# MINERAL NUTRITION

## Introduction:

- It is the study of source, mode of absorption, distribution and metabolism of various inorganic substances of minerals by plants for their growth, development, structure, physiology and reproduction.

## Historical background:

- **Liebig (1840)** reported the essentiality of mineral nutrition & stated that productivity of soil depends upon the proportionate amount of that essential elements which is deficient in that soil.
- **Sachs and knopp (1960)** published a list of major elements of plants ash.
- **Hogland** & **Arnon** proposed the formula of nutrient solution containing all the micronutrients.

The cultivation of plants by placing the root in nutrient solution is called **hydroponics** discovered by Sachs and the term hydroponics coined by **Gericke.**

## METHODS TO STUDY THE MINERAL REQUIREMENTS OF PLANTS

In 1860, Julius von Sachs, a prominent German botanist, demonstrated, for the first time, that plants could be grown to maturity in a defined nutrient solution in complete absence of soil. This technique of growing plants in a nutrient solution is known as hydroponics. Since then, a number of improvised methods have been employed to try and determine the mineral nutrients essential for plants. The essence of all these methods involves the culture of plants in a soil-free, defined mineral solution. These methods require purified water and mineral nutrient salts.

After a series of experiments in which the roots of the plants were immersed in nutrient solutions and wherein an element was added / substituted / removed or given in varied concentration, a mineral solution suitable for the plant growth was obtained. By this method, essential elements were identified and their deficiency symptoms discovered. Hydroponics has been successfully employed as a technique for the commercial production of vegetables such as tomato, seedless cucumber and lettuce. It must be emphasised that the nutrient solutions must be adequately aerated to obtain the optimum growth.

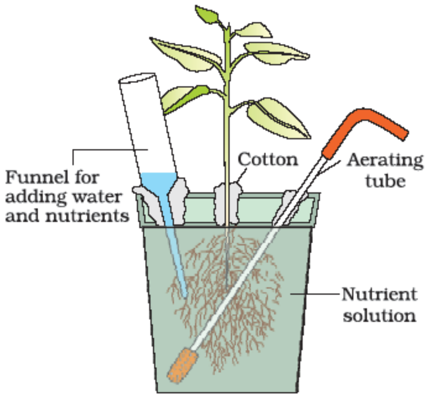



**Fig.:** Diagram of a typical set-up for nutrient solution culture

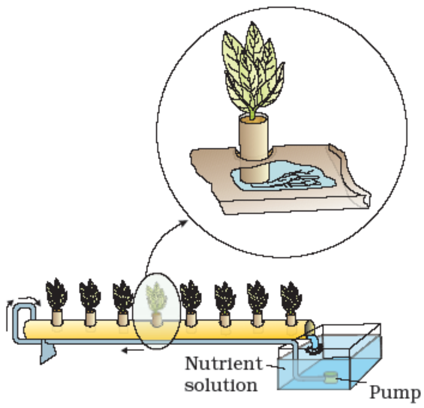



**Fig.:** Hydroponic plant production. Plants are grown in a tube or trough placed on a slight incline. A pump circulates a nutrient solution from a reservoir to the elevated end of the tube. The solution flows down the tube and returns to the reservoir due to gravity. Inset shows a plant whose roots are continuously bathed in aerated nutrient solution. The arrows indicates the direction of the flow.

- **Sand culture:** The plants are grown in sand supplemented with nutrients. It is better than solution culture because it provides solid medium and natural aeration.
- **Aeroponics:** It is a system of growing plants with their roots bathed in nutrient mist. The plants of citrus and olive have been successfully grown aeroponically (Zobel).

## ESSENTIAL MINERAL ELEMENTS

Most of the minerals present in soil can enter plants through roots. In fact, more than sixty elements of the 105 discovered so far are found in different plants. Some plant species accumulate selenium, some others gold, while some plants growing near nuclear test sites take up radioactive strontium. There are techniques that are able to detect the minerals even at a very low concentration ($10^{-8}$ g/mL).

### Criteria for Essentiality

The criteria for essentiality of an element are given below:

(a) The element must be absolutely necessary for supporting normal growth and reproduction. In the absence of the element the plants do not complete their life cycle or set the seeds.

(b) The requirement of the element must be specific and not replaceable by another element. In other words, deficiency of any one element cannot be met by supplying some other element.

(c) The element must be directly involved in the metabolism of the plant.

Based upon the above criteria only a few elements have been found to be absolutely essential for plant growth and metabolism. These elements are further divided into two broad **categories based on their quantitative requirements.**

(i) Macronutrients, and

(ii) Micronutrients

**(i)** **Macronutrients** are generally present in plant tissues in large amounts (in excess of 10 mmole $Kg^{-1}$ of dry matter). The macronutrients include carbon, hydrogen, oxygen, nitrogen, phosphorous, sulphur, potassium, calcium and magnesium. Of these, carbon, hydrogen and oxygen are mainly obtained from $CO_2$ and $H_2O$, while the others are absorbed from the soil as mineral nutrition.

**(ii)** **Micronutrients** or trace elements, are needed in very small amounts (less than 10 mmole $Kg^{-1}$ of dry matter). These include iron, manganese, copper, molybdenum, zinc, boron, chlorine and nickel.

- In addition to the 17 essential elements named above, there are some **beneficial elements** such as **sodium, silicon, cobalt and selenium.** They are required by higher plants.
- Essential elements can also be grouped into four broad categories **on the basis of their diverse functions.** These categories are:
  (a) Essential elements as **components of biomolecules** and hence structural elements of cells e.g., carbon, hydrogen, oxygen and nitrogen).
  (b) Essential elements that are **components of energy-related chemical compounds** in plants (e.g., magnesium in chlorophyll and phosphorous in ATP).
  (c) Essential elements that **activate or inhibit enzymes**, for example $Mg^{2+}$ is an activator for both ribulose bisphosphate carboxylaseoxygenase and phosphoenol pyruvate carboxylase, both of which are critical enzymes in photosynthetic carbon fixation; $Zn^{2+}$ is an activator of alcohol dehydrogenase and Mo of nitrogenase during nitrogen metabolism.
  (d) Some essential elements can **alter the osmotic potential of a cell.** Potassium plays an important role in the opening and closing of stomata. You may recall the role of minerals as solutes in determining the water potential of a cell.

**Resonate the Concept**

**(i) Frame work elements:** They form cell walls and storage products of plants, **Eg: C, H, O, N**

**(ii) Protoplasmic elements:** They form protoplasm **Eg: C, H, O, N, S, P, Mg, Fe.**

**(iii) Balancing Elements:** They minimize the toxic effect of heavy elements. **Eg: $Ca^{++}$, $Mg^{++}$, $K^{+}$.**

**(iv) Critical elements:** Some macronutrients become commonly deficient in the soils that are called critical elements. The latter are three**–N, P & K**. Deficiency caused by a critical element is known as **primary deficiency.** Most fertilisers contain critical elements. They are called complete fertilisers. They are labelled 15 : 15 : 15, 18 : 17 : 19, etc, depending upon the proportions of N, P and K. Components of fertilizers are N, P, K, S(macro) Cu, Zn, Fe, Mn(micro) elements.

**(v) Storage elements: Eg: C, N, P, S.**

**(vi) Toxic elements: Eg: Pb, Hg, As, Al , Ag.** Any mineral ion concentration in tissues that reduces the dry weight of tissues by about 10% is called toxic. Mn toxicity causes brown spot & **excess of Manganese causes deficiency of Iron, Magnesium and Calcium.**

**(vii) Permeability:** Monovalents like **$Na^{+}$, $K^{+}$** increase membrane permeability whereas Calcium and other divalents decrease it.

**(viii) Catalytic Effects:** Activation of many enzymes require mineral elements as cofactors.

**(ix) Osmotic potential:** Inorganic salts cause osmotic potential of cell sap. The latter is required for absorption of water and maintenance of cell turgidity.

**(x) Constituents of Biomolecules**

**Table: Role of Macro nutrients**

| S.No. | Macro Element | Absorbed as | Major functions | Deficiency Symptoms |
|---|---|---|---|---|
| 1. | Nitrogen (Required in greatest amount) | $NO_3^-$, $NH_4^-$ rarely $NH_2^-$ | Part of proteins, enzymes, Cytochromes, chlorophyll. ATP,some coenzymes-NAD, NADP, FMN, FAD, nucleotides of DNA & RNA, vitamins, hormones like IAA | (i) Chlorosis appears firstly in older leaves. (ii) Stunted growth. (iii) Premature leaf fall. (iv) Purple colouration of stem. (v) Reduced yield. (vi) Delaying flowering. |
| 2. | Phosphorus | $HPO_4^{2-}$ $H_2PO_0^-$ | Phospholipids, Nucleic acids-DNA & RNA, NAD, NADP, TPP, ATP, AMP,ADP, nucleoproteins Energy transfer, cell division, phosphorylation reactions | (i) Chlorosis with necrosis. (ii) Premature leaf fall. (iii) Delayed flowering & seed germination. (iv) Poor vascular tissues. |
| 3. | Potassium | $K^+$ | Stomatal movements, Osmotic regulation and hydration, Membrane Permeability, Enzymes related with Photosynthesis, respiration, protein synthesis, nitrate reduction, translocation of sugars | (i) Mottled interveinal chlorosis. (ii) Loss of apical dominance. (iii) Die back. (iv) Loss of cambial activity. (v) Plastid disintegration, (vi) Bushy habit. (vii) Marginal or apical yellowing or scorch & curling. (viii) Shorter internodes. (ix) Lodging in cereals |
| 4. | Calcium | $Ca^{2+}$ | Calcium pectate of middle lamella, activator of enzymes | (i) Degeneration of meristems |

| | | | | |
|---|---|---|---|---|
| | | | related with chromosome formation,Spindle formation, Detoxification,activators of amylases, ATPase, adenyl kinase, Selective permeability of cell Membrane, meristematic activity | Especially in root apex.<br>(ii) Stunted growth.<br>(iii) Chlorosis & necrosis.<br>(iv) Curling appearing first in young leaves.<br>(v) Blossom end rot of Tomato.<br>(vi) Irregularity in chromosome.<br>(vii) Premature flower abscission. |
| 5. | Magnesium | $Mg^{2+}$ | Association of ribosome subunits, formation of Chlorophyll,carotenoids activator of enzymes related with photosynthesis, phosphate transfer in respiration, Nitrogen metabolism, DNA and RNA synthesis, carbohydrate & fat metabolism | (i) Interveinal chlorosis with purple anthocyanin pigmentation.<br>(ii) Marginal curling.<br>(iii) Premature leaf abscission.<br>(iv) Reduced growth.<br>(v) Chlorotic areas may turn necrotic |
| 6. | Sulphur | $SO_4^{2-}$ & as $SO_2$ from air | Component of Amino acids- cysteine & methionine, ferredoxin, lipoic acid, CoA, vitamins like thiamine and biotin, nodule formation in legumes ,Chlorophyll formation. | (i) Chlorosis appearing first in young leave.<br>(ii) Stunted growth.<br>(iii) Accumulation of anthocyanins.<br>(iv) Tea yellow disease.<br>(v) Reduced nodulation in legumes. |

**Table: Role of Micro nutrients**

| S. No. | Micro Element | Absorbed as | Major functions | Deficiency Symptoms |
|---|---|---|---|---|
| 1. | Iron | $Fe^{3+}$ or $Fe^{2+}$ in acidic soil | Component of ferredoxin, Cytochromes, nitrogenase, synthesis of chlorophyll, Electron transport in respiration photosynthesis,Activator of catalases, peroxidase & Aconitase | (i) Interveinal chlorosis in young leaves.<br>(ii) Reduced growth. |
| 2. | Copper | $Cu^{2+}$ | Activator or Component of cytochrome Oxidase,ascorbic acid oxidase, tyrosinase, plastocyanin, RuBP carboxylase | (i) Die back of citrus.<br>(ii) Exuding gummy substance<br>- Exanthema.<br>(iii) Reclammation disease.<br>(iv) Apical necrosis of Young leaves.<br>(v) Blackening of Potato tubers. |
| 3. | Zinc | $Zn^{2+}$ | Component or activator of some enzymes like carbonic anhydrase, dehydrogenases and carboxylases, | (i) Interveinal chlorosis.<br>(ii) Little leaf. |

| | | | | |
|---|---|---|---|---|
| | | | synthesis of IAA, RNA and protein, formation of seed | (iii) Leaf rosettes.<br>(iv) White bud.<br>(v) Stunted growth.<br>(vi) Khaira disease of rice.<br>(vii) Whip tip of maize |
| 4. | Boron | $BO_3^{-3}$ or $B_4O_7^{2-}$ | Translocation of sugars, seed, pollen and spore germination, synthesis of pectins, proteins and nucleic acids, uptake and utilization of calcium, nodule formation in legumes, flowering and fruiting | (i) Brown heart of Turnip.<br>(ii) Internal cork of apple.<br>(iii) Heart rot of sugar beet.<br>(iv) Death of shoot & root tips.<br>(v) Stunted growth.<br>(vi) Small size of fruits.<br>(vii) Decreased nodulation of legumes.<br>(viii) Browning of cauliflower. |
| 5. | Manganese | $Mn^{2+}$ | Activator of enzymes of photosynthesis, respiration, and nitrogen metabolism, Photolysis of $H_2O$ in photosynthesis, synthesis of chlorophyll | (i) Interveinal chlorosis.<br>(ii) Marsh spot of pea.<br>(iii) Grey speak of oat.<br>(iv) Stunted growth.<br>(v) Flowers sterile. |
| 6. | Molybdenum | $MoO_2^{2+}$ | Cofactor of nitrate reductase, Important in $N_2$ fixation, ascorbic acid synthesis. | (i) Mottled chlorosis with marginal necrosis.<br>(ii) Whip tail of cauliflower.<br>(iii) Loosening of inflorescence in Cauliflower. |
| 7. | Chlorine | $Cl^-$ | Anion-cation balance, transfer of electron from water to PS II (Photolysis) | (i) Bronze colour in leaves.<br>(ii) Swollen root tips.<br>(iii) Chlorosis and necrosis.<br>(iv) Flower abscission reduced fruiting |
| 8. | Nickel | $Ni^{2+}$ | Activator of Urease and required for hydrogenase | (i) Necrosis of leaf tip |

## Deficiency Symptoms of Essential Elements

- Concentration of essential elements below which plant growth is retarded is called **critical concentration.**
- Deficiency symptoms appear in different plant parts depend on the mobility of element in plants, such as–

  (i) Actively mobilized elements causes deficiency first in older parts of plant Eg. N, K, Mg, S.

  (ii) Structural elements which are immobile create deficiency first in younger parts of plants Eg.Ca.

- Necrosis, or death of tissue, particularly leaf tissue, is due to the deficiency of Ca, Mg, Cu, K. Lack or low level of N, K, S, and Mo causes an inhibition of cell division. Deficiency of some elements like N, S, Mo causes delaying in flowering.

## Toxicity of Micronutrients

The requirement of micronutrients is always in low amounts while their moderate decrease causes the deficiency symptoms and a moderate increase causes toxicity. In other words, there is a narrow range of concentration at which the elements are optimum. Any mineral ion concentration in tissues that reduces the dry weight of tissues by about 10 per cent is considered toxic. Such critical concentrations vary widely among different micronutrients. The toxicity symptoms are difficult to identify. Toxicity levels for any element also vary for different plants. Many a times, excess of an element may inhibit the uptake of another element. For example, the prominent symptom of manganese toxicity is the appearance of brown spots surrounded by chlorotic veins. It is worth mention that manganese competes with iron and magnesium for uptake and with magnesium for binding with enzymes. Manganese also inhibit calcium translocation in shoot apex. Therefore, excess of manganese may, in fact, induce deficiencies of iron, magnesium and calcium. Thus, what appears as symptoms of manganese toxicity may actually be the deficiency symptoms of iron, magnesium and calcium.

## Nitrogen Metabolism:

## Nitrogen Cycle:

- It is a regular circulation of nitrogen among living organisms, reservoir pool in the atmosphere and cycling pool in the lithosphere.
- Plants obtain nitrogen from soil as **Nitrate, ammonium, nitrite and urea.**
- Nitrogen compounds are obtained from reservoir pool through nitrogen fixation. Reservoir pool is replenished through denitrification, Cycling pool is augmented by ammonification and nitrifcation.

## (A) Nitrogen Fixation:

Process of conversion of nitrogen ($N_2$) to ammonia is called nitrogen fixation. It is of two types.

**(i) Abiological**

**(ii) Biological**

**(i) Abiological $N_2$ Fixation - It is of two types**

**(a) Natural Abiological $N_2$ Fixation:** Different types of nitrogen oxides are produced by the fusion of atmospheric nitrogen and oxygen in the presence of electric discharges and ultraviolet radiation. Ozonization, combustion and through automobile.

**(b) Industrial Abiological $N_2$ Fixation:** Ammonia is formed by the fusion of $N_2$ & $H_2$ in the presence of high temperature, pressure in Industries and power generating stations.

**(ii) Biological Nitrogen Fixation:** It was discovered by **Winogradsky (1891)**. It is of two types.

**(a) Asymbiotic: e.g.** Bacillus, Anabaena and Nostoc are free living.

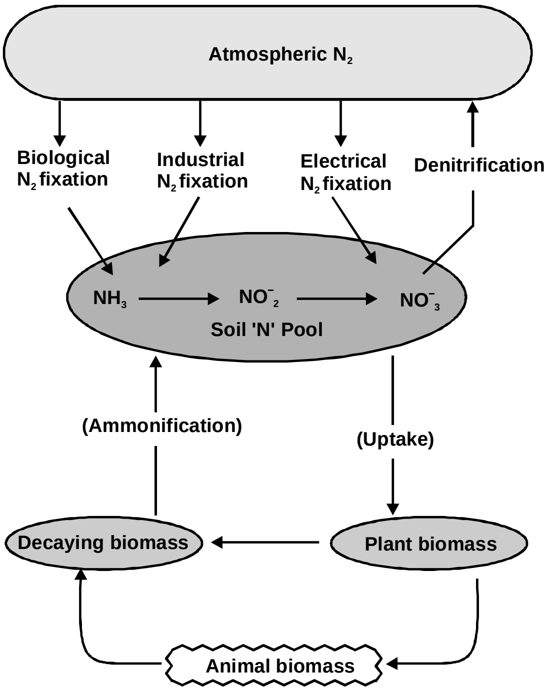



**Fig : Nitrogen Cycle**

It involves following catagories

**(1) Free living Nitrogen fixing Bacteria : e.g. *Azotobacter* and *Beijerinckia* (aerobic), *Clostridium* and *Rhodospirillum*(Anaerobic).**

**(2) Free living Nitrogen fixing Cyanobacteria: e.g. *Nostoc, Anabaena, Aulosira, Cylindrospermum.***

**(b) Symbiotic:** It includes two types

**(1) Symbiotic Nitrogen fixing Cyanobacteria: e.g. (i)** *Anabaena azollae* in *Azolla pinnata* fern (ii) *Anabaena cycadae* and *Nostoc* in coralloid roots of Cycas.

**(2) Symbiotic Nitrogen fixing Bacteria:**

| **S.No.** | **Name of symbiotic $N_2$ fixing bacteria** | **Plant** |
|---|---|---|
| **1.** | *Rhizobium leguminosarum, R.meliloti* | Root nodules of Leguminous plants – Pea, soyabeen, gram, Groundnut |
| **2.** | *Frankia* | Root nodules of Casuarina, Alnus |
| **3.** | *Azorhizobium* | Stem nodules of Sesbania |
| **4.** | *Xanthomonas* & *Mycobacterium* | Leave of Ardisia |

- Both Rhizobium and Frankia are free living in soil but are symbiont also.
- Root hair of legume secretes flavonoids and betaines that attract Rhizobium sps. The latter 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. The latter stimulate cortical cells resulting they undergo proliferation and form nodules. Bacteria also perform multiplication and finally they become immobilized called bacteriods which are found in groups or vesicles.

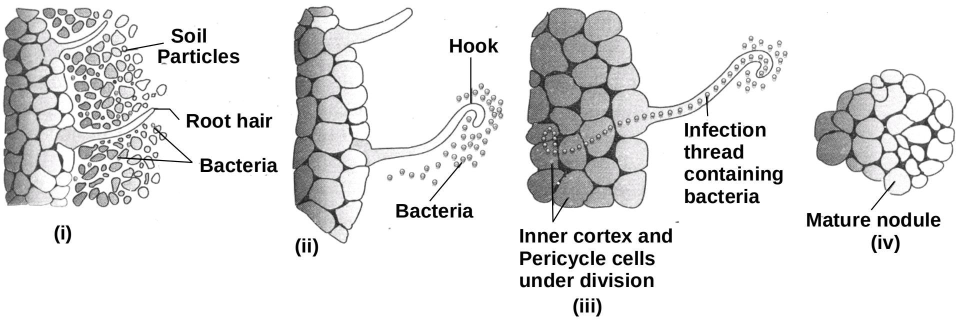



**Fig:- Deveploment of root nodules in soyabean**

## Role of Leghaemoglobin :

- It is pinkish pigment (It heme part comes from Rhizobium & globin from legumes). It acts as oxygen scavenger, protecting enzyme nitrogenase from oxygen.
- **Enzyme nitrogenase** consists of **Mo-Fe protein** and catalyses the conversion of atmospheric nitrogen to ammonia,

$$\mathbf{N_2 + 8H^+ + 8e^- + 16ATP \longrightarrow 2NH_3 + H_2 + 16ADP + 16Pi}$$

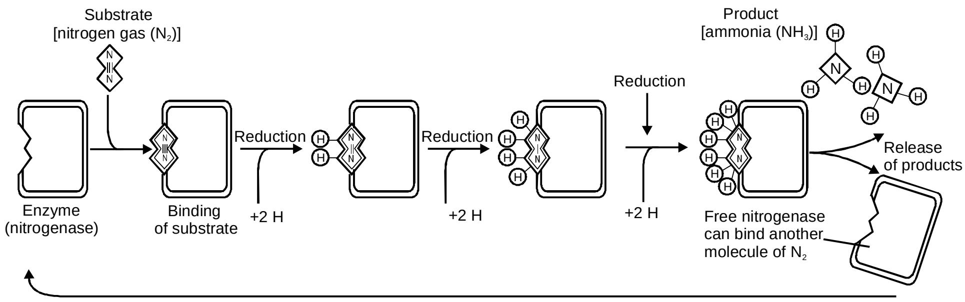



**Fig : Steps of conversion of atmospheric nitrogen to ammonia by nitrogenase enzyme complex found in nitrogen-fixing bacteria**

- Symbiotic nitrogen fixation requires **Nod genes** of legume, **nod, nif** and **fix gene** clusters of bacteria.

## (B) Ammonification and Nitrification:

- Free living nitogen fixers do not immediately enrich the soil. It is only after their death the fixed nitrogen transfer to the cycling pool. It occurs in two steps, **ammonification** and **nitrification**.

**(1) Ammonification:** Decomposers **(*Bacillus ramosus, B. vulgaris*)** degrade nitrogen excretions and proteins of dead organisms. They first form amino acids and then ammonia.

$$\text{Proteins} + H_2O \longrightarrow R-\underset{}{\overset{NH_2}{\overset{|}{CH}}}-COOH \xrightarrow{+H_2O} \underset{\text{Organic acid}}{RCOOH} + \underset{\text{ammonia}}{NH_3}$$

**(2) Nitrification:** Conversion of ammonia into nitrate involves two steps

**(i)** $\mathbf{2NH_3 + 3O_2 \xrightarrow[\text{Aspergillus flavus}]{\text{Nitrosococcus, Nitrosomonas}} 2NO_2^- + 2H^+ + 2H_2O + energy}$

**(ii)** $\mathbf{2NO_2 + O_2 \xrightarrow{\text{Nitrobacter}} 2NO_3 + Energy}$

All the bacteria are called chemoautotrophs.

## (C) Nitrate Assimilation:

**(i) Reduction of Nitrate to Nitrite:**

After absorption, Nitrate is reduced by nitrate reductase with the help of NADPH & FAD/FMN.

$$NO_3 + NAD(P)H + H^+ \xrightarrow[\text{FAD/FMN}]{\text{Nitrate Reductase}} NO_2^- + H_2O + NADP^+$$

**(ii) Reduction of Nitrite:** In the presence of NAD(P)H and ferredoxin, Nitrite is further reduced by enzyme nitrite reductase.

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

At physiological pH $NH_3$ is converted into $NH_4^+$ ion while most of the plants can assimilate $NH_4^+$ like nitrate but later is quite toxic to plants and hence can not accumulate.
Now Ammonia is fused with organic acids to form amino acids

## (D) Synthesis of Amino Acids:

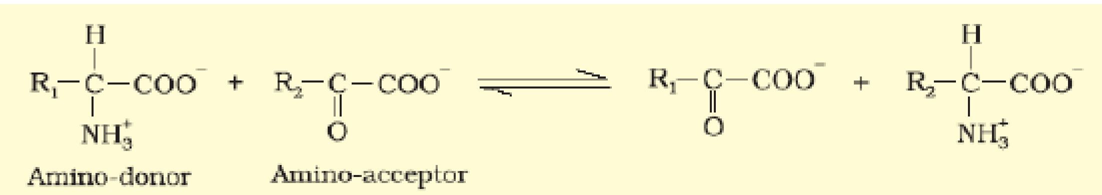
They are synthesised by three methods.

**(i) Reductive amination:**

(a) $\alpha\text{–ketoglutaric acid} + NH_4^+ + NAD(P)H \xrightarrow[\text{dehydrogtenase}]{\text{glutamate}} \text{Glutamate} + H_2O + NAD(P)$

(b) $\text{Oxaloacetic acid} + NH_4^+ + NAD(P)H \xrightarrow[\text{dehydrogenase}]{\text{aspartate}} \text{Aspartate} + H_2O + NAD(P)$

**(ii) Transamination:** It involves the transfer of amino group from one amino acid to the keto group. The enzyme **transaminase** catalyse all the reactions.




$$\text{Glutamic acid} + \text{Oxaloacetic acid} \xrightarrow[\text{Aminotransferase}]{\text{Glutamate aspartate}} \alpha\text{–ketoglutaric acid} + \text{Aspartic acid}$$

**(iii) Catalytic Amidation:**

$$\text{Glutamate} + NH_4^+ + ATP \xrightarrow[\text{synthetase}]{\text{glutamine}} \text{Glutamine} + ADP + Pi$$

$$\text{Glutamine} + \alpha\text{-ketoglutaric acid} + NAD(P)H \xrightarrow[\text{synthetase}]{\text{glutamate}} 2\,\text{Glutamate} + NAD(P)$$

Since amides contain more nitrogen than the amino acids, they are transported to other parts of the plant via xylem vessels. In addition, along with the transpiration stream the nodules of some plants (e.g., soyabean) export the fixed nitrogen as ureides. These compounds also have a particularly high nitrogen to carbon ratio.

### (E) Denitrification:

Dentirifying bacteria like, *Pseudomonas denitrificans, Thiobacillus denitrificans* convert nitrate into gaseous nitrogen in the soil.

$$2NO_3^- \longrightarrow 2NO_2^- \longrightarrow 2NO \longrightarrow N_2O \longrightarrow N_2$$

### Resonate the Concept

**(1)** **Liebig's law of Minimum:** He stated that the yield of the crop plants is determined by the amount of that essential element which is present in minimum quantity.

**(2)** **Phytotron:** When plant is grown in controlled environmental condions (temperature, light, pH etc).

**(3)** **Single Ion channels:** These are transmembrane proteins that help in the entry of specific ions.

**(4)** **Sodium and Iodine:** Essential for animals but not for plants.

**(5)** **Amides:** These are amino acid derivatives in which OH part of carboxylic group (–COOH) is replaced by amino group (–$NH_2$). Thus Amides are double keto acids. The two most common amides are glutamine and asparagine. They are formed by amidation of glutamic acids and aspartic acid respectively.