Mineral Nutrition:

Mineral Nutrition is defined as the naturally occurring inorganic nutrient found in the soil and food that is essential for the proper functioning of animal and plant body. Minerals are vital elements necessary for the body. Both the plants and animals require minerals essentially. For example, Zinc is necessary for the manufacture of protein and for cell division.

Nutrients which are required by plants in very small amounts are termed as Micro Elements or macronutrients. Some of them include boron, copper, manganese, iron, chlorine, and molybdenum.

Nutrients which are required by plants in larger amounts are termed as Macronutrients. Some of them include sulfur, nitrogen, carbon, phosphorus, calcium, potassium and magnesium.

Let us have a detailed look at the mineral nutrition notes to explore the role of micronutrients and macronutrients in maintaining human health.

Role of Nutrients

- **Balancing function:** Some salts or minerals act against the harmful effects of the other nutrients thus balancing each other.
- **Maintenance of osmotic pressure:** Several minerals cell sap is present in organic or inorganic form to regulate the organic pressure of the cell.
- **Influencing the pH of the cell sap:** Different anions and cations has an influence on the pH of the cell sap.
- **Construction of the plant body:** Carbon, Hydrogen, and Oxygen are elements that help to construct the plant body by entering protoplasm and constitution of the wall.

- **Catalysis of the biochemical reaction:** Certain elements like zinc, magnesium, calcium and copper act as metallic catalysts in biochemical reactions.
- **Effects of Toxicity:** Certain minerals like arsenic and copper has a toxic effect on the protoplasm under specific conditions.

Minerals in Plants:

Julius von Sachs, a German botanist, was the first to grow plants to maturity in a nutrient solution in the complete absence of soil. This technique of growing plants in a soil-free, nutrient solution is ‘Hydroponics’. The essential minerals were identified by adding or omitting an element in the nutrient solution or using varying concentrations. Today, hydroponics is commercially used as a technique to grow tomatoes, lettuce, and seedless cucumbers.

Essential Mineral Elements:

So far, 105 elements have been discovered, of which more than 60 exist in plants. But, are all these necessary for plants? How do we know which minerals are essential for plants and which are not? There are certain criteria to determine this. Let’s learn what they are.

Criteria for Essentiality:

- The element must be critical for the growth and development of the plant. The plant can not complete its life cycle or produce seeds in the absence of the element.
- The requirement for the element must be specific and not replaceable by another element. This means the deficiency of one element cannot be compensated by supplying any other element.
- The element must have a direct role in the metabolism of the plant.

According to the above-mentioned criteria, only a few mineral elements were found to be absolutely necessary for plant growth and development. Based on the quantity in which these minerals are required, they are further classified as follows.

Macronutrients:

These are present in plant tissues in large (macro) amounts (i.e. more than 10mmole/kg of dry matter). Macronutrients include carbon, hydrogen, nitrogen, oxygen, sulphur, phosphorus, calcium, potassium and magnesium. Carbon, hydrogen and oxygen are absorbed from CO_2 and H_2O while the others are absorbed from the soil.

Micronutrients:

These are needed in small (micro) amounts (i.e. less than 10mmole/kg of dry matter). Therefore, they are also called trace elements. Micronutrients include iron, copper, manganese, molybdenum, chlorine, nickel, zinc and boron.

All the 17 elements mentioned above are essential elements. In addition to these, elements such as sodium, silicon, selenium and cobalt are also important for higher plants.

Classification of Essential Mineral Elements

Essential mineral elements can also be classified as follows based on their diverse functions:

- As components of biomolecules and hence structural elements of cells. Examples – carbon, hydrogen, nitrogen and oxygen.
- As components of energy-related chemical compounds in plants. Examples – phosphorus in ATP and magnesium in chlorophyll.

- As activators or inhibitors of enzymes. Examples -Zinc is an activator of alcohol dehydrogenase while molybdenum activates nitrogenase during nitrogen metabolism. Magnesium activates multiple enzymes involved in photosynthesis.
- As elements that can alter the osmotic potential of a cell. Example – Potassium is very important in the opening and closing of stomata.

Role of Macro and Micronutrients

The table below shows the diverse functions the essential minerals perform in plants.

Element	Absorbed as	Points to remember
Nitrogen	Mainly as NO_3^-, some as NO_2^- and NH_4^+	• Required in the greatest amount by plants. • Needed by all parts of a plant, especially meristematic tissues and metabolically active cells. • Major constituent of nucleic acids, proteins, vitamins and hormones.
Phosphorus	Phosphate ions (either $H_2PO_4^-$ or HPO_4^{2-})	• In a constituent of cell membranes, all nucleic acids and nucleotides, and certain proteins. • Required for all phosphorylation reactions.

		• Required in large amounts in meristematic tissues, leaves, buds and root tips.
Potassium	Potassium ion (K^+)	• Helps to maintain an anion-cation balance and maintains the turgidity of cells. • Involved in protein synthesis, activation of enzymes and opening and closing of stomata.
Calcium	Calcium ions (Ca^{2+})	• Required by meristematic and differentiating tissues. • Used in the synthesis of cell wall during cell division (calcium pectate in the middle lamella). • Needed during mitotic spindle formation. • Required for normal functioning of cell membranes. • Activates certain enzymes and regulates metabolic activities.
Magnesium	Magnesium ion (Mg^{2+})	• In a constituent of the ring structure of chlorophyll. • Activates the enzymes of respiration and

		photosynthesis. • Involved in RNA and DNA synthesis. • Helps to maintain ribosome structure.
Sulphur	Sulphate (SO_4^{2-})	• Present in amino acids – cysteine and methionine. • It is the main constituent of several coenzymes, vitamins (Biotin, Thiamine) and ferredoxin.
Iron	Ferric ions (Fe^{3+})	• Required in large amounts by plants. • An important constituent of proteins like ferredoxin and cytochromes. • Important for electron transfer (reversibly oxidized from Fe^{2+} to Fe^{3+}) • Activates catalase enzyme and is needed for chlorophyll formation.
Manganese	Manganous ions (Mn^{2+})	• Activates enzymes involved in respiration, photosynthesis and nitrogen metabolism. • Very important in splitting water to release oxygen during photosynthesis.

Zinc	Zinc ios (Zn^{2+})	1. Activates various enzymes, especially carboxylases. 2. Needed in the synthesis of auxin.
Copper	Cupric ions (Cu^{2+})	• Needed for overall plant metabolism. • Associated with enzymes involved in redox reactions (reversibly oxidized from Cu^{+} to Cu^{2+}).
Boron	BO_3^{3-} or $B_4O_7^{2-}$	• Required for calcium uptake and use. • Needed for membrane functioning, pollen germination and carbohydrate translocation. • Essential for cell elongation and differentiation.
Molybdenum	Molybdate ions (MoO_2^{2+})	• Component of enzymes involved in nitrogen metabolism – nitrogenase and nitrate reductase.
Chlorine	Chloride anion (Cl^{-})	• Helps to determine the solute concentration and anion-cation balance in cells. • Essential to split water and release

oxygen during photosynthesis.

Deficiency Symptoms of Essential Elements:

When a plant gets limited amounts of an essential mineral, its growth becomes retarded. The concentration of the essential element below which the growth of a plant is retarded is the ‘critical concentration’. Below this concentration, the plant is said to be deficient in that particular element.

Deficiencies are indicated by morphological changes in plants. These are called ‘deficiency symptoms’. These symptoms differ from mineral to mineral and disappear when sufficient levels are provided. However, if the deficiency continues then it leads to plant death.

The part of the plant that shows the effect of the deficiency depends on the mobility of the mineral. For example, the deficiency of nitrogen, potassium and magnesium first appears in the old leaves after which they are mobilised to younger leaves.

But for minerals that are immobile or not transported out of the mature organs, the deficiency first appears in the young leaves. For example, calcium is the structural component of the cell and therefore is not easily mobilised. Plants show the following types of deficiency symptoms:

- Chlorosis (loss of chlorophyll) due to lack of N, K, S, Fe, Mg, Mo, Mn and Zn.
- Necrosis (tissue death, particularly leaf tissue) due to lack of Ca, Mg, K and Cu.
- Inhibition of cell division due to lack of N, K, S, and Mo.
- Delayed flowering due to low levels of N, S, Mo.

Note: Deficiency of one element can cause multiple symptoms or same symptoms can be caused by the deficiency of multiple elements. Mineral deficiencies that affect crop yield are provided through fertilizers. Macro and micronutrients are important parts of fertilizers.

Toxicity of Micronutrients:

There is a narrow range of concentration at which the micronutrients are optimum. Just like a little less than the critical concentration leads to deficiency, little more can cause toxicity. The mineral concentration that reduces the dry weight of plant tissue by 10% is considered toxic.

The critical concentration varies for each micronutrient and the toxicity level for any element also varies for different plants. Therefore, toxicity symptoms are difficult to identify. Moreover, the excess of one element may inhibit the uptake of another element. For example, the excess of manganese may cause deficiencies of iron, calcium and magnesium.

Absorption of Elements:

The mechanism of absorption of mineral elements involves two phases:

- The first phase involves the rapid uptake of ions into the ‘free space’ or ‘outer space’ of cells called the ‘apoplast’. This usually occurs through ion channels, transmembrane proteins that act as selective pores and is therefore passive (does not need energy).

- The second phase involves the slow uptake of ions into the ‘inner space’ of plants called the ‘symplast’. This uptake requires energy and therefore is an active process. The entry of ions into cells is ‘influx’ and exit of ions from cells is ‘efflux’.

In summary, mineral elements are pulled up from the soil along with water through the xylem. Soil acts as a reservoir for minerals. Weathering and breakdown of rocks enrich the soil with inorganic salts and dissolved ions. In addition to minerals, soil also provides water and air; and holds beneficial microbes like nitrogen-fixing bacteria.

Absorption of Mineral Salts by Higher Plant:

The association of a fungus with root of a plant is called as mycorrhiza (plural, mycor-rhizae). Mycoirhizae play very important and significant role in facilitating absorption of mineral salts by plant roots through them. In nature, more than 80% angiosperms (both dicots and monocots) including virtually all plant species of economic importance and almost all gymnosperms are known to form mycorrhizal associations.

However, mycorrhizae are rarely present in:

(i) Aquatic plants,

(ii) Plants belonging to the families Brassicaceae, Chenopodiaceae and Proteaceae,

(iii) Hydroponically grown plants,

(iv) Young rapidly growing crop plants and

(v) Plants growing in flooded or very dry or saline soils or soils with very low or very high fertility.

i. The relationship of mycorrhizae is symbiotic or of mutualism in which both partners are benefited. The fungus absorbs mineral salts from the soil and releases them into cells of host root. In return, the host root cells provide carbohydrates supply to the fungus.

ii. The mycorrhizal fungi extend the rhizosphere and also the nutrient depletion zone in the soil. This greatly facilitates absorption of mineral elements especially those which are less soluble and relatively immobile in soil such as phosphorous.

Those parts of mycorrhizal fungi which are in direct contact with organic litter in the soil, may also hydrolyze complex organic compounds to release minerals which are subsequently absorbed by them.

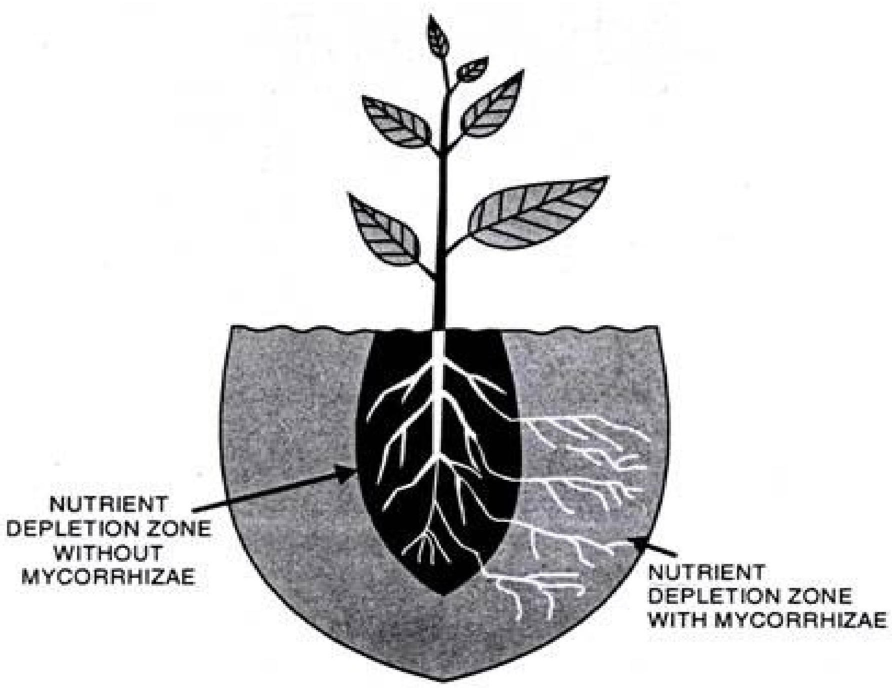

Fig. 7.11. Extension of nutrient depletion zone in the soil by mycorrhizae.

Numerous studies done with pines and other tree seedlings by scientists in U.S.A., Australia and other countries have shown an increase of 30-150% in dry weight of seedlings infected with mycorrhizal fungi as a result of increased absorption of mineral salts through mycorrhizae as compared to non-infected controls. Similar results have also been obtained with agricultural plants like maize.

The myeorrhizal fungi many of which are specific to host species may be grouped in two categories:
(i) Eciotrophic mycorrhizae and

(ii) Vesicular arbuscular mycorrhizae (VAM).

1. Ectotrophic Mycorrhizae:

These mycorrhizae form a thick mantle around the roots, part of which enters in between the cortical cells of the roots (without penetrating them) and forming an intercellular network of hyphae which is called as Hartig net. Some of the hyphae from thick mantle around the roots extend into the soil reaching beyond nutrient depleted areas of the soil near the roots to tap fresh supply of mineral nutrients.

The amount of ectotrophic fungal mycelium may be so considerable that its total weight may be comparable to the weight of host roots infected by it.
i. Ectotrophic mycorrhizal fungi infect exclusively gymnosperms (such as pines) and woody angiosperms.

ii. The mineral salts absorbed by ectotrophic mycorrhizal fungi directly diffuse into cortical cells of host roots through Hartig net.

2. Vesicular Arbuscular Mycorrhizae (VAM):

Vesicular arbuscular mycorrhizal fungi infect roots of most of the species of herbaceous angiosperms, but unlike ectotrophic mycorrhizae do not form a thick mantle around the roots. Their total weight also is far lesser (about 10%) as compared to weight of roots which they infect.

The mycelium of VAM penetrates the host roots through root hairs and epidermal cells. The hyphae extend in between the cortical cells and also penetrate the latter where they form small ellipsoid oval structures called as vesicles and highly branched tree like structures called as arbuscles .

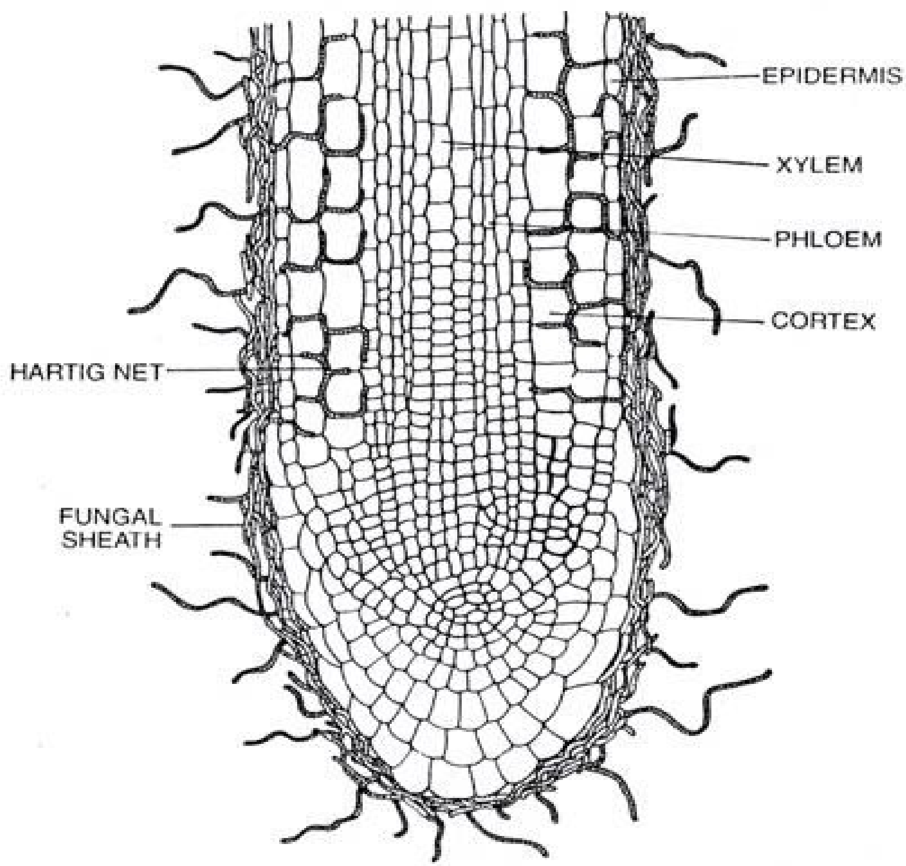

Fig. 7.12. Section of a root infected with ectotrophic mycorrhizal fungi.

In arbuscles, the branches of fungal hyphae are surrounded by plasma membrane or tonoplast of host cortical cells. Therefore, the fungal hyphae actually penetrate only the cortical cell walls and not the protoplast.

As a result of infection by VAM, the cytoplasmic volume of the cortical cells of host roots may increase by 20-25%. The arbuscles serve to increase the contact surface area between hyphae and cortical cells for exchange of nutrients by 2-3 times.

In VAM, the minerals may diffuse from arbuscles to cortical cells of host root either (i) directly or (ii) by releasing their contents into the latter when they disintegrate.

As with ectotrophic mycorrhizae, in VAM also some of the finer hyphae from mycelium present around the roots extend into the soil beyond the nutrient depleted areas to tap fresh supply of minerals.

Absorption of Mineral Salts from Soil by Plant roots:

Mechanism of Mineral Salt Absorption:

Previously, it was thought that the absorption of mineral salts from the soil took place along with the absorption of water but it is now well established that the mineral salt absorption and water absorption are two different processes. Mineral salts are absorbed from the soil solution in the form of ions. They are chiefly absorbed through the meristematic regions of the roots near the tips.

However, some mineral salts may also be absorbed at other locations on the root surface or over the entire root surface including zone of elongation and root hairs that depends upon the high availability of such minerals around them and/or strong tissue demand at such locations.

Plasma membrane of the root cells is not permeable to all the ions. It is selectively permeable. All the ions of the same salt are not absorbed at equal rate but there is unequal absorption of ions. First step in the absorption of mineral salts is the process of Ion-Exchange which does not require metabolical energy but greatly facilitates mineral salt absorption.

Ion-Exchange:

The ions adsorbed on the surface of the walls or membranes of root cells may be exchanged with the ions of same sign from external solution. For example, the cation K^+ of the external soil solution may be exchanged with H^+ ion adsorbed on the surface of the root cells. Similarly, an anion may be exchanged with OH^- ion. There are two theories regarding the mechanism of ion exchange:

(i) Contact Exchange Theory:

According to this theory, the ions adsorbed on the surface of root cells and clay particles (or clay micelles) are not held tightly but oscillate within small volume of space. If the roots and clay particles are in close contact with each other, the oscillation volume of ions adsorbed on root-surface may overlap the oscillation volume of ions adsorbed on clay particles, and the ions adsorbed on clay particle may be exchanged with the ions adsorbed on root-surface directly without first being dissolved in soil solution (Fig. 7.1 A).

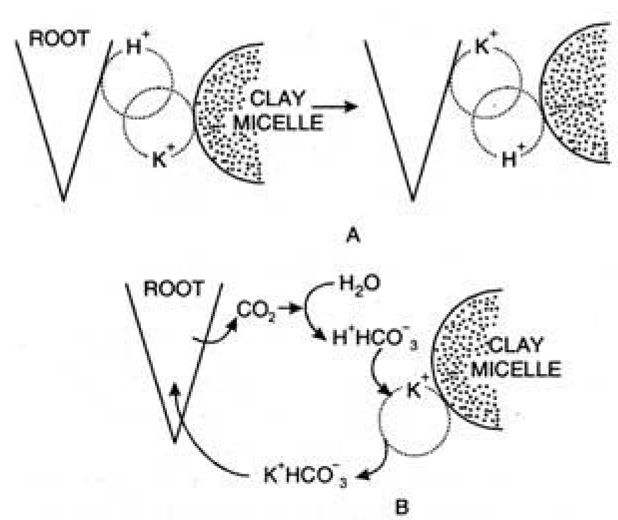

Fig. 7.1. Diagrammatic representation of (A) the contact-exchange theory and (B) the carbonic acid exchange theory.

(ii) Carbonic Acid Exchange Theory:

According to this theory, the CO_2 released during respiration of root cells combines with water to form carbonic acid (H_2CO_3). Carbonic acid dissociates into H^+ and an anion HCO_3^- in soil solution. These H^+ ions may be exchanged for cations adsorbed on clay particles.

The cations thus released into the soil solution from the clay particles, may be adsorbed on root cells in exchange for H^+ ions or as ion pairs with bicarbonate. Thus, soil solution plays an important role in carbonic acid exchange theory.

The further process of the absorption of mineral salts may be of two types:

(1) Passive

(2) Active

(1) Passive Absorption of Mineral Salts:

When the concentration of mineral salts is higher in the outer solution than in the cell sap of the root cells, the mineral salts are absorbed according to the concentration gradient by simple process of diffusion. This is called as passive absorption because it does not require expenditure of metabolic energy.

It is now known that during passive absorption, the mineral salts may diffuse through cell membranes directly through lipid bilayer but mainly through trans-membrane ion-selective protein channels or trans-membrane carrier proteins. Carrier or channel mediated passive transport of mineral salts across the membrane is also called as facilitated diffusion.

(2) Active Absorption of Mineral Salts:

It has often been observed that the cell sap in plants accumulates large quantities of mineral salts ions against the concentration gradient. For example, in alga Nitella the cell sap accumulated K^+ and phosphate ions to such an extent that their concentrations were thousands and hundreds times greater than in the pond water in which the plant was growing.

This cannot be explained by simple diffusion or Donnan's Equilibrium and has led people to believe that absorption and accumulation of mineral salts against the concentration gradient is an active process which involves the expenditure of metabolic energy through respiration.