

Mineral Nutrition Class 11 Notes Biology

Chapter 12

Topic 1 Minerals and Their Importance

Living organisms require a number of macromolecules, such as carbohydrates, proteins, fats, water and minerals in order to grow and develop.

Thus, the inorganic substances or minerals that provide nourishment to the living organisms or work as a raw material for body building and maintaining its normal functions are termed as mineral nutrients and the mode of taking all required nutrients is called mineral nutrition. Nutrients are basically divided into two main types

(i) Organic nutrients

(ii) Inorganic nutrients The product of photosynthesis (various sugars) are considered as organic nutrients, while, those absorbed by the roots via various methods are known as inorganic nutrients.

In this chapter we will concentrate mainly on inorganic nutrients.

Methods to Study the Mineral Requirements of Plants

Mineral requirements of plants was determined by the culture experiment, developed by a prominent German botanist Julius Von Sachs (1860) for the first time.

Hydroponics or Soilless Culture

This technique was demonstrated from Julius Von Sach's experiments that plants could be grown to their maturity in a well defined nutrient solution even in the absence of soil. This technique of growing plant in a nutrient solution without soil is well known and is also known as water culture.

The methods involved in hydroponics require a very careful purification of water and nutrient salts. This is essential in order to assess the role of a particular mineral.

Hydroponic Setup

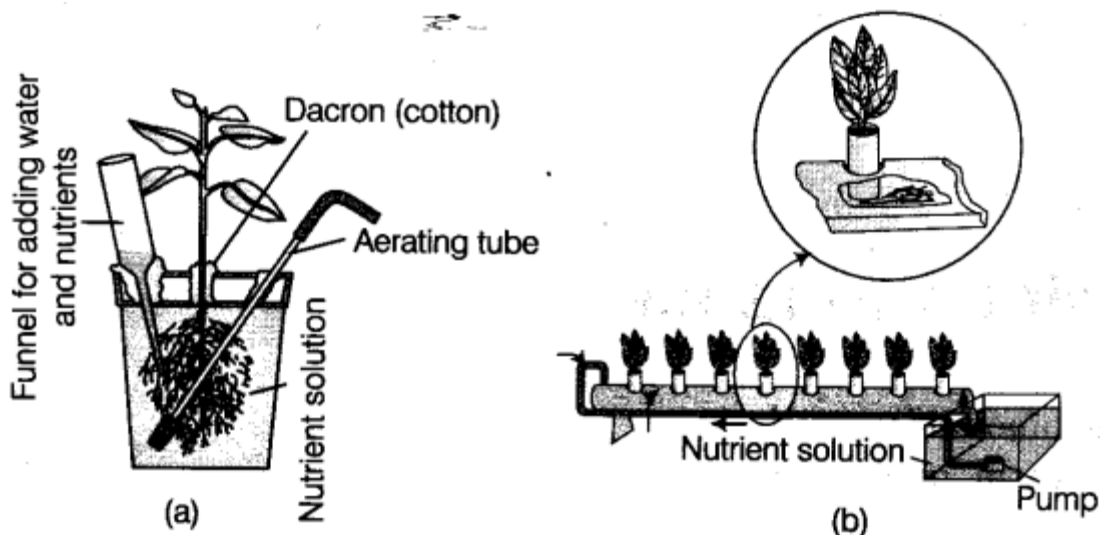
(a) In hydroponic plant production, plants are grown in a tube or trough that are placed in slightly inclined position.

(b) A pump is used to circulate the nutrient solution from the reservoir to the elevated (upper) end of the tube.

(c) Funnel is used for adding solution (water and nutrients).

(d) Bent tube is used for aeration.

The nutrient solution flows down due to gravity and returns to the reservoir of the hydroponic setup. In this way, roots are bathed in aerated nutrient solution continuously.



**Fig. 12.1 (a) A typical set-up for nutrient solution culture
(b) Hydroponic plant production (set-up)**

On conducting a series of experiments, in which roots of the plants were immersed in nutrient solution by eliminating or adding an element in varied concentration. From this, mineral nutrition suitable for the growth of the plant was obtained. Result Hydroponic revealed the identification of essential elements for plant growth and also helps in discovering their deficiency symptoms.

Conditions Necessary in Hydroponics to Achieve Optimum Growth

- The concentration of mineral nutrients must be constantly maintained.
- The solution must be aerated adequately for proper growth and activities of roots.
- pH of the solution is checked from time to time and corrections are made if necessary.

Uses of Hydroponics

- This technique has been successfully employed for commercial production of vegetables (like tomato, seedless cucumber, lettuce, etc) and also in knowing the toxicity of plant (if element is present in high amount).
- Useful in determining the essential role of nutrients or mineral elements for the metabolism of plant.

Essential Mineral Nutrients (Elements)

Essential elements are those which have structural or physiological role and without which plants are unable to complete their life cycle.

Plants can absorb most of the minerals present in the soil. More than sixty minerals present in soil have been recorded essential in plants out of 105 discovered so far. Apart from all these elements some plants accumulate other elements also, that are heavy and toxic in nature such as silicon, cobalt, selenium and gold. Some other plants growing near nuclear test sites also accumulate radioactive elements like strontium.

However, techniques had developed in order to detect the mineral even at very low concentration,

i. e., 10 g/mL. Thus, all the elements found in plants are not essential for plant growth and development.

Criteria for Essentiality

In order to determine whether the particular element is essential or non-essential, the element must follow the criteria for essentiality given below

- The element must be able to support normal growth and reproduction, i.e., in the

absence of a particular element, the plant becomes unable to complete its normal life cycle.

(ii) Requirement of the particular element in appropriate amount must be specific and it should not be replaced by any other element, i.e., if the deficiency of one element occurs, it should not be fulfilled by the addition of some other element.

(iii) The element must be involved directly in the functioning and metabolism of the plant.

Classification of Essential Mineral Elements

Essential elements occur in different proportions in plants. On the basis of the above mentioned criteria of essentiality some elements have been found to be absolutely essential for the normal and better growth, metabolism and development of plants. These elements have been grouped into following two categories based on quantitative requirements

i. Macronutrients

These are the elements generally found in plant tissues in large amounts (in excess of around 10 m mole kg⁻¹ or 10 mg per gram of dry matter) and also called major elements. These elements are generally involved in the synthesis of organic molecules and development of osmotic potential.

These are carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium, calcium and magnesium. Out of all these elements, carbon, hydrogen and oxygen are obtained from CO₂ and H₂O while, the others are obtained from the soil.

ii. Micronutrients

These are the elements generally found in traces (very small amount only, i.e., less than 10 m mol kg⁻¹ or less than 0.1 mg per gram of dry matter). Micronutrients are generally eight in number and include iron, manganese, copper, molybdenum, zinc, boron, chlorine and nickel. These are mostly involved in the functioning of enzymes as co-factors or activators of metals.

Differences between Macronutrients and Micronutrients

Macronutrients	Micronutrients
Their quantities can be easily detected in plants as they occur in large amounts.	They occur in very small amounts in plants.
These are needed for growth, metabolism and other body functions.	These nutrients help in detoxifying the body and warding off harmful diseases.
Their required concentration is at least 1 mg/g of dry matter.	Their required concentration is equal to or less than 0.1 mg/g of dry matter.
These have significant role in development of osmotic potential.	These do not have any role in osmotic potential.
Their higher concentration do not cause toxicity.	They cause toxicity even with slight increase from their maximal range.
Compounds of macronutrients contain calories.	Compounds of micronutrients do not contain calories.
e.g., Proteins, carbohydrates and fats.	e.g., Vitamins and minerals.

Based on the diverse functions of essential elements, these are also categorised into four other categories given below

- (i) As the constituents of biomolecules These are the essential components of biomolecules. Hence, known as the structural elements of cells, e.g., carbon, hydrogen, oxygen and nitrogen.
- (ii) As the energy related chemical compounds Some elements also function in providing energy to the cell, e.g., Phosphorus is a component of ATP which functions as an energy currency of all the living systems, while magnesium is a component of chlorophyll, which is involved in the conversion of light energy into chemical energy.
- (iii) As the part of enzymes showing catalytic effects Many of the essential elements are required in the form of cofactors by enzymes. They function as the activator or inhibitor of enzymes, e.g., Mg^{2+} acts as an activator of several enzymes in both photosynthesis (e.g., Ribulose biphosphate (RuBP) carboxylase, phosphoenol pyruvate (PEP) carboxylase) and respiration (e.g., hexokinase and phosphofuctokinase).
While Zn^{2+} acts as an activator of alcohol dehydrogenase and Mo of nitrogenase during the course of fixation of nitrogen.
- (iv) As the elements altering osmotic potential Some of the essential elements also alter the osmotic potential. Most of the osmotic potential of cell is due to the inorganic salts.

Osmotic potential is necessary for absorption of water and maintaining turgidity of cell.

Role of Macro and Micronutrients

The essential elements perform several important rot, most important of them are given below

1. Regulation of permeability of cell membrane.

2. Maintenance of osmotic potential of cell sap.
3. Some of them takes part in an electron transport system.
4. Others function in buffering action, enzymatic activity and also function as a major constituent of macromolecules and co-enzymes.

Macronutrients

Various macronutrients with their sources, regions and numerous junctions are given below

i. Nitrogen (N)

It is a major constituent of amino acids, proteins, nucleic acids, hormones, vitamins, etc. It was the first macronutrient to be discovered and is required in very large amount by plants.

Nitrogen is not utilised by plants directly as such. It is mainly absorbed in the form of nitrates (NO_3^-), while others absorb, it in the form of nitrites (NO_2^-) or as ammonium ion (NH_4^+)

Region It is usually required by all parts of plants, mainly the meristematic tissues, and by all the cells, which are metabolically active in nature

Functions Its main function is in growth, metabolic activities and also serves as enzymes in photosynthesis, etc.

Carbon, Hydrogen and Oxygen

These are although not considered as mineral elements still, they have an essential role in growth of plants. Together they constitute about 94% of the total dry weight of the plant. All of these are also important part of carbohydrates, fats and proteins.

C, H, O and N are all together called structural elements because they are the components of biomolecules of the cell.

ii. Phosphorus (P)

Most soils are phosphorus deficient. It is present in plants as both organic and inorganic forms. Organic form of phosphorus is not absorbed by plant as such, instead, it is either taken from the solid or the solution phase of soil. It is a constituent of certain proteins, all nucleic acid and cell membranes.

The decomposition organic form results into an inorganic form of phosphorus, which is then utilised by the plants.

It is generally absorbed by roots from soil in the form of phosphate ions (either as H_2PO_4^- or HPO_4^{2-}).

Regioii It is required in all meristems or young tissues and in the regions of developing fruits and seeds.

It generally gets withdrawn from the older tissues which becomes metabolically less active.

Functions It is mainly involved in phosphorylation reactions and also has its importance in energy transfer reactions.

Phosphorus is also present in high energy biomolecules such as adenosine triphosphate (ATP) and guanosine triphosphate (GTP). It also has its major role in ripening of grains and fruits.

iii. Potassium (K)

It does not acts as a constituent of any organic substance, so potassium (K^+) is available to plants in its inorganic form such as potassium sulphate, potassium nitrate, etc. It is one of the major constituents of protoplasm.

Region It is found in all tissues of plants that has the property of differentiating themselves like meristematic tissues, bud, leaves and root tips.

Its amount is equal in whole plant except in seeds where it is found in lesser quantity.

Functions It helps in maintaining anion-cation balance in cells and is also involved in the synthesis of proteins. It has its major role in opening and closing of stomata, in activation of enzymes and also helps in maintaining the turgidity of cells.

iv. Calcium (Ca)

It is an element which is always found in green plants and is absorbed by them in the form of calcium ions (Ca^{2+}) from the soil.

Region It is needed much in differentiating and meristematic tissues. It gets accumulated mostly in the older leaves.

Functions It functions in the synthesis of pectin (calcium pectate) found in middle lamella of the cell wall during cell division. It is also involved in the organisation of mitotic spindle. It activates certain enzymes and plays an important role in the regulation of cellular activities.

v. Magnesium (Mg)

It is the major component of ring structure of chlorophyll, without which the formation of chlorophyll does not take place. It is absorbed by the plants in the form of a divalent magnesium ion (Mg^{2+}) from the soil.

During rainy season magnesium is leached out from the soil due to which its amount becomes deficient in plants.

Region It is required in growing areas of roots, stems, seeds.

Functions It helps in the activation of enzymes of photosynthesis and respiration, in the formation of chlorophylls, carotenoids and nucleic acids (DNA and RNA) and to maintain the structure of ribosome.

vi. Sulphur (S)

It is found usually in the complex proteins of plants.

The most abundant reservoir of sulphur in soil is in the organic form, such as lipids, amino acids, proteins, etc.

It is absorbed by the plants in the form of sulphate ions (SO_4^{2-}) from mineral fraction of soil.

Region It is required mostly in young leaves and meristems.

Functions It acts as a major constituent in amino acids like cysteine and methionine and also of several co-enzymes, vitamin (like thiamin, biotin, coenzyme-A (Co-A) and ferredoxin).

It is due to the presence of sulphur constituent in Liliaceae family plants like onion, garlic, etc., that they have a characteristic odour.

Micronutrients

Various micronutrients with their sources, regions and numerous functions are given below

i. Iron (Fe)

It is required in huge amount by plants in comparison to other micronutrients. It occurs in the soil mainly in the form of hydroxides and oxides and is absorbed in the form of ferric ions (Fe^{3+}).

Region It is required by every part of plant but is found abundantly along veins of the leaves.

* Excess amount of iron is stored as ferritin in plants.

Functions It is involved in the transfer of electrons like ferredoxin and cytochromes. Also plays an important role in reactions involving conversion of energy in both photosynthesis and respiration.

i. e., $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$ helps in the development of chloroplasts, chlorophyll and other pigments.

a. Manganese (Mn)

The oxides of manganese are common in soil. However, its highly oxidised form is not available to plants.

It is absorbed by the plants in the form of manganous ions (Mn^{2+}).

Region It is required in leaves and seeds of plant.

Functions It is helpful in activating many enzymes that are involved in photosynthesis, respiration and nitrogen metabolism. It also functions majorly in photolysis of water in order to liberate oxygen during the process of photosynthesis.

iii. Zinc (Zn)

Zinc is absorbed in the form of Zn^{2+} ions. Zinc occurs in ferromagnesium minerals.

These minerals are weathered in order to liberate bivalent form of Zn^{2+} .

It is considered to be more soluble in soil than other heavy metals.

Region Zinc is required in every part of the plant. Functions It helps in activation of various enzymes like carboxylases, oxidases, dehydrogenases, kinases, etc., and also in the formation of chlorophyll pigment. It is also needed in the synthesis of auxin.

iv. Copper (Cu)

It is found in very low amount in soils. It is absorbed as cupric ions (Cu^{2+}). It acts as a component or activator of plastocyanin, cytochrome oxidase and many other enzymes.

Region It is also required in every part of plants like zinc.

Functions Like iron, it is also involved with enzymes that are required in redox reactions.

It can also oxidise in the reversible direction, i.e., from Cu to Cu_2 :

v. Boron (B)

It is one of the most essential element for the growth of nearly all plants, e.g., Tomato, lemon, mustard, cotton, etc.

It is absorbed by the plants in the form of BO_3^{3-} or $B_4O_7^{2-}$ ions from the soil.

Region It is required mostly by leaves and seeds.

Functions It is essential in transportation of carbohydrate through phloem tissues.

Boron is needed for uptake and utilisation of calcium, in the germination of pollen and root nodulation elongation of cell differentiation and carbohydrate translocation.

If pH increases, availability of boron to plant gets decreases.

vi. Molybdenum (Mo)

The amount of this element in soil vary widely. Plants obtain it in the form of molybdate ions (MoO_4^{2-}).

Region It is required everywhere in plants but mostly utilised by roots.

Functions It is an essential component of several enzymes including two enzymes involved in metabolism of nitrogen, i.e., nitrogenase and nitrate reductase. It also has role in reduction of nitrate to nitrite during the synthesis of amino acids.

vii. Chlorine (Cl)

It is abundant in nature. It is absorbed by the plants in the form of chloride ions (Cl^-).

Region It is also required everywhere like zinc and copper. Functions It helps in transfer of electrons from H_2O to photosystem-II in photosynthesis (water splitting reaction in order to evolve O_2). It is also helpful in determining the concentration of solute with Na^+ and K^+ . It seems to be essential in balancing cationic and anionic ratio in cells.

Nickel (A micronutrient)

It is also added as a micronutrient recently. It is found to be very mobile in plants and is absorbed by the plant in the form of Ni^{2+} ions.

Region It is required in whole plant.

Function It acts as an essential part of enzyme urease which hydrolyse urea—>
 $\text{CO}_2 + \text{NH}_4$.

Deficiency symptoms Plant produces non-viable seeds upto 3rd generation due to its absence and may also leads to necrotic spots on leaf tips.

Deficiency Symptoms of Essential Elements

The deficiency symptoms vary from element to element and they tend to disappear when the particular deficient mineral nutrient is provided to the plant.

Whenever the supply of an essential element becomes limited, growth of the plant gets retarded.

However, if the deprivation of the same nutrient continue for a long period of time, it may eventually leads to the death of the plant.

(i) Critical Concentration is limited concentration of the essential element below which the growth of plant get reduced, retarded or stops.

Each essential element plays a vital role in structural and functional composition of plant. Thus, in the absence of any particular element, plants shows various morphological changes, which are indicative of certain element deficiencies and are called deficiency symptoms.

The plant parts show symptoms of deficiency depending on the mobility of that element in the plant.

Accordingly, these can also be divided as

(i) Mobile elements When the elements are actively mobile within the plants, the symptoms tend to appear first in older leaves and tissues. It is because the elements get mobilised from senescing regions to young tissues.

For example, deficiency symptoms of N, K and Mg are visible in the senescent leaves first because these elements are actively mobile.

In the older leaves, biomolecules containing these elements are broken down, making these elements available for mobilising to younger leaves.

(ii) Immobile elements When the elements are immobile within the plants, the symptoms appear first in young leaves and tissues, because the elements are not transported out of the mature organs.

For example, Elements like sulphur and calcium are not released out easily from the plant as they act as an important part of the structural component of the cell.

This aspect (mobility of elements) of mineral nutrition in plants play a very vital role in agriculture and horticulture.

Some Major Deficiencies in Plants

Various kinds of deficiency symptoms shown by the plants are given below

(i) Necrosis It is the phenomenon, which leads to the death of tissues, cell or organ mainly leaf tissue, while it is still a part of the living plant.

It is caused due to the deficiency of elements like Ca, Mg, Cu, K, etc.

(ii) Chlorosis It is the loss of chlorophyll which leads to the yellowing of leaves. This symptom is caused by the deficiency of elements like N, K, Mg, S, Fe, Mn, Zn and Mo in plants.

(iii) Inhibition of cell division It occurs due to the lack or low levels of elements like N, S, Mo, K, etc.

(iv) Delay flowering Deficiency of elements, like N, S, Mo leads to delay in flowering of plants.

(v) Stunted plant growth If the low availability of element occurs, it may leads to inhibition of growth in plant and may eventually lead to the dwarfing (shortening) of whole plant, e.g.y N, K, Ca, S, Zn, B, Mo and Cl.

(vi) Premature fall of leaves and buds It is another type of deficiency symptom that

occurs due to the lack of different minerals like P, Mg, Cu, etc.

Differences between Necrosis and Chlorosis

Necrosis	Chlorosis
The death of a cell or group of cells, while it is still a part of the living plant is known as necrosis.	The yellowing of leaves due to reduction of chlorophyll content is known as chlorosis.
It is caused due to the deficiency of copper, calcium and chlorine.	It is caused by the deficiency of magnesium, sulphur, iron, manganese and nitrogen.
It results in appearance of brown spots.	It results in appearance of yellow spots.
Brown colour spot does not give mosaic pattern.	Yellow appearance of spots give mosaic pattern.

Toxicity of Micronutrients

A moderate decrease of micronutrients cause deficiency symptoms, while a moderate increase leads to toxicity. Thus, whenever the concentration of mineral ion in tissues reduces the dry weight by about 10%, it is considered to be toxic.

The level of toxicity varies for different micronutrients from plant to plant. When the toxicity of element increases to certain level it may also inhibit the uptake of another element. e.g., the prominent symptom of manganese toxicity is the appearance of brown spots surrounded by chlorotic veins.

It is important to know that manganese competes with iron and magnesium for uptake and with magnesium for binding with enzymes. Manganese also plays role to inhibit the calcium translocation in shoot apex.

Therefore, presence of manganese in excess amount may, induce deficiencies of iron, magnesium and calcium.

Topic 2 Mechanism of Absorption and Nitrogen Metabolism

Mineral Absorption

Absorption of mineral salts by plants from the soil occurs through the roots mainly from the root hairs and the zones of absorption. Hence, plants absorb the minerals from the soil for their translocation to other parts of the body through stream of xylem.

Minerals are not absorbed as such by the plants instead they are absorbed in their ionic forms.

For example, chlorine is not absorbed as such by the plant instead it gets accumulated in the form of chloride ions.

Mineral absorption by plants is done by two different phases

(i) Initial Phase (Passive transport) It is the pathway by which water or ions present in the free space or outer space of cells are up taken by roots of plants by taking apoplast pathway (avoid entry into cellular membranes and cytoplasm).

In this phase, the plant absorbs mineral very rapidly and does not need any metabolic energy in the form of ATP. Thus, it is called passive process. The passive movement of ions occur through ion-channels and the transmembrane proteins that functions as selective pores into apoplast.

(ii) Metabolic Phase (Active transport) It is the pathway which is dependent on

metabolic energy in the form of ATP for the uptake of mineral ions by the roots into the inner spaces i.e., symplast of the cell. Hence, is called active process. The movement of ions from cell-to-cell is called flux. It can be further divided into two main types

- (i) Influx (inward movement of ions into the cells)
- (ii) Efflux (outward movement of ions out of the cells)

Differences between Active and Passive Absorption

Active Absorption	Passive Absorption
It involves expenditure of energy.	It does not involve expenditure of energy.
The movement of molecules or ions takes place against a concentration gradient.	The movement of molecules takes place along the concentration gradient.
The movement is usually unidirectional.	The movement is reversible.
It results in the accumulation of ions.	It results in an equilibrium of the molecules on both sides of a membrane.

Translocation of Solutes

After absorption the mineral salts pass readily inward with the transport of water. The translocation of mineral elements to different parts of the body is done through tracheary elements of the xylem to reach upwardly to the leaves and other parts (ascent of sap). It is done through the plants by the transpirational pull.

Note:

- * The upward movement of water through stem is called ascent of sap. It occurs mainly through xylem.
- * Minerals pass through xylem (not phloem) is proved by Stout and Hoaglan in 1939.

Soil as Reservoir of Essential Elements

Soil itself acts as a mineral nutrient reservoir in natural conditions, but it is not essential for the growth of plant. The majority of nutrients studied as far are essential for the growth and development of plants. These elements become available to the roots of plants by the weathering and breakdown of rocks.

Due to which the soil become enriched with ions and inorganic salts which are ultimately taken up by the plants itself.

Functions of Soil

Following functions are being performed by the soil

- (i) Soil supplies minerals to plant and also harbours nitrogen fixing bacteria and other microbes.
- (ii) It contains wide variety of substances essential for plant.
- (iii) It holds water and supplies air to the roots.
- (iv) It also acts as a matrix that helps in stabilisation of plant.

Fertilisers, are the organic or inorganic materials that are added to soil to supply one or more nutrients which are essential to the growth of plants. Since, deficiency of essential mineral affects yields of crop thus, both macro (N, P, K, S, etc) and micronutrients (Cu, Fe, Zn, Ni, M, B, -etc) acts as component of fertiliser and applied as per requirement.

Metabolism of Nitrogen

Nitrogen exists as two nitrogen atoms joined by a very strong triple covalent bond (=) Nitrogen is needed by plants for the production of proteins, nucleic acids (DNA and RNA), chlorophyll and many other vitamins. It is also the most prevalent element apart from carbon, hydrogen and oxygen.

It is absorbed as an inorganic compound which is changed into its organic form by plants and certain microbes.

The ultimate source of nitrogen is the nitrogen gas present in the atmosphere. As nitrogen is limited in nature, plants compete with microbes for available nitrogen in the soil. Thus, nitrogen acts as a limiting nutrient for both natural and agricultural ecosystems.

Nitrogen Cycle

It is the process of cycle of events by which free atmospheric nitrogen is converted into its various chemical forms.

The nitrogen cycle consists of four important processes, i.e., nitrogen-fixation, ammonification, nitrification and denitrification.

1. Nitrogen-Fixation

In this process, atmospheric nitrogen is fixed which is to be used by the plants. In this step, the molecular nitrogen .

2. converted into inorganic nitrogenous compounds like nitrate, nitrite and ammonia.

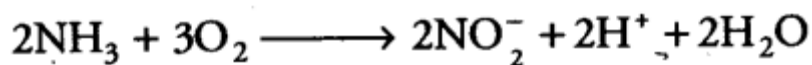
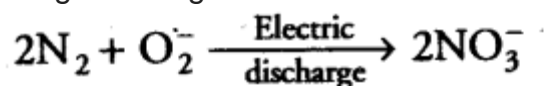
Nitrogen fixation is of two types

- (i) Physical nitrogen-fixation
- (ii) Biological nitrogen-fixation

i. Physical Nitrogen-Fixation

It is the conversion of N₂ to inorganic nitrogenous compounds without the involvement of microorganisms.

Fixation occurs in nature by lightening and ultra violet radiations by which nitrogen gets converted into its oxides (as NO, NO₂, N₂O etc) on combining with O₂. These oxides also gets generated by forest fires, industrial combustions and by some power generating stations.



ii. Biological Nitrogen-Fixation

The conversion of atmospheric nitrogen into inorganic nitrogenous compounds (nitrate, nitrite and ammonia) through microorganisms (bacteria, cyanobacteria, etc) are called biological nitrogen-fixation.

As only few organisms utilise atmospheric nitrogen, certain prokaryotes are capable of fixing nitrogen. The prokaryotic organism that reduce nitrogen has an enzyme called nitrogenase such microbes are called 2 fixers.

NEN Nitrogenas

The organisms that fix nitrogen can be of two types

(a) **Asymbiotic or Free living bacteria** These are bacteria that are not present in close relationship with another bacteria or other organisms in order to convert nitrogen into ammonia, e.g., number of cyanobacteria like Anabeana and Nostoc.

The free living bacteria can also further divided as

* Free living aerobic These include microbes like Azotobacter and Beijerinckia.

* Free living anaerobic These include microbes like Rhodospirillum and Clostridium.

(b) Symbiotic bacteria These are bacteria that fix nitrogen by forming close associations with each other or with another organism, e.g., relationship between Rhizobium bacteria with legumes and mycorrhizae with vascular plants, etc.

Frankia and Rhizobium, both are unable to fix nitrogen when present as free living (aerobes) in soil. But when present as symbionts they become anaerobes and are able to fix atmospheric nitrogen.

Symbiotic Biological Nitrogen-Fixation

The process of symbiosis involves two organisms living together in different associations. Several types of biological nitrogen fixing associations are known. The most familiar one is the relationship of Rhizobium with the roots of several legumes belonging to class-Leguminosae like sweet pea, lentils, garden pea, alfalfa, sweet clover, broad bean, clover beans, etc.

They get associated mostly on the root hair cells, the root hair curls and the bacteria invade it. An infection thread is produced carrying the bacteria into the cortex where they initiate root nodule formation. Root nodules are small, irregular outgrowths on the roots.

They are internally pinkish in colour due to the presence of leguminous haemoglobin or leghaemoglobin (similar to the haemoglobin, the red pigment present in human blood).

Symbiotic nitrogen fixing bacteria are also known to occur in the roots of certain non-leguminous plants (both angiosperms and gymnosperms) i.e., Alnus and Cycas respectively.

Insectivorous Plants

The carnivorous angiosperms (insectivorous plants) are autotrophic in nature. But, the strange thing about these plants is they behave as heterotrophic organisms for supplementing their nitrogen requirements by trapping insects and other small animals enzymatically and digesting them.

They usually grow in water logged soil or swamps where the soil is deficient in nitrogen supply. Thus, these plants fulfil their need from insects and small animals by trapping them through the leaves, e.g., Pitcher plant (Nepenthes), Venus fly trap, sundew, water flewtrap etc.

Nodule Formation

The process of formation of nodules is a series of multiple interactions that takes place between Rhizobium bacterium and the root system of legume plant (host). During the process, bacteria initially grow in soil near the roots of higher plants. They are unable to fix nitrogen there, but after coming in contact with the roots of leguminous plants, they interact chemically and enter into roots through root hairs.

The process of nodule formation is as follows

(i) Rhizobium multiply and colonize itself to the surrounding of the roots of host plant where it gets physically attached to the epidermal root hair cells.

(ii) After attachment, the root hair gets curled up at the tip due to which bacteria invade the root hair.

(iii) The enzymes from the bacteria degrade the parts of root hair cell wall which produces a thread-like structure called infection thread.

(iv) The bacteria invade the infection thread and reach upto the inner cortex of the root.

(v) The bacteria after reaching cortex (mainly tetraploid cells) stimulate the initiation

of formation of nodule.

(vi) Bacteria enlarges in size and become bacteroid (rod-shaped) thus, leaving the infection thread and enter the cells, i.e., inner cortical and pericycle cells to divide.

(vii) This growth and division of pericycle and . cortical cells leads to the formation of a knob-like structure called mature root nodule.

(viii) The nodule, thus formed after division is finally responsible for the direct vascular connection with the host for the exchange of nutrients.

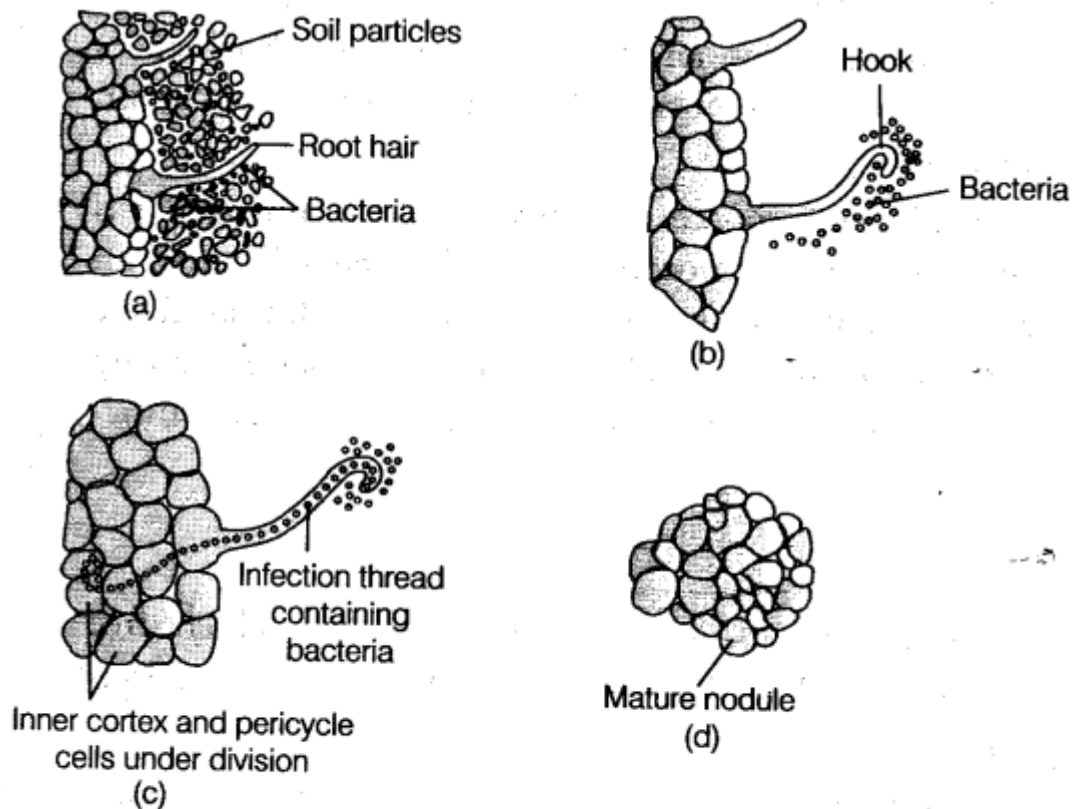


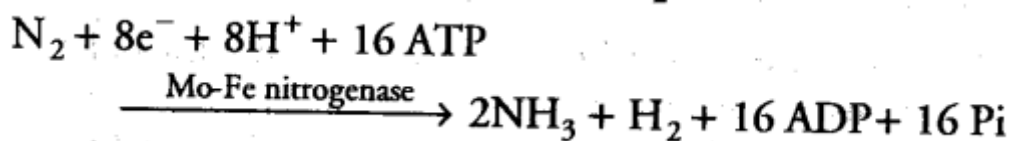
Fig. 12.2 Development of root nodules in soyabean
 (a) Chemical recognition (b) Curling of root hair
 (c) Formation of infection thread (d) Nodule formation

Mature Nodule

The mature nodule thus, formed after a series of events (as discussed above) and chemical changes contains all the essential biochemical components i.e., leghaemoglobin and the enzyme nitrogenase. The enzyme nitrogenase catalyses the conversion of free nitrogen into ammonium, (first stable product).

The enzyme nitrogenase has two subunits, i.e., Fe protein (non-heme iron protein) and Mo-Fe protein (iron molybde-num protein).

The Fe protein component reacts with ATP and reduces Mo-Fe protein which then reduces 2 to ammonia.



Nitrogenase enzyme, cannot function in aerobic conditions as it is highly sensitive to molecular oxygen (O₂). Thus, for its activity it requires anaerobic conditions. Hence, in order to protect this enzyme from oxygen, the nodules produce a substance known as leg-haemoglobin (oxygen scavenger). Nitrogenase is not active when

these microbes live in aerobic conditions, i.e., free-living but become active or functional in anaerobic conditions during events of nitrogen fixation.

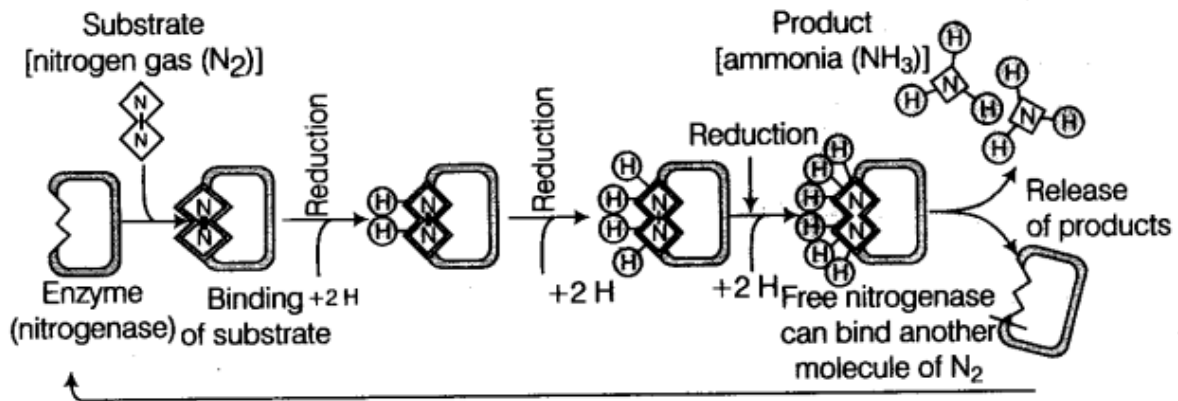


Fig. 12.3 Steps of conversion of atmospheric nitrogen to ammonia by nitrogenase enzyme complex found in nitrogen-fixing bacteria

Note:

- * Winogradsky (1891) discovered biological nitrogen fixation.
- * The reaction involving NH₃ synthesis by nitrogenase enzyme requires a very high input of energy (8 ATP for each NH₃ produced). The energy required, thus, is obtained from the respiration of the host cells.

2. Ammonification

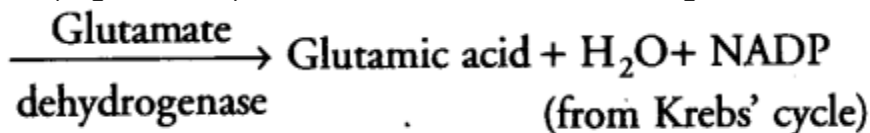
In next step, organic matter (proteins and nucleic acids) of the dead remains are decomposed in order to produce ammonia (NH₃) by microorganisms (like Actinomycetes, Clostridium etc.). Out of the ammonia product, some of the ammonia gets volatilised and re-enters into the atmosphere, while most of it undergoes the process of nitrification by soil bacteria.

Fate of Ammonia

Nitrogen assimilation results in the formation of ammonia which is further used for the synthesis of amino acid. Most of the plants can assimilate both nitrate and ammonium ions (NH₄) (the ammonium ions are formed by the protonation of ammonia at physiological pH). Ammonium ions are toxic to plants and cannot accumulate in them.

Thus, these 4 are used in the synthesis of amino acids in plants by following two methods

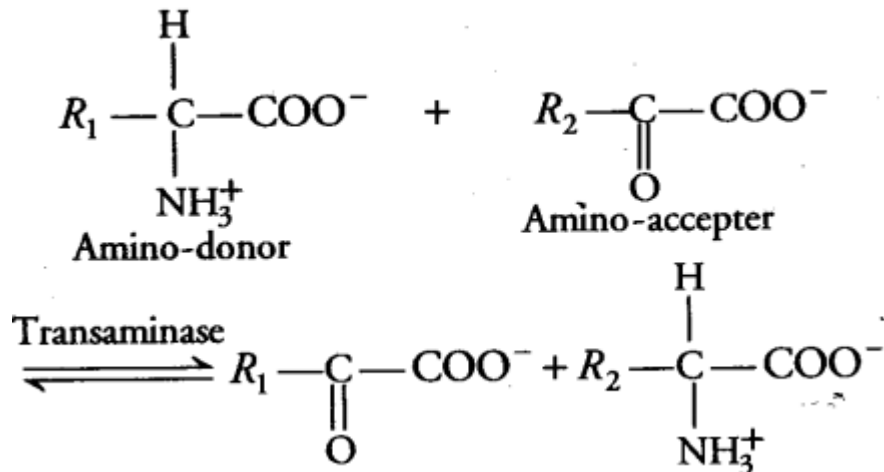
- (i) Reductive amination During this process, the ammonia reacts with a-ketoglutaric acid (organic acid) and forms an amino acid, i.e., glutamic acid.



- (ii) Transamination It is the transfer of amino group (—NH₂) of one amino acid to keto group (C = O) of another keto acid. The enzyme responsible for this is transaminase or aminotransferase.

Glutamic acid is the main amino acid involved in the synthesis of other amino acids through transamination.

Glutamic acid is mainly responsible for making the transfer of amino group to keto group possible.



Amides

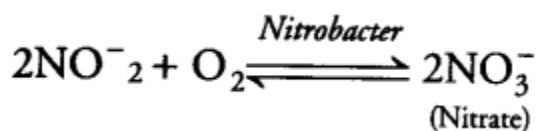
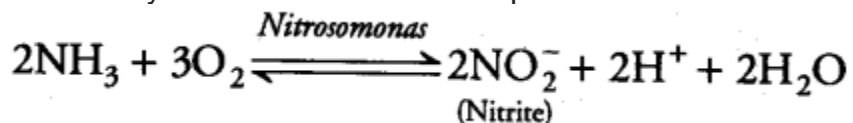
These are generally formed by the combination of amino acids and ammonia. Their formation takes place by replacement of hydroxyl ions of amino acid by NH_2 ion. The two most common amides formed in plants are asparagine and glutamine formed by the addition of another amino group to amino acids i. e., aspartic acid and glutamic acid respectively,

Uses of Amides

- (i) Both of the amides, i.e., asparagine and glutamine acts as metabolic reservoirs. They get accumulated in the tissue of healthy plants at the time of assimilation of ammonia (if assimilation occurs in excess amount).
- (ii) They are translocated to other parts of plant through xylem vessels in the form of nitrogen rich compounds because they contain more nitrogen than the amino acids. In some plants ureides acts as transporters of fixed nitrogen along with transpiration stream (e.g., soyabean). These also have high nitrogen to carbon ratio.

3. Nitrification

It is the process in which ammonia produced by the degradation of manures may not be available to plants. So, it is first oxidised to nitrite by the soil bacterium *Nitrosomonas* or *Nitrococcus*. This nitrite is then further oxidised to nitrate by another soil bacterium i.e., *Nitrobacter*. The bacteria which helps in the process of nitrification are collectively known as chemoautotrophs.



The nitrate thus, formed are absorbed by plants and then transported to the leaves where it gets reduced to ammonia that finally forms amino-group of amino acids.

4. Denitrification

It is the process in which the nitrate present in the soil is reduced back to free nitrogen (N_2). The process of denitrification is carried out by denitrifying bacteria (like *Thiobacillus denitrificans*, *Pseudomonas denitrificans* etc).

Denitrifying bacteria utilises nitrate and nitrite ions as electron acceptors in place of

oxygen.

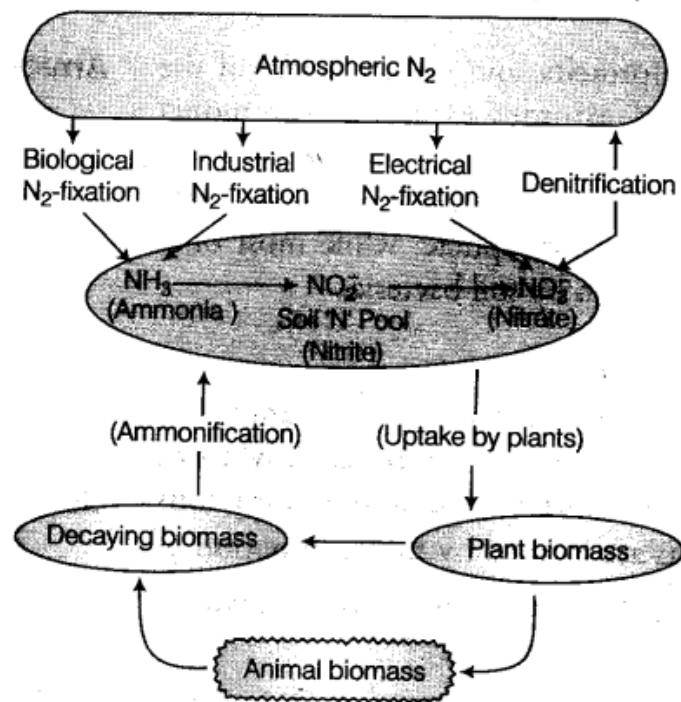


Fig. 12.4 The nitrogen cycle showing relationship between the three main nitrogen pools-atmospheric, soil and biomass