MINERAL NUTRITION

- The plants require inorganic elements which they chiefly obtain from the soil where these elements occur in the form of minerals. The absorption, distribution and metabolism of various mineral elements by plants is called **mineral nutrition.**

CLASSIFICATION OF MINERAL NUTRIENTS

- Mineral elements can be classified into two types: essential and non-essential mineral elements.

Non-essential mineral elements

- Some mineral elements such as cobalt, silicon, sodium, vanadium etc. have found to be required in metabolic activities of certain plants and not all plants. They are not indispensible for plant growth. Their absence does not produce any major deficiency symptoms which are mineral specific (*i.e.*, cannot be cured by supplying other minerals). Such elements are called as functional elements or non-essential elements.

Essential mineral elements

- An essential element is the one which has a specific structural or physiological role and without which plants cannot complete their life cycle.
- Different criteria for knowing the essentiality of elements are as follows :
  - The element must be **absolutely essential** for supporting normal growth and reproduction of plants.
  - **Withholding** of the element **must cause the deficiency symptoms.** These disorders are removed by supplying the particular element.
  - The deficiency arising must be specific for the element *i.e.*, its deficiency symptoms may not be cured by any other element.
  - The element must be **directly involved in the nutrition of plants.** It must be either a component of an organic molecule or participants in a biochemical reaction.
  - Essential elements have been further classified into macroelements and microelements.

Macroelements (macronutrients)

- These are those essential elements which are present in easily detectable quantities, at least one milligram (1000 microgram) per gram of dry matter.
- These are usually involved in the synthesis of **organic molecules** and development of osmotic potential. They are **9 in number** – C, H, O, N, P, K, S, Mg and Ca. Around 90% of the dry weight is formed of carbon, hydrogen and oxygen. On fresh weight basis, oxygen is almost as abundant as carbon.
- Among these C, H and O are obtained by air mainly thus are termed as non-mineral elements. Iron occurs in the concentration of less than 1 mg/gm. However, its essentiality was discovered alongwith other macroelements long before microelements were found to be required. Therefore it is often regarded as macroelement.

Microelements (micronutrients)

- These essential elements are required by plants in traces only less than 1 mg/gm of dry matter. Microelements are mostly involved in the functioning of enzymes, as **cofactors** or **metal activators.** These are **eight in number** – Zn, Mn, B, Cu, Mo, Cl, Ni, Fe.
- In addition to the 17 elements, other elements Na, Si, Co etc have been established as being essential for a few species of higher plants.
- Now, world authorities disregard the distinction between micro and macronutrients, because an element can be micronutrient for one plant while macronutrient for the other or its requirement may vary drastically in a single plant according to environment.

Table : Differences between macroelements and microelements

	Macroelements	Microelements
1.	They occur in plants in easily detectable quantities.	They occur in plants in very small amounts.
2.	The concentration of a macroelement per gm of dry matter is at least 1 mg or 1000 μg.	The concentration of a microelement is less than 1 mg/gm of dry matter.
3.	They build up the plant body and different protoplasmic constituents.	Microelements do not have such a role.
4.	Some macroelements accumulate in cell sap and take part in developing osmotic potential.	Microelements, being found in traces only, have no significant role in the development of osmotic potential.
5.	Turgor movements are mostly caused by influx and efflux of potassium, a macroelement.	None of the microelements have any such function.
6.	They do not become toxic in slight excess.	Microelements are toxic in slight excess.

- The functions and deficiency symptoms of essential elements are summarized in the table given *on next page.*

DEFICIENCY SYMPTOMS

- Deficiency symptoms appear in plants whenever the supply of an essential element becomes limited. The concentration of the essential element below which plant growth is retarded is termed as **critical concentration.** Certain common deficiency symptoms can appear which are given below:
- **Chlorosis** – Non-development or loss of chlorophyll. This symptom is caused by the deficiency of elements N, K, Mg, S, Fe, Mn, Zn and Mo.
- **Mottling** – Patches of green and non-green areas.
- **Necrosis** – Death of tissues, stunted growth. It is due to the deficiency of Ca, Mg, Cu, K. Lack or low level of N, K, S, Mo causes an inhibition of cell division.

Table : Essential elements at a glance

	Elements	Functions	Deficiency symptoms
		Macroelements	
1.	C, H, O (obtained from air and water)	**Structural framework**, protoplasmic constituents H^+ governs pH, oxygen is the terminal electron acceptor in respiration, storage of food, etc.	Normal growth cannot occur as they are **building blocks** of body.
2.	Nitrogen (N)	Required for the synthesis of **amino acids, proteins, nucleic acids, vitamins, hormones, coenzymes, ATP and chlorophyll.**	Stunted growth. Chlorosis that appears first in older leaves.
3.	Phosphorus (P)	Required for the synthesis of **nucleic acids, phospholipids, ATP, NAD and NADP.** Constituent of cell membrane and some proteins.	Poor growth especially of roots. Leaves appear dull green. Often leads to premature leaf fall.
4.	Potassium (K)	Activates about forty enzymes. Associated with K^+/Na^+ pump in active transport, **anion-cation balance** in the cells. Brings about **opening and closing of stomata.** Common in cell sap in plant vacuoles and helps in turgidity of cells.	Stunted growth. Yellow and shrivelled leaf margins. Mottled appearance of older leaves and premature death.
5.	Calcium (Ca)	Present as **calcium pectate in the middle lamella** of cell wall that joins adjoining cells together. Activates enzymes needed for the growth of root and shoot tip. Needed for normal cell wall development. Required for cell division, cell enlargment and translocation of carbohydrates.	Chlorosis of young leaves. Die-back of shoots due to death of apical buds. Poor root growth. Leaf tips become hooked. Causes **black heart of celery.**
6.	Magnesium (Mg)	Forms **part of the chlorophyll** molecule. Activates enzymes of phosphate metabolism. Important for synthesis of fats and respiration. Essential for **binding components of ribosomes.**	Interveinal chlorosis especially of older leaves. In severe cases leads to necrosis.
7.	Sulphur (S)	As a constituent of amino acids- **cysteine, cystine,** and **methionine** and hence some of the proteins. Present in coenzyme A, vitamins, thiamine and biotin. Increases root development. Increases the nodule formation in legumes.	Chlorosis lose in nitrogen deficient plants but first in young leaves. Causes **tea yellow disease.** Extensive root system.
		Microelements	
8.	Iron (Fe)	Needed for the synthesis of chloroplast proteins and so affects the chlorophyll and carotenoid synthesis. As a constituent of ferredoxin and cytochromes. **Activates** the enzyme **catalase.**	Interveinal chlorosis, particularly in young leaves. May be localised to single leaf or branch due to limited mobility.
9.	Manganese (Mn)	**Activates carboxylase** enzymes. Acts as electron donor for chlorophyll *b*. Involved in decarboxylation reactions during respiration.	Leaf - flecking or greyspots due to chlorosis and necrosis in interveinal zones. **Grey speck of oat, marsh spot disease of pea.**
10.	Molybdenum (Mo)	Required for nitrogen fixation. Activates the enzyme **nitrate reductase.**	Fall in the ascorbic acid content of the plant. Mottling and necrosis first in older leaves and then in young leaves. May lead to abscission of flowers. Causes **whiptail disease.**

11.	Boron (B)	Increases the uptake of water and calcium. Essential for meristem activity and growth of pollen tube. Involved in translocation of carbohydrates.	Death of stem and root apices. Thickened leaves that curl and become brittle. Reduced flower production. Causes **heart rot of beets, stem crack of celery, brown heart of turnip,** etc.
12.	Copper (Cu)	Component of oxidase enzymes and plastocyanin. Involved in electron transport in photosynthesis.	Reduced absorption of CO_2. **Dieback of shoots.** Necrosis at the tip of young leaves & then the margin. Exanthema in *Citrus*.
13.	Zinc (Zn)	Component of indol-acetic acid (IAA) - a plant growth substance. **Activates dehydrogenases** and **carboxylases.** Present in enzyme **carbonic anhydrase.**	Little leaf and mottle leaf condition. Reduction in internode length. Rossette type growth. **Whip tip of maize, khaira disease of rice, sickle leaf of cocoa.**
14.	Chlorine (Cl)	Essential for O_2 evolution in photosynthesis. Anion-cation balance in cells.	Bronze colour in leaves. Chlorosis, necrosis. Swollen root tips. Flower abscission.
15.	Nickel (Ni^{2+})	Metabolism of urea and ureides.	Leaf tip necrosis.

- **Abscission** – Premature fall of flowers and fruits, leaf fall, Leaf curl.
- **Wilting** – Loss of turgor, internal cork.
- **Internal or heart rot** – Softening or rotting of internal tissues, external cracks.
- **Die back** – Killing of root apex.
- **Little leaf disease** – Leaves are quite small in size.
- **White bud** – Chlorosis affecting young leaves as well as buds so that the latter are whitish instead of greenish colour.
- **Deficiency symptoms of mobile elements** tend to appear first in the older tissues, *e.g.*, the deficiency symptom of nitrogen, potassium and magnesium are visible first in the senescent leaves, In the older leaves, biomolecules containing these elements are broken down, making these elements available for mobilising to younger leaves.
- **Deficiency symptoms of immobile elements** tend to appear first in the young tissues whenever the elements are relatively immobile and are not transported out of mature organs, *e.g.*, elements like sulphur and calcium are a part of the structural component of the cell and hence are not easily released.
- This aspect of minerals nutrition of plants is of a great significance and importance to agriculture and horticulture.

MINERAL TOXICITY

- Slightly higher doses of micronutrients can produce toxicity. Any tissue concentration which reduces dry weight of tissue by 10 percent is called **toxic concentration.** Critical toxic concentration is different for different micronutrients as well as different plants. For example, Mn^{2+} is toxic beyond 600 $\mu g\ g^{-1}$ for soyabean and beyond 5300 $\mu g\ g^{-1}$ for sunflower.
- Toxic effects may be due to direct excess of the micronutrient or its interference in the absorption and functioning of other nutrients.For example, manganese toxicity (brown spots surrounded by chlorotic veins) causes:
  - Reduction in uptake of iron and magnesium.
  - Inhibition of binding of magnesium to specific enzymes.
  - Inhibition of calcium translocation into shoot apex
- Therefore, excess of manganese causes deficiency of iron, magnesium and calcium. The toxicity symptoms of Mn are actually combined deficiency symptoms of Fe, Mg and Ca.

HYDROPONICS (GOERICK, 1940)

- The soilless production of plants is called hydroponics. Plant are raised in small tanks of concrete or metal. They are filled up with a water solution containing appropriate quantities of all mineral elements. The solution is changed from time to time.
- **Advantages of hydroponics** are that it can regulate pH optimum for a particular crop, control soil borne pathogens, avoid problems of weeding and obtain consistently better yield. Out of season, vegetables and flower can also be obtained. However, the cost of setting up of a hydroponic system is very high.
- Hydroponics or soilless culture helps to know :
  - The essentiality of mineral elements.
  - The deficiency symptoms developed due to non-availability of particular nutrient.
  - Toxicity to plant when element is present in excess.
  - Possible interaction among different elements present in plants.
  - The role of essential element in the metabolism of plant.

NITROGEN NUTRITION IN PLANTS

- Nitrogen is a gaseous nutrient but it is unabsorbable by plants in its gaseous form. A **regular supply of nitrogen to the plants is maintained through nitrogen cycle.** Plants obtain nitrogen from soil as NO_3^- (nitrate), NH_4^+ (ammonium) and NO_2^- (nitrite) ions.

Nitrogen fixation

- The phenomenon of conversion of free nitrogen into nitrogenous salts to make it available for absorption by plants is called **nitrogen fixation.**
- It may be **abiological** (due to lightning and thundering) or biological. **Biological nitrogen fixation** is the second most important natural process and the major source of nitrogen fixation which is performed by two types of prokaryotes; bacteria and cyanobacteria (blue green algae). They include both free living and symbiotic forms.

Free living nitrogen fixing bacteria

- *Azotobacter*, *Beijerinckia* (**both aerobic**) and *Bacillus*, *Klebsiella*, *Clostridium* (**all anaerobic**) are **saprotrophic bacteria** that perform nitrogen fixation. *Desulphovibrio* is **chemotrophic** nitrogen fixing bacterium. *Rhodopseudomonas*, *Rhodospirillum* and *Chromatium* are nitrogen fixing **anaerobic photoautotrophic** bacteria.

Free living nitrogen fixing cyanobacteria

- Many free living blue-green algae (BGA) or cyanobacteria perform nitrogen fixation, *e.g.*, *Anabaena*, *Nostoc*, *Calothrix*, *Lyngbia*, *Aulosira*, *Cylindrospermum*, *Trichodesmium*, etc.

Symbiotic nitrogen fixing cyanobacteria

- *Anabaena* and *Nostoc* species are common symbionts in lichens, *Anthoceros*, *Azolla* and cycad roots. *Azolla pinnata* (a water fern) has *Anabaena azollae* in its fronds. It is often inoculated to rice fields for nitrogen fixation.

Symbiotic nitrogen fixing bacteria

- *Sesbania rostrata* has *Rhizobium* in **root nodules** and *Aerorhizobium* in **stem nodules.** *Frankia* is symbiont in root nodules of several nonlegume plants like *Casuarina* (Australian pine), *Myrica* and *Alnus* (Alder). *Rhizobium* is the most important for crop lands because it is associated with pulses and other legumes of family fabaceae. Several species of the bacterium (*e.g.*, *Rhizobium leguminosarum*, *R. meliloti*) live in the soil but are unable to fix nitrogen by themselves. They can fix nitrogen only inside root nodule.

Nodule formation

- Roots of a legume secrete chemical attractants (flavonoids and betaines). Bacteria collect over the root hairs and release *nod* factors that cause **curling of root hairs,** around the bacteria, **degradation of cell wall** and **formation of an infection thread** enclosing the bacteria. Infection thread grows alongwith multiplication of bacteria and reaches opposite protoxylem points of vascular strand. The infected cortical cells differentiate and start dividing to produce swellings called **nodules.**
- Nodule formation is stimulated by auxin produced by cortical cells and cytokinin liberated by invading bacteria. The infected cells enlarge and bacteria stop dividing and form irregular polyhedral structures called **bacteriods.** In an infected cell, bacteriods occur in groups surrounded by host membrane and cell develops a pinkish pigment called **leghaemoglobin.** It is **oxygen scavenger** and protects nitrogen fixing enzyme **nitrogenase** from oxygen. Symbiotic nitrogen fixation requires co-operation of *Nod* genes of legume and *nod*, *nif* and *fix* gene clusters of bacteria.

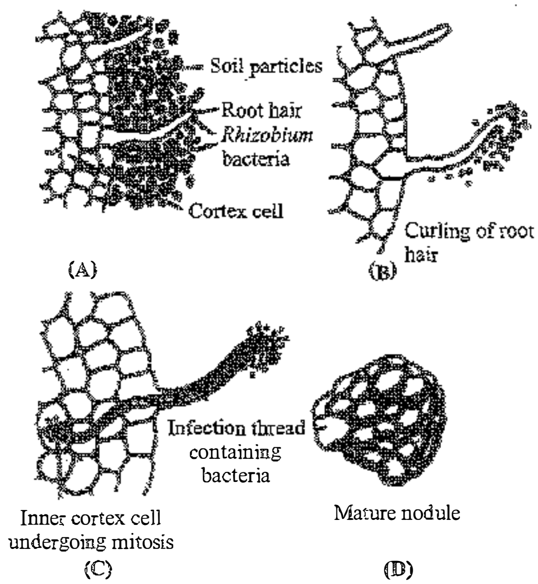

Fig.: Mode of development of root nodules in soyabean

Mechanism of biological nitrogen fixation

- In the process of biological nitrogen fixation by free living and symbiotic nitrogen fixers, the dinitrogen molecule ($N \equiv N$) is progressively reduced step-by-step to ammonia (NH_3) by the addition of pairs of hydrogen atoms. The overall process occurs in presence of enzyme **nitrogenase,** which is **active in anaerobic condition.** The enzyme nitrogenase consists of two sub-units – a non-heme iron protein commonly called **Fe protein** (or dinitrogen reductase) and an iron molybdenum protein called **Mo-Fe proteiu** (or dinitrogenase). The Fe-protein component reacts with ATP and reduces Mo-Fe protein which then reduces N_2 to ammonia. The overall biochemical reaction is as follows :

$$N_2 + 8\,e^- + 8\,H^+ + 16\,ATP \dashrightarrow 2\,NH_3 + H_2 + 16\,ADP + 16\,Pi$$

- The product of nitrogen fixation is ammonia which is toxic to plants. At physiological pH, the ammonia is protonated to form NH_4^+ (ammonium) ion. While most of the plants can assimilate nitrate as well as ammonium ions, the latter is quite toxic to plants and hence cannot accumulate in them. This nitrogen reaches animals *via* food chain.
- Decomposition of organic nitrogen of dead plants and animals, brings it back into the nitrogen cycle. The recycling is brought about by three processes namely ammonification, nitrification and denitrification.

Ammonification

- It is carried out by decay causing organisms. They act upon nitrogenous excretions and proteins of dead bodies of living organisms, *e.g., Bacillus ramosus, B. vulgaris, B. mesentericus, Actinomyces*.
- Proteins are first broken up into amino acids. The latter are deaminated. Organic acids released in the process are used by microorganisms for their own metabolism.

Nitrification

- It is the phenomenon of conversion of ammonium nitrogen to nitrate nitrogen. It is performed in two steps – **nitrite formation** and **nitrate formation**.

Denitrification

- In the process, nitrates are reduced to gaseous compounds of nitrogen. The latter escape from the soil. Common bacteria causing denitrification of soil are *Pseudomonas denitrificans*.

NITROGEN ASSIMILATION

- Use of nitrogen in protein synthesis is called **nitrogen assimilation. Symbiotically fixed nitrogen** is assimilated as follows:
- **Reductive amination:** In these processes, protonated ammonia reacts with α-ketoglutaric acid and forms glutamic acid as indicated in the equation given below:

$$\alpha\text{–ketogluataric acid} + NH_4^+ + NADPH \xrightarrow[\text{dehydrogenase}]{\text{Glutamate}} \text{glutamate} + H_2O + NADP$$

- **Transamination:** It involves the transfer of amino group from one amino acid to the keto group of a keto acid. Glutamic acid is the main amino acid from which the transfer of NH_2, the amino group takes place and other amino acids are formed through transamination. The enzyme **transaminase** catalyses all such reactions.
- Amides (aminated keto acids) have high N to C ratio, they perform storage of excess nitrogen and transport. These amino acids form proteins.
- Assimilation of **non-symbiotically fixed nitrogen** *i.e.*, present in soil as nitrates involves some extra initial steps.

(i) Reduction of nitrate to nitrite

$$\underset{\text{Nitrate}}{NO_3} + \underset{\text{Electron donor}}{NAD(P)H} + H^+ \xrightarrow[\textit{FAD/FMN}]{\textit{Nitrate reductase}} \underset{\text{Nitrite}}{NO_2^-} + H_2O + NADP^+$$

(ii) Reduction of nitrite

$$2NO_2^- + 7NAD(P)H + 7H^+ \xrightarrow[\textit{Ferredoxin}]{\textit{Nitrite reductase}} 2NH_3 + 4H_2O + 7NAD(P)^+$$

- Rest of the process is same and proteins are formed as assimilation product.

CONCEPT MAP

Plant Nutrients

- **Mineral**: Nutrients that are absorbed from soil *e.g.*, Fe, Mg, Ca, etc.
- **Non-mineral**: Nutrients that are absorbed from atmosphere. These are C, H and O.
- **Essential**: Nutrients absolutely necessary for normal growth and development. Their deficiency produces visible symptoms which are nutrient specific.
  - **Microelements**: Elements that are present in plant tissues in concentration less than 10 mmole kg^{-1} of dry matter. They include Mn, Fe, Cu, Mo, Zn, B, Cl & Ni.
  - **Macroelements**: Elements that are present in plant tissues in excess of 10 mmole kg^{-1} of dry matter. They include C, H, O, N, P, K, S, Ca and Mg.
- **Non-essential**: Required for normal functioning of plant but their deficiency can be supplemented by another elements.

Metabolism of Nitrogen: Gaseous form of nitrogen is unusable by plants it must be 'fixed' into its salts.

- **Nitrogen fixation**
  - **Abiological fixation**: By lightning and industries etc.
  - **Biological fixation**: By free living or symbiotic bacteria. Symbiotic bacteria directly provide nitrates to plant. Free living bacteria release fixed nitrogen after their death. They fix N_2 by ammonification and nitrification.
- **Nitrogen assimilation**: Incorporation of N into aminoacids is called nitrogen assimilation. It is required for protein synthesis. Nitrogen assimilated by plants reaches animals *via* food chain.
- **Denitrification**: Denitrifying bacteria work upon dead organisms and release nitrogen trapped in their tissue. This released nitrogen re-enters