12. MINERAL NUTRITION

➔ **Mineral Nutrition**: - *The study of how plants get their mineral elements for growth and development*.

HYDROPONICS: -

✓ It is a method to study the mineral nutrition by growing plants in a defined nutrient solution (without soil, by Julius von Sachs).
- It was used to identify the essential elements required for plants and their deficiency symptoms. This method requires **purified water** and **mineral nutrient salts**.
- It has been used in the commercial production of vegetables such as tomato, seedless cucumber and lettuce (leaves used in salad).

ESSENTIAL MINERAL ELEMENTS

- More than 60 elements are found in different plants.
- Only 17 elements are absolutely essential for plant growth and metabolism.

CRITERIA OF ESSENTIALITY OF AN ELEMENT

a) The element must be necessary for normal growth and reproduction. (In the absence of the element, the plants do not complete their life cycle).
b) The requirement of the element must be specific and not replaceable by another element.
c) It must be directly involved in the plant metabolism.

- Based on quantitative requirements, essential elements are divided into 2 types: **Macronutrients** & **Micronutrients**.

Essential Elements

Macronutrients
(Needed in excess of 10 mmole Kg $^{-1}$ of dry matter)

Carbon, Hydrogen, Oxygen } from CO_2 and H_2O

Nitrogen, Phosphorous, Sulphur, Potassium, Calcium, Magnesium } from soil (as mineral nutrition)

Micronutrients
(Less than 10 mmole Kg $^{-1}$ of dry matter is required)

Iron
Manganese
Copper
Molybdenum
Zinc
Boron
Chlorine
Nickel

➔ **Beneficial elements** (not essential, beneficial if present)-**Na**, **Si**, **Co** & **Se**

Categorization of Essential elements based on their functions-

(i) **Components of biomolecules** (Structural elements). e.g.: **C, H, O** & **N**
(ii) **Components of energy-related chemical compounds**. e.g.: **Mg** in chlorophyll and **P** in ATP.
(iii) **Elements that activate or inhibit enzymes**
e.g.:**Mg^{2+}** -an activator for both RUBP carboxylaseoxygenase and PEP carboxylase;
Zn^{2+}- an activator of alcohol dehydrogenase and Mo of nitrogenase (during N-metabolism)
(iv) **Elements altering the osmotic potential** of a cell. eg: **K** for opening and closing of stomata.

Role of Macro-nutrients

Sl no.	Nutrient	Absorbed as	Role
1	**Nitrogen**	NO_3^-, NO_2^-, NH_4^+	▪ Synthesis of proteins, nucleic acids, vitamins and hormones.
2	**Phosphorus**	$H_2PO_4^-$, HPO_4^{2-}	▪ Constituent of cell membranes, certain proteins, nucleic acids and nucleotides (ATP). ▪ Required for all phosphorylation reactions.
3	**Potassium**	K^+	▪ Maintenance of anion-cation balance in cells. ▪ Involved in protein synthesis. ▪ Opening and closing of stomata, activation of enzymes. ▪ Maintenance of the turgidity of cells.
4	**Calcium**	Ca^{2+}	▪ Used as calcium pectate in formation of the middle lamella of cell wall. ▪ For the formation of mitotic spindle ▪ Involved in the normal functioning of the cell membranes. ▪ Activates certain enzymes
5	**Magnesium**	Mg^{2+}	▪ Activates the enzymes of respiration, photosynthesis (RuBisCO, PEPcase) ▪ Enzyme activation in the synthesis of DNA and RNA ▪ Constituent of the ring structure of **chlorophyll** ▪ Helps to maintain the ribosome structure.
6	**Sulphur**	SO_4^{2-}	▪ Present in two amino acids – cysteine and methionine ▪ Main constituent of several coenzymes, vitamins (thiamine, biotin, Coenzyme A) and ferredoxin.

Role of Micro-nutrients

1	**Iron**	Fe^{3+}	▪ Constituent of proteins involved in the transfer of e^- like ferredoxin & cytochromes. ▪ Activates catalase enzyme ▪ Essential for <u>the formation of chlorophyll</u>.
2	**Manganese**	Mn^{2+}	▪ Activates many enzymes involved in photosynthesis, respiration and N_2 metabolism. ▪ <u>Splitting of water</u> to liberate O_2 during photosynthesis.
3	**Zinc**	Zn^{2+}	▪ Activates various enzymes, e.g.: carboxylases. ▪ Needed in <u>the synthesis of auxin.</u>
4	**Copper**	Cu^{2+}	▪ Associated with certain enzymes involved in redox rxns.
5	**Boron**	BO_3^{3-}, $B_4O_7^{2-}$	▪ Required for uptake and <u>utilisation of Ca^{2+}</u>, ▪ Membrane functioning ▪ <u>Pollen germination</u> ▪ Cell elongation & <u>cell differentiation</u> ▪ Carbohydrate translocation.
6	**Molybdenum**	MoO_2^{2+}	▪ Component of nitrogenase and nitrate reductase (in nitrogen metabolism)
7	**Chlorine**	Cl^-	▪ Helps in determining the solute concentration ▪ The <u>anion-cation balance</u> in cells ▪ Essential for the <u>water-splitting</u> reaction in photosynthesis.

Deficiency Symptoms of Essential Elements

- **Critical concentration** - The concentration of the essential element below which plant growth is retarded**.** The element is said to be **deficient** when present below the critical concentration.
- **Deficiency symptoms-** The morphological changes indicating deficiency of certain element**.** It depends on
  - Element deficient
  - On the mobility of the element in the plant.

Sl no.	Deficiency Symptoms	Minerals lacking or in low level
a)	Chlorosis (loss of chlorophyll leading to yellowing in leaves)	**N, K, Mg, S, Fe, Mn, Zn, Mo**
b)	Necrosis (death of leaf tissue)	**Ca, Mg, Cu, K**.
c)	Inhibition of cell division	**N, K, S, Mo**
d)	Delayed flowering	**N, S, Mo**

- Deficiency of essential minerals affects the crop-yield. So there is a need for supplying them through fertilisers.

Toxicity of Micronutrients

- ✓ A moderate increase in micronutrients causes **toxicity**. Toxicity levels for any element also vary for different plants.
  - ***Any mineral ion concentration in tissues that reduces the dry weight of tissues by about 10% is considered toxic.***
- ✓ **Excess of an element** may inhibit the uptake of another element.

Eg: **Mn** toxicity induces deficiencies of **Fe, Mg & Ca** because
- Mn competes with **Fe & Mg** for uptake and with **Mg** for binding with enzymes.
- Mn inhibits **Ca** translocation in shoot apex.

Thus symptoms of **Mn** toxicity (brown spots surrounded by chlorotic veins) may actually be the deficiency symptoms of **Fe, Mg & Ca.**

SOIL AS RESERVOIR OF ESSENTIAL ELEMENTS

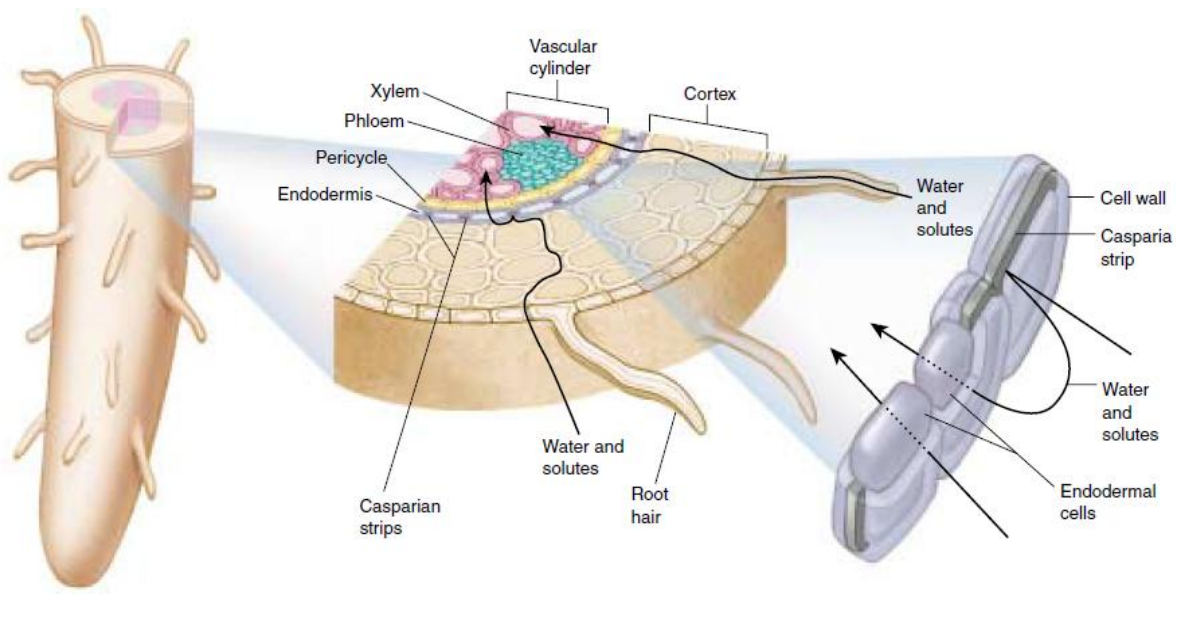
- **Role of soil:**
  - It supplies minerals (Weathering and breakdown of rocks enrich the soil with dissolved ions and inorganic salts)
  - It holds water.
  - It harbours nitrogen-fixing bacteria and other microbes.
  - It supplies air to the roots.
  - It acts as a matrix that stabilizes the plant.

MECHANISM OF ABSORPTION OF ELEMENTS

The process of absorption has 2 main phases:-

a) **First phase:** Initial rapid and passive uptake of ions into the 'free space' or 'outer space' of cells (*apoplast*). It usually occurs through ion-channels, the trans-membrane proteins that function as selective pores.

b) **Second phase**: The ions are taken in **actively** and slowly into the 'inner space' of cells (*symplast*).
- The inward movt. of ions into the cells is called ***influx*** and the outward movt. is ***efflux***.



The pathways of mineral transport in roots.

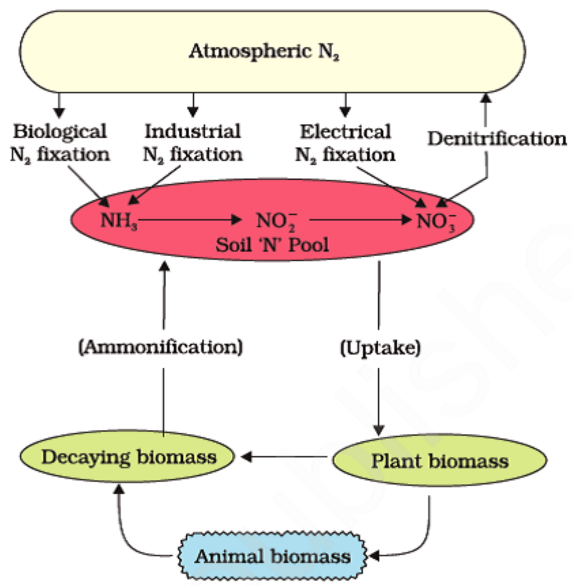
Translocation of solutes

- Mineral salts are translocated through xylem **along with the ascending stream of water.**

METABOLISM OF NITROGEN

Nitrogen Cycle

- It is the cyclic movement of N_2 between atmosphere and living organisms.
- N_2 exists as 2 nitrogen atoms joined by a very strong triple covalent bond ($N \equiv N$).
- N_2 is a limiting nutrient for both natural and agricultural ecosystems.



I- Nitrogen fixation

➔ The process of conversion of N_2 to ammonia or nitrous oxides**.**
It is of 2 types-

A. Biological Nitrogen Fixation

Conversion of N_2 to ammonia by living organisms.

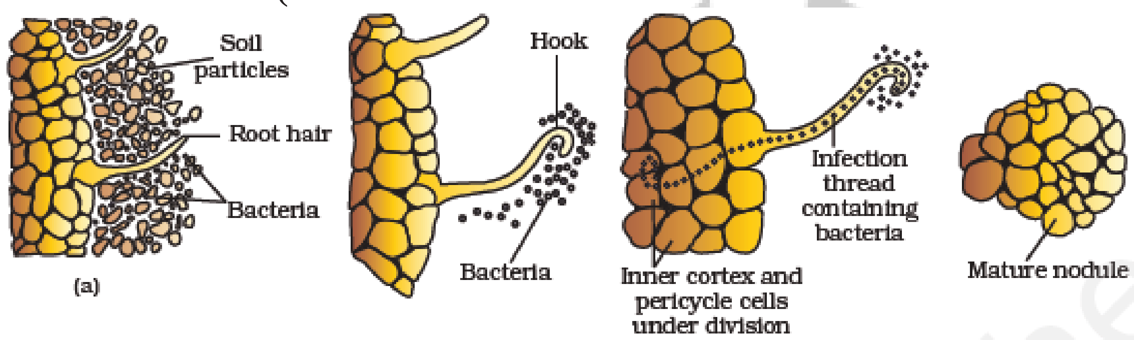
Ex: *Azotobacter*, *Beijernickia*, *Bacillus* – Aerobic bacteria
Rhodospirillum –Anaerobic bacteria
Anabaena and *Nostoc*- Cyanobacteria
} Free-living

Rhizobium (in roots of Legumes*)*
Frankia (in roots of non legumes)
} Symbionts

Nodule formation:-

- **Nodule** act as a site for N_2 fixation in legumes. It is a little out growth on the legume roots

(1st-Stage) *Rhizobia* **multiply and colonise** the surroundings of roots and get attached to epidermal and root hair cells.
(2nd-Stage) The **root-hairs curl** and the **bacteria invade** the root-hair.
(3rd-Stage) An **infection thread** is produced carrying the bacteria into the cortex of the root, where they **initiate the nodule** formation.
(4th-Stage) Bacteria are released from the thread into the cells which leads to the differentiation of specialised nitrogen fixing cells
(5th-Stage) Nodule formed →(establishes a direct vascular connection with the host for exchange of nutrients).

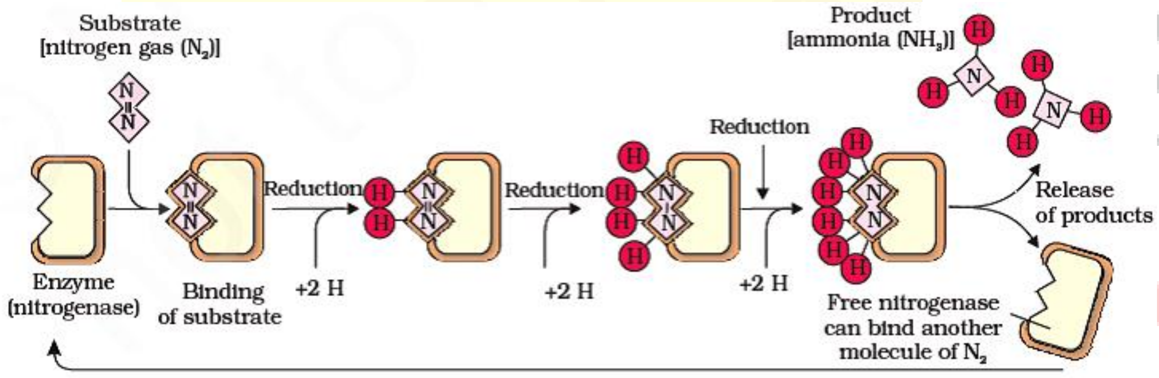


- Nodule contains all the necessary biochemical components, such as the enzyme *nitrogenase* and *leghaemoglobin*.

1. Nitrogenase

➔ It is a **Mo-Fe protein**, catalyse the conversion of atmospheric N_2 to NH_3.
- Highly sensitive to the O_2 (it requires anaerobic conditions).

$$N_2 + 8e^- + 8H^+ + 16ATP \longrightarrow 2NH_3 + H_2 + 16ADP + 16P_i$$



2. Leghaemoglobin
- O_2 scavenger to protect *nitrogenase*.
- It gives pink colour to root nodules.

B. Physio-Chemical Nitrogen fixation

- **Industrial**-By industrial combustions, forest fires, automobile exhausts and power-generating stations, atm. N_2 is converted to NO/ NO_2/ N_2O.
- **Electrical**-By lightning and UV radiation.

II- Ammonification

- Decomposition of organic nitrogen of dead plants and animals into ammonia.

III- Nitrification

- The conversion of soil ammonia into nitrates

$2NH_3 + 3O_2 \longrightarrow 2NO_2 + 2H^+ + 2H_2O$ by: *Nitrosomonas* / *Nitrococcus*
$2NO_2 + O_2 \longrightarrow 2NO_3$ by: *Nitrobacter*

- The nitrate thus formed is absorbed by plants and is transported to the leaves.
- In leaves, it is reduced to form ammonia that finally forms the amine group of amino acids.

IV- Denitrification

- Reduction of nitrate present in the soil into nitrogen which is released to the atmosphere.
- By bacteria *Pseudomonas* and *Thiobacillus*

Fate of ammonia:

Most of the plants assimilate ammonia as nitrate as well as NH_4^+ (protonated ammonia).

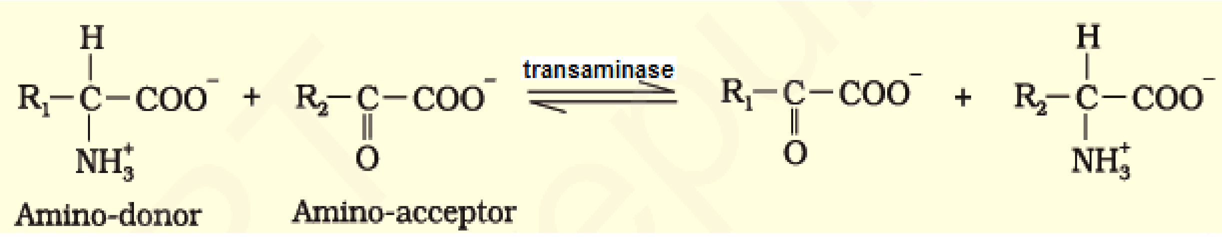
- In plants, NH_4^+ is used to synthesize amino acids by 2 steps:

  Step I. Reductive amination: Here, ammonia reacts with α–ketoglutaric acid to form **glutamic acid.**

  $$\alpha\text{- ketoglutaric acid} + NH_4^+ + NADPH \xrightarrow{\text{Glutamate dehydrogenase}} \text{Glutamate} + H_2O + NADP$$

  Step II. Transamination : It involves the transfer of amino group from one amino acid to the keto group of a keto acid in the presence of enzyme *transaminase*.

  - ***Glutamic acid*** is the main amino acid from which the transfer of NH_2 (amino group) takes place to form all other amino acids.



- **Amides** – Derivatives of amino acids, which are the structural part of proteins.
  Since amide contain more nitrogen (than the amino acids) they are transported to other parts of the plant via xylem vessels.
  Eg: asparagines, glutamine
- **Ureides-** Fixed nitrogen transported along with the transpiration stream the nodules of some plants (e.g., soyabean)