CHAPTER 6

Mineral Nutrition

(Material Income of the Plant)

INTRODUCTION

To complete the life cycle normally, a living organism requires the supply of a large number of substances from outside. This supply is called *nutrition.* If the supply needed by the organism is both organic and inorganic, the organism is called *heterotrophic* but if the supply needed by the organism is that of inorganic substances only, the organism is called *autotrophic* or self-feeding. All green plants synthesizing their own organic requirements are autotrophic whereas, the animals, non-green plants, and albino mutants of the green plants which require the supply of their organic requirements from outside are heterotrophic.

Under normal conditions of growth, however, all green plants are autotrophic and they require from outside the supply of only inorganic substances. With the exceptions of hydrogen, carbon and oxygen, all other inorganic plant requirements are obtained directly or indirectly from soil. As the sources of these inorganic requirements are minerals, the elements are known as mineral nutrients and the nutrition is called *mineral nutrition.* Strictly speaking nitrogen is not a mineral element but it has been included in the list because it is normally obtained by the plant from soil.

As analysis of a plant reveals the presence of a large number of mineral elements. The amount and number of elements present in plants may also differ from plant to plant, place to place and medium to medium in which the plants grow. Actually some sixty elements have been found in plants.

Known as framework elements, carbon, hydrogen and oxygen enter into the constitution of the plant body, cell wall, protoplasm etc. The bulk of the plant body is composed of these elements as these are the constituents of a large number of carbon containing compounds such as carbohydrates, fats, proteins, cellulose, lignin etc. Protoplasm constituents, proteins and nucleic acids require the protoplasmic elements—nitrogen, sulphur and phosphorus for their composition. As calcium pectate, calcium forms an important component of cell wall and chlorophyll requires magnesium for its synthesis. As components of enzyme systems, elements like iron, copper, zinc, manganese etc. are involved in catalytic reactions of plant metabolism. Apart from this, many other elements are needed for the synthesis of plant metabolites.

The osmotic pressure of cell is the result of mineral salts and organic compounds dissolved in the cell sap. Depending on the nature of elements, absorbed mineral salts affect the pH of the cell also. In general, elements and their salts are also responsible for antagonistic and balancing effects in the cell.

The overall cytoplasmic permeability is the outcome of combined effects of cations and anions of the medium in contact.

Making about 1 to 60 per cent of the total plant weight, C, H, O, N, P etc. are essentially found in all plants and are invariable primary elements. Known as invariable secondary elements Ca, Na, Mg, K, Fe, S, Cl etc. are found in all plants and form about 0.05 to 1 per cent of the total plant weight. Zn, Cu, B, Mo, Si, Mn, F, I etc. are known as invariable micronutrients. These elements constitute about less than 0.005 per cent of the plant weight. Ti, V, Br etc. are found in some plants. In certain plants extremely low concentrations or variable micro-elements such as Li, Rb, Cs, Ag, Be, Sr, Cd, Ge, Sn, Pb, As, Cr, Co, Ni, Al, Ba etc. are also found.

According to Thatcher (1934) elements like H, O and P take part in energy transfer reactions; Mg, Fe, Co, Ni, Cu, Zn, Mn, Mo etc. act as oxidation reduction controllers; C, N, S and P form storage elements; Ca, Mg, P, F, Si act as structural elements; Na^+, K^+, Ca^{++}, Cl^-, PO_4^{---}, CO_3^{--}, Br^-, NO_3^- etc. work as regulators of osmostic concentrations and electrolytic equilibrium; Fe, Cu, Mn, Zn, I, S, Mo, Ca, Mg, Co etc. perform the catalytic role and Ca, Mg, K, Co, Zn, Cu and Mo act as enzyme activators.

ESSENTIAL ELEMENTS

In fact, all elements found in a plant are not essential for its growth and life cycle. A large number of them are non-essential. For finding out whether an element is essential or not for a plant, the plant is raised in complete absence of that particular element under controlled culture conditions. If the plant grows normally, the element is non-essential and if it does not grow normally, it means that the element is truly essential. In order to show that an element is truly essential, it is necessary to show not only that:

(*i*) a deficiency of the element makes it impossible for a plant to complete its vegetative and reproductive cycle but also that

(*ii*) it cannot be replaced by another element and that

(*iii*) the effect is not simply the result of an interaction with (*e.g.* detoxification of) other non-essential elements, organism etc. outside the plant but that the element should also have some part to play in metabolism.

These three requirements form the criteria for essentiality (Arnon and Stout, 1939). However, recent studies have shown that some of these elements can be partially replaced by others, for example, magnesium by manganese and potassium by rubidium.

The list of essential macronutrient elements includes C, N, O, Ca, H, K, Mg, P and S. These elements are required by the plants in major amounts. Of these, N, P and K are considered as *primary nutrients* and Ca, Mg and S as *secondary nutrients*. Fe, Mn, Cu, Zn, Mo, B and Cl are included in the list of essential micronutrient elements or trace elements. These elements are required by the plants in minute quantities. Apart from these essential elements recently some more elements have been shown to be essential for the normal growth of at least some plants such as Na for *Atriplex vesicaries* and Cl, Al, Si, Va and Co for ferns, *Scenedesmus* etc. However, evidence for the essential requirements of these elements for growth of majority of plants is still lacking.

The methods mostly in use for study of mineral nutrition of plant are plant analysis, solution cultures and sand cultures.

PLANT ANALYSIS

In plant analysis, the different mineral nutrient elements are determined even in micro and semi-micro quantities by spectrophotometric, colorimetric, turbidimetric, flame photometric, titrametric or by other methods. These estimations are done according to the needs either in extracts of fresh plant tissue such as organic extracts or in the plant tissue from which organic material has been completely removed either by ashing it at 600°C or by digesting it with nitric acid and perchloric acid on a hot plate.

Although plant analysis may be thought of as a method for determining the relative quantities of mineral elements in plants, it is at least a crude technique. The overall analytical error, resulting from vaporisation and sublimation of some of the elements due to high temperature, presence of elements in impure state in the plant ash or digest and different chemical treatments given during analysis, is too large to allow heavy reliance on any quantitative data obtained from the analysis. The average chemical composition of a plant body is given in the first chapter.

cultures have certain advantages over *geoponics* (soil culture or agriculture) such as:

1. a controlled chemical composition of nutrient solution may be provided,
2. there are no soil colloids present to immobilize any of the nutrients through adsorption,
3. frequent replacement of culture solution prevents the accumulation of toxic organic decomposition products.
4. the growth of bacteria and higher fungi is minimised which may otherwise cause diseases of crop plants,
5. the culture solution is kept aerated and well circulated ensuring better environment for plant growth.
6. no tillering is required,
7. there is no weed growth, and
8. natural calamities such as floods, droughts, erosion etc. can be avoided.
9. growth and reproductive phases can be manipulated upto a certain extent by supplying modified nutritional medium etc.

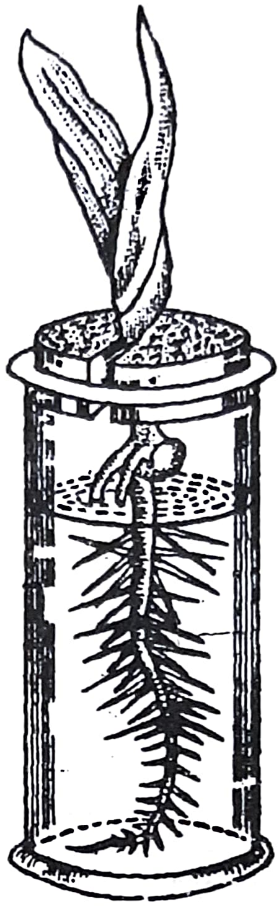

Fig. 6.1. Diagram showing method adopted in solution culture studies.

In India, hydroponic culture practices have been widely adopted. Tomatoes grown through this system in Bengal have yielded an average of over 200 tons per acre as against 15-20 tons under ordinary soil conditions. Paddy grown by this method produced 1,400 lbs of rice per acre and potatoes upto 70 tons per acre. These values are quite high as compared to normal conditions. A Hydroponic Information Centre has been set up in Bombay, Post Box-31 to provide literature and suggestions for popularising the process. It is rather a recent method of cultivation which has a vast scope in the near future both because of its advantages and higher yield of crop plants.

Aeroponics

It is a system for growing plants with their roots supplied with moisture in the air. The rooted plants are placed in a special type of box with their shoots exposed to air and roots inside the box with computer controlled humid atmosphere. It is, however, a recent method developed particularly for research purposes because plants show a very good growth of root hairs. Plants like *Cirus* and olive have been successfully grown through this method.

MACRONUTRIENTS

Carbon, Hydrogen and Oxygen

These are not minerals in origin but are discussed here because they enter into the composition of practically all organic compounds present in the plant and account for a major part of the dry weight. The significance of water (H_2O) can be felt when it is said that water is the liquid of life. (Its importance has already been discussed earlier.)

The source for carbon and oxygen is atmosphere and for hydrogen, it is water.

NITROGEN

Source. The chief source of nitrogen is the soil. Plants absorb it either in the form of nitrate or ammoniacal salts. Some bacteria and heterocysts containing blue green algae fix the nitrogen of the atmosphere which can be utilised by plants.

Functions. Nitrogen is an essential constituent of different proteins, nucleic acids and many other organic molecules such as chlorophyll. Thus the processes like protein synthesis, role of nucleic acids and chlorophyll synthesis are related to nitrogen.

Deficiency symptoms. In absence or low supply of nitrogen the following symptoms develop:

1. The plants always look thin and poorly furnished.
2. Chlorophyll content is reduced due to which leaves turn pale yellow. The older leaves turn completely yellow and fall because nitrogen moves rapidly from older to younger leaves.
3. Flowering and fruitings are reduced.
4. In certain plants such as tomato leaf, veins turn purple or red due to development of abundant anthocyanin pigment. Often apple plants are supplied less nitrogen to develop more attractive colour.
5. The protein and starch contents are decreased.
6. Due to reduction in protein, plant growth remains stunted and lateral buds remain dormant. As a result cereals do not show characteristic tillerings.

7. Shoots remain short and thin with upright spindly growth.

8. In tomato, potato, cereals and other grasses, the younger leaves, however tend to remain erect. The angle between stem and leaves is reduced.

9. Prolonged dormancy and early senescence appear.

10. Roots get more lengthened as in wheat.

In excess supply of nitrogen, vegetative growth, flowering and susceptibility of plants to infection increase. The sclerenchymatous tissues are reduced and stems become weak and tender. Collenchyma increases. The leaves become dark green and succulent. Tillering in cereals becomes more pronounced.

Disease. In case of nitrogen deficiency, plants look so sickly and conspicuously pale that the condition is called *general starvation*.

Corrective measures. For correcting the nitrogen deficiency, fertilisers like ammonium sulphate, calcium ammonium nitrate, urea etc. are supplied. Foliar spray of urea is a quick method in ameliorating nitrogen deficiency.

SULPHUR

Source. Sulphur is available to plants in the form of soluble sulphates of soil.

Functions. Sulphur is the constituent of amino acids (cysteine and methionine), vitamin (B_1), coenzyme A and volatile oils. The characteristic odour of cruciferous plants, onion, garlic and tropeolae is due to sulphur as a constituent of volatile oils. Through the different amino acids it participates in protein synthesis. Sulphur is known for its uneven distribution in various organs of a plant, *e.g.* in a mature corn, the percentage observed was 40% in leaves, 23% in stem, 26% in grain and 11% in roots. Sulphur affects an increase in nodule formation in roots of leguminous plants. It favours soluble organic nitrogen and there is a decrease in the quantity of insoluble nitrogen with its increase. Sulphur adversely affects chlorophyll synthesis.

Deficiency symptoms. The deficient plants show symptoms similar to nitrogen deficiency, though its deficiency is very rare in nature. Some symptoms are as follows.

1. Marked decrease in leaf size and general paling with red or purple pigmentation are general symptoms.

2. In case of severe sulphur deficiency, necrosis of young leaf tips and margins, shorter internodes, premature development of lateral buds, multiple branches with dead tips and shoot die back occur.

3. Leaves remain small and turn pale green, *i.e.*, symptoms of chlorosis. Chlorosis affects young leaves because of the immobile property of sulphur. The young leaves develop orange, red or purple pigments.

4. Leaf fall is rapid and fruit formation is suppressed.

5. In tobacco, tea and tomato, the leaf-tips are characteristically bent downwards. The leaf margins and tips roll inwards.

6. The apical growth is inhibited whereas lateral buds develop prematurely.

7. Sclerenchyma, xylem and collenchyma formation gets increased.

Disease. The *tea yellow* disease is caused in tea plants growing in sulphur deficient soils.

Corrective measures. The common fertilisers used for supplying nitrogen and phosphorus contain appreciable amount of sulphur sufficient to meet the crop requirements. However, in case of severe deficiency, gypsum is added to the soil.

PHOSPHORUS

Source. The plants absorb phosphorus in the form of soluble phosphates such as $H_3PO_4^-$ and HPO_4^-. The ability of absorption differs from plant to plant, *e.g.* cabbage and alfalfa can absorb phosphate from rocks whereas barley, corn and oats cannot absorb so efficiently.

Functions. Phosphate is found about 0.2 to 0.8 per cent of the total dry weight. Comparatively it is found in greater quantity than sulphur and magnesium. Phosphorus is present abundantly in the growing and storage organs such as fruits and seeds. It promotes healthy root growth and fruit ripening by helping translocation of carbohydrates. An increased concentration of carbohydrates is also reported.

It is an essential element participating in the skeleton of plasma membrane, nucleic acids, many coenzymes and organic molecules such as ATP (adenosine triphosphate) and other phosphorylated products. It plays an important role in the energy transfer reactions and in oxidation reduction processes.

Deficiency symptoms. A few symptoms are as follows:

1. Young plants remain stunted with dark blue green, or some times purplish leaves.
2. Leaves sometimes develop anthocyanins in veins and may become necrotic.
3. Cambial activity is checked.
4. Tillering of crop plants is reduced.
5. The dormancy is prolonged.
6. Premature leaf falls take place.
7. Growth is retarded and dead patches appear on leaves, petioles and fruits.
8. Variable colours develop, *e.g.* pale green in *Pisum,* olive green in *Phaseolus* and blue green in *Brassica* and cereals.
9. Thickening of tracheidial cell is reduced and phloem differentiation is found incomplete.

Disease. *Sickle leaf disease* is caused in phosphorus deficiency which is characterised by chlorosis adjacent to main veins followed by leaf asymmetry.

Corrective measures. Phosphate fertilisers are supplied in case of phosphorus deficiency.

CALCIUM

Source. It occurs in soil with a variety of minerals. The soil derived from stone or chalk rocks contains a larger percentage of carbonate of lime (calcium carbonate) while sandy soils show calcium deficiency which is met by adding lime or lime-stone. The presence of CO_2 dissolved in the soil water promotes solubility of carbonate of lime in soil ensuring quick calcium absorption. Calcium also comprises the major proportion of the elements held as exchangeable bases where soils are not strongly acidic or alkaline.

Heavy application of potassium fertilizers reduces the absorption of calcium.

Functions. A larger quantity of calcium is found in leaves and relatively low quantity of it is found in the seeds and fruits. Calcium is the chief constituent of plants as calcium pectate of the middle lamella of the cell wall. It is irreplaceable by any other element such as magnesium or potassium. It provides a base for the neutralisation of organic acids and is also concerned with the growing root apices. It is not easily transportable, therefore, its concentration in older parts is higher than in younger parts. It may be a reason for the development of early deficiency symptoms at the tips of shoots and growing points.

It also acts as an activator of *ATPase*, some *kinase*, phospholipids and *succinate dehydrogenase*. It is essential for fat metabolism, formation of membrane, carbohydrate metabolism, nitrate assimilation, binding of nucleic acids with proteins and counteraction of metal toxicity.

Deficiency symptoms. These are as follows:

1. The deficiency of calcium appears in the young leaves and near the growing points of stem and root.
2. Margins of leaves often appear irregular in form or often show brown scorching or spotting effects.
3. Thin chlorotic marginal bands develop.
4. The young leaves may be severely distorted with the tips hooked back and the margins curled backward or forward or rolled.
5. Roots poorly developed, lack fibre and may appear gelatinous.
6. In tomato, growing points are often killed.
7. In flax, clovers and many plants, petioles and pedicels also frequently collapse due to its deficiency.

Diseases. Two common diseases are found due to deficiency of calcium.

(*i*) *Tip hooking*. The disease is found in cauliflower, beet and tobacco where characteristic hooking of leaf tip is found. This condition arises because of unequal growth in marginal and central regions of the leaf.

(*ii*) *Blossom end rot*. Commonly found in tomato, the disease is characterised by presence of a depressed region near the distal end of the youngest fruit. The depressed region remains surrounded by dark green tissues and the flesh is orange coloured.

Corrective measures. Calcium ammonium nitrate or superphosphate are supplied in deficient soils. However, in Indian soils, calcium deficiency is not a serious problem.

POTASSIUM

Source. Potassium is widely distributed in soil minerals. Forms such as potash felspar, mica and glauconite are slowly converted into soluble forms by weathering processes. It is strongly fixed in soils, largely as an exchangeable base. It is also found in less available forms. Small amounts of potassium are normally present in the soil. Exchangeable potassium appears to be readily available to the plants.

Functions. Potassium is not known to be a constituent of important metabolites such as protein, chlorophyll, fats and carbohydrates etc. That is why it is difficult to assign a particular role to it. It is found frequently in all parts of a plant but in fairly large proportion at growing points. It is considered that the whole of potassium in a plant is present in soluble forms and most of it seems to be contained in the cell sap and cytoplasm. It is readily mobile within the plant tissues. Its utilisation in plant is concerned with the formation of carbohydrate and proteins, photosynthesis, transpiration regulation, enzyme action, synthesis of nucleic acid and chlorophyll, oxidative and photophosphorylation, translocation of solute etc.

Deficiency symptoms. The deficiency symptoms vary with the extent of the shortage of the element.

1. *In acute deficiency cases*
   (*a*) shoots may die back, eventually plant may die,
   (*b*) plants may become stunted with numerous tillers, and
   (*c*) there may be little or no flowering.
2. *In mild deficiency cases*
   (*a*) thin shoots may develop and
   (*b*) there may be restricted shoot growth.
3. The colour of the leaf may be dull or bluish green.
4. Chlorosis occurs in interveinal regions.
5. In older leaves, browning of tips (tip burns), marginal scorching (leaf scorch), or development of brown spots near the margins occur.
6. Scorched margins often turn sharply forward (upward).
7. Reduced internodes of stem and reduced production of grains occur.
8. The lamina of broad leaved plants curl backward towards the undersurface or roll forwards towards the upper surface parallel to the midrib.
9. The broad leaved plants, shorter internode and poor root system are important symptoms.

Diseases. Two diseases are common.

(*i*) *Rosette.* In beet, celery and carrot, bushy growth or rosette condition develops due to its deficiency. Rosette condition may also be found in pea, cereals and potato.

(*ii*) *Die back.* In acute deficiency cases, there is a loss of apical dominance and regeneration of lateral buds and bushy growth. In prolonged cases, die back of laterals also results.

Corrective measures. Muriate or sulphate of potash are commonly supplied to overcome potassium deficiency.

MAGNESIUM

Source. Magnesium occurs as carbonate fairly similar to that of calcium and held in soils as an exchangeable base. It is easily leached and for this reason may become deficient in sandy soils during wet periods. Heavy application of potassium fertilisers reduces its absorption.

Functions. It is a constituent of chlorophyll and, therefore, essential for the formation of this pigment. It acts as a phosphorus carrier in the plant, particularly in connection with the formation of seeds of high oil contents which contain compound lecithin. It is readily mobile and when its deficiency occurs, it is apparently transferred from older to younger tissues where it can be reutilised in growth processes. As a result, deficiency symptoms develop first on older leaves.

Magnesium is essential for the synthesis of fats and metabolism of carbohydrates and phosphorus. It is required to combine two subunits of ribosomes.

Deficiency symptoms. These are as follows:

1. Deficiency symptoms develop on the older leaves and proceed systematically towards the younger leaves.
2. Mottled chlorosis occurs with veins green and leaf web tissue yellow or white.
3. Severely affected leaves may wither and shed or abscise without the withering stage. Defoliation may be quite severe.
4. Leaves, sometimes, develop necrotic spots.
5. Stem becomes yellowish-green, often hard and woody.
6. Carotene is reduced.

Disease. In tobacco, *sand-drown* disease is found due to its deficiency which is characterised by the loss of colour at the tips of lower leaves and between the veins. The veins remain green but in acute cases, the leaf becomes nearly white.

Corrective measures. Magnesium sulphate is usually supplied for quick removal of its deficiency. It can also be supplied as foliar spray (20 per cent soln.)