Mineral Nutrition

Essential Mineral Elements

Study of Mineral Requirements by Plants

- Technique: Hydroponics
- Given by: Julius Von Sachs
- Requirements: Purified water and mineral nutrient salts
- Hydroponics: Growing plants in a defined nutrient solution, in the complete absence of soil
- This enables us to study the effect of adding, removing or varying the concentration of any particular mineral element.
- Essential elements can be identified by this method, and their deficiency symptoms can be worked out.

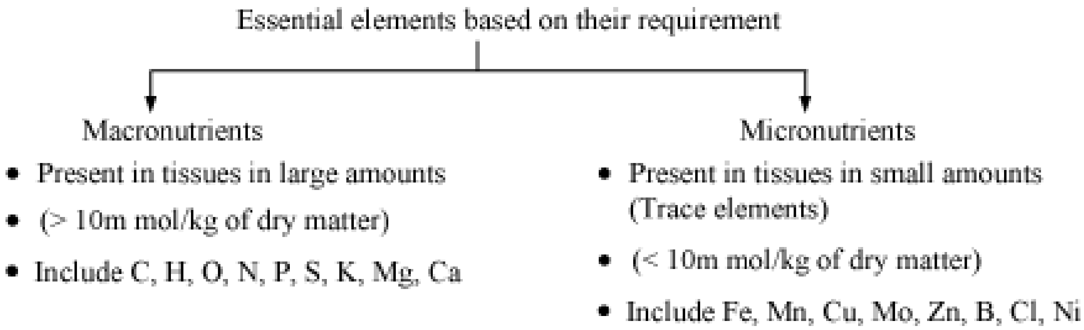
Essential Mineral Elements

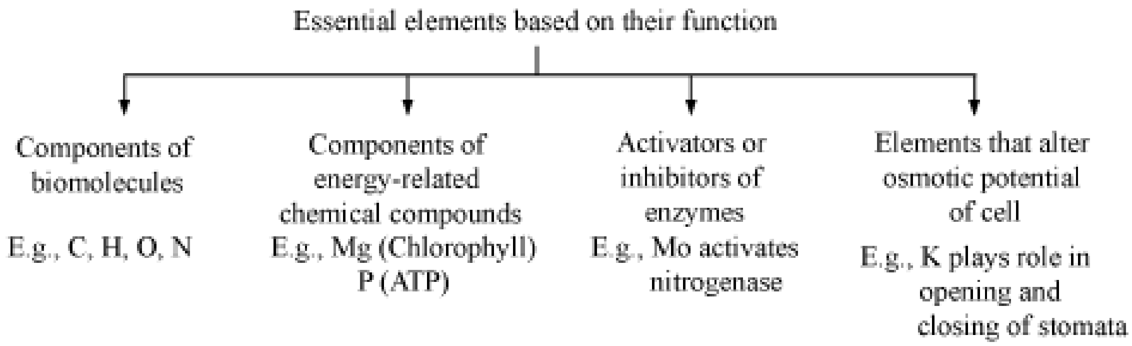
- All elements found in or accumulated by a plant may not be essential for its growth and survival.
- Criteria for the essentiality of an element are:
- Absolutely necessary for the completion of the life cycle of a plant; necessary for its growth and reproduction
- Its requirement is specific, and not replaceable by any other element
- Directly involved in the metabolism of the plant

Categories of Essential Elements

- Essential elements are 17.
- Basically categorised according to:
- Their requirements

- Functions performed in a plant





To test your knowledge of this concept, solve the following puzzle.

Role of Micro and Macro Nutrients

	Nutrient	**Absorbed as**	**Role**
Macronutrients	Nitrogen	NO_3^- , NO_2^- and NH_4^+ in some cases	Required by all metabolically active cells Constitutes proteins, nucleic acids, vitamins, and hormones
	Phosphorus	($H_2PO_4^-$ or HPO_4^{2-})	Constitutes cell membranes, proteins, all

			nucleic acids, and nucleotides Required for phosphorylation reaction
	Potassium	K^+	Required in abundance by meristematic tissues Maintains anion-cation balance in cells Involved in protein synthesis and activation of enzymes Involved in opening and closing of stomata Maintains turgidity of cells
	Calcium	Ca^{2+}	Synthesis of middle lamella (Ca pectate) of cell wall during cell division Formation of mitotic spindle Proper functioning of cell membranes Activates enzymes; help in regulating metabolism
	Magnesium	Mg^{2+}	DNA and RNA synthesis

			Constitutes ring structure of chlorophyll Maintains ribosome structure Activates enzymes of respiration and photosynthesis
	Sulphur	SO_4^{2-}	Constitutes several coenzymes, vitamins (thiamine, biotin), and ferredoxin Found in amino acid cysteine and methionine
Micronutrients	Iron	Fe^{3+}	Constitutes proteins involved in electron transport system such as cytochromes and ferredoxin Activates catalase Essential for formation of chlorophyll
	Manganese	Mn^{2+}	Activates enzymes involved in photosynthesis, respiration, and nitrogen metabolism Splits water to liberate oxygen during photosynthesis

	Zinc	Zn^{2+}	Activates carboxylases Synthesis of auxins
	Copper	Cu^{2+}	Overall metabolism of plants Activates enzymes involved in redox reactions
	Boron	BO_3^{3-} or $B_4O_7^{2-}$	Uptake and utilization of calcium ion Involved in pollen germination Involved in cell elongation and differentiation Carbohydrate translocation Involved in membrane functioning
	Molybdenum	MoO_2^{2+}	Component of enzymes involved in nitrogen metabolism such as nitrogenase and nitrate reductase

	Chlorine	Cl^-	Determines solute concentration and anion-cation balance in cells Involved in water splitting reaction of photosynthesis

Symptoms of Nutrient's Deficiency and Toxicity of Micronutrients

Deficiency Symptoms of Essential Elements

- Critical Concentration − Concentration of essential elements below which plant growth is retarded
- Deficiency symptoms are the morphological changes that are indicative of deficiency of certain elements.
- Deficiency symptoms may depend upon mobility of the element in plant.
- Actively mobilizing elements such as N, K, Mg are mobilized from older to younger parts of the plant. Hence, their deficiency symptoms appear first in old senescent leaves.
- Relatively immobile elements such as S, Ca have their deficiency symptoms first seen in younger parts of plant.

Deficiency Symptom	Caused by Deficiency of
Chlorosis (Loss of Chlorophyll) - leads to yellowing of leaves	N, K, Mg, S, Fe, Mn, Zn, Mo
Necrosis (Death of Tissue)	Ca, Cu, K, Mg
Inhibition of Cell Division	N, K, S, Mo

Delayed flowering	N, S, Mo

Toxicity of Micronutrients

- Increase in concentration of micronutrients causes toxicity.
- Any mineral ion concentration that reduces the dry weight of tissues by 10% is considered toxic.
- Toxicity of one element may lead to deficiency of other elements since the former may inhibit the uptake of latter.
- For example → Mn competes with Fe, Mg for uptake and also inhibits Ca translocation to shoot apex. Therefore, Mn toxicity symptoms may actually be the deficiency symptoms of Fe, Mg, and Ca.

Nitrogen Cycle

Nitrogen Metabolism

- Nitrogen is a limiting nutrient in agricultural and natural systems as plants compete with microbes for nitrogen present in soil.
- **Nitrogen fixation**: Process of conversion of nitrogen (N_2) into ammonia (NH_3)
- **Ammonification**: Decomposition of organic nitrogen of plants and animals into ammonia
- The ammonia so formed may volatilise and re-enter the atmosphere, or some of the ammonia may be converted into nitrate by soil bacteria.
- $$2NH_3 + 3O_2 \xrightarrow{\textit{Nitrosomonas/Nitrococcus}} 2NO_2^- + 2H^+ + 2H_2O$$

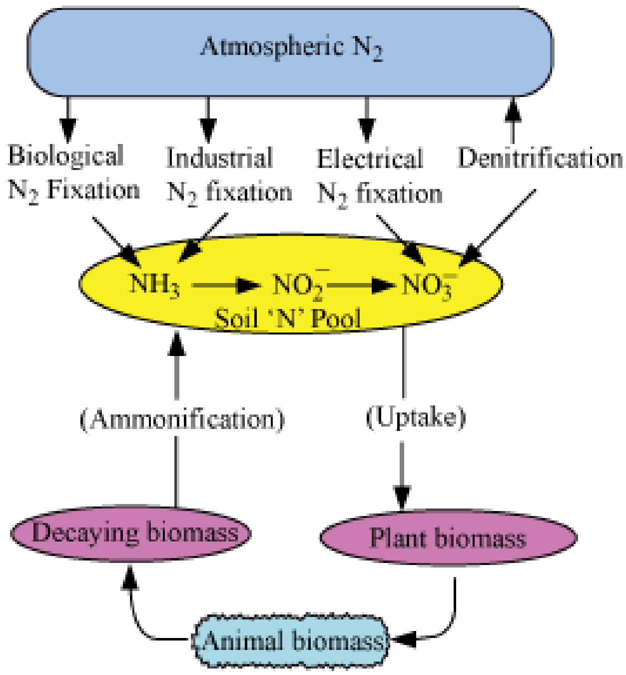
$$\underset{\text{nitrite}}{2NO_2^-} + O_2 \xrightarrow{\textit{Nitrobacter}} \underset{\text{nitrate}}{2NO_3^-}$$

These are the steps involved in **nitrification**.

Nitrifying bacteria are chemoautotrophs.

- The nitrate so formed can be easily absorbed by the plants, and transported to leaves. In leaves, nitrate is reduced to ammonia to form the amine group of amino acids.

- **Denitrification**: Process of reduction of the nitrate present in soil to nitrogen. Carried out by bacteria like *Pseudomonas* and *Thiobacillus*



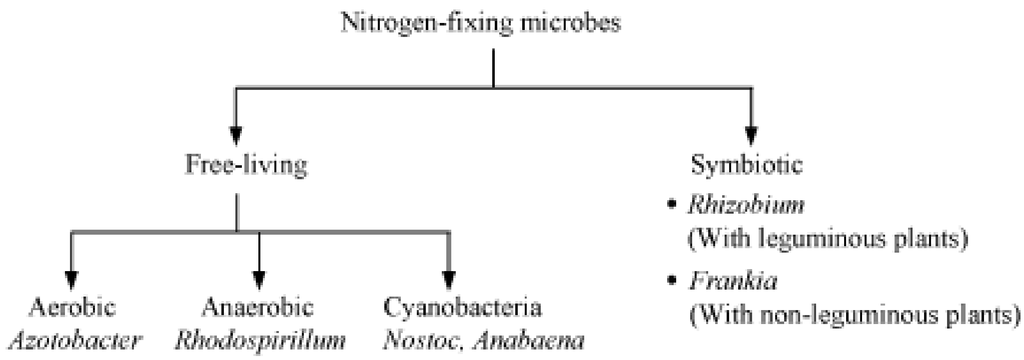
Biological Nitrogen Fixation

- Reduction of nitrogen to ammonia by living organisms is called biological nitrogen fixation.

- Certain prokaryotes are able to fix nitrogen because the enzyme nitrogenase is present exclusively in them.

$N \equiv N \xrightarrow{\text{nitrogenase}} NH_3$

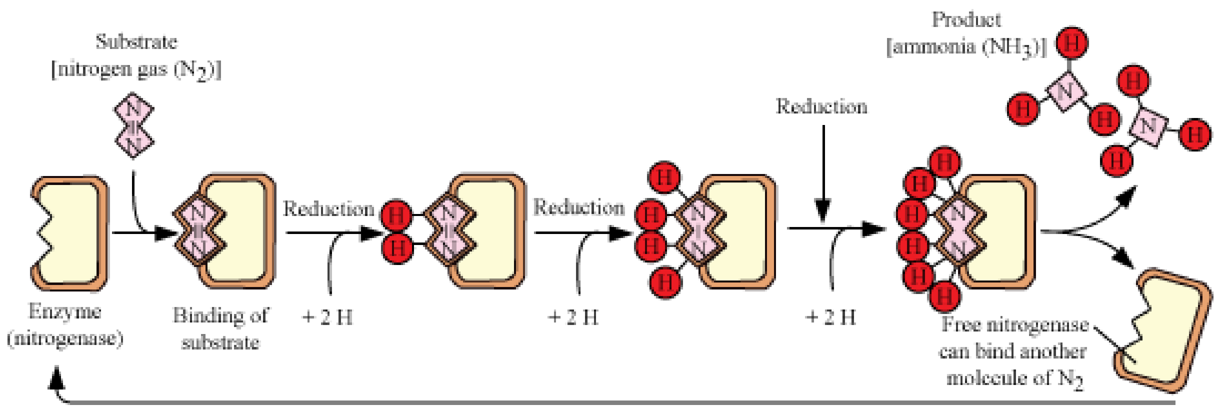
- Nitrogen-fixing microbes can be classified as follows:



Nodule Formation

- Nodules are the small outgrowths on roots.
- Involves interaction between the roots of the host plant and *Rhizobia* that multiply and colonise the roots, attaching themselves to the root hair cells and the epidermal cells
- Root hair curls and bacteria infest there, and finally, reach the cortex, where it starts nodule formation.
- An infection thread carries the bacteria to the cortex. In the next step, the bacteria get released from the thread and invade the cortex cells.
- Specialised nitrogen-fixing cells differentiate and form the nodules.
- Nodules establish a direct vascular connection with the host for exchange of nutrients.
- Nodules also carry the enzyme nitrogenase and the pink coloured leg haemoglobin.
- Nitrogenase: A Mo−Fe protein; catalyses the conversion of N_2 to ammonia; strictly anaerobe
- Leg haemoglobin: Oxygen scavenger, which protects the oxygen-sensitive enzyme nitrogenase
- $N_2 + 8e^- + 8H^+ + 16ATP \rightarrow 2NH_3 + H_2 + 16ADP + 16P_i$

- The energy required in this process comes from cellular respiration of root cells.



- Ammonia, so formed, can either form nitrate (which plants can assimilate), or form NH_4^+ (which is quite toxic, but can undergo further reactions to produce amino acids).

- NH_4^+ (ammonium ion) can undergo two types of reactions to produce amino acids:

- *Transamination* − transfer of the amino group from one amino acid to the keto group of the keto acid catalysed by the enzyme transaminase

  E.g., formation of amides, asparagine and glutamine from amino acids, aspartic acid and glutamic acid, by the addition of the amino group Fixed nitrogen, as in soyabean, is sometimes transported as ureides along with transpiration.

- *Reductive amination* − glutamate is formed from NH_4^+ by the reaction with α-ketoglutaric acid.

  α -ketoglutaric acid + NH_4^+ + NADPH

  $\xrightarrow[\text{dehydrogenase}]{\text{Glutamate}}$ Glutamate + H_2O + NADP