CHAPTER 2

Plant Nutrition

One of the main characteristics of living things is their ability to feed. This is referred to as nutrition. Nutrition is the process by which organisms obtain and use food. Some organisms are able to manufacture their own food, while others must obtain it from their environment.

In animals, the food materials taken in are usually in the form of complex compounds. These are broken down to simpler compounds which can be absorbed into the cells during digestion. In green plants, complex food materials are first synthesized and then distributed to all parts of the plantâ€™s body.

Plants are autotrophs. This is because they are able to manufacture their food from simple inorganic substances in their environment and build up complex organic substances. Autotrophs are of two main types:

(1) Photosynthethic autotrophs
(2) Chemosynthetic autotrophs

Photosynthethic autotrophs are green plants that use sunlight energy to fix carbon to organic compounds.

Chemosynthetic autotrophs use the energy from oxidizing substances around them to fix carbon to organic compounds e.g. iron, bacteria, sulphur, bacteria and nitrogen - fixing bacteria.

Photosynthesis

Photosynthesis is the process by which green plants (autotrophs) manufacture food (organic compounds) from carbon (IV) oxide and water using the energy absorbed from sunlight by the chlorophyll with the help of enzymes, while oxygen is liberated as a by-product.

The net chemical equation of photosynthesis can be written thus:

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

This equation shows that carbon (IV) oxide and water combine in the presence of light to form simple sugar and oxygen. This oxygen is a by-product which is released into the atmosphere. Photosynthesis goes on in the chloroplast found in any green part of plants.

Mechanism of photosynthesis

The process of photosynthesis is not as simple as the equation for photosynthesis suggests. Photosynthesis consists of a series of complex reactions. These reactions can be divided into two groups: the light reaction (photophase) and the dark reaction.

Light reaction (Photophase)

Light energy absorbed by chlorophyll in green parts of plants is used to split water molecules into hydrogen (H^+) and hydroxy 1 (OH^-) ions. This is known as photolysis of water.

The reactions between the hydroxyl ions lead to the formation of oxygen and water molecules. Hence, water, and not carbon (IV) oxide, is the source of excess oxygen liberated during photosynthesis as a by-product. The overall chemical equations of the light reaction can be represented thus:

$$H_2O \xrightarrow[\text{chlorophyll}]{\text{light energy}} H^+ + OH^-$$

$$2OH + 2OH \longrightarrow 2H_2O + O_2 \uparrow$$

Dark reaction

Although the dark reaction normally occurs in the absence of light either in the day or night, it is conventionally called a dark reaction because neither light energy nor chlorophyll is needed.

First, hydrogen ions and carbon (IV) oxide molecules combine chemically in a complex series of reaction each of which is controlled by a particular enzyme. Simple sugars are first formed followed by other carbohydrates, lipids and proteins. The overall chemical equation of the reaction can be represented thus:

$$4H + CO_2 \xrightarrow{\text{enzymes}} CH_2O + H_2O.$$

Note: CH_2O is the carbon skeleton from which simple sugars and other organic foods or compounds are synthesized.

A part of the radiant energy absorbed by the chlorophyll is stored as chemical energy in the organic molecules (i.e. foods) synthesized during the dark reaction. As a result, photosynthesis is an endodermic reaction. Carbohydrates, fats and oils, and proteins are formed during the dark reaction.

Materials and conditions necessary for photosynthesis

The materials needed for photosynthesis are water, carbon(IV) oxide, light energy, and suitable temperature. These we can call external factors. *Water:* The root hairs of plants absorb water and mineral salts by the process of osmosis and diffusion respectively from the soil. Water passes to the root xylem before being conducted to the stem xylem; from where, it is conducted to the leaf veins, then to the mesophyll cells and finally to the chloroplast where the light energy captured is used for photolysis of the water molecule. Without water, photosynthesis will not take place.

Carbon (IV) Oxide: Carbon(IV) oxide from the atmosphere diffuses through the stomata into the intercellular air spaces and then to the spongy mesophyll. It then dissolves in the water film in the spongy mesophyll cells. From here, the carbon (IV) oxide diffuses to the chloroplasts where it combines with the hydrogen ions from the light reaction.

Light Energy: Part of the light energy is absorbed from sunlight by the chlorophyll. Most of the radiant energy (especially the green spectrum) is reflected by the leafâ€™s chlorophyll. It is the red and blue ends of light spectrum that are mainly used in photosynthesis.

Suitable Temperature: Photosynthesis preceeds by a series of chemical reactions controlled by many enzymes. This can be shown by comparing a plantâ€™s rate of photosynthesis at different temperatures and observing that the optimum temperature for photosynthesis is around 30Â°C. At lower temperatures, the rate is slowed down. If the temperature exceeds 40Â°C, the process stops altogether since the enzymes involved are proteins which are denatured at a high temperature of 40Â°C and above.

Chlorophyll: Chlorophyll is the pigment found in the palisade and mesophyll cells of a leaf. What we have been calling chlorophyll is in fact a mixture of closely related pigments of which chlorophyll is one. These pigments are chlorophyll â€˜aâ€™ (blue-green), chlorophyll â€˜bâ€™ (yellow-green), xanthophyll (yellow), carotene (orange) and phaeophytin (grey).

Chlorophyll â€˜aâ€™ is the most abundant pigment and is of universal occurrence in all photosynthesizing plants. Its function is to absorb light energy and convert it into chemical energy. The other pigments do this too and then probably hand on the energy to chlorophyll â€˜aâ€™.

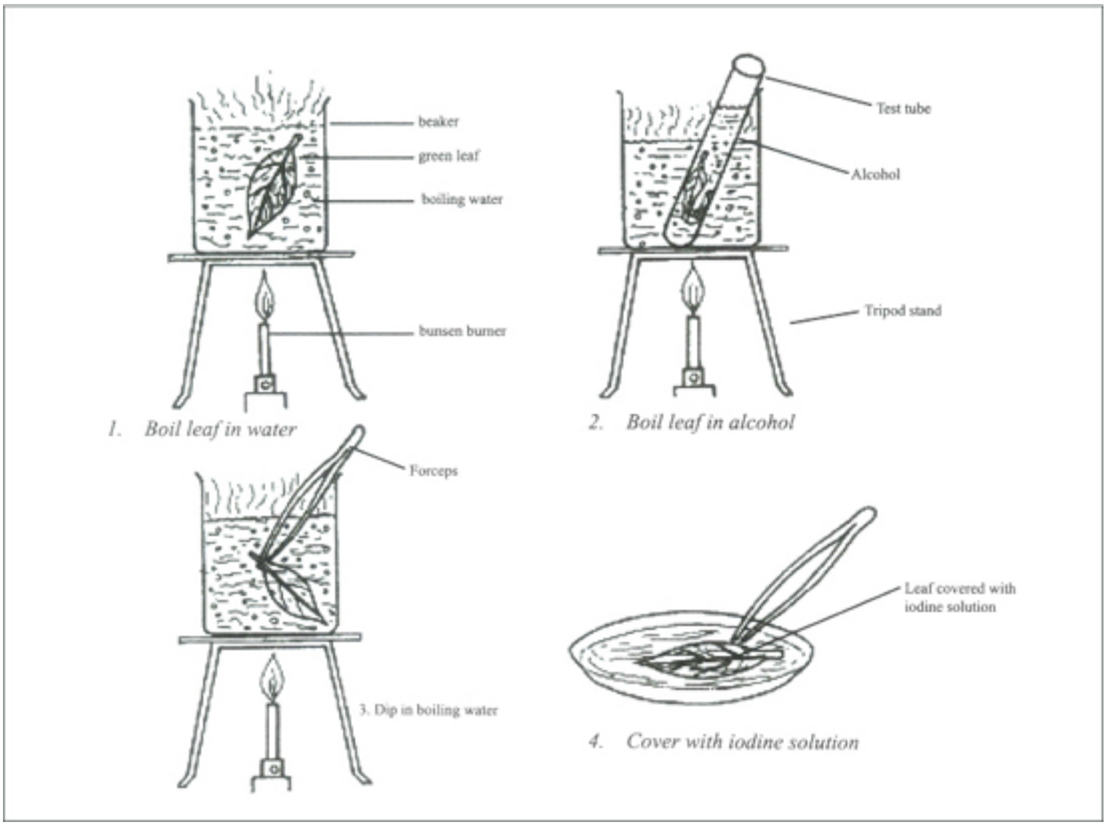

Fig. 2.1 Testing a leaf for starch

Evidence of photosynthesis

The first main product of photosynthesis is simple sugar. In many plantsâ€™ leaves, it is immediately converted into starch for storage. Some plants may convert the simple sugar into fats and oils or proteins depending on their food requirements. Since many plants usually convert their excess simple sugar into starch, the simplest way of testing whether a plant has photosynthesized or not is to test its leaves for starch.

Some plants, especially many monocotyledons, do not change their sugar into starch. Hence, if their leaves are tested for starch, a negative result would be obtained.

Part of the foods synthesized are converted into soluble forms and carried in the phloem vessels to various parts of the plant where they are needed or stored when not needed. This process is called translocation. See chapter 5, Book 2.

Experiment 2.1

Aim: To test for starch

Materials: A fresh green leaf, bunsen burner, tripod stand, test tube, petri dish, beakers, water, iodine solution, forceps, dropping pippette, water and alcohol.

Method:

1. Pluck a fresh green leaf from a plant in the sunlight.

2. Boil the leaf in water for five minutes, to kill the protoplasm, inactivate the enzymes and burst any starch grains present (Fig. 2.1)
3. Roll up the leaf loosely and place it in a boiling tube about one third full of 70% alcohol. Plug the top of the tube with cotton wool. Place the tube in a beaker of water. This is known as waterbath and warm the water gently until the alcohol begins to simmer. The alcohol will decolourize the leaf. (This method must be carefully followed because alcohol is highly inflamable).
4. Dip the leaf in warm water to soften it.
5. Place the leaf in a petri dish containing dilute iodine solution for five minutes.

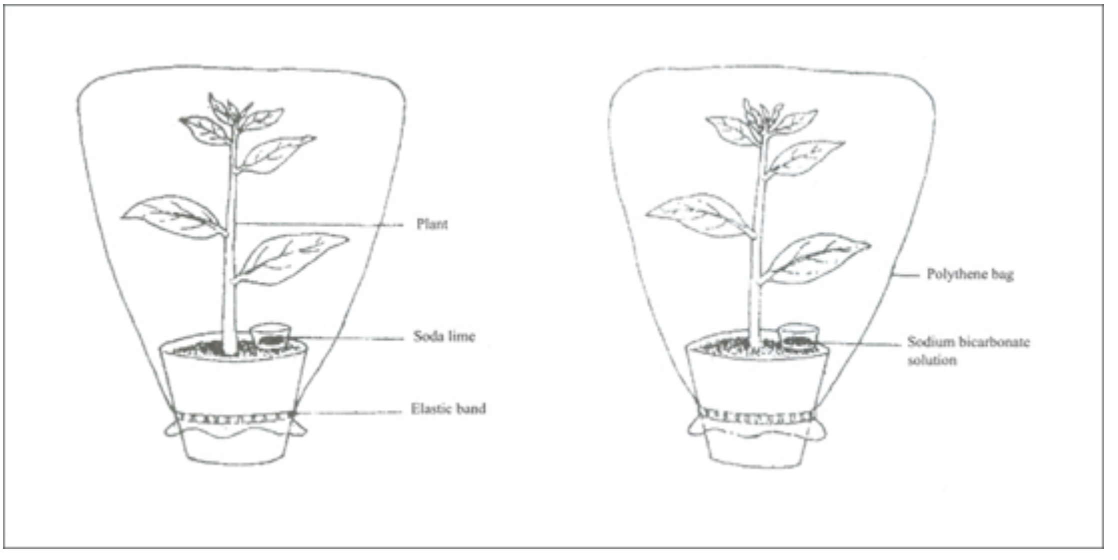

Fig. 2.2 Demonstrating the importance of Carbon (IV) oxide in photosynthesis

Observation: If starch is present, a blue black colour will be seen.

Conclusion: This shows that the leaf has photosynthesized.

Experiment 2.2

Aim: To show that carbon (IV) oxide is necessary for photosynthesis.

Materials: Two potted plants, transparent polythene bag, dark cupboard, beaker of soda lime, beaker of sodium bicarbonate solution, elastic band and materials to test for starch.

Method

1. Destarch two potted plants (A and B) by keeping them in a dark, airy cupboard for two days.
2. Put a dish of dampened soda lime on the soil beside one of the plants(A). Cover the plant with a transparent polythene bag as shown in *Fig. 2.2*. The soda lime will absorb the carbon(IV) oxide from the air inside the bag, so this plant will be deprived of carbon(IV) oxide.
3. Put a dish of saturated sodium bicarbonate solution on the soil

beside the other plant (B). Cover the plant with a polythene bag as in *Fig. 2.2*. The sodium bicarbonate will slowly give out more carbon (IV) oxide into the bag. Therefore, this plant will have plenty of carbon(IV) oxide.

4. Place both plants side by side in a well lit place for about 48 hours.
5. After about 48 hours take a leaf from each plant and test them for starch (see experiment 2.1).

Observation: The leaf from plant (A) will remain colourless indicating that no starch was formed, while the leaf from plant (B) will turn blue-black showing that starch was formed.

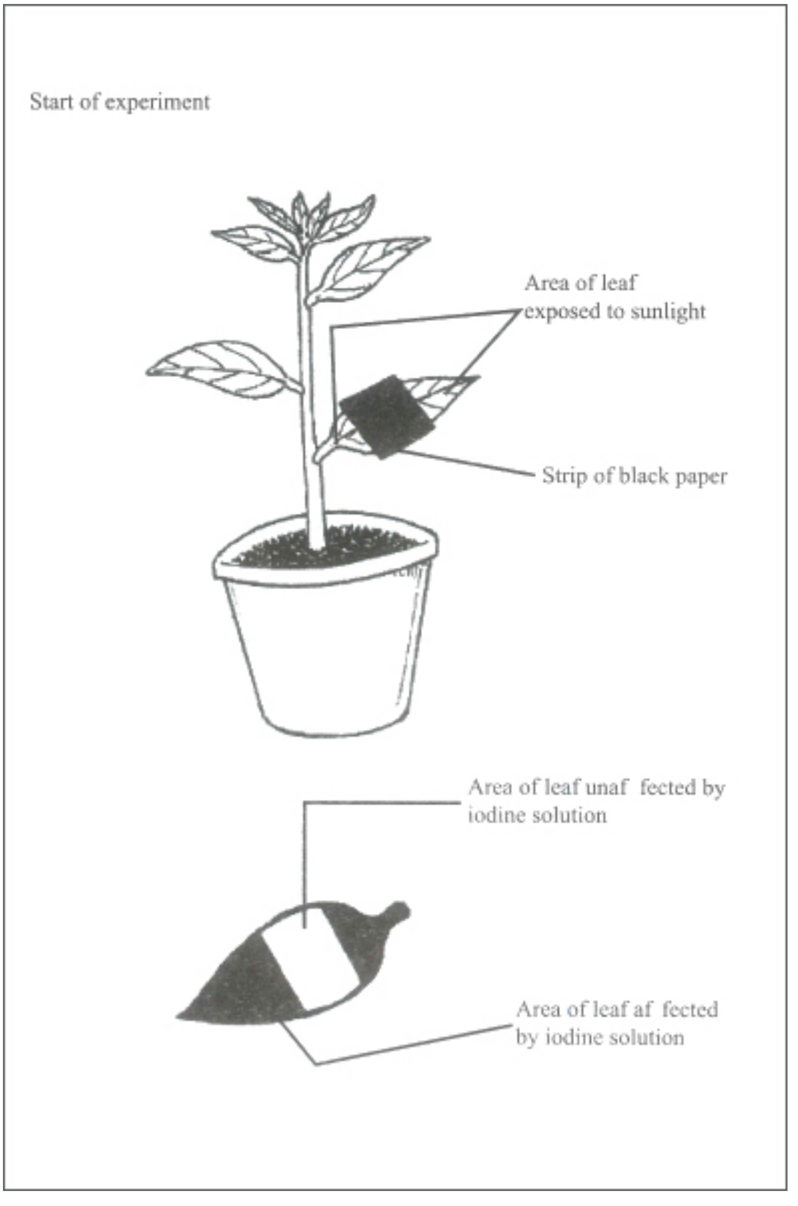

Fig. 2.3 Demonstrating the importance of sunlight in photosynthesis

Conclusion: Carbon (IV) oxide is necessary for photosynthesis.

Experiment 2.3

Aim: To show that sunlight is necessary for photosynthesis.

Materials: A potted plant, strip of black paper and materials to test for starch.

Method

1. Destarch a potted plant by putting it in a dark, airy cupboard for one or two days.
2. Attach a strip of black paper or metal foil to the upper and lower sides of a leaf as shown in *Fig. 2.3*.
3. Put the plant where it can get sufficient sunlight.
4. After 3–4 hours, detach the leaf and test it for starch (see experiment 2.1).

Observation: Only the exposed parts of the leaf will turn blue-black with the iodine solution indicating the presence of starch, while the portion that was covered will remain colourless showing the absence of starch.

Conclusion: This shows that sunlight is necessary for photosynthesis.

Experiment 2.4

Aim: To show that chlorophyll is necessary for photosynthesis.

Materials: Potted variegated plant, paper to mapout, materials to test for starch.

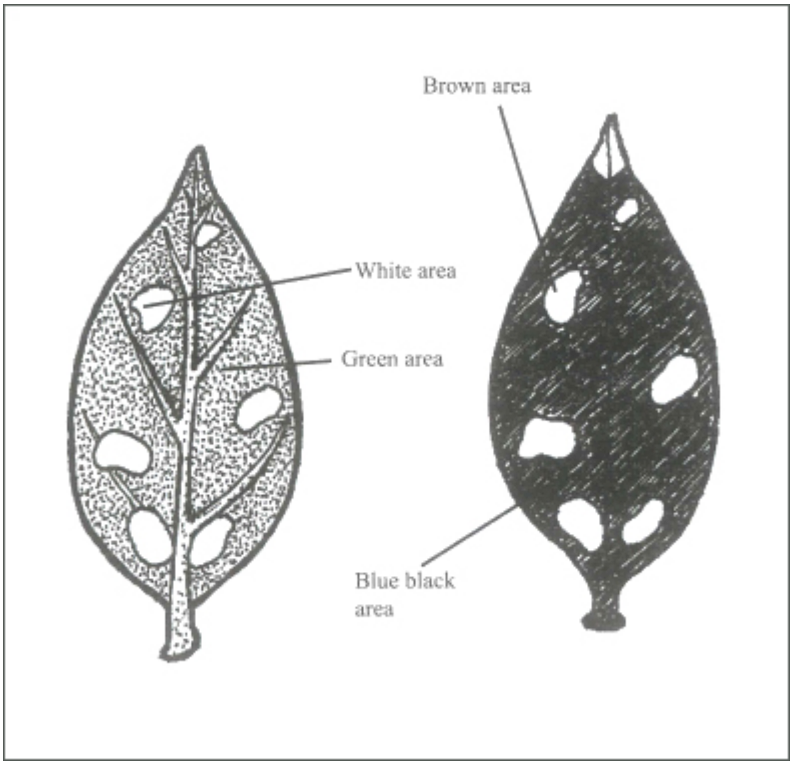

Fig. 2.4 Demonstrating that chlorophyll is necessary for photosynthesis

Method

1. Expose potted variegated plant such as those of ice plant or croton to sunlight for 3-4 hours.
2. Pluck a variegated leaf fresh from the plant in the sunlight.
3. Make a drawing of the leaf and map out the green and white patches.
4. Now carry out a starch test on the whole leaf (see experiment 2.1).
5. Spread the leaf out and compare the iodine map with the chlorophyll map. *Fig. 2.4*.

Observation: It will be found that the green parts are stained blue-black with iodine solution, while the white parts remain colourless.

Conclusion: This shows that chlorophyll is necessary for photosynthesis.

Water

The necessity for water in photosynthesis is difficult to demonstrate by a simple experiment. Depriving a plant of water will certainly kill it. This might be due to a number of reasons, not necessarily concerned with photosynthesis. The only way of showing unequivocally that water is required for photosynthesis is to trace what happens to it after it has been taken into the plant. This can be done by supplying a plant *Chlorella* with a heavy isotope of water H_2O (radiocative water). When they were supplied with radioactive water, it was found that the carbohydrates within the cells became radio-active and radioactive oxygen gas was given off by the plant. These experiments show that during photosynthesis, the water molecule is split. The hydrogen is used in the formation of carbohydrate and the oxygen atoms combine to form molecules of oxygen gas.

Experiment 2.5

Aim: To show that oxygen is given out as a byproduct of photosynthesis.

Method

1. Fill a beaker with water.
2. Place a water plant such as *Elodea* in it.
3. Invert a glass funnel in the beaker so as to enclose the water plant.

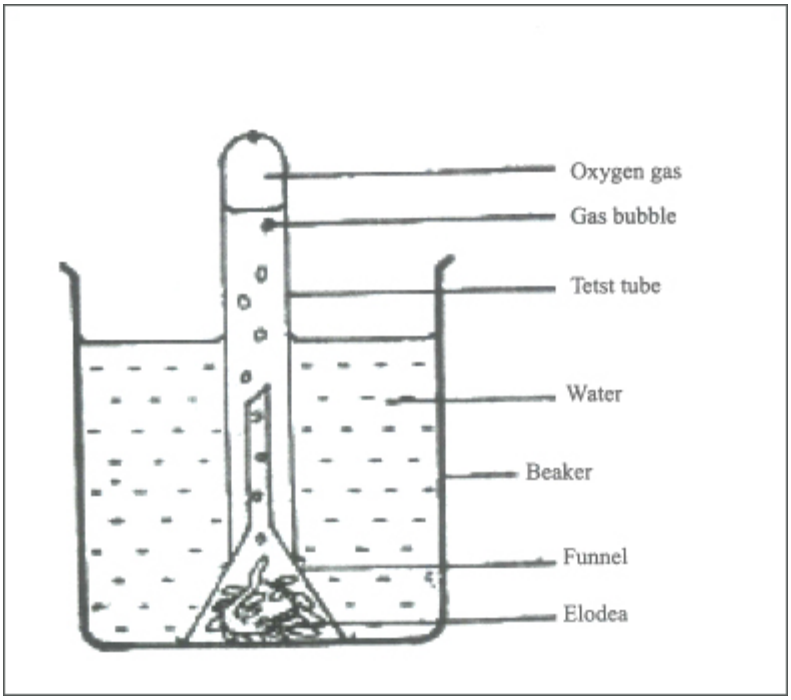

Fig. 2.5 Demonstrating that oxygen is a by-product during photosynthesis

4. Fill a test tube with water and invert over the stem of the funnel (*see Fig. 2.5*).
5. Place the apparatus in bright sunlight or near a bright lamp. Little bubbles of gas appear on the surface of the *Elodea* leaves and these accumulate in the test tube.
6. Test the gas with a glowing splint.

Observation: The gas rekindles a glowing splint.

Conclusion: This shows that oxygen is given off during photosynthesis.

Importance of Photosynthesis

1. For photosynthesis to occur, green plants trap light energy from the sun to make food substances used for their growth.
2. All other organisms depend on this process as their ultimate source of energy because they feed on plants directly or indirectly.
3. Carbon atoms present in the organic molecules of organisms are derived from carbon(IV) oxide of the atmosphere either directly during photosynthesis by autotrophs or indirectly when heterotrophs use organic molecules formed in photosynthesis.
4. During the process of photosynthesis, carbon(IV) oxide is removed from the atmosphere and oxygen is added to it. The oxygen is used for respiration by plants and animals. Hence photosynthesis helps to maintain a fairly constant concentration of the oxygen and carbon(IV) oxide in the atmosphere.

Mineral element requirement of plants

Green plants synthesize proteins and fats from sugars manufactured during photosynthesis. All these are organic substances containing the elements carbon, hydrogen, oxygen and some other elements. These other elements are found in form of mineral salts.

Mineral salts are absorbed from the soil by the roots. Some of these elements help to form important structures in plants, others help the action of enzymes and therefore help to control metabolism. Some of the elements are needed in large quantities while others are needed in small quantities.

The macro elements

The major elements needed are nitrogen, sulphur, phosphorus, potassium, calcium, iron and magnesium. These are needed in large quantities by the plant, hence they are called major/macro/ main elements.

Trace elements

The trace elements (micro/minor elements) are zinc, manganese, cobalt, boron, copper, chlorine, silicon and molybdenum. These are needed in very small quantities by the plant, hence, they are called trace elements or minor or micro elements.

If a plant is grown in a mineral solution lacking adequate supplies of one of the essential elements, it will not grow healthy and will develop a deficiency symptom for that element missing *(see Table 2.1).*

Table 2.1 *Mineral Salts and their effect*

Macro Elements	**Use in plant**	**Effect of deficiency**
Nitrogen	Formation of protein	Poor growth and yellow leaves.
Sulphur	Formation of certain proteins in the protoplasm	Slender stems, yellow leaves.
Phosphorus	Present in enzymes and nucleus	Thin stems, reddish or purple colour in the leaves.
Potassium	Cell formation and regulation of certain ceil activities	Little stem growth, scorching of leaves.
Calcium	Development of the cell wall, activating certain enzymes	Poor root growth, yellow low leaves, folding margins.
Magnesium	Formation of chlorophyll	Young leaves turn yellow older leaves become orange or red.
Iron	Formation of chlorophyll	Leaves turn yellow but veins may remain green.

Trace Elements	**Use in plant**	**Effect of deficiency**
Boron	Transport of calcium and sugars	Brown shoot
Cobalt	For action of some enzymes	Poor growth

Copper	For respiratory enzymes	Poor growth
Manganese	Activation of some enzymes	Death of shoot
Silicon	For cellwall formation	May affect growth
Zinc	Activation of some enzymes	Poor leaf formation
Molybdenum	Required as a co-factor for enzyme action	Reduced plant growth

The method used to determine the mineral salt needs of plants and the effects of their deficiency is called water culture. Here seedlings are grown in distilled water to which various substances, including salts of the various elements are added. The effects of the presence or absence of the elements on the plantsâ€™ growth can then be observed.

Experiment 2.6 To demonstrate the importance of macro elements in normal plant growth.

Method

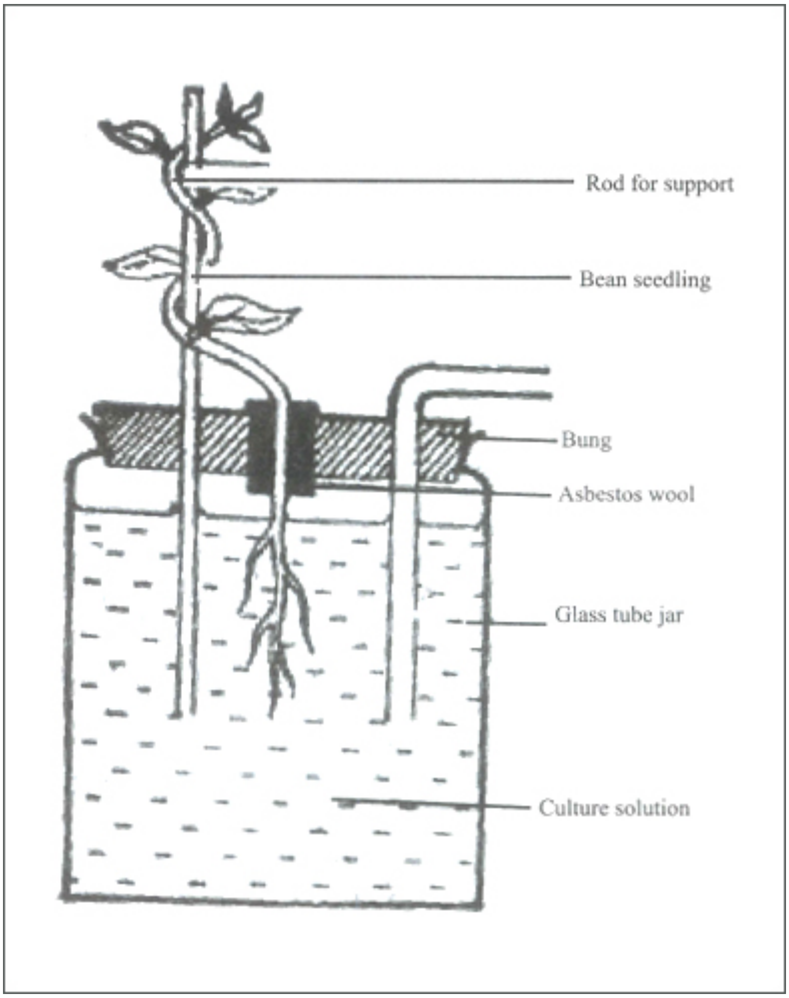

Fig. 2.6 Demonstrating the importance of macro elements in plant growth

1. Sterilize the first jar and fill it with complete culture solution, which is a solution containing all the essential elements in the

right proportion, i.e. magnesium, calcium, potassium, iron in form of sulphates, nitrates and phosphates in their correct proportions. This serves as a control.

2. Sterilize the second jar and fill it with a solution containing all the essential elements except magnesium.
3. Cover the mouth of each jar with a bung that has three holes. In each bung, place a bean seedling. Wedge it into the hole with asbestos wool. Place a support for the growing seedling. Place a right-angled glass tube in the third hole.
4. Finally, cover the jar with black paper and expose it to light and other favourable conditions for four weeks.

Observation: After four weeks, the plant in the water culture solution in the first jar will increase in height while more green leaves and roots will be produced. The plant in the second jar will have its leaves turn yellow.

Conclusion: Magnesium is important for normal plant growth.

Note: Precautions to be taken.

1. If the seedling for the experiment was germinated in saw dust or soil, the roots must be washed to remove the particles of sawdust or soil.
2. The jar must be covered with black paper or painted black to keep out light and prevent growth of algae in the culture solution.
3. Keep the underside of the cork dry to prevent rotting of the stem.
4. Air must be blown into the solution daily for adequate aeration and growth of the roots.
5. The solution must be renewed weekly to keep up the balance of nutrients.

Note: This experiment should be performed replacing magnesium with each of the other macro elements to demonstrate their importance to plant growth.

The Nitrogen Cycle

The element nitrogen is crucial to life because it is a component of protein and nucleic acid. The reservoir for nitrogen is the atmosphere. This nitrogen is not biologically active. It cannot be used in this form by plants and animals. The way nitrogen enters the chemistry of life processes is explained by the nitrogen cycle.

Atmospheric nitrogen is converted to soil nitrogen in the following ways:

1. *Thunderstorms:* During thunderstorms, nitrogen combines with oxygen to form gaseous oxides of nitrogen such as nitrogen(II) oxide (NO) and nitrogen(IV) oxide (NO_2). These form nitrous acid and nitric acid respectively with rain water. When these acids go into the soil, they combine with mineral salts to produce nitrates.

Nitrates dissolve in soil water and are absorbed by the root hairs of plants.

2. *Nitrogen fixation:* Certain bacteria like *Azotobacter* and *Rhizobium* are capable of absorbing atmospheric nitrogen and converting it to organic nitrogenous compounds, e.g. protein within their bodies. Some of these bacteria get their energy from carbohydrates obtained from humus and are said to carry out non-symbiotic fixation. Others live in the root nodules of leguminous plants and get their carbohydrates from their host plant. In return, they give their host nitrogenous compounds. This is symbiotic nitrogen fixation. Soils generally become richer in nitrogen as a result of having leguminous crops growing in them. Some nitrogen-containing compounds are released into the soil when old nodules decay. Some are excreted directly into the soil and some will be present in the living and dead fibres of the roots.

3. *Putrefaction:* Living plants and animals add nitrogen to the soil by giving out nitrogenous compounds as excretory products. Dead plant and animal tissues which occur in the soil as humus, also add nitrogen to the soil. Putrefying bacteria and fungi are responsible for this decay or putrefaction. These organisms convert organic nitrogenous compounds in the soil to simple substances like carbon(IV) oxide, water and ammonia. The carbon(IV) oxide is given back to the atmosphere and ammonia is converted by other micro-organisms to nitrates.

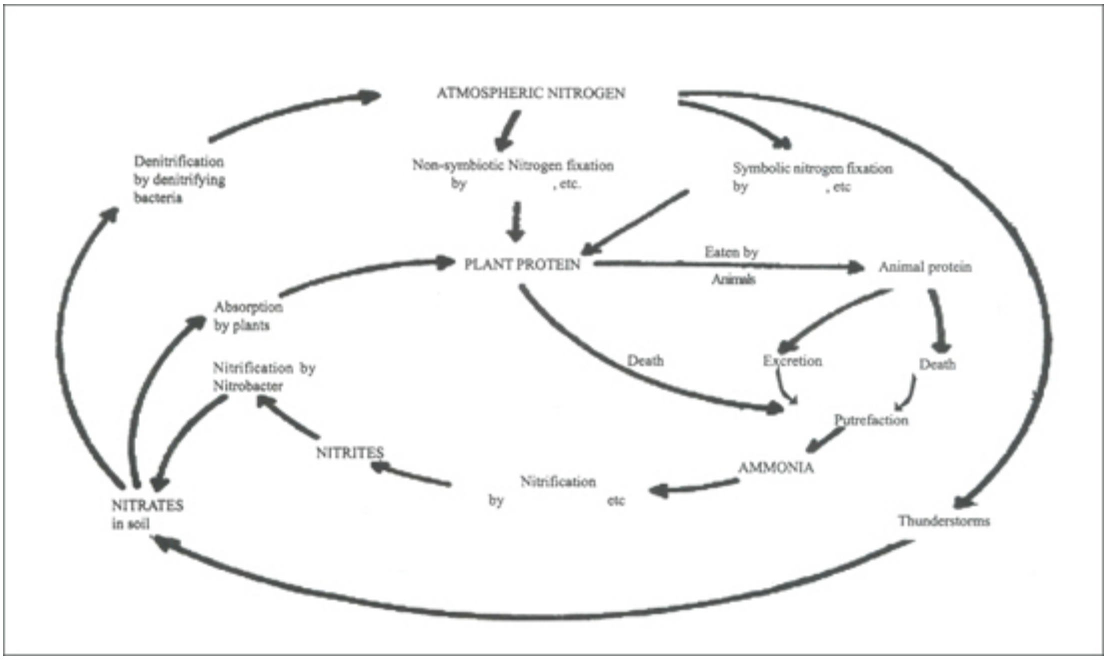

Fig. 2.7 The nitrogen cycle

4. *Nitrification:* The micro-organisms which convert ammonia to nitrates are known as nitrifying bacteria. They are in two groups: bacteria in the first group convert ammonia to nitrites, e.g. *Nitrosomonas*. The second group of bacteria converts nitrites to nitrates e.g. *Nitrobacter*. Nitrates in the soil can be absorbed

directly by plant roots. Within the plant, they are converted to plant protein. Some plants are eaten by animals and are finally converted into animal proteins.

5. *Denitrification:* Nitrates in the soil can also be reduced to gaseous nitrogen by denitrifying bacteria. The nitrogen so formed escapes into the air where it becomes atmospheric nitrogen. Denitrifying bacteria, therefore, reduces the quantity of soil nitrates.

The use and release of nitrogen from the atmosphere by the soil and organism is a continuous process.

Suggested Practicals

1. Examination of a leguminous plant to observe the root nodules.

(a) Collect some leguminous plants such as beans and groundnuts from your school garden.
(b) Wash the roots properly with water to remove the soil.
(c) Look for swellings or nodules, on the roots.
(d) Collect some maize plants.
(e) Compare the roots of the maize plant with that of the beans or groundnut plants.

2. *Demonstration of the difference in growth of plants grown in soil deficient in nitrates and soil rich in nitrates.*

(a) Your teacher will supply you with maize seedlings, soil, nitrogen fertilizer and two beakers.
(b) Fill the two beakers, A and B, with wet soil.
(c) Put about four maize seedlings in each beaker.
(d) In Beaker A, add some nitrogen fertilizer to the soil. Do not add any fertilizer to the soil in Beaker B.
(e) Allow the plants to grow for seven days.
(f) Observe the plants and record your observations under these headings:
(I) Growth of shoot.
(II) Appearance of leaves.
(III) Growth of root.
(IV) Any other remarks.

Summary

1. Green plants use light from the sun to make food containing chemical energy through the process of photosynthesis.

2. In addition to light energy, photosynthesis requires carbon(IV) oxide, water, chlorophyll and enzymes.

3. Photosynthesis produces sugar and oxygen. In addition, lipids, proteins and vitamins are formed.

4. Plants require certain mineral salts to grow well. Some are

required in large quantities (macro-elements). Examples are nitrogen, sulphur phosphorus, potassium, calcium, iron and magnesium. Others are required in small quantities (trace elements). Examples are boron, copper, cobalt, manganese, silicon and zinc.

5. The element nitrogen is crucial to life. The nitrogen in the atmosphere is not biologically active. The nitrogen cycle helps to maintain a continuous flow of nitrogen in nature.

Objective Questions

1. Which of the following conditions need not be present for photosynthesis to take place:
   A. Oxygen.
   B. Water.
   C. Light
   D. Carbon(IV) oxide.
   E. Chlorophyll

2. When testing a leaf for starch to see if it has carried out photosynthesis, why is it necessary to boil it first in water?
   A. To isolate the starch.
   B. To kill the protoplasm and burst the starch grains.
   C. To kill the germs on the leafs.
   D. To extract chlorophyll
   E. To sterilize the leaf.

3. Which of the following processes is carried out by denitrifying bacteria in the nitrogen cycle?
   A. Conversion of nitrates into gaseous nitrogen.
   B. Conversion of ammonia into ammonium compounds.
   C. Conversion of atmospheric nitrogen into nitrogenous compounds.
   D. Conversion of ammonium compounds into nitrates.
   E. Conversion of nitrites into nitrates.

4. All the following elements are required in large quantities except
   A. nitrogen.
   B. manganese.
   C. calcium.
   D. sulphur
   E. magnesium.

5. Which one of the following sets of symptoms in a maize crop would make you suspect that the soil in which the crop is growing is deficient in magnesium?
   A. Yellow leaves and yellow stems.
   B. Small stems and thin leaves
   C. Little root growth and purple leaves.

D. Dropping stems and orange-brown leaves.
E. White upper leaves and normal lower leaves.

Essay Questions

1(a) What is photosynthesis?
(b) List the materials necessary for photosynthesis to occur.
(c) Describe an experiment to show that carbon(IV) oxide is necessary for photosynthesis.

2(a) Make a list of the major elements that are needed for the healthy growth of plants.
(b) (i) How would you show that magnesium is an essential element for plant growth?

(ii) List the precautions you will take in carrying out this experiment.

3(a) Why is nitrogen important to plants?
(b) Describe the processes of nitrification, denitrification and nitrogen fixation.

4(a) What is the importance of photosynthesis to organisms?
(b) How would you show experimentally that a green leaf manufactures starch?