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PRE-MEDICAL

BOTANY

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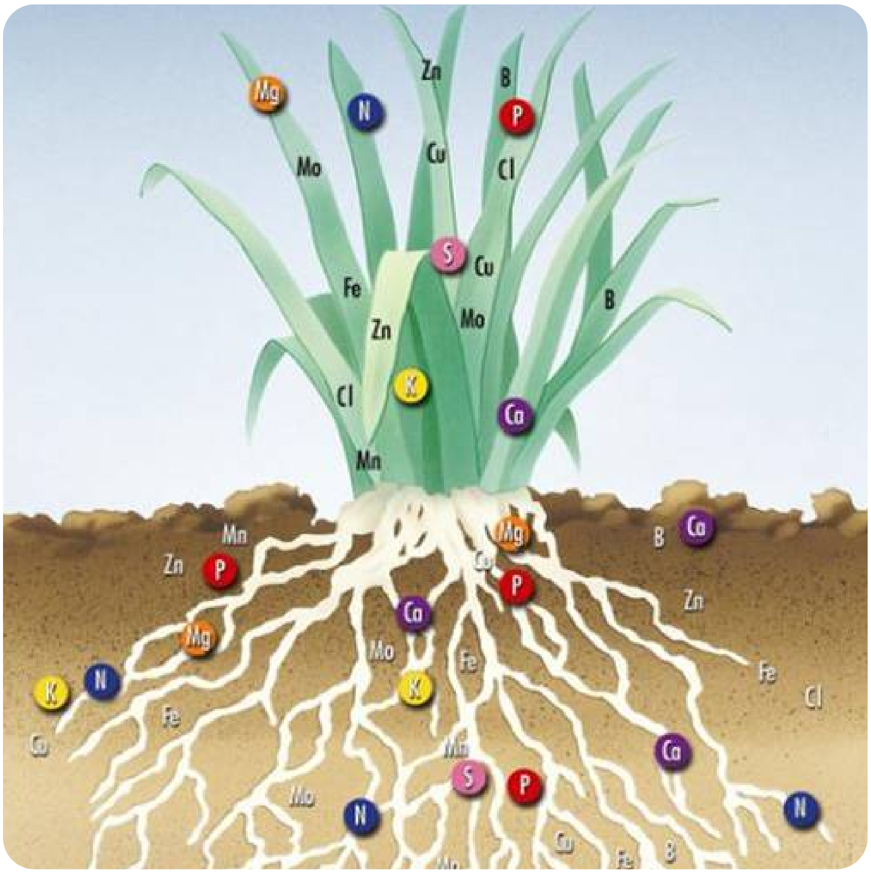

STUDY MATERIAL

Mineral Nutrition

ENGLISH MEDIUM

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MINERAL NUTRITION

01. INTRODUCTION

- Introduction
- Methods to Study the Mineral Requirements of Plants
- Essential Mineral Elements
- Mechanism of Absorption of Elements
- Translocation of Mineral ions/Solutes
- Soil as Reservoir of Essential Elements
- Metabolism of Nitrogen

- Most of the minerals present in the soil can enter into plants through roots. More than 60 types of elements are found in different plants. Which elements are found in plants, can be determined by the method called **Ash analysis.**

02. 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.
- The technique of growing plants in a nutrient solution without soil is called as **hydroponics.**
- By this method, essential elements were identified and their functions and deficiency symptoms were discovered.
- The nutrient solutions must be **adequately aerated to obtain the optimum growth.**
- **Hydroponics has been successfully employed as a technique for the commercial production of vegetables like, tomato, seedless cucumber and lettuce.**

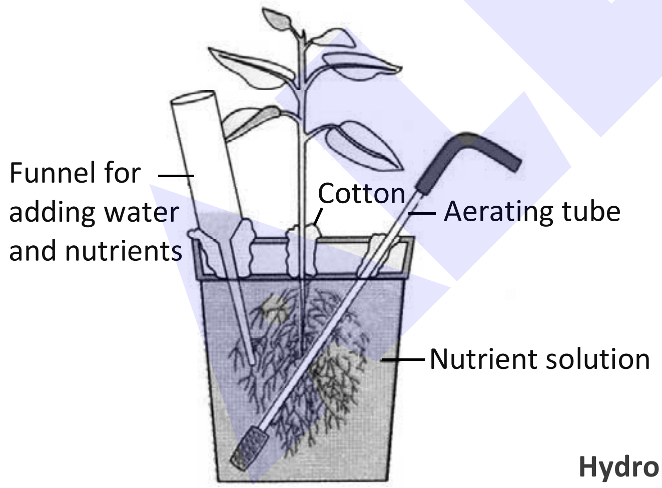
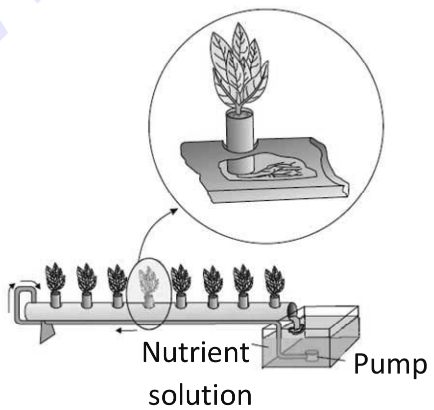


Diagram of a typical set-up for nutrient solution culture



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.

NCERT XI Page No. 195, Figure No. 12.1 & 12.2

03. ESSENTIAL MINERAL ELEMENTS

- About more than 60 types of elements are present in the plant body but only **17 elements are considered as essential elements.**

  C, H, O, N, K, S, Ca, Fe, Mg, P, Cu, Mn, B, Cl, Zn, Mo, Ni
- Except these seventeen essential elements there are some **beneficial elements such as Na, Si, Se, Co.**
- Among 17 essential elements C, H & O are obtained from the air and soil in the form of CO_2 & H_2O not in the form of ions, so these are called **nonmineral nutrients or elements. Others are mineral nutrients.**

(1) CRITERIA FOR ESSENTIALITY

- According to Arnon-criteria for essentiality of minerals are :
  - (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.

(2) CLASSIFICATION OF NUTRIENTS

(A) On the Basis of Function :

- Essential elements can also be grouped into four broad categories on the basis of their diverse functions. Theses categories are :
  - (i) Essential elements as components of biomolecules and hence structural elements of cells (e.g., **carbon, hydrogen, oxygen and nitrogen**)
  - (ii) Essential elements that are components of energy - related chemical compounds in plants (e.g., **magnesium in chlorophyll and phosphorous in ATP**).
  - (iii) Essential elements that activate or inhibit enzymes. (e.g., **Mg, Zn, Mo etc.**)
    - **Mg^{2+} is an activator for both Ribulose bisphosphate carboxylase oxygenase (RuBisCO) and Phosphoenol pyruvate carboxylase (PEPCase), 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.**
  - (iv) Some essential elements can alter the osmotic potential of a cell. (e.g., **K, Cl** etc.)

(B) On the Basis of Quantity or Requirement :

- Arnon divided essential elements into two groups on the basis of their requirement of plants –
  - (i) **Major element/Macro nutrients :**
    - Concentration must be excess of 10 m mole kg^{-1} of dry matter.
    - **C, H, O, N, P, K, S, Ca, Mg,**
  - (ii) **Minor element/Micro nutrients :**
    - Concentration required less than 10 m mole $kg^{-1}$of dry matter.
    - **Fe, Cu, Zn, B, Cl, Mn, Mo, Ni**

(3) ROLE OF MACRO AND MICRO-NUTRIENTS

Essential elements perform several functions. They participate in various metabolic processes in the plant cells such as permeability of cell membrane, maintenance of osmotic concentration of cell sap, electron transport systems, buffering action, enzymatic activity and act as major constituents of macromolecules and co-enzymes. Various forms and functions of mineral elements are given below.

1. **Nitrogen :** This is the mineral element required by plants in the **greatest amount**. It is absorbed **mainly as NO_3^-** though some are also taken up as NO_2^- or NH_4^+. Nitrogen is required by **all parts of a plant**, particularly the **meristematic tissues** and the **metabolically active cells**. Nitrogen is one of the major **constituents of proteins, nucleic acids, vitamins** and **hormones**.
2. **Phosphorus:** Phosphorus is absorbed by the plants from soil in the form of phosphate ions (either as $H_2PO_4^-$ or HPO_4^{2-}). Phosphorus is a **constituent of cell membranes**, **certain proteins**, **all nucleic acids and nucleotides**, and is required for **all phosphorylation reactions**.
3. **Potassium :** It is absorbed as potassium ion (K^+). In plants, this is required in **more abundant quantities in the meristematic tissues, buds, leaves** and **root tips**. Potassium helps to maintain an **anion-cation balance** in cells and is involved in **protein synthesis, opening and closing of stomata, activation of enzymes** and in the maintenance of **the turgidity of cells**.
4. **Calcium :** Plant absorbs calcium from the soil in the form of calcium ions (Ca^{2+}). Calcium is required by **meristematic and differentiating tissues**. During cell division it is used in the synthesis of cell wall, **particularly as calcium pectate in the middle lamella**. It is also needed during the formation of **mitotic spindle**. It accumulates in **older leaves**. It is involved in the normal **functioning of the cell membranes**. It activates certain enzymes and plays an important role in regulating metabolic activities.
5. **Magnesium :** It is absorbed by plants in the form of divalent (Mg^{2+}). It activates the **enzymes of respiration, photosynthesis** and are involved in the **synthesis of DNA and RNA**. Magnesium is a constituent of the **ring structure of chlorophyll** and helps to **maintain the ribosome structure**.
6. **Sulphur :** Plants obtain sulphur in the form of sulphate (SO_4^{-2}). Sulphur is present in **two amino acids – cysteine and methionine** and is the main constituent of several **coenzymes, vitamins (thiamine, biotin, Coenzyme A) and ferredoxin**.
7. **Iron :** Plants obtain iron in the form of ferric ions (Fe^{3+}). It is required in **larger amounts in comparison to other micronutrients**. It is an important constituent of proteins involved in the **transfer of electrons** like **ferredoxin and cytochromes**. It is reversibly oxidised from Fe^{2+} to Fe^{3+} during electron transfer. It activates **catalase enzyme**, and is essential for the **formation of chlorophyll**.
8. **Manganese :** It is absorbed in the form of manganous ions (Mn^{2+}). It activates many **enzymes involved in photosynthesis, respiration and nitrogen metabolism**. The best defined function of manganese is **in the splitting of water to liberate oxygen during photosynthesis**.

9. **Zinc :** Plants obtain zinc as (Zn^{2+}) ions. It activates various enzymes, **especially carboxylases**. It is also needed in the **synthesis of auxin**.

10. **Copper :** It is absorbed as cupric ions (Cu^{2+}). It is **essential for the overall metabolism in plants**. Like iron, it is associated with certain enzymes involved in **redox reactions** and is reversibly oxidised from Cu^{+} to Cu^{2+}.

11. **Boron :** It is absorbed as BO_3^{3-} or $B_4O_7^{2-}$. Boron is **required for uptake and utilisation of Ca^{2+}, membrane functioning, pollen germination,** cell elongation, **cell differentiation** and **carbohydrate translocation**.

12. **Molybdenum :** Plants obtain it in the form of molybdate ions (MoO_2^{2+}). It is a component of several enzymes, including **nitrogenase** and **nitrate reductase** both of which **participate in nitrogen metabolism**.

13. **Chlorine :** It is absorbed in the form of chloride anion (Cl^{-}). Along with Na^{+} and K^{+}, it helps in **determining the solute concentration** and the **anion cation balance in cells**. It is essential for the **water-splitting reaction in photosynthesis**, a reaction that leads to oxygen evolution.

(4) DEFICIENCY SYMPTOMS OF ESSENTIAL ELEMENTS

Whenever the supply of an essential element becomes limited, plant growth is retarded. The concentration of the essential element below which plant growth is retarded is termed as critical concentration. The element is said to be deficient when present below the critical concentration.

Since each element has one or more specific structural or functional role in plants, in the absence of any particular element, plants show certain morphological changes. These morphological changes are indicative of certain element deficiencies and are called deficiency symptoms. The deficiency symptoms vary from element to element and they disappear when the deficient mineral nutrient is provided to the plant. However, if deprivation continues, it may eventually lead to the death of the plant.

Mobility of minerals : The parts of the plants that show the deficiency symptoms also depend on the mobility of the element in the plant. For elements that are **actively mobilised within the plants and exported to young developing tissues, the deficiency symptoms tend to appear first in the older tissues.** For example, the deficiency symptoms of nitrogen, potassium, magnesium and phosphorus 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.

The deficiency symptoms tend to appear first in the young tissues whenever the elements are relatively immobile and are not transported out of the mature organs, for example, elements like sulphur and calcium are a part of the structural component of the cell and hence are not easily released. This aspect of mineral nutrition of plants is of a great significance and importance to agriculture and horticulture.

The kind of deficiency symptoms shown in plants include chlorosis, necrosis, stunted plant growth, premature fall of leaves and buds, and inhibition of cell division.

- **Chlorosis is the loss of chlorophyll leading to yellowing in leaves.** This symptom is caused by the deficiency of elements N, K, Mg, S, Fe, Mn, Zn and Mo.
- Likewise, **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, Mo causes an **inhibition of cell division.**
- Some elements like N, S, Mo **delay in flowering if their concentration** in plants is low.

You can see from the above that the deficiency of any element can cause multiple symptoms and that the same symptoms may be caused by the deficiency of one of several different elements. Hence, to identify the deficient element, one has to study all the symptoms developed in all the various parts of the plant and compare them with the available standard tables. We must also be aware that different plants also respond differently to the deficiency of the same element.

(5) TOXICITY OF MICRONUTRIENTS

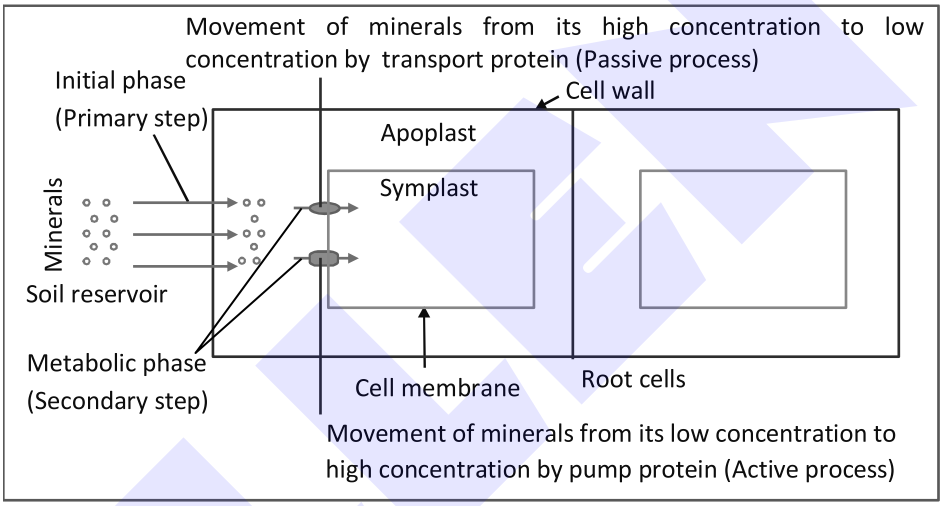
- **Any mineral ion (micronutrient) concentration in plant tissue that reduce the dry weight of tissues by about 10 percent is considerd as toxic and this effect is called as toxicity.**
- **The toxicity symptoms are difficult to identify. Toxicity levels for any element also vary for different plants. Many a times excess of an element may inhibit the uptake of another element.**
- Ex : Excess of Mn (Manganese) cause appearance of brown spots surrounded by chlorotic veins **(prominent symptom).** Mn competes with iron (Fe) and magnesium (Mg) for uptake and with Mg for binding with enzymes. Mn also inhibits, calcium translocation into the shoot apex. **So the excess of Mn may, in fact, induce deficiencies of Fe, Mg and Ca. Thus, what appears as symptoms of manganese toxicity may actually be the deficiency symptoms of Fe, Mg & Ca.**

04. MECHANISM OF ABSORPTION OF ELEMENTS

- Soil is the main source of mineral salts. These mineral salts are absorbed by the root hairs.
- The movement of mineral ions is usually called as flux. The inward movement inside the cell is called influx and outward movement is efflux.

(1) THE MINERAL ABSORPTION OCCURS MAINLY IN TWO PHASES

- In **first phase,** an initial rapid uptake of ions into the **Free space or Outer space** of the cell occurs, the **apoplast (intercellular spaces and cell wall),** which is a **passive process.**
- In the **second phase** of uptake, the ions are taken in slowly into the **inner space,** the **symplast** of the cell which is **both active and passive process (mainly active process)**. The passive movement of ions in **symplast** occurs through ion channels which are trans-membrane proteins and act as selective pores. The active influx and efflux from symplast occurs with the help of pump proteins and with expenditure of energy/ATP.



(2) METHODS OF MINERAL ABSORPTION

(A) Passive (Some minerals) **(B) Active (Most minerals)**

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

(i) **By diffusion :** According to this method mineral ions may diffuse into root cells from the soil solution.

(ii) **By mass flow :** According to this method mineral ions absorption occurs with flow of water under the influence of transpiration pull.

- **Unlike water all minerals cannot be passively absorbed by the roots because -**

(1) Minerals are present in the soil as charged particles (ions) which mostly can not move across cell membranes passively.

(2) The concentration of minerals in the soil is usually lower than the concentration of minerals in the roots.

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

- Specific proteins in the membrane of root hairs actively pump ions from the soil into the cytoplasm of the epidermal cells.
- Like all cells, endodermal cells of root have many transport proteins embedded in their plasma membrane; they let some solutes cross the membrane, but not others. **Transport proteins of endodermal cells of root are control points, where a plant adjust the quantity and types of solutes that reach the xylem. The root endodermis because of the layer of suberin has the ability to actively transport ions in one direction only.**

05. TRANSLOCATION OF MINERAL IONS/SOLUTES

- When ions reach to the xylem of root by active or passive absorption or by cumulative activity of both then transport of these ions towards stem and all the parts of plant occurs due to transpiration flow through xylem.
- **Main storage regions or sinks for minerals elements are growing regions of the plants like apices and lateral meristem, young leaves, developing flowers, fruits, seeds and storage organs.**
- Unloding of mineral ions occurs at the fine vein endings **through diffusion** and **actively uptake** by cells of sink.
- **Analysis of xylem sap shows that some nitrogen is translocated in the form of inorganic ions and most of it is translocated in the organic form i.e. amides and related compounds.**
- Like this small amount of phosphorus and sulphur are also translocated in the form of organic compounds. Except this, small amount of materials are also transfered between xylem and phloem. So **we cannot distinctly differentiate that xylem only translocate inorganic nutrients and phloem translocate only organic materials, as was believed before.**

06. SOIL AS RESERVOIR OF ESSENTIAL ELEMENTS

Majority of the nutrients that are essential for the growth and development of plants become available to the roots due to **weathering** and **breakdown of rocks.** These processes enrich the soil with dissolved ions and inorganic salts. Since they are **derived from the rock minerals,** their role in plant nutrition is referred to as **mineral nutrition.**

- Soil consists of a wide variety of substances. Thus, soil play several roles :

(i) Soil is **reservoir of water** for plants.

(ii) Soil **supplies minerals** and **harbours nitrogen-fixing bacteria.**

(iii) Soil **supplies air** to the roots.

(iv) Soil **acts as a matrix** that stabilises the plant.

(v) In terrestrial habitat soil is the **site for decomposition** (decomposition is a process to recycle minerals from detritus).

Since deficiency of essential minerals affect the crop-yield, there is often a need for supplying them through fertilisers. Both macro-nutrients (N, P, K, S, etc.) and micro-nutrients (Cu, Zn, Fe, Mn, etc.) form components of fertilisers and are applied as per need.

Golden Key Points

- **Hydroponics has been successfully employed as a technique for the commercial production of vegetables like tomato, seedless cucumber and lettuce.**
- Phosphorus is a **constituent of cell membranes**, **certain proteins**, **all nucleic acids and nucleotides**, and is required for **all phosphorylation reactions**.
- Sulphur is present in **two amino acids – cysteine and methionine.**
- The best defined function of manganese is **in the splitting of water to liberate oxygen during photosynthesis**.
- For elements that are **actively mobilised within the plants and exported to young developing tissues, the deficiency symptoms tend to appear first in the older tissues.**
- **The deficiency symptoms tend to appear first in the young tissues whenever the elements are relatively immobile and are not transported out of the mature organs.**
- **Transport proteins of endodermal cells of root are control points, where a plant adjust the quantity and types of solutes that reach the xylem.**
- **Analysis of xylem sap shows that some nitrogen is translocated in the form of inorganic ions and most of it is translocated in the organic form i.e. amides and related compounds.**

BEGINNER'S BOX

INTRODUCTION, METHODS TO STUDY THE MINERAL REQUIREMENTS OF PLANTS, MECHANISM OF ABSORPTION OF ELEMENTS, TRANSLOCATION OF MINERAL IONS/ SOLUTES, SOIL AS RESERVOIR OF ESSENTIAL ELEMENTS

1. Which of the following essential elements of plants is a non mineral nutrient?

(1) Carbon (2) Manganese
(3) Magnesium (4) Calcium

2. Which of the following mineral elements required by plants in greatest amount?

(1) Iron (2) Sulphur
(3) Phosphorus (4) Nitrogen

3. Deficiency of potassium in plants can cause :-

(1) Chlorosis (2) Necrosis
(3) Inhibition of cell division (4) All of the above

4. In plants excess of manganese may induce deficiency of :-

(1) Iron (2) Magnesium
(3) Calcium (4) All of the above

5. Which of the following is not correct?

(1) Second phase of uptake of ions in plants is slower than the first phase.
(2) Most of the mineral absorption in plants is active.
(3) Analysis of xylem sap shows that most of the nitrogen is translocated in the form of inorganic ions.
(4) Both macronutrients and micronutrients form components of fertilisers.

- C, H, O, N, P and S are called **protoplasmic elements** as they are main constituent of organic part of protoplasm.
- C, H and O are called **frame work elements** as they are main constituent of proteins, carbohydrates and fats.
- N, P and K are called **critical elements** as they are required by plants in high doses. To fulfil this great demand soil mostly faces a shortage of such elements. Therefore, farmers frequently supply them in the form of fertilisers to obtain optimum crop yield.
- Plants grown in moistened air with nutrients is called Aeroponics.
- About **98 percent** of the mass of every living organism is **composed of six elements** including carbon, hydrogen, oxygen, nitrogen, calcium and phosphorus.
- Nitrogen is required in maximum quantity among all the essential mineral elements.
- Among micronutrients, Fe is required in maximum quantity and Mo is required in minimum quantity.
- Some plants store nutrients e.g. (1) Peach plant - Strontium
  (2) *Astragalus* & *Neptunia* plant - Selenium.
  (3) *Equisetum* and mustard plant - Gold.

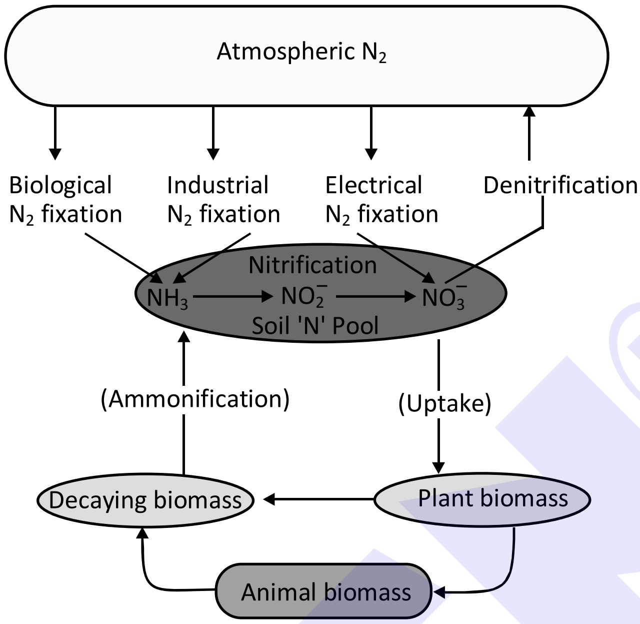
07. METABOLISM OF NITROGEN

(1) INTRODUCTION

- **Nitrogen is an essential element in all living organisms.** It is the constituent of amino acids, proteins, hormones, chlorophylls and many of the vitamins.
- Nitrogen is present in the atmosphere abundantly in N_2 form, but eukaryotes and many prokaryotes can't uptake nitrogen directly from the atmosphere. The nitrogen enter into the soil from atmosphere by fixation process, then from the soil, plants absorb it and from plants it moves to animals and fulfil the requirements of all living beings.
- **Plants competes with microbes for the limited nitrogen that is available in the soil, so nitrogen is a limiting nutrient for both natural and agricultural ecosystem.**

(2) NITROGEN (N_2) CYCLE

- Process of conversion of atmospheric N_2 into nitrogenous compounds (NH_3, NO_3^-) is called nitrogen fixation.



The nitrogen cycle showing relationship between the **three main nitrogen pools - atmosphere, soil and biomass**

NCERT XI Page No. 201, Figure, No. 12.3

(3) ABIOLOGICAL NITROGEN FIXATION

- **Abiological Nitrogen Fixation / Physicochemical N_2 fixation is further divided into two types :**

  (A) Atmospheric or electrical N_2 fixation (B) Industrial N_2 fixation

  (A) Atmospheric or electrical N_2 fixation :

  - In nature, lightening and ultraviolet radiation provide enough energy to convert nitrogen to nitrogen oxides (NO, NO_2, N_2O).
  - Industrial combustions, forest fires, automobile exhausts and power-generating stations are also sources of atmospheric nitrogen oxides.

  (B) Industrial N_2 Fixation :

  In the presence of high pressure, temperature and catalysts nitrogen (N_2) and hydrogen combines to form ammonia (NH_3). This ammonia is used in the formation of chemical fertilizers.

(4) BIOLOGICAL NITROGEN FIXATION OR DIAZOTROPHY

- Conversion of atmospheric nitrogen (N_2) into inorganic nitrogenous compounds like - NH_3 by living organisms is called biological nitrogen fixation or Diazotrophy. Only certain prokaryotic species are capable of fixing nitrogen.

(A) Nitrogen Fixing organisms (Diazotrophs) :

(i) Free living or non–symbiotic :

- Eubacteria :– *Azotobacter*, *Beijernickia*, (both aerobic) and *Rhodospirillum* (anaerobic).
- Cyanobacteria (Blue green algae) – *Nostoc, Anabaena*

(ii) Symbiotic :

Symbiotic Diazotrophs or N_2 fixers			
	Micro-organism	**Symbiotic structure**	**Host**
1.	**Eubacteria e.g.:**		
(i)	***Rhizobium* & *Bradyrhizobium***	**Root nodules**	**Leguminous plants**
(ii)	***Azorhizobium***	**Stem nodules**	**Leguminous plant – *Sesbania***
2.	**Actinomycetes (Filamentous bacteria) e.g.:**		
	Frankia	**Root nodules**	**Non-leguminous** angiosperms **e.g. *Alnus, Casuarina***
3.	**Cyanobacteria e.g.:**		
(i)	***Anabaena azollae***	–	**Pteridophyte : *Azolla*** (in leaves)
(ii)	**A. *cyacadae***	–	**Gymnosperm : *Cycas*** (in coralloid roots)
(iii)	***Nostoc***	–	**Bryophyte : *Anthoceros*** (in thallus) **Angiosperm : *Gunnera*** (in stem)

- **Both *Rhizobium* & *Frankia* live freely in the soil but fix nitrogen only when in symbiotic association with host plant.**
- Enzyme nitrogenase catalyses the conversion of atmospheric N_2 to NH_3. It posses two units unit-Ist is **Mo-Fe protein & unit-IInd is Fe-S protein.**
- Nitrogenase is extremely sensitive to oxygen. So to protect it from oxygen, leguminous nodules contains an O_2 scavanger called leghaemoglobin (LegHb) which combines with O_2 to form oxyleghaemoglobin (LegHbO_2)
- **Leghaemoglobin is pink or red in colour (Globin part synthesised by plant and haem part synthesised by bacteria).**
- Many cyanobacteria capable of fixing nitrogen are filamentous and contain thick walled cells called heterocyst. These are the sites of nitrogen fixation.
- **Heterocyst lacks oxygen evolving photosystem II thus do not evolve O_2 and protect nitrogenase.**

(B) Mechanism of Biological N_2 Fixation :

- Nitrogenase enzyme reduces N_2 by the addition of hydrogen atoms.
- The three bonds between two nitrogen atoms $N \equiv N$ or dinitrogen are broken step by step & ammonia (NH_3) is formed by reduction of $N \equiv N$.
- N_2 fixation requires 3 components :

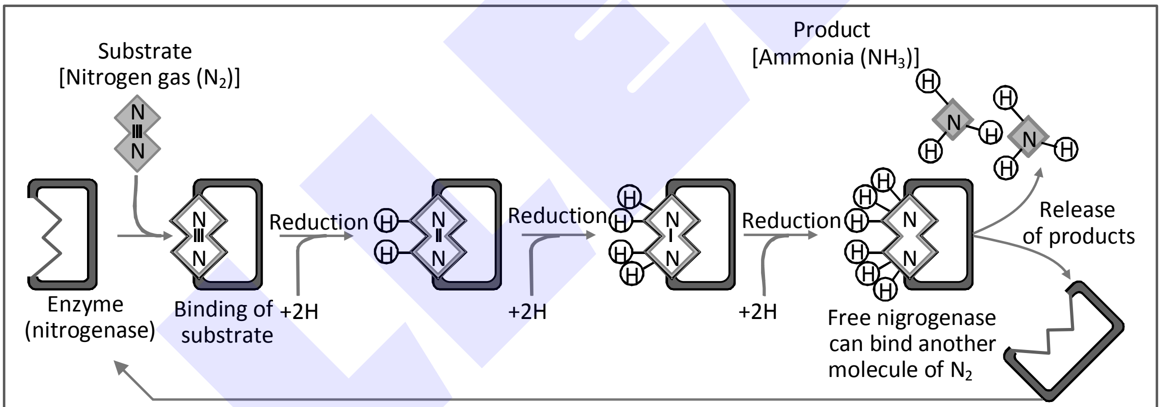
(i) **A strong reducing agent** - $NADPH_2/FADH_2/NADH_2$ – from photosynthesis & respiration.

(ii) **ATP** – from respiration. (In symbiotic fixation from the respiration of host cells).

(iii) **Nitrogenase enzyme.**

(iv) **Genes (nod, nif, fix) : nod** gene present in both plant and bacterium while **nif** (nitrogenase inducing factor) and **fix** present only in bacterium.

$$\boxed{N \equiv N + 8e^- + 8H^+ + 16\ ATP \longrightarrow 2NH_3 + H_2 + 16\ ADP + 16Pi}$$



NCERT XI Page No. 203 , Figure No. 12.5

- ***Rhizobium*** is a free-living, gram negative non sporulating, aerobic and motile rod shaped bacterium. *Rhizobia* are more prominant in the rhizosphere of leguminous plants.

(C) Nodule formation :

Nodule formation involves a sequence of multiple interaction between *Rhizobium* and roots of the host plant. Principal stages in the nodule formation are summarised as follows:

(i) ***Rhizobia* multiply** and colonise the surroundings of roots and get attached to epidermal and root hair cells.

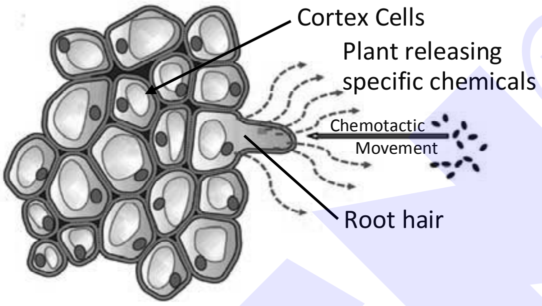
(ii) The **root-hairs curl** and the bacteria invade the root-hair.

(iii) An **infection thread is produced** carrying the bacteria into the cortex of the root, where they initiate the **nodule formation in the cortex and pericycle of the root.**

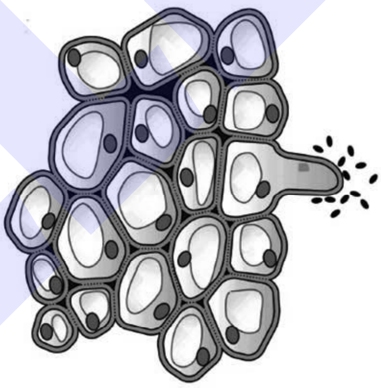
(iv) Then the bacteria are released from the thread into the cells which leads to the **differentiation of specialised nitrogen fixing cells.**

(v) The **nodule** thus **formed, establishes a direct vascular connection with the host for exchange of nutrients.**

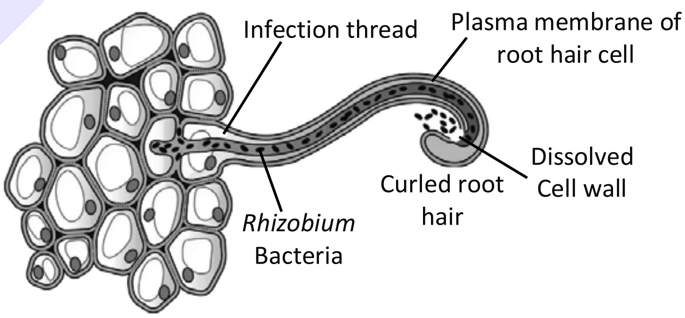
- Plant releases specific chemicals in surrounding soil, which attracts *Rhizobium* bacteria and bacteria start moving towards roots. (Chemotactic movement)

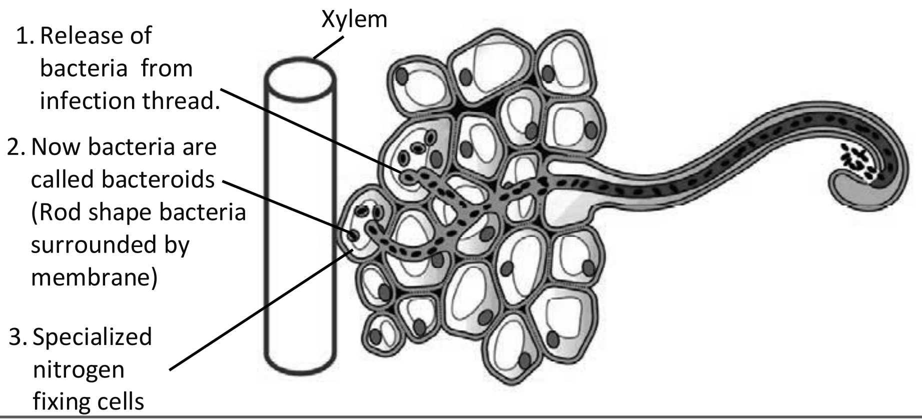


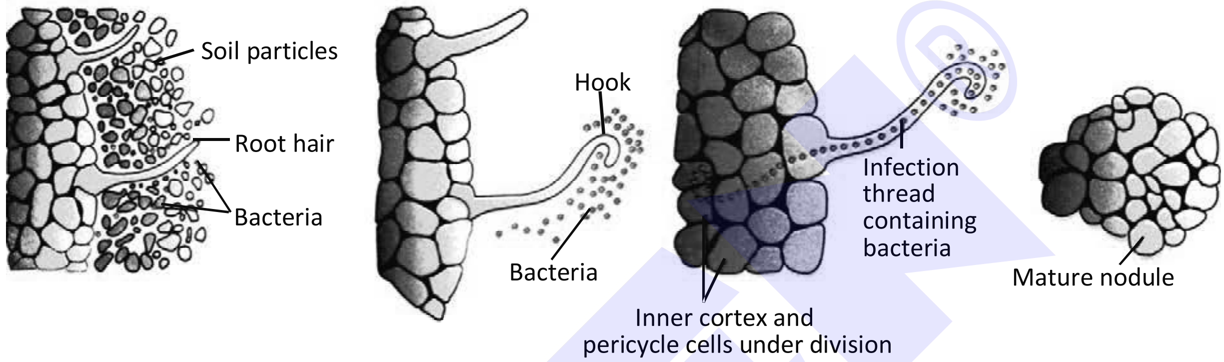
- Bacteria attach to root hairs.
- This attachment involves the interaction between specific proteins present on root hairs and specific proteins & polysaccharides of bacteria.



- The root-hairs curl and the bacteria invade the root-hair.
- An infection thread is produced carrying the bacteria into the cortex of the root.







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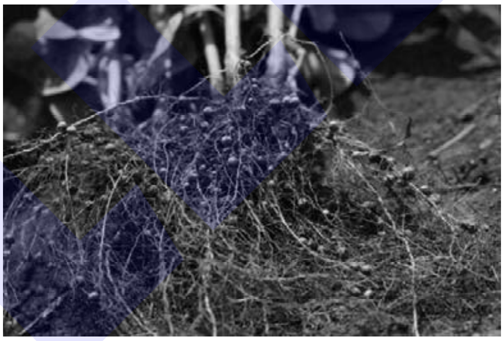


Root Nodules of Leguminous plant

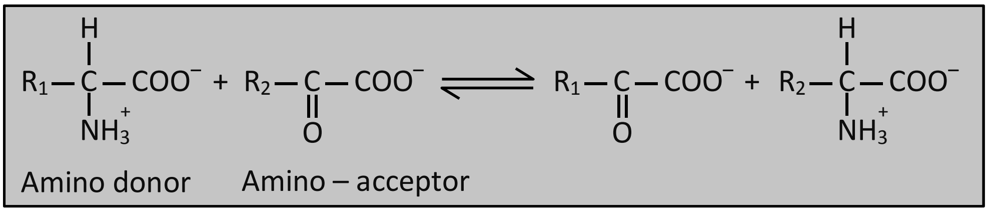
(D) Uptake and Assimilation of Nitrogen By Plants (Fate of Ammonia) :

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. Ammonium ions are quite toxic to plants and hence cannot accumulate in them. Let us now see how the NH_4^+ is used to synthesise amino acids in plants. There are two main ways in which this can take place :

(i) **Reductive amination –** NH_4^+ reacts with α–ketoglutaric acid to form an amino acid **glutamic acid.** This process known as **Reductive amination.**

$$\alpha - \text{Ketoglutaric acid} + NH_4^+ + NADPH + H^+ \underset{\text{dehydrogenase}}{\overset{\text{Glutamate}}{\rightleftharpoons}} \text{Glutamate} + H_2O + NADP^+$$

(ii) Transamination – Transfer of amino group from one amino acid to the keto group of a keto acid is known as transamination. This is a process of formation of other amino acids mainly from glutamic acid and catalysed by transaminase enzyme.



Glutamic acid + OAA $\rightleftharpoons$ **Aspartic acid** + α–keto glutaric acid.

Glutamic acid + Pyruvic acid $\rightleftharpoons$ **Alanine** + α-ketoglutaric acid

(iii) Transportation of Assimilated N_2 :

- **In plants, transportation of assimilated N_2 through xylem occurs mainly in form of amides (Glutamine and Asparagine), especially in leguminous plants.**
- **Amides are more stable** than amino acids and posses high nitrogen to carbon ratio (2N to 5C in glutamine, while glutamic acid posses 1N to 5C).
- Formation of amides from amino acids by the addition of amino group, **(The hydroxyl part of acid replaced by NH_2 radicle) is called Catalytic amidation.**
- In addition, along with the transpiration stream the nodules of some plants (e.g., soyabean-*Glycine max*) export the fixed nitrogen as **ureides.** These compounds also have a particularly **high nitrogen to carbon ratio.**

(5) AMMONIFICATION

- After the death of plants and animals the protein (organic nitrogen) present in dead biomass, degraded or decomposed by some bacteria, in the form of ammonia, the process is called ammonification & the soil bacteria used in process are called **ammonifying bacteria.**
- This breakdown is both **anaerobic** as well as **aerobic.** Anaerobic breakdown of protein is called **putrefaction** while aerobic breakdown is called **decay.**

  e.g. ***Bacillus vulgaris, Bacillus ramosus, Bacillus mycoides.***
- The ammonia produced by ammonification is divided into two fractions –

  (i) Some amount volatilises

  (ii) **Most of the amount is converted into nitrate in soil (Nitrification).**

(6) NITRIFICATION

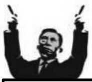
- **Oxidation of ammonia into nitrates (NO_3^-) by nitrifying bacteria (Chemoautotrophs) is called nitrification.** During this process energy is released with the help of which, bacteria synthesise their own food.

(i) $2NH_3 + 3O_2 \xrightarrow{Nitrosomonas/Nitrococcus} 2NO_2^- + 2H_2O + 2H^+ + \text{Energy}$

Ammonia → Nitrite ion

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

Nitrite ion → Nitrate ion



Nitrate reduction :

- **The nitrate formed by nitrification in soil is absorbed by plants and transported to the leaves.**
- In leaves this nitrate is reduced to form ammonia that finally forms the amine groups of amino acid.
- **The process of nitrate reduction into ammonia is called assimilatory nitrate reduction.** It is catalysed by enzyme nitrate reductase and nitrite reductase.

$$NO_3^- \xrightarrow[\text{(Cytoplasm)}]{\text{Nitrate reductase}} NO_2^- \xrightarrow[\text{(Plastid)}]{\text{Nitrite reductase}} NH_3$$

(7) DENITRIFICATION

- **Some amount of nitrate present in the soil is also reduced to nitrogen (N_2) by the process of Denitrification.**

$$NO_3^- \longrightarrow NO_2^- \longrightarrow N_2$$

- The soil bacteria involved in this process are called denitrifying bacteria.

  Ex. ***Pseudomonas* and *Thiobacillus*.**

Golden Key Points

- **Plants competes with microbes for the limited nitrogen that is available in the soil, so nitrogen is a limiting nutrient for both natural and agricultural ecosystem.**
- **Both *Rhizobium* & *Frankia* live freely in the soil but fix nitrogen only when in symbiotic association with host plant.**
- The nodules of some plants (e.g., soyabean-*Glycine max*) export the fixed nitrogen as **ureides.**
- **Oxidation of ammonia into nitrates by nitrifying bacteria (Chemoautotrophs) is called nitrification.**
- **Some amount of nitrate present in the soil is also reduced to nitrogen (N_2) by the process of Denitrification.** Ex. ***Pseudomonas* and *Thiobacillus*.**

BEGINNER'S BOX — METABOLISM OF NITROGEN

1. Which of the following is correct?
(1) Nitrogen that is available in soil is a limiting nutrient for natural ecosystem.
(2) Nitrogen that is available in soil is a limiting nutrient for agricultural ecosystem.
(3) Both (1) and (2)
(4) Nitrogen can never be a limiting nutrient.

2. During formation of leghaemoglobin in root nodules of legume plants :-
(1) globin part is synthesised by *Rhizobium* and heam part is synthesisd by plant.
(2) globin part is synthesised by plant and and heam part is synthesisd by *Rhizobium*.
(3) globin part is synthesised by *Frankia* and and heam part is synthesisd by plant.
(4) globin part is synthesised by plant and and heam part is synthesisd by *Frankia*.

3. Glutamic acid + A $\rightleftharpoons$ Aspartic acid + B
Choose correct identification for A and B :-
(1) A = NH_4^+, B = H_2O
(2) A = NADPH, B = NH_4^+
(3) A = Pyruvate, B = Alanine
(4) A = OAA, B = α-KGA

4. Which of the following bacteria convertes organic nitrogen into NH_3 ?
(1) *Bacillus*
(2) *Nitrobacter*
(3) *Rhizobium*
(4) *Frankia*

5. Which of the following is assimilitory nitrate reduction?
(1) $NO_3^- \rightarrow N_2$
(2) $NO_2^- \rightarrow N_2$
(3) $NO_3^- \rightarrow HNO_3$
(4) $NO_3^- \rightarrow NH_3$

BEGINNER'S BOX — ANSWER KEY

INTRODUCTION, METHODS TO STUDY THE MINERAL REQUIREMENTS OF PLANTS, ESSENTIAL MINERAL ELEMENTS, MECHANISM OF ABSORPTION OF ELEMENTS, TRANSLOCATION OF MINERAL IONS/ SOLUTES, SOIL AS RESERVOIR OF ESSENTIAL ELEMENTS

Que.	1	2	3	4	5
Ans.	1	4	4	4	3

METABOLISM OF NITROGEN

Que.	1	2	3	4	5
Ans.	3	2	4	1	4

ESSENCE

- **Hydroponics** is the technique of growing plants in a nutrient solution. This concept, for the first time demonstrated by German Botanist Julius Von Sach.
- By **hydroponics method, essential elements were identified** and their **deficiency symptoms can be discovered.**
- Hydroponics has been successfully employed for commercial production of **tomato, seedless cucumber** and **lettuce.**

ELEMENTS IN PLANTS

- **Beneficial elements**
  Na, Si, Co, Se
- **Essential elements**
  - **Macro-nutrients**
    Required in excess of 10 m mole kg^{-1} of dry matter.
    C, H, O, N, P, K, S, Ca & Mg.
    (C, H, O ⇧ Non minerals)
  - **Micro-nutrients**
    Required in amount less than 10 m mole kg^{-1} of dry matter.
    Fe, Cu, Zn, Mn, Mo, Cl, B & Ni.

Nitrogen – Absorbed in the form of NO_3^- (Nitrate), NO_2^- (Nitrite) and NH_4^+ (Ammonium) (Mainly NO_3^-).

Phosphorus – Absorbed in the form of $H_2PO_4^-$ or HPO_4^{-2}. Phosphorus is a constituent of **certain proteins** and all **nucleic acids.**

Potassium – Required in **more abundant quantities in meristematic tissues.** Helps in **opening and closing of stomata** and **maintenance of the turgidity of cells.**

Calcium – In the middle lamella as calcium pectate and **formation of mitotic spindle.** Involved in the normal functioning of the cell membranes.

Magnesium– Constituent of chlorophyll structure and **maintain the ribosome structure.**

Sulphur – Present in amino acids – cysteine and methionine. Constituent of thiamine, biotin, Coenzyme A and **Ferredoxin.**

Iron – Absorption in the form of Fe^{+++}. **Part of ferredoxin and cytochromes ($Fe^{++} \rightleftharpoons Fe^{+++}$). Not the constituent of chlorophyll but essential for the formation of chlorophyll.**

Manganese – Involved in **splitting of water (photolysis)** in photosynthesis.

Zinc – Needed in the **synthesis of auxin.**

Copper – Like iron, involved in redox reaction ($Cu^{+} \rightleftharpoons Cu^{++}$) as a part of plastocyanin (PC), **cytochrome a and a_3.**

Boron – Absorbed as BO_3^{-3} or $B_4O_7^{-2}$. Required for **pollen germination** and **carbohydrate translocation.**

Molybdenum – Absorbed in the form of MoO_2^{+2} (molybdate ion). Participate in **nitrogen metabolism** as the part of enzymes. (Nitrogenase and Nitrate reductase.)

Chlorine – Involved in **water splitting** in photosynthesis (water splitting involved - Mn, Cl and Ca but main role is of Mn).

- Essential **Mineral element** required by plants in the **greatest amount – Nitrogen.**
- Among **micronutrients, Iron is required in greatest amount.**
- **Actively mobile elements –** N, K, Mg (Deficiency symptoms first in senescent leaves).
- **Immobile Elements –** Ca, S (Deficiency symptoms first in young tissues)

DEFICIENCY SYMPTOMS

Chlorosis
(loss of chlorophyll leading to yellowing in leaves)
N, K, Mg, S, Fe, Mn, Zn, Mo.

Necrosis
Death of tissues particularly leaf tissues
Ca, Mg, Cu, K.

Inhibition of cell division
N, K, S, Mo.

Delay in flowering
N, S, Mo.

ABSORPTION OF MINERAL IONS

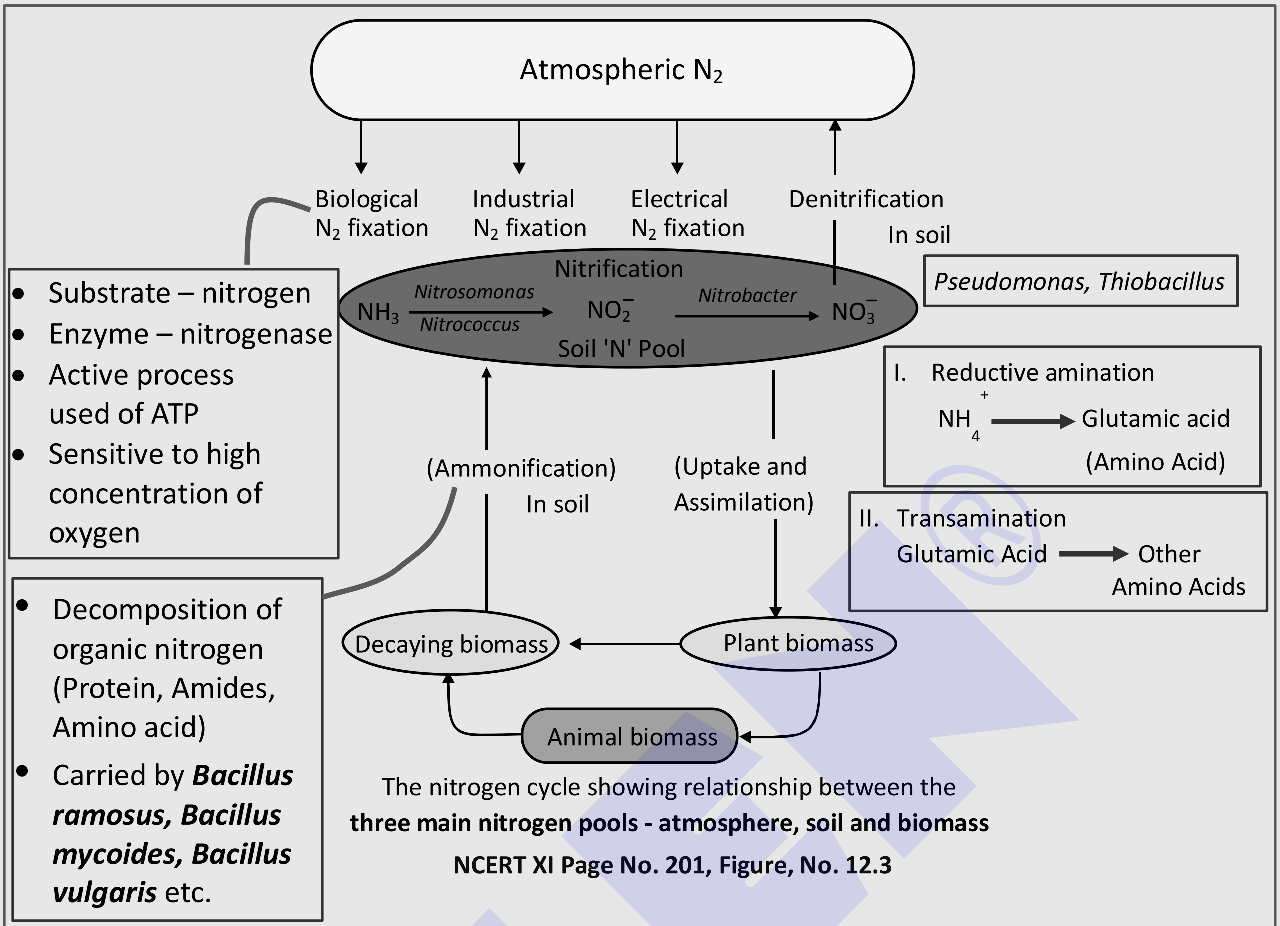
First Phase (Passive & rapid)
Soil ⟶ Apoplast / Outer space of root cells
(Cell wall & Intercellular spaces)

Second phase
[Active(Mainly) or Passive & Slow]
Apoplast ⟶ Symplast
(from outer space of cell to cytoplasm)

Crossing the cell membrane can be

Passive
(According to concentration gradient)
By **ion-channels**

Active (Mainly)
(Against the concentration gradient)
By **Pump Protiens**



The nitrogen cycle showing relationship between the
three main nitrogen pools - atmosphere, soil and biomass

NCERT XI Page No. 201, Figure, No. 12.3

Free Living N_2 Fixers

- Aerobic bacteria - *Azotobacter* and *Beijerinckia*
- Anaerobic bacteria - *Rhodospirillum*
- Cyanobacteria - *Anabaena* and *Nostoc*

Symbiotic N_2 Fixers

- *Rhizobium (in* alfalfa, sweet clover, sweet pea, lentils, garden pea, broad bean, clover beans, etc.)
- *Frankia* (*Alnus, Casurina*)