Mineral Nutrition

Syllabus

Mineral Nutrition

Name : _____ **Contact No.** _____

MINERAL NUTRITION

INTRODUCTION

- Soil the main source of mineral nutrients. These mineral nutrients are mainely absorbed by the **meristemetic region of roots**.
- Mineral nutrients are present with soil particles in colloidal form and in water as soil solution. Conduction of mineral nutrients is done through the xylem.
- Absorption of meneral in plant is an active process.

ESSENTIAL ELEMENTS

About 50-60 elements are present in plant body but **16** elements are considered as essential elements

According to **Arnon-Criteria of essentiality of minerals:**

- The element must be **neccessary for normal growth and reproduction** of all plants.
- The requirement of element **must be specific for plant life**. That is indespensible element to plant.
- The Element must be **directly involved in metabolism** of plant.

C, H, O, N, K, S, Ca, Fe, Mg, P, Cu, Mn, B, Cl, Zn, Mo, Ni

CLASSIFICATION OF ESSENTIAL ELEMENTS

Arnon divides these necessary elements in two group on the basis of requirement of plant

- **Major element/Macro nutrients:** Concentration must be **1-10 mg L^{-1} more than 10 m mole $kg^{-1}$of dry matter. (mmole-Milimolar)**
  C, H, O, N, P, Mg, S, K, Ca
- **Minor element/Micro nutrients:** (Concentration **present 1.0-0.1 mg L^{-1} less than 10 m mole kg^{-1} per gram of dry matter)**
  Cu, Zn, N, Mo, Mn, B, Cl, Fe

General functions of essential elements-

1. **Protoplasmic elements - C, H, O, N, P, S**
2. **Elements of Redox Reaction - Fe, Cu, Mn, Cl**
3. **Balancing / Antagonetic - K, Ca**
4. **Membrane Permeability - K, Ca**
5. **Co-factor of enzymes - All micronutrients except B**
6. **Osmotic pressure of cell.**

Benificial nutrients: Mineral elements other than essential elements, which satisfy specific additional nutrient requirement of some specific plants.

Ex. **Na** - Halophytes (eg. Atriplex - helps in C_4 pathway)
Si - Grasses (Provides mechanical strength)
Se - Astragalus
Co - Leguminous plants (root nodule formation)

- **Toxic elements/Toxicity:-** Any mineral ion concentration in plant tissue, that reduces the dry weight of tissue by about 10 percent is considerd as toxic or toxic element and this effect is called toxicity.

- Most of the micronutrients become toxic as their required amount for plants is very low. This excess concentration inhibits activity of other essential elements.

  Ex : Toxicity of Mn (Manganese) may induce deficiency of iron, magnesium and calcium cause appearance of brown spots surrounded by chlorotic veins. Mn competes with iron (Fe) and magnesium (Mg) for uptake and for binding to enzymes. Mn also inhibits, calcium translocation into the shoot apex and causes disease **'Crickle leaf '**.

  So the dominant symptoms of Mn toxicity may actually be the symptoms of Fe, Mg and Ca deficiency.

Deficiency symptoms and mobility of minerals.

- The deficiency symptoms of highly **mobile elements** in plants like **N, P, K, Cl** and **Mg** first appear in **older plant parts.** These minerals are present as structural constituent of biomolecules of mature plant parts and when plant parts become older, these biomolecules broken down making these elements available for younger plant parts.
- The deficiency symptoms of **immobile elements** like **Ca, S, B, Fe** first appear in **young plant parts,** as they are not transported from older plant parts.

MINERAL SALT ABSORPTION/M ECHANISM OF MINERAL ABSORPTION

(A) Passive absorption of minerals : (Without expenditure of ATP)

(1) By simple diffusion : According to this method mineral ions may diffuse in root cells from the soil solution. Facilitated diffusion of minerals also occurs with help of carrier proteins.

(2) By mass flow : Proposed by Hymo (Supported by Kramer) According to this method mineral ions absorption occurs with flow of water under the influence of transpiration.

(3) By ion exchange : By Jenny and Over street. This is exchange of mineral ions with the ions of same charge.

(i) By contact exchange : When the mineral ion exchange occurs with the H^+ and OH^- ions.

(ii) Carbonic acid exchange : When the mineral ion exchange takes place with the ions of carbonic acid.

(4) By Donnan equilibrium : This theory explains the passive accumulation of ions against the concentration gradient or electrochemical potential (ECP) without ATP. At the inner side of cell membrane, which separates from outside (external medium), there are some anions, which are fixed or non diffusible and membrane is impermeable to these anions, while cations are diffusible.

- In such condition, for maintenance of equilibrium additonal cations are needed to balance negative charges of anions (at inner side of membrane). Thus some cations moves, inside the cell from soil solution.
- So according to this theory Donnan equilibrium is attained, if the anions and cations in the internal solution become equal to the anions and cations in external solutions.

Objections for passive mineral absorption / evidences in favour of active mineral absorption :

(1) Absorption of K^+ions in **Nitella** algae is observed against the concentration gradient.

(2) Rate of respiration of a plant is increases, when plant transferred to mineral solution. (Salt respiration)

(3) Factors like deficiency of oxygen, CO, CN, which inhibits rate of respiration, these factors also inhibit the absorption of mineral ions in plants.

Thus ion absorption in plants is considered mainly as an active process.

(B) Active ion absorption : (By expenditure of ATPs)

(1) Cytochrome pump theory : By **Lundegardh and Burstrom (1933)** according to this theory, **only anions** are absorbed by active mechanism through cytochrome pumping and absorption of cation is passive process.

According to cytochrome pump theory **salt respiration** is called as **anion respiration.**

(2) Carrier concept : By **Vanden Honert.** According to this theory some specific carrier molecules made up of **proteins** are present in cell membrane of root cell, which absorb both the ions and form **ion-carrier complex.** This complex is broken inside the cell membrane with the use of energy.

(3) Protein - Lecithin theory : By **Bennet Clark**

According to this theory a **phospholipid lecithin** in root cell membrane works as carrier for both type of ions.

Lecithin has two type of groups:

Lecithin → **Phosphate** group (⊕ **ions** absorption)
Lecithin → **Choline** group (Θ **ions** absorption)

☛ **Goldacre** - A contractile protein is associated, with absorption of minerals.

Mineral absorbed by the roots of plants are carried by xylem by two pathways, apoplastic and symplastic pathway.

☛ **P.R. Stout** and **Hoagland** (1939) proved that **mineral salts are translocated through xylem** along with transpiration pull (exp. with help of radioisotopes).

SPECIFIC ROLES OF DIFFERENT ELEMENTS

Mineral Element	Principl Functions	Deficiency symptoms
1. Nitrogen NO_3^- /Nitrate form	(a) All living matter (b) Amino acids, proteins (c) Purines, pyrimidines (d) Early defoliation (e) NAD, NADP, FMN, FAD (f) Chlorophyll, cytochromes	**Chlorosis** first in older leaves, premature leaf fall reduced yield. Development of anthocyanin pigment **(Mottled chlorosis)**
2. Phosphorus $H_2PO_4^-$ & HPO_4^- orthophosphate anion form	(a) Nucleic acids (b) Nucleoproteins (c) Phspholipids (d) AMP, ADP, ATP, (e) NAD, NADP (f) Indispensible role in energy metabolism	Chlorosis with necrosis, **premature abscission of leaf,** poor vasculature.
3. Potassium K^+ in free form	(a) Permeability (b) Osmotic regulation and hydration (c) Commonest free ion in cell (d) Stomatal movements (e) Translocation of sugars (f) Enzymes concerned with photosynthesis, nitrate reduction, protein bio -synthesis, respirations, etc	**Mottled chlorosis,** premature death, **loss of apical dominance** lodging in cereals. Bushy habit. Cotton rust

4. Calcium Ca^{++} form	(a) Cell wall Structure (b) Membrane structure (c) Influence nitrate reductase (d) In ion transport (e) In cell elongation and spindle formation (f) Activators of amylases, adenyl kinase, ATPase, etc.	Stunted growth, **degeneration of meristems,** chlorosis, curling first in young leaves. Black heart of *Celery*.
5. Magnesium Mg^{++} form	(a) Component of chlorophyll (b) Activators of a number of photosynthetic and respiratory enzymes (c) Combiness the subunits of ribosomes (d) Synthesis and hydrolysis of ATP	Marginal curling, interveinal chlorosis with anthocyanin accumulation first appearing in older leaves. 'Sand drown' of Tobacco.
6. Sulphur SO_4^{2-} form (Sulphate)	(a) Part of CoA, Ferredoxin, Vit. H, Thiamine, Lipoic acid. (b) Amino acids e.g. Cysterine, Cystine, methionine	Chlorosis first in young leaves, reduced nodulation in legume. **Tea yellow,** extensive root system.
7. Iron Fe^{++}/Fe^{+++} Form	(a) Structural component of porphyrin molecules, cytoch -romes, catalase, peroxidase leghaemoglobin	**Interveinal chlorosis** first in young leaves. Green Netting of Citrus.
8. Molybdenum MoO_4^{2-} form	(a) Component of nitrate reductase (b) Important in N_2 fixation	Mottled chlorosis, **whiptail of cauliflower,** loosening of inflorescence of cauliflower. Scald of beans.
9. Boron H_3BO_3 / BO_3^{-3} (Borate) form	(a) Translocation of sugars (b) For seed, pollen and spore germination (c) Enzymes of phosphorylation (d) RNA metabolism (e) Phenol metabolism and cell differentiation (f) Regulates pentose phosphate pathway (g) Flowering and fruiting	**Brown heart of turnip**, **internal cork** of apple, **heart rot** of sugarbeet, decreased nodulation in legumes. Hollow stem of caulifilower, stem crack of *Celery*.
10. Copper CU^{++} form	(a) Oxidase enzyme: tyrosinass plastocyanin, cytochrome oxidase.	**Dieback, exantheme, reclamation disease,** blackening of potato, tubers, chlorosis

11. Manganese Mn^{++} form	(a) In chlorophyll synthesis (b) In photolysis of H_2O in phtosynthesis (c) Maintenance of chloroplast membrane structure (d) Enzyme systems; RNA polymerase, NAD-malic enzyme in C_4 plants	Interveinal chlorosis, **grey speck** of oat, **marsh spot disease of pea**.
12. Zinc Zn^{++} form	(a) Tryptophan synthesis (precursor of auxin) (b) Dehydrogenase enzymes, pyriding nucleotide, alcohol, glucose-6-p and triose phosphate (c) Carbonic anhydrase (d) Promotes synthesis of cytochromes (e) Stabilizes ribosomal fractions.	**Little leaf,** leaf rosettes leaf malformations. White bud, whip tip of maize, sickle leaf of cocao, **khaira disease of rice.**
13. Chlorine	(a) In the transfer of electron from water to PS II (Photolysis) (b) Maintain cation-anion balance	Bronze colour in leaves, chlorosis, necrosis, swollen root flower abscission.
14. Nickel	(a) Urease and hygrogenase activity	It helps in germination and early seeding growth of Jack Bean seeds. It causes necrotic spots.

N_2 METABOLISM

Role of Nitrogen in Plants:- Constituent of proteins, nucleic acids ATP, GTP, Vitamins, chlorophyll, alkaloids, cytochromes, hormones. Nitrogen is necessary to plants for heridity, reproduction, growth metabolism and development.

Sources of Nitrogen to plants :

(1) Atmospheric nitrogen:
N ≡ N (Molecular, inert or elemental form) used by Rhizobium (Legumes), BGA, Lichens.

☛ These **converts atm. N_2 into metabolically usefull ammonia(NH_3).** This process is called as biological nitrogen fixation.

(2) NO_3^-,NO_2^-,NH_4^+ in soil:

These are major source of nitrogen to plants.

☛ **Nitrate ions (NO_3^-)** are **cheif form of nitrogen used by majority of plants.**

Plants grow in acidic soil & found in forest use ammonium ions (NH_4^+) as major N_2 source.
Nitrate ions are cheif source of N_2 for plants but they can not be used directly in metabolic pathway in plant cells, as it is highly oxidised form. so NO_3^- (Nitrate) first converted into NO_4^+ **(ammonium ions)** called **nitrate reduction**. So NH_4^+ ions enters in plant metabolism.

(3) Organic nitrogen in soil: as amino acids, protein body.
Due to death & decay of organisms. This is not a major source of N_2.

(4) Insect bodies: for some plants (insectivorous plants)

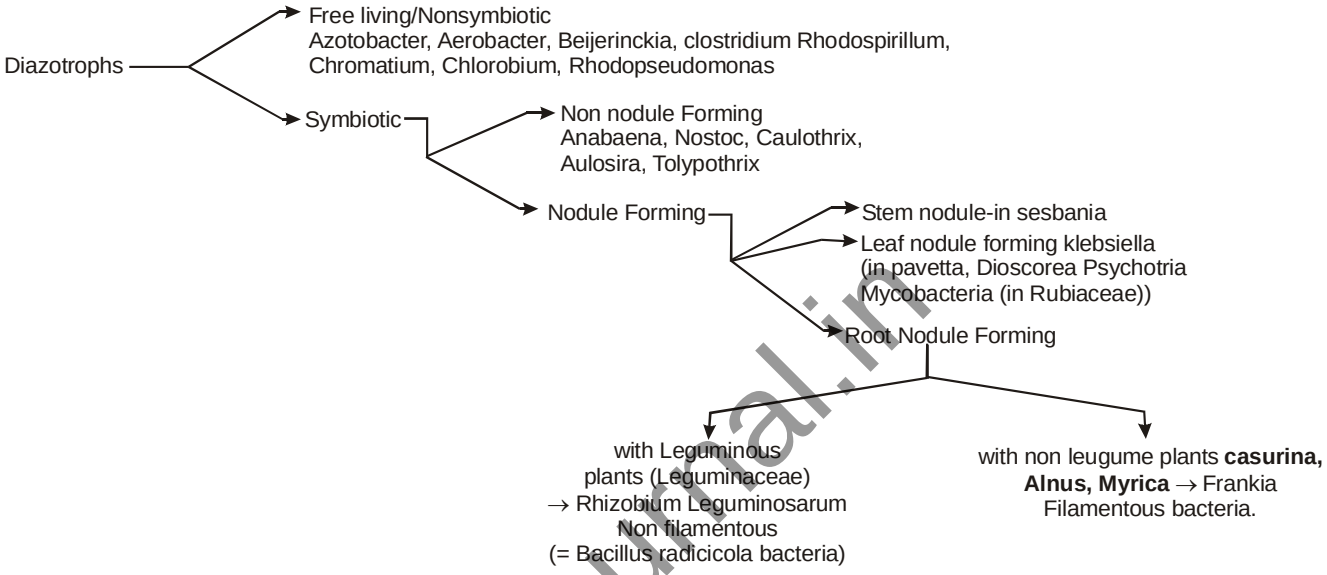
(5) Urea as chemical/artificial fertilizers

Nitrogen (N_2) Cycle:

(1) Biological Nitrogen Fixation/Diazotrophy ($N_2 \rightarrow NH_3$):- Conversion of molecular or elemental nitrogen ($N \equiv N$) into inorganic nitrogenous compounds (NH_3) through agency of living organisms is called as **biological nitrogen fixation** or **Diazotrophy**

Nitrogen Fixing organisms (Diazotrophs):

☛ Free living diazotrophs carry out diazotropy only in free living condition while symbiotic diazotrophs only in symbiotic condition.



(2) Ammonification: Conversion of dead organic nitrogenous compounds into ammonia. **Bacillus mycoides**, **B. ramosus.**

(3) Nitrification: Oxidation of ammonia, produced by ammonification **into nitrates** by **nitrifying bacteria** is called as nitrification.

(i) $2NH_3 + 2O_2 \xrightarrow{\text{Nitrosomonas}} 2NO_2^- + 2H_2O + 2H^+$

Ammonia — Nitrite ion

(ii) $2NO_2^- + O_2 \xrightarrow{\text{Nitrobacter}} 2NO_3^-$

Nitrate ions

Some fungi like **Aspergillus**, **Penicillium** can also carry out this process.

(4) Denitrification: Nitrates or nitrites converts back into molecular or atm. nitrogen by **denitrifying bacteria** is denitrification. Ex. **Pseudomonas** denitrifications.

(5) Nitrate reduction:

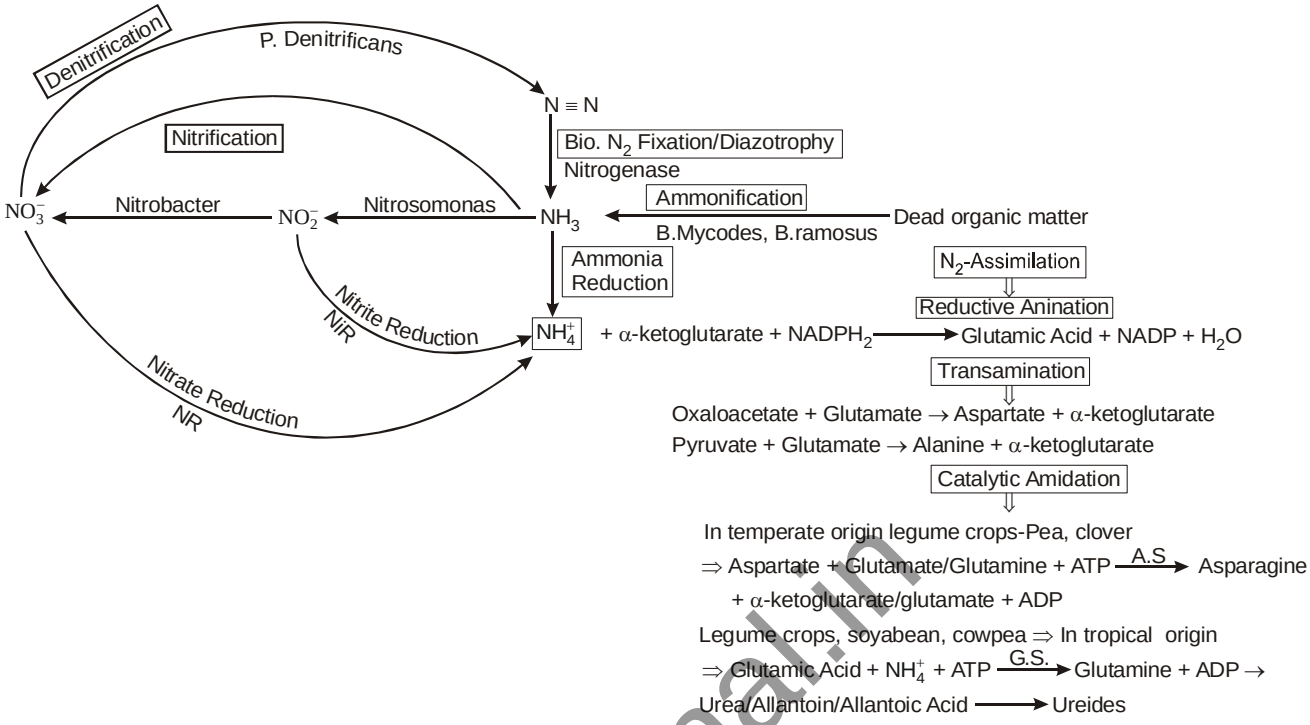
☛ Plants take nitrogen from soil, chiefly in nitrate forms which is highly oxidised form.
so **NO_3 converts in ammonia by following method**

(a) $NO_3^- + NADH_2 + H^+ \xrightarrow{\text{Nitrate reductase}} NO_2 + NAD + H_2O$

(b) $NO_2^- \xrightarrow{2e^-, 2H^+} NOH \xrightarrow{2e^-, 2H^+} NH_2OH \xrightarrow{2e^-, 2H^+} NH_4^+$

or $2NO_2^- + 6H_2O + 4H^+ \xrightarrow{\text{Nitrate reductase}} 2NH_4^+ + 3O_2 + 4H_2O$

☛ Nitrate reductase is Molybdo flavoprotein isolated by Evans and Nason 1953 from Neurospora and Glycin max.



Symbiotic N_2 fixatiion (Diazotrophy): It is done by symbiotic bacteria & free living bacteria. In **leguminous plants (Fabaceae)** by symbiotic bacterium **Rhizobium**, which form nodules in their roots.

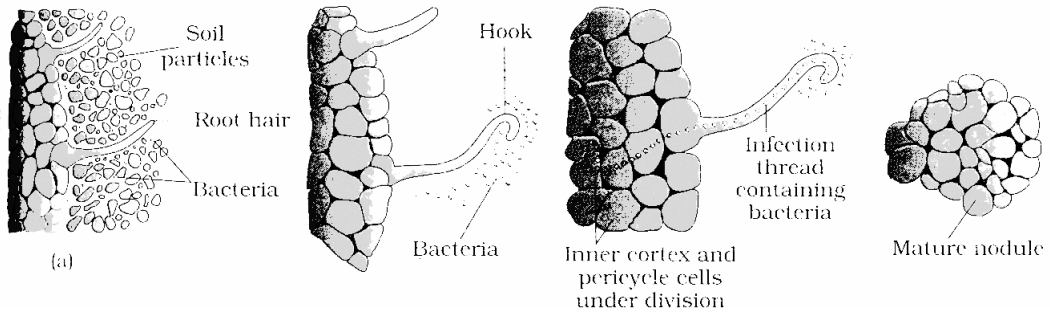
- **N_2 convert into NH_3 ion**, which is used in plant metabolism.
- Root nodules act as site for N_2 fixation. It contains all necessary biochemical components like enzyme Nitrogenase, Leghaemoglobin, required in N_2 fixation.

NODULE FORMATION

It is due to interactions between bacteria and host root. It occurs in following steps:

- **Multiplication & colonization of Rhizobia** at Rhizosphere and attachment to epidermal root hair cells. Initial attraction of Rhizobia to host root is **chemotactic** (Rhicadhesin protein of bacterial cell identify host root) as **root exude amino acids, sugars, organic acids** and **flavonoids**.
- **Characterstic curling of root hairs and invasion of the bacteria** to form an **infection thread,** by the invegination of plasma membrane of root hair cells and it reaches up to the cortex of roots.

  Curling of root hairs is stimulated by **specific complex polysaccharides found on the surface of rhizobia,** recognised by **Lectins (small proteins of host plant roots).**
- **Nodule initiation & development in root cortex. Mitogenic agents secreted (Kinetin) by bacteria & auxin produced by plant cell promotes cell division & extension** leading to nodule formation. Nodule establishes direct vascular connection with host for exchange of nutrients. Root nudule cells have chromosome in double to other somatic cells. Thus nodule cells are polyploid specially **Tetraploid**.



Development of root nodules in soyabean : (a) *Rhizobium* bacteria contact a susceptible root hair, divide near it, (b) Upon successful infectionof the root hair cause it to curl, (c) Infected thread carries the bacteria to the inner cortex. The bacteria get modified into rod-shaped bacteroids and cause inner cortical and pericycle cells to divide. Division and growth of cortical and pericycle cells lead to nodule formation, (d) A mature nodule is complete with vascular tissues continuous with those of the root

Release of bacteria from infection thread and they differentiable as specilized nitrogen fixing cell.

- Bacteria continue to multiply during it's path in root thair cells & bacteria distribute in most of cells.
- The membrane of infection thread bud off to form small vesicles with containing one or more bacteria. Then bacteria stop dividing & enlarge & differentiate in **nitrogen fixing cells called bacteroid** & it's membrane called **peribacteroid membrane.**

MECHANISM OF BIOLOGICAL N_2 FIXATION

By Burris. The atm. N_2 is reduce by the addition of hydrogen atoms.

- The three bonds between two nitrogen atoms N ≡ N or dinitrogen are broken & ammonia **(NH_3) is formed by reduction of N ≡ N.**

$$N \equiv N + 8H^+ + 8e^- + 16ATP \xrightarrow[\text{Nitrogenase}]{} 2NH_3 + H_2 + 16ADP$$

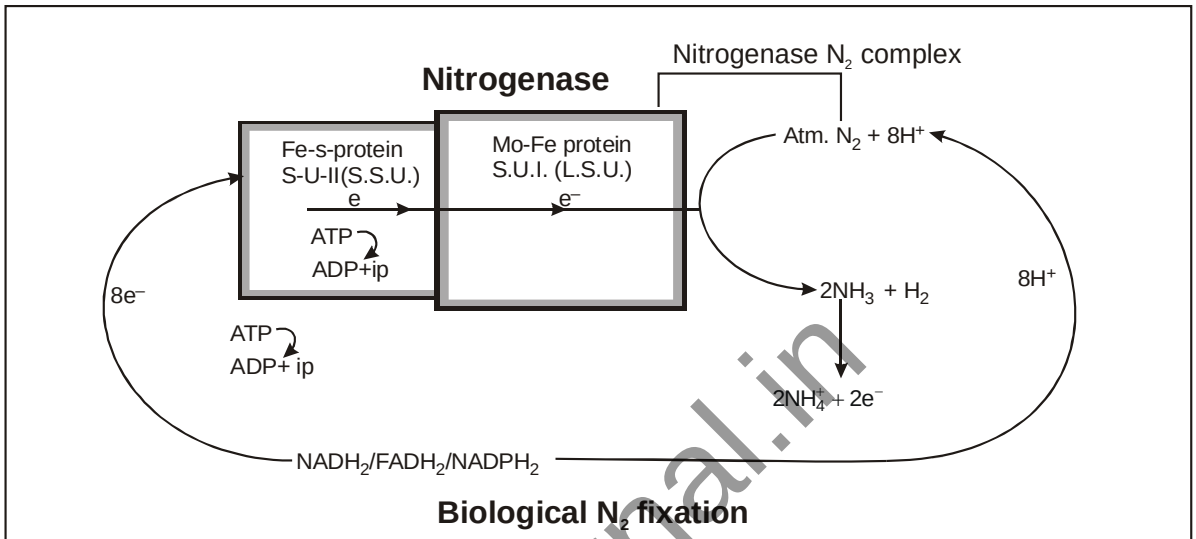
(1) **Nitrogenase:** ⇒ Exclusively present in prokaryotes
⇒ Inducible enzyme
⇒ Larger sub unit/SU-I **Mo-Fe-protein**
smaller Subunit / SU-II-**Fe-S-protein/ ferredoxin**
⇒ Both Subunits bind togather at the time of N_2 fixation.
⇒ Oxygen sensitive enzyene

(2) **O_2 Regulation:** ⇒ Most of diazotrophs are obligate anaerobes
⇒ Some diazotrophs are facultative like Rhizobium, perform anaerobic respiration at the time of diazotrophy
⇒ In root nodule of leguminous plants - O_2 Scavenger Leghaemoglobin (lhb) (similar to haemoglobin of animals) is present, bind with O_2 to become oxyleghaemoglobin (olhb) and regulates minimum O_2 concentration.
⇒ Leghaemoglobin is synthesized by combined activity of host (gives protein part globin) and bacteria (gives haem' part).
⇒ In the Heterocyst- Non photosynthetic and thick walled.

(3) **Source of H^+ and e^-**
⇒ Reducing agents $NADH_2/FADH_2/NADPH_2$ obtained from Photosynthesis and respiration

(4) **Source of ATP** ⇒ From Photosynthesis and respiration

(5) **Genes** — Host-NOD(Nodulin protein forming gene)
Bacteria-nod (Nodule forming gene)
Fix nif (nitrogenase inducing factor)
Fix (Nitrogen fixation gene)



Biological N_2 fixation

Mechanism of nitrogen fixation

(a) The 2nd unit (ferredoxin) of nitrogenase, receive electrons from e^- donar ($FADH_2/NADH_2/NADPH_2$) and become reduced.

(b) This reduced 2nd unit is now activate by ATP and form a complex called **ferredoxin ATP complex.**

(c) On other side unit 1st (Fe-Mo protein) of nitrogenase, reacts with molecular nitrogen to form **nitrogenase-nitrogen complex.**

(d) Ferredoxin ATP complex then transfer electron to nitrogenase-nitrogen complex, so that the later gets reduced. This reaction utilize of ATP.

(e) The reduced nitrogenase-nitrogen complex now receives proton (H^+) resulting in formation of ammonia (NH_3).

SYNTHESIS OF AMINO ACIDS & NITROGEN ASSIMILATION

Nitrogen assimilation:- Inorganic NH_3 (Produced by nitrate reduction or biological fixation or obtained from soil as NH_4^+) reacts with a TCA cycle intermediate-α-ketoglutaric acid to form an amino acid **glutamic acid**.This process known as **Reductive amination or Amino acid Biosynthesis.**

α-Ketoglutaric acid + NH_4^+ + $NADPH_2$ $\underset{\text{dehydrogenase}}{\overset{\text{Glutamate}}{\rightleftharpoons}}$ Glutamic acid + H_2O + NADP

Transamination:- Transfer of Amino group from glutamic acid to other keto acid is known as transamination. This is a process of formation of other amino acids in plats. **(transaminase enzyme)** Ex.
Glutamic acid + Pyruvic acid a ⇌ **Alanine** + α-ketoglutarate
Glutamic acid + OAA ⇌ **Aspartic acid** + α-ketoglutaric acid.

☛ **Glutamic acid is first formed amino acid in plants** & can synthesize different amino acids by transamination.

Catalytic Amidation:

Transportation of fixed N_2/Assimilated N_2 in plats occurs mainly in form of amides especially in leguminous plants as amides are more stable than amino acids and posses high Nitrogen to Carbon ratio (2N to 4C - in Asparagine, 2N to 5C in glutamine (as glutamate posses 1N to 5C)

Formation of amides from amino acids catalysed by enzymes called as catalytic amidation.

In legumes of temperate origine like pea and clover-Asparagine is translocated in non nodulated plant parts.

In legumes of tropical origin like soyabean and cowpea-ureides are translocated in non nodulated plant parts.

Glutamine synthesis:

Glutamic acid/Glutamate + $NH_4^+ + ATP \xrightarrow{\text{Glutamine (G.S.) Synthase}}$ Glutamine + ADP + iP

Asparagine syntnesis:

Glutamine/Glutamate + Aspartate + ATP $\xrightarrow{\text{Asparagine (A.S.) Synthase}}$ Asparagine + ADP + iP + Glutamate/α-Ketoglutaric acid

SPECIAL POINTS

- C, H, O, N and P are main constituents of protoplasm (organic materials). So they are called **protoplasmic elements.** C, N & O from atmosphere and H_2O from soil for H & O.
- **C, H and O** are the main components of **nucleic acid, proteins, enzymes, carbohydrates, fats. (frame work elements)**
- Mostly soil is deficient of **NPK** and these elements are known as **critical elements,** NPK-fetilizer is good for crop yield.
- Silica (SiO_2) is present in cell wall of diatoms grasses and paddy straw.
- **Aℓ** present in pteridophytes i.e. - Lycopodium.
- Mo, required in minimum quantity.
- **Hydroponics/solution culture/**soil less growth/tank farming and **ash analysis** is a technique which determines the role of nutrients in plants. (By Geriack)
- Gold (Au) present in Equisetum, mustard plants.
- Na^+ found in **halophytes** for their grawth (marine plants).
- **Trace - elements are micro-nutrients,** while while **tracer-elements** are **radio-isotopes**.
- Mg present in chlorophyll, as non-ionic form.
- Mg remains after chlorophyll burning.
- One abundant and stable from of Fe in leaves is stored in chloroplasts as an iron protein complex called **phytoferritin** (Seckback 1983).
- C, H, O are provided by H_2O, O_2 and CO_2, but 13 elements essential to all plants are absorbed as ions from the soil solution, is called a **solution mining.** (N_2 from soil & atm.)
- **Putrification/proteolysis:-** Bacillus, Pseudomonas, Clostridium.
- Proteins $\xrightarrow{\text{Proteases}}$ peptides $\xrightarrow{\text{Peptidase}}$ amino acids (conversion of proteins in to amino acids) smell of dead bodies.
- **Deamination:-** Removal of amino group as NH_3 from an amino acid.
- Root pressure is measured by **manometer**