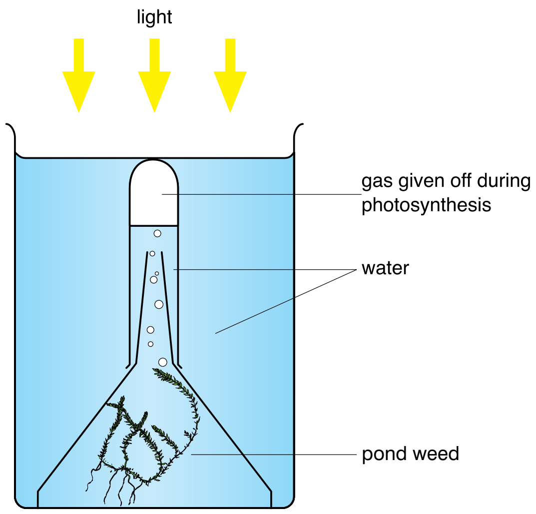


Figure 4.6 *The oxygen-rich gas released by water plants as they photosynthesise gives us another way of showing that light is needed for the process to happen.*

Activity 4.4: To show that oxygen is produced during photosynthesis

In the equation for photosynthesis, we saw that oxygen is given off as a waste product.

When the light intensity is high (bright sunshine), much oxygen is produced.

The oxygen can easily be collected from water since it is not very soluble in water.

This explains why we use an aquatic plant.

You will need:

- local pond weed
- a 250 cm^3 beaker
- a glass funnel
- a test tube
- small stones
- sodium hydrogen carbonate
- water or pond water

Method

1. Place the pond weed in a large beaker filled with about 150 cm^3 of pond water. You may add sodium hydrogen carbonate to the water to produce more carbon dioxide.
2. Carefully invert a funnel over the pond weed as shown in figure 4.6.
3. Fill a test tube with the same amount of water as in the beaker. Carefully and without allowing any water out of the test tube, invert the test tube over the stem of the funnel as shown in figure 4.6.
4. You will need to put some small stones at the bottom of the beaker to support the funnel so that it is raised above the bottom of the beaker. This arrangement allows free water circulation.
5. Place the apparatus in bright sunlight for 3–4 hours.
6. After this period, move the inverted test tube from the inverted funnel stem while still under water. Then cover the test tube with your thumb before removing it from the beaker.
7. Remove your thumb from the test tube mouth and quickly plunge a glowing splint into the test tube.

Activity questions

1. What did you observe during the four hours?
2. What happens to the glowing splint when plunged into the test tube?
3. What is the identity of the gas?
4. What conclusion can you make from this activity?

Activity 4.5: Showing that light is needed for photosynthesis

Follow these steps to plan your own experiment to show that light is needed for photosynthesis to take place.

1. Plan two experiments, one using land plants and one using water plants, which could be used to demonstrate that light is needed for photosynthesis.
2. Make sure that you describe carefully how to demonstrate that photosynthesis has taken place in each case, and think carefully about any safety issues.
3. Once you have planned your demonstrations, ask your teacher to check them through.
4. If you are given permission, set up ONE of your demonstrations and write up your observations and your conclusions on its effectiveness.
5. Make sure you evaluate your method and discuss any ways in which you might improve it.

The need for carbon dioxide

A source of carbon is needed for the plants to synthesise sugars. There are lots of carbon-containing chemicals in existence, but carbon dioxide from the air or in solution in water is the only form that plants can use in photosynthesis. Carbon dioxide is found more or less everywhere. It is even produced by the plants themselves as a result of cellular respiration, so getting hold of it isn't usually a problem. However, although there is always sufficient carbon dioxide available for some photosynthesis to take place, sometimes the levels are too low for plants to take full advantage of the light available.

Demonstrating that plants need carbon dioxide for photosynthesis is not easy. You can easily remove the carbon dioxide from the air surrounding a leaf or a plant using potassium hydroxide, which absorbs CO_2. However, the individual plant cells still produce

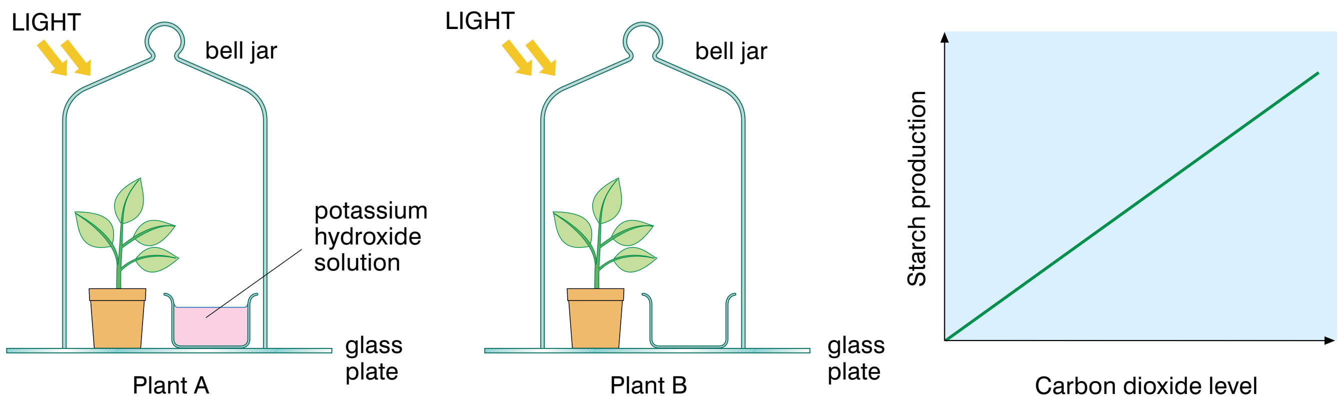


Figure 4.7 *Plant A and plant B are both destarched. Plant A has no carbon dioxide in the surrounding air, while plant B has normal levels of carbon dioxide. Both are given light for 12 hours and tested for the presence of starch. Less starch is produced by plant A than by plant B, but plant A makes a small amount of starch using carbon dioxide produced in the leaves by respiration.*

carbon dioxide as they respire and so it is almost impossible to entirely deprive a plant of the gas. A more valid approach is to change the levels of carbon dioxide in the air surrounding a plant in high-intensity light and measure the changes in the rate of photosynthesis. As the carbon dioxide level increases, the rate of photosynthesis goes up. With plenty of raw materials the plant is able to take full advantage of the light energy falling on it.

The need for water

Carbon dioxide alone is not sufficient to produce carbohydrates. Hydrogen is needed too, and water is the only source of hydrogen that plants can make use of. All the cells of a plant have a constant supply of water both as a waste product of respiration and from the transpiration stream (see section 4.3), so there is always plenty of water for photosynthesis.

Water is vital to all the functions of a plant. This means you cannot demonstrate that water is required for photosynthesis just by depriving the plant of it – the plant would die long before the effect of lack of water on photosynthesis would show. The only way to show that water is needed for the process of photosynthesis is to supply the plant with 'heavy' water containing the ^{18}O isotope of oxygen. These atoms are radioactive, and the radiation they produce can be detected as it is taken up and used by the plant. Substances like this are known as **radioactive tracers**. This experiment not only shows that water is needed for photosynthesis, it also makes clear what part the water plays. It shows that the oxygen gas produced during photosynthesis comes from the splitting of the water molecules using light energy. This is known as photolysis (splitting using light).

The need for chlorophyll

The final requirement for photosynthesis to take place is a way of capturing the energy from the sun and this is carried out by the green pigment chlorophyll.

The simplest way to demonstrate that chlorophyll is needed for photosynthesis to take place is to consider the leaves of a variegated plant. Variegated leaves have areas that contain chlorophyll and areas that do not. The chlorophyll-free regions are usually yellow or creamy-white in colour. If a destarched variegated plant is then exposed to light for several hours and you test one of the leaves for the presence of starch, the iodine solution changes colour only in those regions of the leaf that were green. This shows that without chlorophyll photosynthesis did not take place.

DID YOU KNOW?

There are some plants – known as the **resurrection plants** – which can survive without water. In dry conditions they can lose up to 95% of their water and end up as tiny shrivelled remains. But just add water and within 24 hours they have recovered and are photosynthesising again as good as new!

KEY WORDS

radioactive tracers *radioactive molecules that can be sent through a vascular system (animal or plant) with their progress followed by a radiation-sensitive machine*

resurrection plants *plants with the habit of reviving after seeming to be dead*

DID YOU KNOW?

Chlorophyll is the green pigment in plants that captures the energy from the sun for photosynthesis. But chlorophyll isn't really green – it is a mixture of five different pigments that range in colour from orange and yellow to blue-green and yellow-green and the result is the green colour we see!

Figure 4.8 *The leaves on the left and the right come from plants that have been in bright light for 48 hours. Both plants have had plenty of time to photosynthesise and make glucose to turn into starch. However, only the green areas of the variegated leaf on the right have been able to make starch, because the white areas do not contain chlorophyll. The middle leaf is from a plant that has been in the dark for 48 hours.*

Activity 4.6: Showing that chlorophyll is needed for photosynthesis

You can see how important chlorophyll is for photosynthesis by carrying out the following experiment on a variegated leaf. You are going to keep one plant with variegated leaves in the dark, and place another variegated plant in bright light for several hours, and then test a leaf from both plants for the presence of starch. What do you expect to see – and why?

You will need:

- two potted plants with variegated leaves, e.g. geraniums (pelargoniums) or ivy, that have been destarched. Keep one plant in the dark, and bring the other into the light for several hours before the investigation
- a large beaker
- a Bunsen burner, a tripod, gauze and a heatproof mat
- ethanol (NB. Keep ethanol away from the naked flame.)
- a boiling tube
- forceps
- a white tile

Method

1. Remove one leaf from the destarched plant with variegated leaves that has been kept in the dark and one leaf from the plant that has been exposed to a bright light for several hours.
2. Prepare both leaves to be tested for the presence of starch using the method described on page 148.
3. Spread both leaves on a white tile and add iodine solution.
4. Make careful observations and drawings of your results.
5. Write up your experiment and explain the results you get. Do they fit with your initial hypothesis?

The importance of photosynthesis

Photosynthesis is one of the most important reactions on Earth. It is through photosynthesis that the ultimate source of energy for the Earth – in other words, the sun – is tapped and converted into chemical energy which is available to life. Around 35×10^{15} kg of new biological material is produced every year as a result of photosynthesis. This new material can then be used as a food source by billions of living organisms, including people. On the land, it is plants that photosynthesise and make food. It is easy to forget that actually almost two-thirds of the surface of the Earth is covered in water, and much of the photosynthesis of the world goes on in large bodies of water. The organisms that carry out photosynthesis in water may be true plants, such as water weeds, but they also include many algae and most importantly of all, the photoplankton (also known as phytoplankton). These are tiny organisms, protists and bacteria, which carry out photosynthesis and produce over half of the biomass of the Earth. That is a lot of material – remember the total biomass made by photosynthesis each year is around 36.8×10^{13} kg!

At the moment people rely mainly on the photosynthesis which takes place on land to supply them with their food. Most of our food crops such as teff, sorghum, millet, corn, barley, beans and other pulses are all plants grown in the soil. Some cultures such as China use seaweeds and other algae which photosynthesise in water as an important source of food but most only use the biomass created by photosynthesis in the oceans indirectly, when they eat fish. So in many ways the photosynthesis which takes place in large bodies of water is a wasted resource.

Scientists are looking hard at ways in which algae might be used as a future source of both human food and fuels to replace fossil fuels. Algae grow at a tremendous rate and replace themselves very rapidly. They not only produce biomass very rapidly, they also produce large amounts of oxygen and use up carbon dioxide. At the moment there are a number of problems to overcome, including how to grow and harvest algae in a controlled way, how to make food from algae acceptable to eat in cultures which are not familiar with it and how to convert algae into fuel. However, as the human population grows and food becomes more of a problem, scientists will almost certainly overcome these difficulties and algae will become a regular part of the human diet around the world.

Photosynthesis is very important as the source of energy for almost all living organisms, because of the way in which photosynthesis provides us with new biological material. However, it is important to the health of the environment in other ways as well.

Almost all living organisms need oxygen for cellular respiration. That oxygen is produced as a waste product of photosynthesis. We need enormous numbers of plants to photosynthesise to maintain atmospheric and water oxygen levels. Living organisms produce carbon dioxide as a waste product when they respire. Carbon dioxide is a greenhouse gas – it helps to trap heat from the sun around the surface of the Earth. It is also poisonous at high levels. However, carbon dioxide is also vital for photosynthesis to take place. Plants and other photosynthesising organisms remove carbon dioxide from the atmosphere all the time. So photosynthesis is very important for maintaining the balance of oxygen and carbon dioxide in the atmosphere.

If something happens to affect this balance, it can affect the life of everyone on Earth. For example, if carbon dioxide levels build up, this may lead to global warming. Anything which reduces the amount of carbon dioxide removed from the atmosphere by photosynthesis can lead to a carbon dioxide build-up. In many countries around the world, people have been cutting down trees both to use for timber and also to provide more open land for growing food crops or grazing cattle. This deforestation results in the loss of massive areas not only of trees but of all the other plants which grow in a wooded area. In South America deforestation is a tremendous problem with vast areas of tropical rainforests being destroyed every year. Once they are lost it is hard to replace that richness and variety of plants.

Figure 4.9 *Billions of photosynthesising plants have been lost in Ethiopia as we have cut down our forests – and huge amounts of carbon dioxide remain in the atmosphere which should have been taken up as the trees and other plants photosynthesised.*

We in Ethiopia have been involved in the process of deforestation – between 1990 and 2005 only we reduced our beautiful forests by 14% – that is about 2.1 million hectares of photosynthesising woodland. Loss of photosynthesising power like this can lead to a build-up of carbon dioxide in the atmosphere and ultimately an increase in global warming. However, here in Ethiopia we have recognised the problem and we are leading the way in replanting forests with native trees. You will learn more about global warming in unit 5, section 5.5.

Summary

In this section you have learnt that:

- Photosynthesis is the process by which:

  carbon dioxide + water [+ chlorophyll + light energy] → glucose + oxygen

  $6CO_2 + 6H_2O$ [+ chlorophyll + light energy] $\rightarrow C_6H_{12}O_6 + 6O_2$
- The light energy needed for photosynthesis is captured by the green pigment chlorophyll.
- The light-dependent reactions of photosynthesis depend on the presence of light to occur, while the light-independent reactions do not need light directly (although they need the products of the light reactions).
- The glucose made in photosynthesis can be converted to insoluble starch for storage to avoid osmotic problems.

- The glucose made in photosynthesis can be used in respiration to provide energy.
- The energy released in the plant during respiration is used to build up smaller molecules into larger molecules, e.g. cellulose, lipids and oils and chlorophyll.
- Leaves are well adapted to allow the maximum photosynthesis to take place.
- The need for carbon dioxide, water, chlorophyll and light in photosynthesis can all be demonstrated experimentally.
- The glucose made in photosynthesis is converted into starch for storage in the cells. It may be stored in special storage organs such as stems or root tubers to help the plant survive adverse conditions.
- Explain how photosynthesis helps to balance the concentrations of oxygen (O_2) and carbon dioxide (CO_2) in the atmosphere.
- Photosynthesis is very important in agriculture as the source of all the new plant biomass.
- Much photosynthesis takes place in water bodies and that people need to try and make use of this.
- Deforestation may lead to a CO_2 build-up in the atmosphere and finally to global warming.

Review questions

1. Iodine is used to test for which substance to show that photosynthesis has taken place in the leaf of a plant?

   A glucose

   B cellulose

   C protein

   D starch

2. Which of the following is not needed for photosynthesis to take place?

   A carbon dioxide

   B oxygen

   C chlorophyll

   D light

3. Photosynthesis is a process that requires a pair of raw materials, a pair of conditions and produces a pair of products.

   Name the:

   i) pair of raw materials

   ii) pair of conditions

   iii) pair of products

4.3 Transport

By the end of this section you should be able to:

- Explain water uptake by the roots.
- Explain the mechanism of water movement in plants.
- Describe transpiration, the factors affecting it and its implications for agriculture.
- Demonstrate water transport in plants using simple experiments.
- Explain the mechanism of uptake of mineral salts through roots.
- Describe the movement of organic materials in the phloem.

As you saw in grade 9, osmosis plays a very important role in plants. Now you are going to look at the main transport systems in plants. These transport systems rely heavily on osmosis, diffusion and active transport.

Trees are obviously supported by their woody trunks. But many plants do not have woody tissue, and so they have no structural support. They rely on having cells which are rigid and firm. These firm cells are maintained by the movement of water into the cells by osmosis to create turgor. This is one reason why osmosis is so important for plants.

KEY WORDS

root hairs *hair-like extensions that increase the surface area, thereby enhancing osmosis*

Osmosis is not only vital for keeping the plant cells turgid. It is also very important for moving water around within the plant itself. Plants take up water through their roots. The water in the soil has a very low concentration of dissolved minerals. In other words, there is a very high concentration of water. Water moves into the plant root cells across the cell membrane along a concentration gradient. The roots are covered with special cells, which have tiny hair-like extensions called the **root hairs**. These root hairs increase the surface area for osmosis to take place. Once water has moved into the root hair cells, the cytoplasm of the root hair cells is more

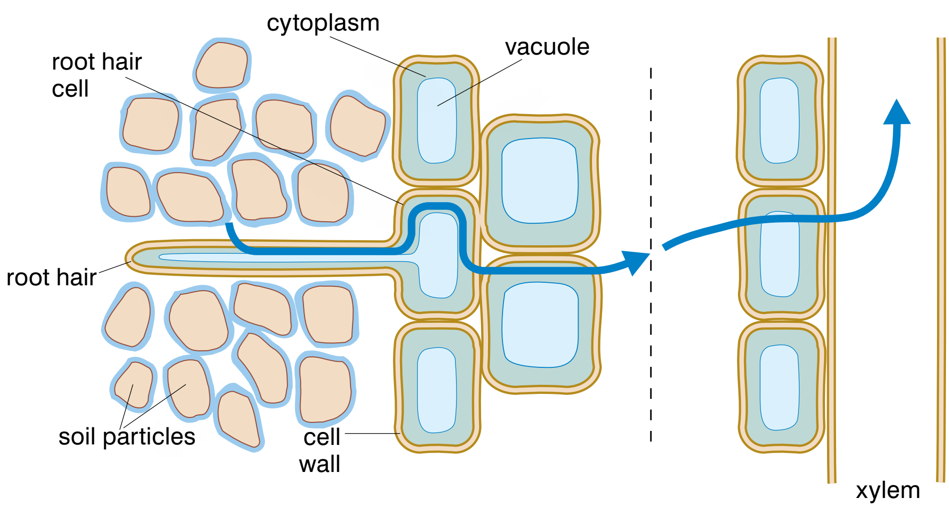


Figure 4.10 *Water moves across the tissues of a plant by osmosis. It moves along a water potential gradient.*

dilute than the cytoplasm of the surrounding cells. Water moves into the neighbouring cells by osmosis (see figure 4.10). These cells now have more dilute cytoplasm than the cells next to them, and the water moves on by osmosis until it reaches the xylem and the transpiration stream.

Active transport in plants

Plants don't just rely on osmosis and diffusion. Active transport is also widely used in plants. There are some situations where active transport is particularly important. For example, the mineral ions in the soil are usually found in very dilute solutions – more dilute than the solution within the plant cells. By using active transport plants can absorb these mineral ions, needed for making proteins, and other important chemicals from the soil, even though it is against a concentration gradient. Active transport like this involves the use of energy produced by respiration in the cells.

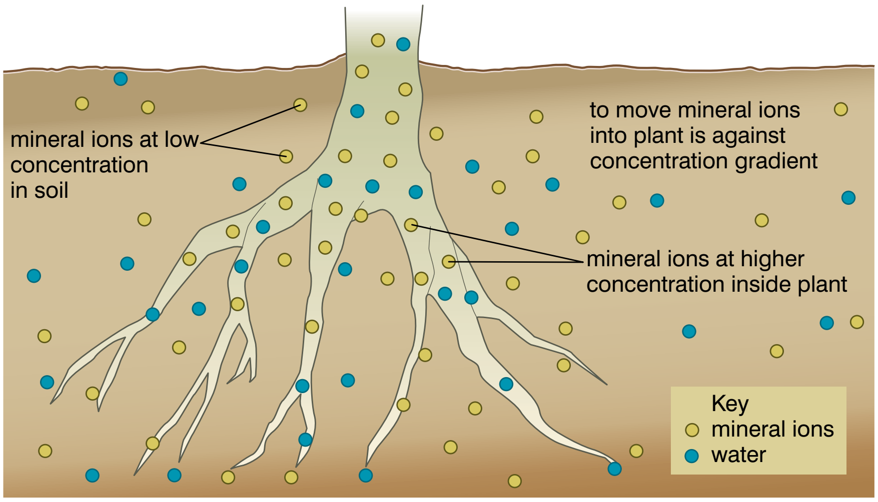


Figure 4.11 *It takes the use of energy in active transport to move mineral ions against a concentration gradient like this.*

So far we have looked at how substances – water and minerals – are transported into plants. Now you are going to study the ways in which substances are transported around the plants themselves.

Transport of materials around the plant

As you have seen in this unit, plants make food by photosynthesis in the leaves and other green parts but it is needed all over the plant. Similarly water and minerals move into the plant through the roots in the soil, but they are needed by every cell in the body of the plant. Plants need a transport system to move substances around their bodies.

A double transport system

There are two separate transport systems in plants. The **phloem** is made up of living tissue and it is involved in the transport of organic materials – the nutrients made by photosynthesis – from the leaves to the rest of the plant. Phloem cells are thin walled and are regularly replaced when they are worn out. They contain a liquid rich in sugar.

Figure 4.12 *Trees like this Keraro can be many metres tall – and then the roots go down almost as far underground. Plants need a very effective transport system to move substances distances like these.*

KEY WORDS

transpiration *the process by which water absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface, principally from the leaves*

passive *requires no energy from the plant*

When insect pests such as aphids attack plants, they stick their feeding parts into the phloem to suck up the food-rich liquid. By depriving much of the plant of food, these pests can destroy crops and cause terrible hardship.

The plant has to use energy to move substances around the phloem, and food substances can move both up and down the plant. The nutrients are carried to all the areas of the plant including the growing regions where they are needed for making new plant material, and the storage organs where they are needed to provide a store of food for the winter.

The **xylem** is the other transport tissue. It carries water and mineral ions from the soil around the plant. The xylem tissue is dead and there is no active transport taking place. The movement of the water in the xylem is due to **transpiration** (see the next few pages) and it is **passive**. This means it uses no energy from the plant. Water only moves up from the roots to the leaves.

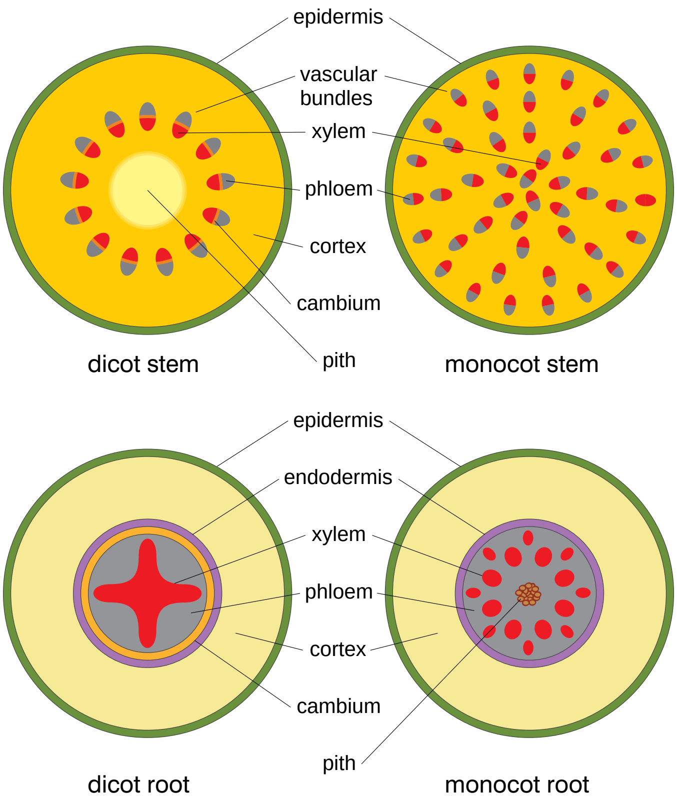


Figure 4.13 *The transport system in a non-woody plant is arranged in bundles around the outside of the stem, with the xylem and the phloem arranged together. In the root the transport tissue is all in the centre.*

In woody plants like trees the xylem tissue makes up the bulk of the wood, and the phloem is found in a ring just underneath the bark. This makes young trees in particular very vulnerable to damage by animals because, if a complete ring of bark is nibbled, transport in the phloem comes to a complete halt and the tree will die. Sometimes the animals have to be killed to protect the young trees.

The need for transport in plants

The importance of moving the food made by photosynthesis around the plant is obvious – all the cells need glucose for cellular respiration as well as materials for growth. The sugars that are produced in the leaves and carried all around the plant can also be

Activity 4.7: Finding out about the distribution of plant transport tissues

You will need:

- either a small plant with its leaves and roots intact or a bean seedling which has been grown in the dark so it is very pale or a plant with white flowers
- a beaker or jar containing water with a coloured dye
- a sharp knife or scalpel
- a sheet of white paper or a white tile

Method

1. Wash the soil off the roots of your plant if there is any attached.
2. Stand your plant in the jar containing coloured water for about 24 hours.
3. Remove the plant from the water. Observe its appearance, particularly if it is a pale plant or has white flowers. Make a note of what you see.
4. Cut the stem of the plant in half across the plant – where is the dye? Use a hand lens to look more closely and draw what you see.
5. Then cut the stem lengthways to see if you can find out more about where the dye is found within the stem. Draw and label your findings.
6. Repeat these steps with the roots.
7. Explain your observations.

stored. However, plants cannot store sugars, because they have an osmotic effect. If a cell had lots of sugar in it, lots of water would move into it by osmosis. So sugars are converted into starch, which is osmotically inert. This means that a cell can contain lots of starch and it has no effect on the movement of water by osmosis into or out of the cell. The starch stored in plant cells is broken down to sugars again to provide them with energy when the need arises – for example, when there isn't enough light to photosynthesise.

One of the main places where starch is stored is in the storage organs of plants. Root tubers, stems and leaves can all be filled with starch to form storage organs. These enable plants to survive difficult conditions and also to reproduce.

Starch is also deposited in large amounts in many fruits and seeds. In fruits the starch provides a reason for animals – including people – to eat the fruit and the seeds, helping to disperse the seeds. In the seeds, starch is one of the energy stores for the developing embryo to use as the seed starts to develop. We take advantage of these starch stores in plants and use them as food. Starch from plants is a very good energy source for people all around the world!

Figure 4.14 *These bananas and cassava are very rich in starch, which provides energy for the plant, and also for any people who eat them!*

The movement of water and minerals from the roots is just as important as the movement of food. The minerals are needed for the production of proteins and other molecules within the cells. The water is needed for two main reasons. One is that water is needed for photosynthesis and without water photosynthesis cannot take place. Less obviously, but just as important, water is needed to maintain the turgor pressure within the cells. As you saw earlier, water moves into plant cells by osmosis. This produces turgor so the cytoplasm presses against the cell walls. In fact for young plants and non-woody plants this is the main method of support. This pressure in the cells is very dependent on water moving up through the xylem from the soil. It is also very important in keeping the leaves firm and spread out to catch the sunlight. If the supply of water stops, the whole plant, or just the leaves, will wilt and all the chemical processes of photosynthesis and respiration will be affected.

Activity 4.8: Using food tests to investigate the content of plant storage organs

You will need:

- plant storage organs such as cassava roots, potatoes or onions
- iodine solution
- Benedict's solution
- a pestle and mortar
- a beaker
- test tubes
- a white tile
- a Bunsen burner
- a heatproof mat
- gauze
- goggles
- tongs

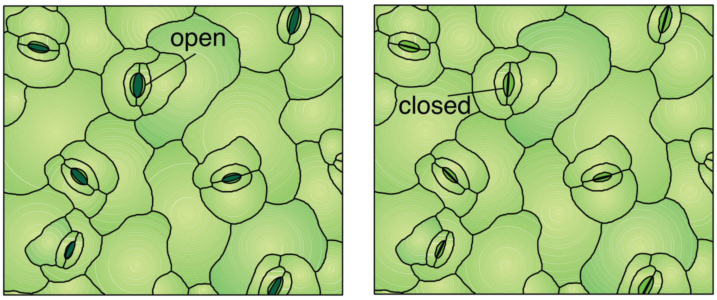
Method

1. Draw and label the storage organ you are investigating.
2. You are going to test the contents of a plant storage organ for the presence of starch and of reducing sugars.
3. Take a small sample of the storage organ and carry out the iodine test for starch. Record your results.
4. Take another sample of the same storage organ and grind it up with a little water in the pestle and mortar.
5. Now use Benedict's solution to test for reducing sugars in the plant tissue.
6. Write up your investigations, including your observations, and record your results. What does this tell you about the contents of the plant material you have investigated?

The transpiration stream

Water is taken into a plant through the roots and moves by osmosis to the xylem tissue. There is no active transport in the xylem. So how is water moved from the roots of a plant up to the uppermost leaf, a distance which can be many metres? The transport of water through a plant is the result of the transpiration stream.

Plants lose water vapour from the surface of their leaves. This loss of water vapour is known as transpiration. Most of the transpiration takes place through the tiny holes in the surface of the leaf known as stomata. The stomata are there to allow air containing carbon dioxide into the leaf for photosynthesis. They can be opened and closed by the guard cells which surround them (see activity 4.9). Losing water through the stomata is a side effect of opening them to let carbon dioxide in, but it is vital for transpiration. Most of the stomata are found on the underside of the leaf.



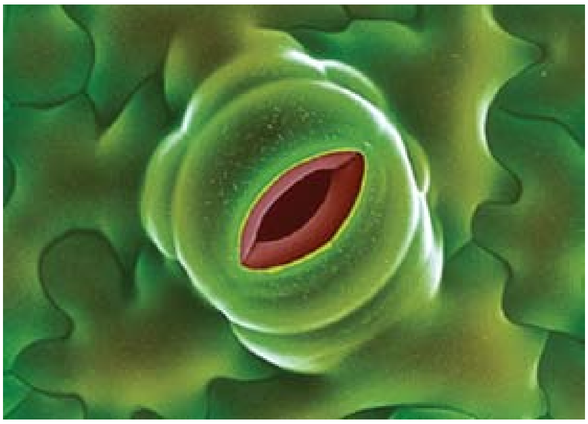


Figure 4.15 *Guard cells open and close the stomata to control both the carbon dioxide going into a cell and the water coming out of it.*

Activity 4.9: Looking at the stomata in a leaf

You will need:

- a *Tradescantia* sp. or a *Commelina* sp. plant
- a pot of clear varnish (for nails, or other varnish)
- a paintbrush
- forceps
- a microscope slide, coverslip, dropper and mounted needle (for making a temporary mount)
- a light microscope

Method

1. Take a leaf from the plant.
2. Apply a thin layer of clear varnish to a small area of the underside of the leaf. It is worth covering several patches in case you have problems with one of them.
3. Once the varnish is dry, peel it off carefully with forceps or your fingernails. The varnish will have made an exact copy of the surface of the leaf.
4. Put the varnish film on a slide with a drop of water and cover with a coverslip – remember to avoid air bubbles if possible.
5. Examine your slide under the low power of the microscope. Can you see the stomata? Approximately how many are visible in your field of view? Can you tell if they are open or closed? If so, what proportion are open?
6. Now move a single stoma to the centre of your field of view and look at it under the higher powers of magnification. Can you see the guard cells? Draw and label the stoma.
7. If you have time, repeat this process for the top surface of the leaf. How do the numbers of stomata compare?

What affects the opening and closing of the stomata? This seems to be linked to osmosis. Guard cells contain chloroplasts so they can photosynthesise, unlike the other cells in the epidermis layer. So when there is sunlight, the concentration of sugar in the guard cells goes up as a result of photosynthesis. Water then moves into the guard cells by osmosis from the epidermal cells around them. The sausage-shaped guard cells become very turgid, and as they swell up they bend, opening a gap – the stoma – between them (see figure 4.15). The pore closes by the reverse process – water moves out of the guard cells by osmosis into the surrounding cells and as the level of turgor in the guard cells falls, the stoma closes.

You can make a model of a stomatal pore using long balloons to represent the guard cells. Try it yourself – when the balloons are fully blown up, the pore is open. When the balloons are slightly deflated, the pore closes.

KEY WORDS

adhesive forces *forces of attraction between different types of molecule*

cohesive forces *forces of attraction between similar types of molecule*

Moving water through the plant

As water evaporates from the surface of the leaves, water is pulled up through the xylem to take its place. This constant moving of water molecules through the xylem from the roots to the leaves is what is known as the transpiration stream. What factors move the water upwards?

There is pressure pushing the water up from the bottom – the root pressure – as water moves in by osmosis.

In the xylem, two physical forces help the water to move upwards. There are **adhesive forces** between the water and the walls of the xylem which support the whole column of water, no matter how tall it is. And as molecules evaporate away from the surface of the leaf, the following molecules are pulled upwards by **cohesive forces** between the water molecules. In other words, the water molecules tend to stick together and get pulled upwards like a string of beads.

However, the main pull which moves water up from the roots to the leaves is the almost constant evaporation of water from the leaves.

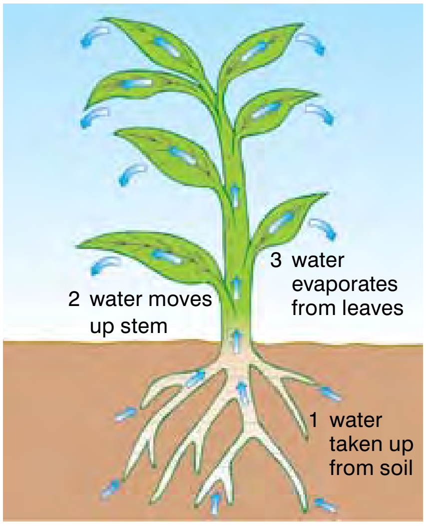


Figure 4.16 *The transpiration stream – capable of pulling a column of water in the xylem up to 30 m above the surface of the Earth.*

When water reaches the xylem in the leaves, there is a reversal of the situation in the roots. Now the solution in the xylem has a much higher concentration of water than the solution in the mesophyll cells in the leaf. Water moves out from the xylem into the mesophyll cells and so across the leaf by osmosis. When it reaches a mesophyll cell which is surrounded by air, water evaporates from the surface into the air and diffuses out through the stomata along a concentration gradient.

Factors affecting the role of transpiration

Because the transpiration stream is driven mainly by the evaporation of water from the leaves, anything which affects the rate of evaporation will affect transpiration.

Conditions which increase the rate of evaporation also increase the rate of transpiration. The higher the temperature, the more evaporation takes place. Water evaporates more rapidly into dry air than into humid air. If the air is moving – it is windy – then water-vapour-rich air is always being removed from around the leaf. This maintains a good concentration gradient for diffusion and increases evaporation. So transpiration is more rapid in hot, dry and windy conditions than it is in still or humid conditions.

Plenty of light also speeds up transpiration. In good light conditions, lots of photosynthesis takes place and so the stomata are opened to allow plenty of carbon dioxide in. When the stomata are open, lots more water can evaporate from the surface of the leaves.

Activity 4.10: Investigating factors which affect transpiration – 1

In this activity you are going to investigate transpiration using a piece of apparatus which measures the amount of water lost from the leaves of a plant. You can use shoots from a plant or whole plants for this experiment.

You will need:

- apparatus as shown in figure 4.17
- an accurate balance
- Vaseline

Method

You can carry out this investigation by measuring the amount of water taken up by the plant, by measuring any change in mass, or both. Make sure you record whatever observations you make very carefully.

1. Set up several sets of the apparatus as shown in the diagram.
2. Take your initial readings of the water level in the cylinders and of the mass (if used).
3. Place one set of apparatus by the window.
4. Place another set of apparatus with a light shining on it all the time, day and night.
5. Cover the underside of the leaves of another plant with Vaseline.
6. If you have a fan, place one of the plants in a constant gentle air flow.
7. Leave all the plants for 24 hours.
8. Repeat all your measurements and record them.
9. Write up your investigation and discuss your findings.

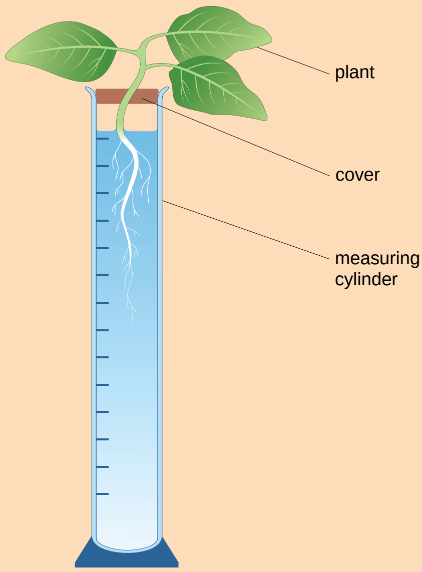


***Figure 4.17** Apparatus for measuring water loss in plants*

Activity 4.11: Investigating factors which affect transpiration – 2

In this investigation you are going to investigate transpiration using a piece of apparatus called a potometer, which measures the amount of water taken up by a plant. You need shoots from a plant for this experiment. Although this is not a perfect measure of transpiration, it can give us a good picture of what affects the rate. If you get your apparatus set up well and quickly, you will be able to investigate several different conditions in a single lesson.

You will need:

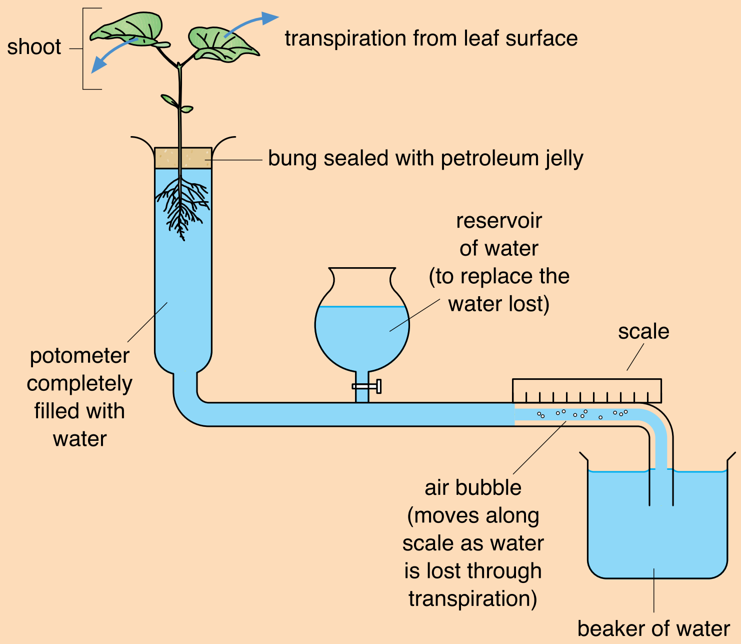


***Figure 4.18** A potometer*

Method

1. Set up your equipment as shown in Figure 4.18. You need to take care with your leafy shoot – cut it under water and transfer the cut end straight into the water-filled tubing. It is important NOT to get air into the stem of the plant.
2. Position your apparatus in good light and, using the reservoir, position the air bubble near the end of the scale.
3. Start timing. You may measure how far the bubble travels in five minutes (set time, measure distance) or you may choose to measure how long it takes your air bubble to travel from one end of the scale to the other (set distance, measure time). Record your measurements. Once you have tried the procedure, decide which way of measuring you want to use.
4. Repeat your investigation twice more to get three readings.
5. Now change the conditions – shine an extra light on your plant to increase the light intensity, fan the plant to increase air movement, etc.
6. Reset the air bubble and again record the movement of the air bubble – distance travelled in a set time or time taken to travel a set distance.
7. Again, repeat this to take three readings.
8. If you have time, change the conditions again – you could use light and breeze or a stronger breeze, etc.
9. Again, repeat the procedure to take three separate readings.
10. Write up your investigations, including all your results. Find the average reading for each set of conditions and plot a graph of your findings. What conclusions can you draw from your investigation? What further investigations would you like to do? How could you make your procedure more reliable and accurate?

Activity 4.12: Investigating factors which affect transpiration – 3

This investigation involves using cobalt chloride (or cobalt thiocyanate) paper. This is blue when it is dry, but turns pink when it is moist. You can use this investigation to look at how different conditions affect the rate of transpiration. If you work in groups, different people can investigate different conditions and then you can share your results.

You will need:

- cobalt chloride paper or cobalt thiocyanate paper
- a plant in a pot or a leafy shoot in water
- clear sticky tape

Method

1. Stick one piece of cobalt chloride (or cobalt thiocyanate) paper to the top surface of a leaf. Make sure the leaf is completely dry and cover the paper completely with the sticky tape.
2. Stick another piece of paper to the lower side of a different leaf in the same way.
3. If working in groups, some people keep the plant in normal lab conditions, some shine a bright light on the plant, some have the plant in a breeze, etc.
4. Note the time and observe the two pieces of indicator paper at intervals. How long does it take for the first trace of pink to appear on each piece of paper? How long does it take for each piece of paper to go completely pink?
5. Write up your experiment and collect results from other groups using the same or different conditions from your own.
6. Work out the average results for each set of conditions and use your findings to help you answer the following questions:

   Which side of the leaf loses water faster – the upper or the lower?

   Why do you think one side loses water faster than the other?

   How do different conditions affect the speed at which the plant loses water by transpiration?

Reducing water loss

If a plant begins to lose water faster than it is replaced by the roots, it runs the risk of wilting. The stomata in the leaves will close to stop this if possible. To make sure that water is not lost from the surface of the leaf generally, most leaves have a waxy, waterproof layer (known as the **cuticle**) to prevent uncontrolled water loss. In very hot environments the cuticle may be very thick and shiny. The fact that the stomata are on the underside of the leaf also helps because this means that they are not as exposed to the heat of the sun as they would be on the top of the leaf.

KEY WORDS

cuticle *waterproof upper surface layer found in many types of leaf*

Activity 4.13: To investigate water loss from the leaves of a plant

You are going to plan and carry out an investigation into the loss of water by a plant through its leaves. If you cover the surface of a leaf with Vaseline, you will block all the stomata and so prevent water loss. You are provided with the following:

- up to four small plants of the same species in pots
- Vaseline
- an accurate balance
- string

You may choose to experiment on whole plants or on individual leaves.

Plan an investigation following clear scientific principles to find out through which surface of the leaves a plant loses most water.

When your teacher has agreed to your plan, you may be allowed to carry out the investigation.

Adaptations of plants to reduce water loss in difficult environments

Plants manage to grow and survive in many different environments. In many places survival is a real struggle. Plants need to balance opening the stomata to allow photosynthesis to take place with the loss of water which takes place when the stomata are open. Plants which live in very hot areas like Somali, or in areas where there is relatively little water, often have adaptations which help them to balance up their different needs. They may have very thick, waxy cuticles to reduce any water loss through the overall leaf surface to an absolute minimum. Others have developed very hairy leaves, which trap a micro-atmosphere around the stomata and reduce water loss. Yet other plants have reduced their leaves to very narrow spikes to reduce the surface area over which water may be lost. On some plants the stomata are sunk into pits. Another way of preventing water loss, which you often see in grasses, is for the

Figure 4.19 *Aloe vera – this plant stores water in its fleshy leaves.*

leaves to be rolled, trapping a micro-environment of moist air inside. The purpose of all these adaptations is to reduce the loss of water from the leaves by transpiration, so the plant can photosynthesise and avoid wilting whatever the conditions around it.

Transpiration and agriculture

Transpiration has many implications for the way we grow our crops – and the crops we choose to grow. If our crop plants do not get enough water, then they will not be able to transpire and they will wilt. This means the cells will not work properly and the crops will not grow as well as they should. So, whenever possible we need to irrigate our fields and water the plants so that they can transpire fully, which allows them to photosynthesise and grow as much as possible.

It is not only the level of sunlight and the temperature which affects transpiration rates in our plants. Wind also increases the rate of transpiration. If we can grow our crops in relatively sheltered places, the rate of water loss will be slower and so our crops are more likely to grow well.

The final way in which transpiration affects agriculture is in our choice of crop plants. Some plants are more resistant to water loss by transpiration than others. By choosing crops which are suited to the conditions where we are growing them, we can improve our yields and make sure that transpiration works for us and does not cause our plants to wilt and fail.

Activity 4.14: Investigating ways of reducing water loss in Ethiopian plants

Explore the area around your home and your school. Collect leaves from a number of plants which you think may be adapted to prevent water loss.

Take them into your class and examine them carefully using a hand lens and possibly a microscope. You may want to make a varnish film from the leaves.

Draw and label the leaves you have investigated and make notes about your findings.

Summary

In this section you have learnt that:

- Water is transported from the roots to the rest of the plant in the xylem in a passive process which does not use energy.
- Water is taken up by the roots of the plants through osmosis.
- Water moves through the cells of the root to the xylem by osmosis. Once in the xylem, adhesive forces between the water and the walls of the xylem support the whole column of water, and as molecules evaporate away from the surface of the leaf, the following molecules are pulled upwards by cohesive forces between the water molecules. The main pull which moves water up from the roots to the leaves is the almost constant evaporation of water from the leaves. In the leaves water moves out of the xylem into the cells and across the leaf. When it reaches a mesophyll cell which is surrounded by air, water evaporates from the surface into the air and diffuses out through the stomata along a concentration gradient.
- The movement of water through the plant is known as transpiration. It is affected by a number of factors including light levels, temperature and wind.

- Plants are constantly losing water through transpiration, farmers need to irrigate their crops. Methods to reduce water loss through transpiration such as sheltered fields reduce the need for irrigation.
- Water transport in plants can be demonstrated using simple experiments.
- Mineral salts are taken in through the roots using active transport.
- Organic materials such as sugars from photosynthesis are moved around the plant in the phloem in an active process.

Review questions

1. Which of the following conditions will not increase the rate of transpiration in a plant?

   A high humidity in the air

   B windy conditions

   C high temperatures

   D high light levels

2. Water moves out of plant leaves through the:

   A epidermis

   B mesophyll

   C stomata

   D chlorophyll

3. Cobalt thiocyanate changes colour in the presence of water. Does it go from:

   A pink to blue

   B blue to pink

   C blue to yellow

   D pink to white

4. Explain why a constant supply of:

   a) food

   b) water

   is so important to the cells of the plant.

5. a) What are stomata?

   b) What is their role in the plant?

   c) Describe exactly how water moves up the plant in the transpiration stream.

4.4 Response in plants

By the end of this section you should be able to:

- Demonstrate the processes of germination in dicots and monocots.
- List the plant hormones.
- State the functions of the plant hormones.
- Outline the mechanism of action of auxins.
- Explain the effect of removing apical dominance on plant growth.
- Demonstrate how sunlight influences plant growth.
- Name the different types of tropisms in plants.
- Explain the processes of tropism.

KEY WORDS

hormones *chemicals produced in one part of an organism which produce specific effects on a different part of the organism*

endosperm *the nutritive tissue of a seed, consisting of carbohydrates, proteins and lipids*

plumule *the bud, or growing point, of the embryo, above the cotyledons*

radicle *the first part of a seedling (a growing plant embryo) to emerge from the seed during the process of germination*

cotyledons *the first leaves sent out by the germinating seed – the seed leaves*

testa *the hard external coating of a seed*

All living organisms need to be able to respond to their surroundings. This may be to find food, move towards the light or avoid danger. To take in information about the surroundings and then react in the right way is known as co-ordination. It is easy to see why animals need to respond, and you will be looking at co-ordination in animals later in this section. But plants need to be co-ordinated too. They need to respond to factors such as light, water and gravity to make sure that they grow the right way up, and that they make as much food by photosynthesis as possible.

Plants achieve their co-ordination and responsiveness through a system of **hormones**. Hormones are chemical messengers which are produced in one part of an organism and have an effect elsewhere. Plant hormones (phytohormones) have several effects on plants. For example, they co-ordinate flowering, cell division and cell elongation. These are essentially growth processes and plant responses of this type are called growth responses. Since growth is a slow process, most plant responses are slow.

Figure 4.20 *Plants respond to a number of things and their responses show clear co-ordination.*

The germination of seeds

In most flowering plants, growth starts when the seed begins to germinate.

Seeds come in many different sizes and shapes, but the basic structure of seeds always contains certain things:

- Food storage tissue known as the **endosperm**.
- An embryo plant made up of three main parts – the **plumule** (embryonic shoot), the **radicle** (embryonic root) and the **cotyledons** (embryonic leaves).
- The **testa** – the seed coat, which may be thin and papery like the covering on a groundnut or very strong and hard like the shell of a nut.

It is the number of these embryonic leaves that are present which gives us the main division of the angiosperms into monocotyledons (one seed leaf) and dicotyledons (two seed leaves).

In monocots the main food store is the endosperm and the embryo remains a very small part of the seed. In dicots the endosperm moves food into the cotyledons which become the main food store. By the time the seed is mature the endosperm has all but disappeared. The embryo with its food-swollen leaves takes up most of the seed (see figure 4.21). Once the food store has been laid down and the embryo has developed the seed dries out (dehydrates). It loses much of its wet mass and becomes dormant.

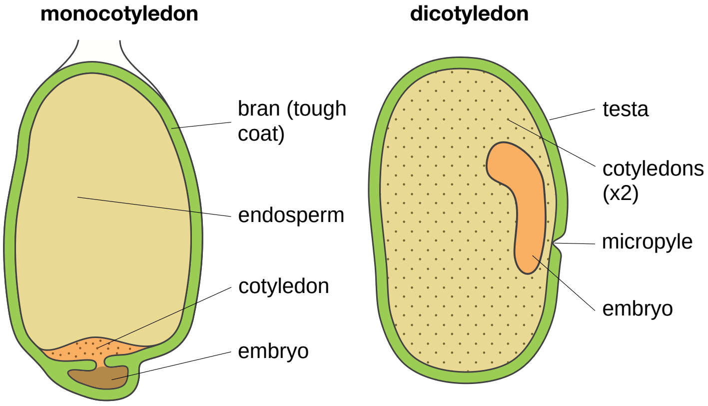


Figure 4.21 *The internal arrangements of monocot and dicot seeds may look very different, but their basic parts are the same – an embryo ready to develop, a food store to supply the energy needed and a protective seed coat.*

Activity 4.15: Investigating dicot and monocot seeds

You will need:

- a fresh or soaked dicot seed such as a bean or a pea
- a fresh or soaked monocot seed such as maize
- a knife or scissors
- a hand lens if available

Method

1. Observe and draw the external appearance of the two different seeds. You should be able to make out the shape of the radical through the testa and you may be able to see the micropyle, the tiny hole through which water enters the seed.
2. Remove the testa of the dicot seed and carefully separate the two cotyledons. Observe the embryo plant carefully (use a hand lens if you have one available) – and draw what you can see. Use figure 4.21 to help you.
3. Cut the monocot seed in half vertically and again observe, draw and label what you see.
4. Make a table comparing the two types of seed.

Once a seed is mature and conditions are right – it needs water, warmth and oxygen – the seed begins to germinate. To begin with chemical changes take place inside the seed. As the seed absorbs water, the large insoluble food molecules stored in it undergo changes. They are broken down (hydrolysed) into soluble food. The main food storage material in seeds is starch, and it is stored either in the cotyledons or in the endosperm. This starch store is converted to sugars by the action of the enzyme diastase. In some seeds fats and oils are stored. In these seeds the enzyme lipase catalyses the hydrolysis of fats to fatty acids and glycerol. Proteolytic enzymes present in the seeds catalyse the hydrolysis of proteins to amino acids.

A lot of energy is needed during germination. The seed cannot make its own food by photosynthesis while it is underground, so the energy needed comes from the stored food materials. It follows

KEY WORDS

hypocotyl *the first leaf-like structure that appears on a germinating seed. Grows upward in response to light*

epigeal *germination cotyledons are carried above the ground*

hypogeal *germination cotyledons remain below the ground*

therefore that as a seed germinates its weight decreases as the stored food is used up. The decrease in weight continues until the seedling is capable of photosynthesising.

The following is a summary of changes which occur during the germination of a bean seed – a dicot seed.

1. The seed absorbs water through the micropyle (small hole) and swells.
2. The testa (seed coat) bursts and the radicle emerges. The radicle continues to elongate and gives rise to many side roots.
3. As the radicle elongates it pushes the seed out of the ground. The curved part of the radicle which protrudes is called the epicotyl. The seed coat is discarded and the two cotyledons (seed leaves) open out and begin to photosynthesise.
4. The plumule emerges from in between the cotyledons and produces the first true leaves. At this stage, the young plant is called a seedling.

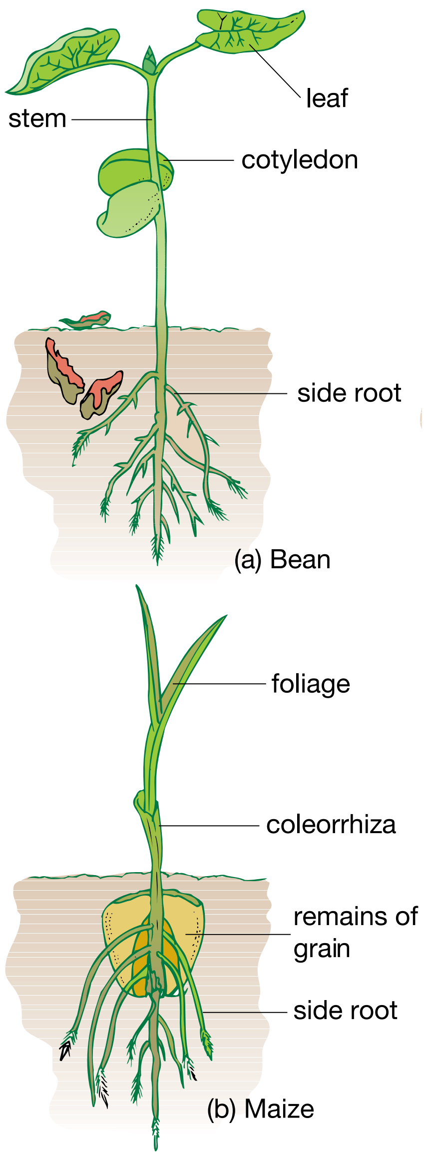


***Figure 4.22** a) Dicot (epigeal) germination, b) monocot (hypogeal) germination*

Epigeal (dicot) and hypogeal (monocot) germination

Seeds germinate in different ways. When the bean seedling emerges from the soil it is curved. The curved portion, the **hypocotyl**, pushes through the soil. As germination continues, the hypocotyl straightens and carries the cotyledons and the plumule above the soil surface. This type of germination, where the cotyledons are carried above the soil, is called **epigeal germination**. Most dicotyledonous plants have seeds which exhibit epigeal germination. Such seeds include castor oil seeds, groundnuts, cotton and bambara nuts. Epigeal germination also occurs in a few monocotyledonous seeds such as onions and lilies.

Germination of a maize grain follows a different pattern from that of a bean seed. The plumule pushes its way out of the soil while the cotyledon remains underground. The plumule does not form a hook as in bean seeds. This type of germination in which the cotyledons remain underground is called **hypogeal germination**. Other examples of grains exhibiting hypogeal germination are wheat, sorghum and millet. A few dicotyledonous seeds such as kidney beans and broad beans exhibit hypogeal germination.

Activity 4.16: Observation of dicot (epigeal) and monocot (hypogeal) germination in bean seeds and maize grains

You will need:

- bean seeds
- maize grains
- two beakers with blotting or absorbent paper around the sides and water in the bottom (see figure 4.23)

Method

1. Germinate some bean seeds and maize grains in two separate beakers.
2. Observe the seedlings as they emerge from the seeds.
3. Draw diagrams of the bean and the maize seedlings.
4. Compare your diagrams with those in figure 4.22.
5. Label your diagrams.

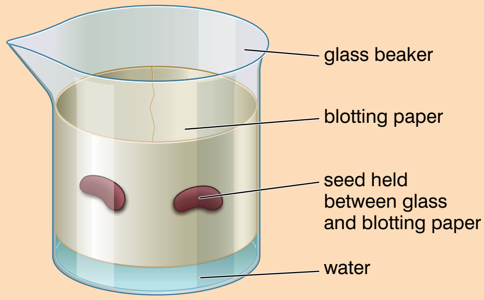


***Figure 4.23** Growing seeds in a beaker*

Germination of any type can occur only in a seed which is viable. A viable seed is one in which the embryo is alive. The length of time a seed can remain viable varies in different species. Many seeds can remain viable for up to 50 years if properly stored.

When seeds germinate it is vital that the parts of the seedling grow in the right directions. The new roots must grow down into the soil to get the water and minerals the new plant needs. The shoot must grow upwards towards the light so that the new shoots can photosynthesise and make as much food as possible so the seedling can grow. How is the direction of growth of plants controlled?

Plant hormones and growth

Growth in plants is influenced by chemical messengers called plant hormones. Examples of plant hormones are **auxins** (including indole-acetic acid, IAA), **gibberellic acid**, **cytokinin**, **ethylene** and **abscisic acid**. Some of these hormones promote growth, others inhibit it. Some of them will promote growth in one type of plant tissue and inhibit it in others!

Auxin (IAA) is the best-known plant hormone and it is involved in general plant growth. It stimulates the elongation of the new plant cells, so they get longer and bigger. It is also involved in **apical dominance**. IAA is made at the tip of the main shoot and as it moves down the stem it slows down the growth of side shoots. So the main shoot dominates the whole plant. If you cut off the growing tip of a plant it will bush out. The side shoots grow quickly once you remove the apical dominance from the auxins produced by the main shoot.

Auxin also stimulates the growth of roots. If auxin is applied to a cut stem it will stimulate new roots to grow – this is widely used by gardeners and farmers in some parts of the world to help them take successful cuttings.

The best-known function of auxins is in the responses of plants to the world around them. The responses of plants towards things such as light and gravity are called **tropisms** and you will be looking at these in more detail later in this section.

Another group of plant hormones are the **gibberellins**. These hormones stimulate the growth of plant stems. If you take a dwarf plant and give it IAA, nothing much will happen. If you give it

KEY WORDS

auxins *plant growth hormones*

gibberellic acid *a growth-stimulating and dormancy-breaking plant hormone*

cytokinin *plant hormones that promote cell division*

ethylene *a gaseous plant hormone that stimulates fruit ripening and the dropping of leaves*

abscisic acid (ABA) *a growth-inhibiting hormone*

apical dominance *growth concentrated in the terminal bud, allowing it to grow taller, thereby increasing its exposure to sunlight*

tropisms *the reactions of plants to stimuli*

gibberellins *group of hormones that regulate plant growth* gibberellins the stems will grow until the plant is a normal size. Gibberellins also help seeds to break their dormant period and start to grow. Scientists think they do this by stimulating the production of the enzymes needed to break down the food stores in the seeds.

Cytokinins are hormones that stimulate cell division in plants so they are very important in plant growth. The balance between auxins and cytokinins in a tissue culture of plant cells decides whether roots or shoots will grow.

Ethylene, a plant hormone, is a gas at room temperature and it causes fruit to ripen. It also causes fruit and leaves to fall from the plant in some species.

Abscisic acid (**ABA**) is another important plant hormone. It inhibits growth and plays a major role in leaf fall. It is also involved in seed dormancy. There is some evidence that it may be involved in geotropisms, but it plays a small part compared to IAA.

KEY WORDS

phototropism *the tendency of plants to move or grow towards light*

Tropic responses

Plants need light for photosynthesis, and they grow towards the light. When a seed germinates the roots grow downwards and the shoots grow upwards. These responses to gravity are vital if the new plant is to be anchored firmly in the soil, and the shoots and leaves held above the ground in the sun. Responses to stimuli that come from one direction are known as tropisms. The following investigations will allow you to observe some tropisms for yourself.

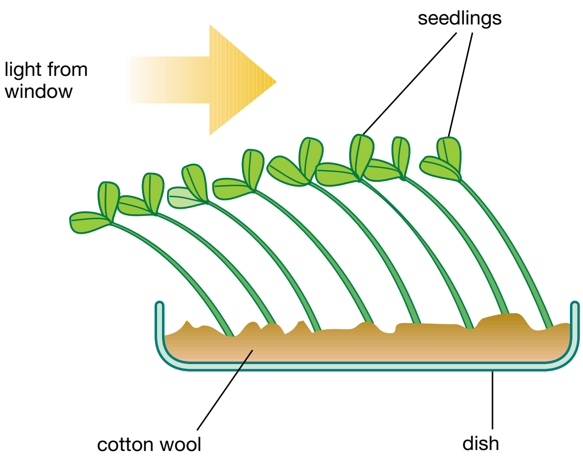
Activity 4.17: Determination of the effect of light on shoot growth

You will need:

- bean seeds
- pots
- soil
- a lightproof box with a hole on one side

Method

1. Germinate some bean seeds in two different pots.
2. When the shoots are about 6 cm long, place one pot in a lightproof box with a hole on one side, and the other pot in full sunlight.
3. Leave both pots in a well-lit place.
4. After 2–3 days observe what has happened to the seedlings in the two pots.



The shoots of seedlings which were uncovered will grow upwards normally. Those which were in a lightproof box grow towards the hole. Since the hole was the only source of light into the box, you can see that the growth curvature of the shoots was a response to light reaching the plants from one side only. This type of response in which shoots grow towards the light is termed positive **phototropism**.

Figure 4.24 *Seedlings respond vigorously to light – and if it only comes from one side, they will grow towards it.*

Light isn't the only thing that plants respond to – they are also affected by gravity.

Activity 4.18: Determination of the effect of gravity on shoot and root growth

You will need:

- bean seeds
- blotting paper
- a Petri dish

Method

1. Germinate some bean seeds on damp blotting paper in a Petri dish.
2. When the radicles and plumules have emerged, arrange the seedlings in two different positions. Place some seedlings in a horizontal position and others vertically with their radicles facing downwards.
3. Leave the setup for 2–3 days in the dark to eliminate the effect of light.
4. Observe what happens to the direction of growth of the radicles and plumules. Make careful annotated drawings of your results.

In activity 4.18 you will have observed that when seedlings are placed horizontally, their roots grow downwards and their shoots upwards. Roots of seedlings which were vertically placed continued to grow downwards and their shoots continued to grow upwards. Whichever way up you put the seeds the roots grow downwards and the shoots upwards. This suggests that the normal direction of growth of roots downwards and shoots upwards is affected by the force of gravity. Movement in response to the stimulus of gravity is called geotropism. Roots are positively geotropic (they grow towards gravity) while shoots are negatively geotropic (they grow away from gravity). The response of seedlings to gravity can also be investigated using a piece of apparatus known as a klinostat. This rotates, so by fixing some seedlings to the klinostat in a horizontal position (see figure 4.25) you can make sure that gravity acts equally all over the plant. You need other seedlings fixed horizontally but not rotated as a control. After two days you can see clearly the effect of the rotation. The root keeps bending towards gravity, and the shoot away from gravity, but because the stimulus is not unilateral, due to the klinostat the movements all cancel out and the plants stay straight!

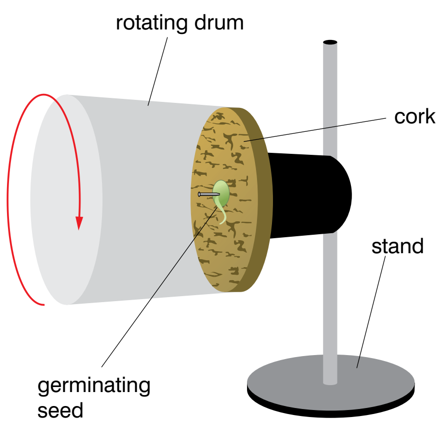


Figure 4.25 *A klinostat can effectively stop gravity from being a unilateral force on your plant.*

Light and gravity both have an important effect on the growth of plants. Water is also very important, and so it is not surprising that plants respond to water as well.

Activity 4.19: Investigating the effect of water on root growth

You will need:

- wire gauze
- bean seedlings
- cotton wool
- retort stand clamps

Method

1. Secure a wire gauze horizontally using two retort stand clamps.
2. Place some bean seedlings on the wire gauze in such a way that the radicles pass through the pores of wire gauze.
3. Surround the seedlings with wet cotton wool above the gauze.
4. Leave the setup for two to three days.
5. Make sure that the cotton wool is kept wet.
6. Observe what happens to the roots.

KEY WORDS

hydrotropism *the tendency of plants to move or grow towards water*

indole-3-acetic acid (IAA) *a plant growth hormone*

In activity 4.19 you should have observed that the radicles grew upwards towards the wet cotton wool. Since the cotton wool was the only wet area, it can be concluded that the growth curvature of the radicles was due to the water present in the cotton wool. The type of response by which roots grow towards water is termed **hydrotropism**. The growth of roots upwards towards water against the force of gravity suggests that water as a stimulus has a greater influence on root growth than gravity.

In each of the activities, the stimulus has been from one direction (unilateral) and the growth responses have been either towards or away from the source of the stimulus. These responses are therefore described as directional responses, tropic responses or tropisms.

How are tropic responses brought about?

As you can see from your earlier experiments, plants respond to unilateral stimuli. Further experiments have allowed scientists to find out more about these responses. Maize grains germinate to produce a straight shoot called a coleoptile. Coleoptiles are widely used in experiments to investigate the role of hormones in shoot growth.

It is known that the growth region of a shoot is some distance below the tip. This fact suggests that removal of the tip would not affect the growth of the shoot. However, when the tips of the coleoptiles are removed (they are decapitated), they don't grow. Since we know that the growth of a shoot is promoted by auxins, failure of decapitated seedlings to grow suggests that the auxins are probably produced in the tip. It has been found out that the growth hormone, auxin, produced in the tip is **indole-3-acetic acid** (**IAA**). IAA diffuses from the tip to the growth region to initiate growth. In the decapitated seedlings, although the source of IAA production was removed, the seedling grew for a while and then stopped. This is because some IAA had already diffused away from the tip before decapitation. This amount of IAA was responsible for the slight growth.

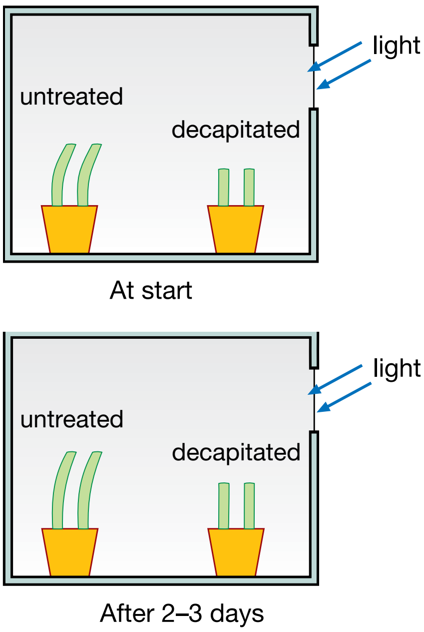


Figure 4.26 *A simple experiment like this suggests that growth is stimulated by something made in the tip of the shoot.*

The fact that IAA promotes growth in shoots suggests that it is also involved in the responses of the shoots to light and gravity. A simple experiment such as that in figure 4.25 shows you clearly that the tropic response of a plant to gravity is brought about by growth. Shoots lit from one side only also respond by growth – the shaded side grows faster than the illuminated side so the shoot bends over towards the light. IAA promotes growth so it seems likely that the shaded side of shoots affected by one-sided light had more IAA than the illuminated side. Since the growth curvature was influenced by light, it suggests that light is somehow involved in the distribution of IAA in the shoot. Experiments have shown that IAA diffuses away from light. When a shoot is illuminated on one side, IAA in that side diffuses towards the dark side of the shoot. This causes a build-up of the hormone in the dark side of the shoot. Since growth is directly proportional to the amount of IAA, the dark side will grow faster than the illuminated side. This explains the observed growth curvature of shoots shown in the experimental set up in figure 4.26.

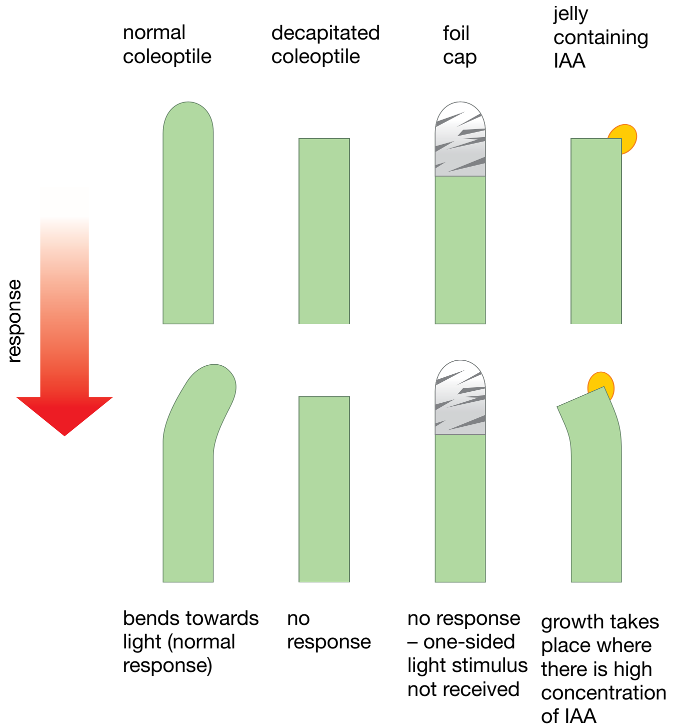


Figure 4.27 Experiments such as these help us to understand how tropic responses in plants work.

The upward growth of the shoot and the downward growth of the root, when the bean seedlings were placed horizontally, involve plant hormones. In the shoot, the force of gravity causes an accumulation of IAA on the underside of the plumule. The build-up of IAA on the underside promoted more growth in that region than the upper portion. This differential growth resulted in the stem growing upwards.

The downward growth of the root is also influenced by IAA, but in the root tip the hormone inhibits growth, rather than stimulating it. The force of gravity causes an accumulation of IAA on the underside of the root, resulting in reduced growth in that region. The corresponding upper side of the root, which had very little or no IAA, grows faster than the underside. This differential growth results in the downward curvature of the roots. The different effects of this hormone on root and shoot growth are illustrated in figure 4.28.

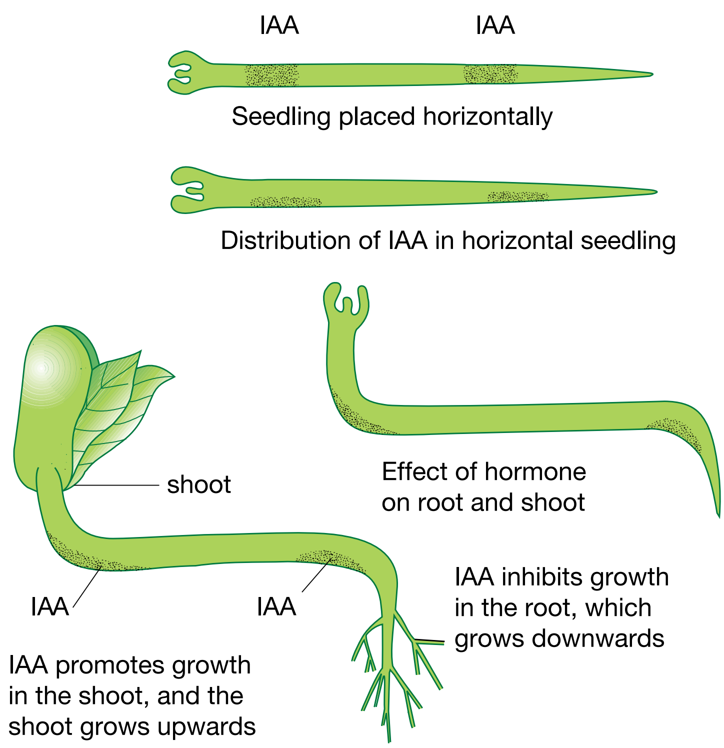


Figure 4.28 The different effects of auxin on the growth of roots and shoots.

Activity 4.20: Investigation of the role of the shoot tip in the growth of a plant

You will need:

- about ten maize grains
- two beakers
- cotton wool
- a lightproof box with hole at one side

Method

1. Germinate about five maize grains on damp cotton wool in each of two beakers. Germination should be done in darkness.
2. When the coleoptiles are about 4 cm long and are not yet open, cut off the tips of five coleoptiles in one beaker.
3. Leave the five seedlings in the other beaker intact.
4. Measure and record the height of each set of seedlings.
5. Place the beakers in a lightproof box which has a hole on one of its sides.
6. Leave the setup for 2–3 days.
7. Observe what has happened to each set of seedlings.
8. Measure and record the height of each set of seedlings.

Importance of tropic and nastic responses

In tropisms, some stimuli to which plants respond positively are the basic requirements for the plant's life. Water, for example, is one of the important requirements for photosynthesis. This means that when positive hydrotropism occurs, roots come into close contact with water. This makes it possible for them to absorb as much water and mineral salts as possible for the plant. In addition to water, plants require light for photosynthesis. When a plant responds positively to light its leaves become well exposed to it. This maximises the amount of light available for photosynthesis.

Summary

In this section you have learnt that:

- Monocot and dicot seeds both undergo germination when the new plant starts to grow, but the process differs in different types of seeds.
- Plants have hormones which include auxins, gibberellins and ethylene.
- Plant hormones have a number of different functions in the plant including the control of growth, the response to stimuli such as light and gravity, flowering and leaf fall.
- Auxins work by affecting the rate of growth and elongation of the cells. For example, if there is more auxin on one side of a shoot than the other, that side will grow more and the shoot will bend.
- If you remove the leading shoot from a plant you remove the apical dominance – this is the effect of the auxin made in the lead shoot which inhibits the growth of side shoots.
- Sunlight influences plant growth – it slows upward growth and causes responses to unilateral light. These effects can be demonstrated experimentally.
- There are several different types of tropisms in plants including phototropisms, and geotropisms.
- In a tropism, a plant responds to a stimulus by producing different levels of auxins which in turn affects growth. As a result, part of a plant grows towards or away from a stimulus.

Review questions

1. Which of the following is NOT a tropic response in plants?
   A phototropism
   B geotropism
   C nitrotropism
   D hydrotropism
2. The young shoots which are often used in experiments on tropisms are known as:
   A coleoptiles
   B adventitious roots
   C cotyledons
   D cornucopia
3. Which of the following is NOT a plant hormone?
   A IAA
   B gibberellin
   C abscisic acid
   D adrenalin

End of unit questions

1. The vascular bundles contain:
   A xylem and epidermis
   B epidermis and phloem
   C xylem and phloem
   D stomata and phloem
2. Which tissue contains the most chloroplasts?
   A epidermis
   B palisade mesophyll
   C spongy mesophyll
   D phloem
3. The stomata open and close to allow:
   A carbon dioxide to diffuse into the leaf and oxygen and water vapour to diffuse out of it
   B oxygen to diffuse into the leaf and carbon dioxide and water vapour to diffuse out of it
   C water vapour to diffuse into the leaf and carbon dioxide and oxygen to diffuse out of it
   D carbon dioxide, oxygen and water vapour to diffuse into the leaf

4. A leaf has large surface areas both outside and inside. Describe three ways in which these adaptations help it to photosynthesise effectively.
5. Which of the following is the correct equation for photosynthesis:
   A carbon dioxide + oxygen [+ chlorophyll + light energy] → glucose + water
   B oxygen + water [+ chlorophyll + light energy] → glucose + carbon dioxide
   C carbon dioxide [+ chlorophyll + light energy] → glucose + oxygen + water
   D carbon dioxide + water [+ chlorophyll + light energy] → glucose + oxygen
6. The glucose made during photosynthesis is converted into which compound to be stored?
   A fat
   B starch
   C cellulose
   D protein
7. Water is split to provide hydrogen to make glucose and oxygen as a waste product during:
   A the light-dependent reaction of photosynthesis
   B the light-independent reaction of photosynthesis
   C the trapping of light by chlorophyll
   D none of the above
8. Explain any two ways in which photosynthesis is important to animal life.
9. a) Define the term photosynthesis.
   b) State the environmental factors that are necessary for photosynthesis.
   c) How would you show the necessity of one of the factors you have given in b) above in photosynthesis?
10. Water is taken up through the roots of plants by a process known as:
   A diffusion
   B osmosis
   C active transport
   D evaporation

11. Farmers need to irrigate their fields to replace water because plants constantly lose water through:

    A osmosis

    B photosynthesis

    C transpiration

    D diffusion

12. Which of the following is not an adaptation used by some plants to reduce water loss?

    A thick waxy cuticle

    B stomata on the underside of the leaf sunk into pits

    C leaves reduced to thin spines

    D stomata on the upper surface of the leaf

13. Make a table to compare and contrast the structure and function of the xylem and the phloem in a plant.

14. Which of the following statements are correct?

    I shoots are positively phototropic but negatively geotropic

    II roots are positively hydrotropic but negatively geotropic

    III roots are positively hydrotropic and geotropic

    IV shoots are negatively hydrotropic but roots are negatively phototropic

    A I, II and III

    B I, III and IV

    C I, II and IV

    D II, III and IV

15. Which of these plant responses are not controlled directly by simple plant hormones?

    A shoots bending towards the light

    B fruit falling when ripe

    C roots bending towards gravity

    D the time of year a plant flowers

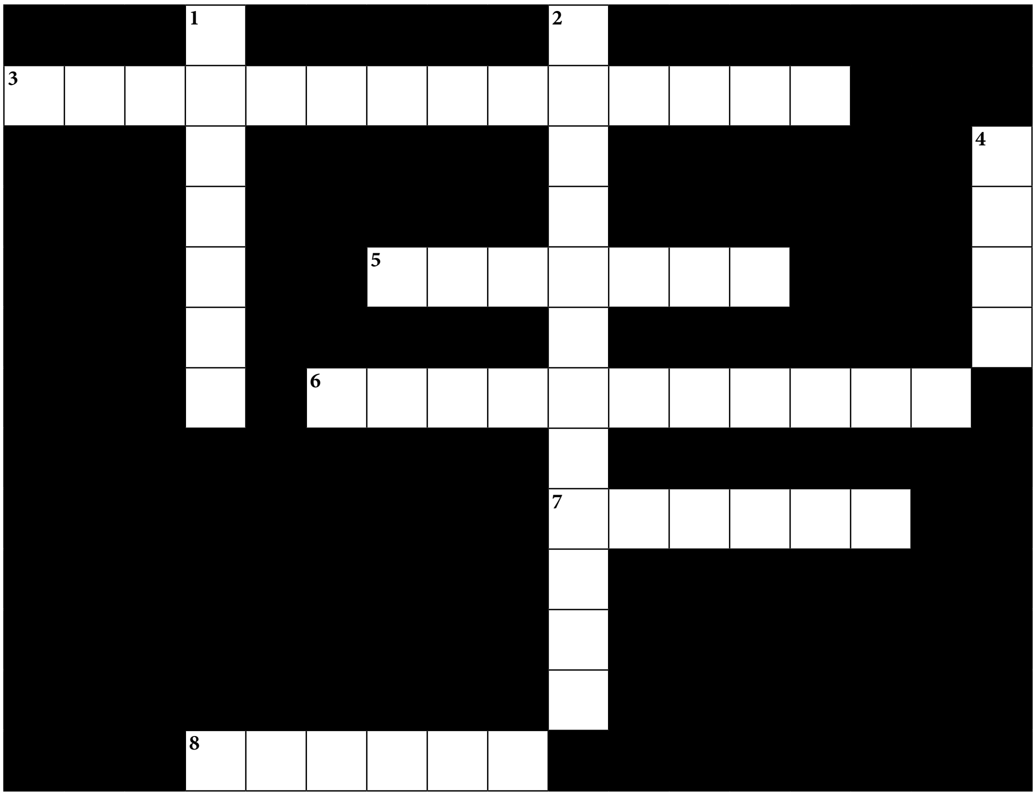
16. a) What is meant by phototropism?

    b) Describe an experiment which would demonstrate phototropism in shoots.

    c) Explain how you could demonstrate directly that IAA is involved in plant phototropisms.

17. Describe how a klinostat can be used to demonstrate the role of gravity in geotropisms.

Copy the crossword puzzle below into your exercise book (or your teacher may give you a photocopy) and solve the numbered clues to complete it.



ACROSS

3 The reaction by which plants make their own food from carbon dioxide, water and light energy (14)

5 A plant with only one cotyledon in the seed (7)

6 Green pigment which traps light energy for photosynthesis (11)

7 Food carrying, living transport tissue in plants (6)

8 Yellow-brown chemical which turns blue-black in the presence of starch (6)

DOWN

1 Pores in the lower surface of a leaf that control the entry and exit of gases (7)

2 The tendency of plants to move or grow towards or away from light (12)

4 Plant organ where most photosynthesis takes place (4)