Mineral Nutrition

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2. MINERAL NUTRITION

2.1 Introduction

- A chemical substance that functions as raw material for synthesis of different structural and functional substances of living beings is called Nutrient.
- The basic needs of all living organisms are essentially the same.
- They require macromolecules, such as carbohydrates, proteins and fats, and water and minerals for their growth and development.
- Liebig for the first time discovered the presence of elements in plant ash.
- Liebig (1840) demonstrated the essentiality of mineral nutrition in plants and proposed Law of minimum which states that productivity of soil depends upon the proportionate amount of that essential elements which is deficient in that soil.
- The symptoms produced by deficiency of mineral substances are called 'hunger sign'.

2.2 Definition

"The inorganic materials obtained from soil that are used as raw materials by plants are called Mineral Nutrients. "

"Absorption, utilization and assimilation of inorganic substances or minerals by plants for synthesis of materials required in their growth, development, structure and physiology is called Mineral Nutrition."

2.3 Mineral Requirements of Plants

- A prominent German botanist Julius von Sachs in 1860 explained 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.
- After a series of experiments in which the roots of the plants were immersed in nutrient solutions and wherein an element was added / 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 emphasized that the nutrient solutions must be adequately aerated to obtain the optimum growth.

2.4 Essential mineral elements

- Essential elements are elements whose absence results in non completion of life cycle of plants because they have vital structural or physiological roles.
- Epstein in 1972 gave two criteria for determining essentiality of an element-
  - In the absence of Essential elements, the plants are unable to complete normal life cycle.
  - The element is component of some essential plant constituents or metabolite.
- Arnon and Stout in 1939 said-
  - The element participates in the nutrition of plants.
  - It is incorporated inside plants as structural component or metabolite.
  - It is required for plant growth.
  - Plants are unable to complete normal life cycle in the absence of the element due to disturbance in vegetative or reproductive phase.
  - No other element can replace it in structure and function.
  - Absence or reduced availability of the element causes disorders.

- The disorders caused by absence or deficiency of an element can be corrected only by the availability of that element.

2.4.1 Criteria for Essentiality

The criteria for essentiality of an element are given below-

- 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.
- 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.
- The element must be directly involved in the metabolism of the plant.
- About 80–90% of a plant is water. Because water contributes most of the hydrogen ions and some of the oxygen atoms that are incorporated into organic atoms, one can consider water a nutrient.
- However, only a small fraction of the water entering a plant contributes to organic molecules.
- More than 90% of the water absorbed by a field of corn is lost by transpiration.
- Most of the water retained by a plant functions as a solvent, provides most of the mass for cell elongation, and helps maintain the form of soft tissues by keeping cells turgid.
- By weight, the bulk of the organic material of a plant is derived not from water or soil minerals, but from the CO_2 assimilated from the atmosphere.
- The dry weight of an organism can be determined by drying it to remove all water. About 95% of the dry weight of a plant consists of organic molecules. The remaining 5% consists of inorganic molecules.
- Most of the organic material is carbohydrate, including cellulose in cell walls.
  - Carbon, hydrogen, and oxygen are the most abundant elements in the dry weight of a plant.
  - Because some organic molecules contain nitrogen, sulfur, and phosphorus, these elements are also relatively abundant in plants.
- More than 50 chemical elements have been identified among the inorganic substances present in plants.
- However, not all of these 50 are **essential elements,** required for the plant to complete its life cycle and reproduce.
  - Roots are able to absorb minerals somewhat selectively, enabling the plant to accumulate essential elements that may be present in low concentrations in the soil.
- However, the minerals in a plant also reflect the composition of the soil in which the plant is growing.
- Some elements are taken up by plant roots even though they do not have any function in the plant.

2.4.2 Roles of Mineral Elements in Plants

- A complete ash analysis of a plant may show at least traces of nearly half the elements in the periodic table, but all of them are not required by the plant for nutrition.
- After they have been absorbed, the elements are never present inside the plant in the free state.

- They are generally in ionic form or as constituents of organic compounds.
- When plant material is burnt in air, the organic matter is destroyed and a residue of inorganic salts, the ash remains.
- Following roles are ascribed to the mineral elements mainly-
  - **Constituents of Plant Body**
  - It is well known that elements like carbon, hydrogen and oxygen are most important plant nutrients required in the production of carbohydrates which enter into the composition of cell wall and protoplasm.
  - They are, therefore called framework elements.
  - Elements like sulphur, phosphorous and nitrogen are required in the formation of protein which is an important constituent of protoplasm.
  - These elements are therefore, known as protoplasmic elements.
  - Elements like calcium and magnesium are important constituents of the cell wall and chlorophyll respectively.
  - **Influence on the Osmotic Pressure of Plant Cells**
  - The cell sap contains mineral salts and organic compounds.
  - Both the constituents are responsible for the osmotic pressure of the cell.
  - **Influence on the pH**
  - The mineral elements absorbed from the soil affect the H ion concentration of the cell sap depending on the nature of the element.
  - **Influence on the Permeability of Cytoplasmic Membranes**
  - The permeability of cytoplasmic membranes is influenced by cations and anions of the medium with which they are in contact.
  - While some ions have decreasing effect on the permeability others have an increasing effect.
  - **Toxic effects of Mineral Elements**
  - Elements like arsenic, copper, mercury etc. are known to have toxic effect upon the protoplasm under certain conditions.
  - **Catalytic Functions**
  - Elements like iron, copper, zinc, manganese etc. act as catalyst in various enzymatic reactions going on in plants.
  - **Antagonistic or Balancing Function**
  - Elements or their salts are generally known to offset the normal effect of each other in the cell.
  - This is known as antagonism or balancing effects.

2.5 Macro Nutrients and Micro Nutrients in plants

- The elements are further divided into two broad categories based on their quantitative requirements.
  - Macronutrients, and
  - Micronutrients

2.5.1 Macronutrients

- Normally the macronutrients form an integral part of complex organic molecule.
- 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.
- Some of them assist in the functioning of enzyme systems.

2.5.2 Micronutrients

- 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.
- Micronutrients like copper and molybdenum act as electron carriers by virtue of valency changes.
- The other important method by which micronutrients act is by combining with the enzyme-substrate complex.

2.5.3 Essential Elements

- Essential elements can also be grouped into four broad categories on the basis of their diverse functions.
- These categories are-
    - **Essential elements as components of biomolecules** and hence structural elements of cells (example- carbon, hydrogen, oxygen and nitrogen).
    - **Essential elements that are components of energy-related chemical compounds in plants** (example- magnesium in chlorophyll and phosphorous in ATP).
    - **Essential elements that activate or inhibit enzymes**, for example Mg^{2+} is an activator for both ribulose bisphosphate carboxylase- oxygenase 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. 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.

2.6 Difference between Macro Nutrients and Micro Nutrients

Macro Nutrients	Micro Nutrients
Macro Nutrients must generally be present in plant tissue in concentration of 1-10 mg/gm of dry matter.	Micro Nutrients or trace elements are needed in very small quantity (equal to or less than 0.1 mg/gm of dry matter.
They include C, H, O, N, P, S, K, Ca, Mg and Si.	These include Fe, Mn, Cu, Mo, Zn, B and Cl. Co, V And Ni may be essential in certain plants

2.7 Role of Macro Nutrients 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.

2.7.1 Nitrogen

- This is the mineral element required by plants in the greatest amount.
- It is absorbed mainly as NO^{-}_{3} or NH^{+}_{4}.
- Nitrogen is required by all parts of a plant, particularly the meristematic tissues and the metabolically active cells.
- This nitrogen is made available to plants by the nitrogen fixing enzyme, example- nitrogenase.
- Nitrogen is one of the major constituents of protein, nucleic acids, vitamins and hormones.

2.7.2 Phosphorus

- Phosphorus is absorbed by the plants from soil in the form of phosphate ions (either as $H_2PO^{-}_{4}$ or $H_2PO^{2-}_{4}$).
- A large amount of phosphorous accumulates in storage tissues of fruits and seeds and during active growth in meristematic tissue.
- Phosphate plays a key role in energy metabolism.
- Through nucleic acids and ATP it plays an important role in protein synthesis, through coenzymes NAD, NADP and ATP it plays an important role in oxidation reduction and energy transfer reactions of cell metabolism, example- Photosynthesis, respiration and fat metabolism.
- Phosphorus is a constituent of cell membranes, certain proteins, all nucleic acids and nucleotides, phytin, phospholipids, sugar phosphates, ATP, coenzymes and NADP and is required for all phosphorylation reactions.
- It helps healthy root growth, translocation of carbohydrates, cambium activity and ripening of fruits.

2.7.3 Potassium

- It is absorbed as potassium ion (K^{+}).
- It is exchangeable cation.
- It is rich in actively dividing cells of buds, young leaves and root tips.
- It is present in less amount in seeds and other mature tissue.
- 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, permeability, osmotic regulation, hydration, chlorophyll synthesis, translocation of food, opening and closing of stomata, activation of enzymes and in the maintenance of the turgidity of cells.

2.7.4 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.
- Calcium is potent activator of the enzyme phospholipase, arginine kinase, ATPase, adenyl kinase and amylase.
- Calcium reduces toxicity of inorganic elements like sodium and organic acid by forming calcium salts.

2.7.5 Magnesium

- It is absorbed by plants in the form of divalent Mg^{2+}.
- Magnesium is a constituent of the ring structure of chlorophyll and helps to maintain the ribosome structure.
- So it is found in all the green parts of plants and helps in photosynthesis.
- It activates the enzymes of respiration, photosynthesis and is involved in the synthesis of DNA and RNA.
- So it plays an important role in various metabolic process including respiration.
- It plays an important role in binding ribosomal particles during protein synthesis and nodule formation in legumes.

2.7.6 Sulphur

- Plants obtain sulphur in the form of sulphate [$SO^{2-}{}_4$].
- It is required by young leaves and meristems and withdrawn from senescent organs.
- 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.
- It is essential for the synthesis of allyl oils of mustard, example- Sinigrin which gives odour and flavour to mustard, garlic and onion.
- Sulphur is also constituent of ferredoxin and some lipids found in the chlorophyll.
- It is essential for nodulation in legumes.
- Disulphide linkage helps to stabilize the protein structure.
- Sulphydryl groups are necessary for activity of many enzymes.

2.7.7 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 oxidized from Fe^{2+} to Fe^{3+} during electron transfer.
- It activates catalase enzyme, and is essential for the formation of chlorophyll.
- Ferredoxin plays important role in biological nitrogen fixation and primary photochemical reaction in photosynthesis.

2.7.8 Manganese

- It is absorbed in the form of manganous ions.
- Poorly aerated acid soils favour the availability of Manganese while it is not available above the soil pH of 6.5.
- It activates many enzymes involved in photosynthesis, respiration and nitrogen metabolism; example- respiratory enzymes nitrate reductase and hydroxylamine reductase.
- The best defined function of manganese is in the splitting of water to liberate oxygen from photolysis of water to photo-oxidized chlorophyll during photosynthesis.
- Mn is essential for oligosaccharide and glycoprotein synthesis.
- It is also involved in synthesis of chlorophyll and metabolism of IAA.

2.7.9 Zinc

- Plants obtain zinc as Zn^{2+} ions.
- It activates various enzymes, especially carboxylases.
- It is also needed in the synthesis of auxin.
- It plays an important role in the synthesis of tryptophan which is precursor of phytohormone auxin.
- It also acts as activator of several enzymes such as carbonic anhydrase which catalyse the decomposition of carbonic anhydrase which catalyse the decomposition of carbonic acid to carbon dioxide.

2.7.10 Copper

- Its higher concentration is toxic to plants.
- So it is required in very small quantity.
- 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 oxidized from Cu^{+} to Cu^{2+}.
- It is the component of cytochrome oxidase, ribulose biphosphate carboxylase, ascorbic acid and polyphenol oxidase and part of plastocyanin.

2.7.11 Boron

- It is absorbed as $BO^{3}{}_{3}^{-}$ or $B_4O_7^{2-}$.
- Boron is required for uptake and utilization of Ca^{2+}, membrane functioning, pollen germination, cell elongation, cell differentiation and carbohydrate translocation, synthesis of pectins, proteins and nucleic acids.
- Boron also regulates water relation, active salt absorption, nodulation in legumes, fat and hormone metabolisms, fertilization and photosynthesis.
- Availability of boron decreases with increasing pH.

- Boron regulates carbohydrate metabolism specially pentose phosphate shunt, many growth process such as regeneration, fruiting and cell division.

2.7.12 Molybdenum

- Plants obtain it in the form of molybdate ions (MoO_2^{2+}).
- It is required by the plants in very little amount.
- It acts as an activator of enzyme nitrate reductase and nitrogenase.
- It is required for nodulation in legumes, nitrogen fixation, protein synthesis and ascorbic acid synthesis.
- It is a component of several enzymes, including nitrogenase and nitrate reductase both of which participate in nitrogen metabolism.

2.7.13 Chlorine

- It is absorbed in the form of chloride anion (Cl^-).
- It is required in PS II of photosynthesis.
- It is involved in photolysis of water and transfer of electrons to pigment system II photo-production of O_2 and normal production of fruits.
- 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.

2.8 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.
- The symptoms of a mineral deficiency depend in part on the function of that nutrient in the plant. For example, a deficiency in magnesium, an ingredient of chlorophyll, causes yellowing of the leaves, or chlorosis.
- The relationship between a mineral deficiency and its symptoms can be less direct. For example, chlorosis can also be caused by iron deficiency because iron is a required cofactor in chlorophyll synthesis.
- Mineral deficiency symptoms also depend on the mobility of the nutrient within the plant. If a nutrient can move freely from one part of a plant to another, then symptoms of the deficiency will appear first in older organs.
- Young, growing tissues have more "drawing power" than old tissues for nutrients in short supply. For example, a shortage of magnesium will initially lead to chlorosis in older leaves. If a nutrient is relatively immobile, then a deficiency will affect young parts of the plant first.
- Older tissue may have adequate supplies, which they can retain during periods of shortage. For example, iron does not move freely within a plant. Chlorosis due to iron deficiency appears first in young leaves.
- The symptoms of a mineral deficiency are often distinctive enough for a plant physiologist or farmer to make a preliminary diagnosis of the problem.
- This can be confirmed by analyzing the mineral content of the plant and the soil.
- Deficiencies of nitrogen, potassium, and phosphorus are the most common problems.
- Shortages of micronutrients are less common and tend to be geographically localized due to differences in soil composition.
- The amount of micronutrient needed to correct a deficiency is usually quite small. Care must be taken, because a nutrient overdose can be toxic to plants.

- One way to ensure optimal mineral nutrition is to grow plants hydroponically on nutrient solutions that can be precisely regulated.
    - This technique is practiced commercially, but the requirements for labor and equipment make it relatively expensive compared with growing crops in soil.
- Mineral deficiencies are not limited to terrestrial ecosystems or to plants.
- Photosynthetic protists and bacteria can also suffer from mineral deficiencies.
    - For example, populations of planktonic algae in the southern oceans are limited by iron deficiency.
        - In a trial in relatively unproductive seas between Tasmania and Antarctica, researchers demonstrated that dispersing small amounts of iron produced large algal blooms that pulled carbon dioxide out of the air.
        - Seeding the oceans with iron may help slow the increase in carbon dioxide levels in the atmosphere, but it may cause unanticipated environmental effects.
- Deficiency of nitrogen causes chlorosis due to failure of chlorophyll formation which appears first in mature leaves because of high mobility of nitrogen in plants.
- Nitrogen deficiency induces the formation of anthocyanin pigments in plants and delayed flowering.
- Deficiency of phosphorus decrease protein synthesis, energy generation, causes premature leaf fall, delays flowerings and develops dead necrotic areas on older leaves, petioles and fruits.
- Leaves may turn dark to blue green in colour and root and shoot become short due to deficiency of phosphorus.
- Deficiency of potassium causes first chlorosis followed by the development of necrotic areas at the tip and margin of the leaves but all these symptoms appear first in more mature leaves, rosette or bushy habit due to reduced apical bud growth, lodging in cereals and decreased resistance to disease.
- Calcium deficiency causes disintegration of growing meristematic regions of root, stem and leaves, chlorosis, necrosis and curling along the margins of younger leaves, premature flower abscission, tips of young leaves become permanently wilted, reduced root growth and blossom end rot of tomatoes.
- Deficiency of magnesium causes extensive inter-veinal chlorosis first in older leaves and dead necrotic patches on leaves.
- Deficiency of sulphur causes chlorosis first in younger leaves production of anthocyanin , extensive root growth, accumulation of soluble nitrogen and nitrogen rich amino acids due to inhibition of protein synthesis, following shortage of sulphur containing amino acids and formation of hard and woody stems and causes tea yellow disease of tea, less juice content in citrus, defoliation and reduced nodule formation in legumes.
- Deficiency of iron causes rapid chlorosis appearing first in young leaves which is usually inter-veinal and inhibits chloroplast formation.
- Deficiency of Manganese causes chlorotic and necrotic spots in the inter-veinal areas of the leaf and disease like 'grey speck' (oats), speckled yellow (beets) and marsh spot disease (peas).
- Deficiency of zinc causes reduction in size of leaves with shortening of internodes, inter-veinal chlorosis and necrosis in older leaves along the margins and tips.

- Its deficiency also caused Khaira disease of rice, little leaf disease, rosette of pecan, white bud of maize, mottle leaf disease of apples and walnut and Sickle leaf of cocoa.
- The absence of zinc also inhibits seed formation and causes malformation in fruiting trees.
- Deficiency of copper cause necrosis of the tip and margin of young leaves and some disease like die back disease of citrus, exanthema in fruit trees and reclamation disease of cereals and legumes.
- Deficiency of boron causes death of shoot tip, inhibition of flower formation, stunted root growth, curling and twisting of leaves.
- Boron deficiency tends to shift metabolism from glycolysis to pentose phosphate pathway and causes some disease such as heart rot of sugar beet, water core in turnip, drought spot and internal cork in apple, browning of cauliflower, brown heart disease in turnip.
- Deficiency of molybdenum causes chlorotic inter-veinal mottling in the older leaves, inhibits the flower formation and some disease like whiptail disease of cauliflower, yellow spot of citrus and scalds of beans and low levels of ascorbic acid and reduced organic nitrogen content.
- Deficiency of chlorine causes chlorotic and necrotic spots on leaves.

2.9 Mineral Deficiency Diseases

Deficiency Elements	**Diseases**
Zinc (Zn)	• Khaira disease of Rice. • Little leaf of Grapes. • Mottle leaf of *Citrus.* • Rosette of Apple • White bud of Maize.
Manganese (Mn)	• Chlorosis of Spinach and Beans. • Spots of Potato. • Speckled yellow of Sugar beet. • Grey speck of Oats. • Marsh spot of Pea.
Boron (B)	• Heart dry rot of Sugar beet. • Decolouration of head in Cabbage. • Brown spots of dead tissues in fruits of Apple.
Copper (Cu)	• Die-back disease of *Citrus*. • Yellow tip of Oat (Reclamation disease of Oat). • Exanthema.
Sulphur (S)	• Tea yellow disease.
Molybdenum (Mo)	• Whip tail disease of *Cauliflower*. • White core in *Turnip*.

2.10 Toxicity of Micronutrients

- Micronutrients are always required in low amounts while their moderate decrease causes the deficiency symptoms and a moderate increase cause toxicity.
- Mineral ion concentration in tissues that reduces the dry weight of tissues by about 10 % 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 important to know that manganese competes with iron and magnesium for uptake and with magnesium for binding with enzymes.
- Manganese also inhibits 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.

2.11 Mechanism of Absorption of Elements

- The process of absorption can be demarcated into two main phases.
    - In the first phase, an initial rapid uptake of ions into the 'free space' or 'outer space' of cells – the apoplast is passive.
    - In the second phase of uptake, the ions are taken in slowly into the 'inner space' – the symplast of the cells.
- The passive movement of ions into the apoplast usually occurs through ion-channels, the trans-membrane proteins that function as selective pores.
- On the other hand, the entry or exit of ions to and from the symplast requires the expenditure of metabolic energy, which is a process.
- The movement of ions is usually called the inward movement into the cells is **influx** and the outward movement, **efflux**.

2.12 Passive and Active uptake of Minerals [translocation of Solutes]

- Mineral salts are translocated through xylem along with the ascending stream of water, which is pulled up through the plant by transpirational pull.
- Analysis of xylem sap shows the presence of mineral salts in it.
- Use of radioisotopes of mineral elements also substantiate the view that they are transported through the xylem.

2.13 Diffusion

- **Molecular diffusion**, often called simply **diffusion**, is a net transport of molecules from a region of higher concentration to one of lower concentration by random molecular motion.
- The result of diffusion is a gradual mixing of material.
- In a phase with uniform temperature, absent external net forces acting on the particles, the diffusion process will eventually result in complete mixing or a state of equilibrium.

2.14 Ion Exchange

- **Ion exchange** is an exchange of ions between two electrolytes or between an electrolyte solution and a complex.
- In most cases the term is used to denote the processes of purification, separation, and decontamination of aqueous and other ion-containing solutions with solid polymeric or mineralic 'ion exchangers'.

2.15 Donnan Equilibrium

- The **Gibbs–Donnan effect** (also known as the **Donnan effect**, **Donnan law**, **Donnan equilibrium**, or **Gibbs–Donnan equilibrium**) is a name for the behavior of charged particles near a semi-permeable membrane to sometimes fail to distribute evenly across the two sides of the membrane.
- The usual cause is the presence of a different charged substance that is unable to pass through the membrane and thus creates an uneven electrical charges.
- For example, the large anionic proteins in blood protein are not permeable to capillary walls. Because small cations are attracted, but are not bound to the proteins, small anions will cross capillary walls more readily than small cations.

2.16 Principle of Mass Flow

- It was proposed by Ernst Munch; in 1930.A high concentration of organic substance inside cells of the phloem at a source, such as a leaf, creates a diffusion gradient that draws water into the cells.

2.17 Soil as Reservoir of Essential Elements

- Soil texture and composition are key environmental factors in terrestrial ecosystems. 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.
- Soil not only supplies minerals but also harbours nitrogen-fixing bacteria, other microbes, holds water, supplies air to the roots and acts as a matrix that stabilizes the plant.
- 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.
- The texture and chemical composition of soil are major factors determining what kinds of plants can grow well in a particular location.
- Texture is the general structure of soil, including the relative amounts of various sizes of soil particles.
- Composition is the soil's organic and inorganic components.
- Plants that grow naturally in a certain type of soil are adapted to its texture and composition and are able to absorb water and extract essential nutrients from that soil. Plants, in turn, affect the soil.
- The soil-plant interface is a critical component of the chemical cycles that sustain terrestrial ecosystems.
- Soil has its origin in the weathering of solid rock.
- Water that seeps into crevices and freezes in winter fractures rock. Acids dissolved in soil water also help break down rock chemically.
- Organisms, including lichens, fungi, bacteria, mosses, and the roots of vascular plants, accelerate the breakdown by the secretion of acids and the expansion of roots in fissures.
- This activity eventually results in **topsoil,** a mixture of particles from rock; living organisms; and **humus,** a residue of partially decayed organic material.

- Topsoil and other distinct soil layers, called **horizons,** are often visible in a vertical profile through soil.
- Topsoil, or the A horizon, is richest in organic material and is thus the most important horizon for plant growth.
- The texture of topsoil depends on the size of its particles, which are classified from coarse sand to microscopic clay particles.
- The most fertile soils are **loams,** made up of roughly equal amounts of sand, silt (particles of intermediate size), and clay.
- Loamy soils have enough fine particles to provide a large surface area for retaining minerals and water, which adhere to the particles.
- Loams also have enough course particles to provide air spaces that supply oxygen to the root for cellular respiration.
- Inadequate drainage can dramatically impact survival of many plants.
- Plants can suffocate if air spaces are replaced by water.
- Roots can also be attacked by molds that flourish in soaked soil.
- Topsoil is home to an astonishing number and variety of organisms.
- A teaspoon of soil has about 5 billion bacteria that cohabit with various fungi, algae and other protists, insects, earthworms, nematodes, and the roots of plants.
- The activities of these organisms affect the physical and chemical properties of soil.
- For example, earthworms aerate soil by burrowing and add mucus that holds fine particles together.
- Bacterial metabolism alters the mineral composition of soil.
- Plant roots extract water and minerals. They also affect soil pH by releasing organic acids and reinforce the soil against erosion.
- Humus is the decomposing organic material formed by the action of bacteria and fungi on dead organisms, feces, fallen leaves, and other organic refuse.
- Humus prevents clay from packing together and builds a crumbly soil that retains water but is still porous enough for the adequate aeration of roots.
- Humus is also a reservoir of mineral nutrients that are returned to the soil by decomposition.
- After a heavy rainfall, water drains away from the larger spaces of the soil, but smaller spaces retain water because of water’s attraction for the electrically charged surfaces of soil particles.
- Some water adheres so tightly to hydrophilic particles that plants cannot extract it, while water that is bound less tightly to the particles can be taken up by roots.
- Many minerals, especially those with a positive charge, such as potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), adhere by electrical attraction to the negatively charged surfaces of clay particles.
- Clay in soil prevents the leaching of mineral nutrients during heavy rain or irrigation because of its large surface area for binding minerals.
- Minerals that are negatively charged, such as nitrate (NO_3^-), phosphate ($H_2PO_4^-$), and sulfate (SO_4^{2-}), are less tightly bound to soil particles and tend to leach away more quickly.
- Positively charged mineral ions are made available to the plant when hydrogen ions in the soil displace the mineral ions from the clay particles.

- This process, called **cation exchange,** is stimulated by the roots, which secrete H^+ and compounds that form acids in the soil solution.

2.17.1 Soil conservation is one step toward sustainable agriculture

- It can take centuries for soil to become fertile through the breakdown of soil and the accumulation of organic material.
- However, human mismanagement can destroy soil fertility within just a few years.
- Soil mismanagement has been a recurring problem in human history.
- For example, the Dust Bowl was an ecological and human disaster that occurred in the southwestern Great Plains of the United States in the 1930s.
    - Before the arrival of farmers, the region was covered with hardy grasses that held the soil in place in spite of long recurrent droughts and torrential rains.
    - In the 30 years before World War I, homesteaders planted wheat and raised cattle, which left the soil exposed to wind erosion.
- Several years of drought resulted in the loss of centimeters of topsoil that were blown away by the winds.
    - Millions of hectares of farmland became useless, and hundreds of thousands of people were forced to abandon their homes and land.
- To understand soil conservation, we must begin with the premise that agriculture is not natural and can only be sustained by human intervention.
    - In natural ecosystems, mineral nutrients are recycled by the decomposition of dead organic material.
    - In contrast, when we harvest a crop, we remove essential elements.
        - In general, agriculture depletes minerals in the soil.
        - To grow 1,000 kg of wheat, the soil gives up 20 kg of nitrogen, 4 kg of phosphorus, and 4.5 kg of potassium.
    - The fertility of the soil diminishes unless minerals are replaced by fertilizers.
    - Most crops require far more water than the natural vegetation for that area, making irrigation necessary.
- The goals of soil conservation include prudent fertilization, thoughtful irrigation, and prevention of erosion.
- Complementing soil conservation is soil reclamation, the return of agricultural productivity to damaged soil.
- A third of the world's farmland suffers from low productivity due to poor soil conditions.
- Farmers have been using fertilizers to improve crop yields since prehistory.
    - Historically, these have included animal manure and fish carcasses.
    - In developed nations today, most farmers use commercial fertilizers containing minerals that are either mined or prepared by industrial processes.
    - These are usually enriched in nitrogen, phosphorus, and potassium, the macronutrients most often deficient in farm and garden soils.
    - Fertilizers are labeled with their N-P-K ratio. A fertilizer marked "10-12-8" is 10% nitrogen (as ammonium or nitrate), 12% phosphorus (as phosphoric acid), and 8% potassium (as the mineral potash).
- Manure, fishmeal, and compost are "organic" fertilizers because they are of biological origin and contain material in the process of decomposing.
    - The organic material must be decomposed to inorganic nutrients before it can be absorbed by roots.
    - However, the minerals that a plant extracts from the soil are in the same form whether they came from organic fertilizer or from a chemical factory.

- Compost releases nutrients gradually, while minerals in commercial fertilizers are available immediately.
- Excess minerals are often leached from fertilized soil by rainwater or irrigation and may pollute groundwater, streams, and lakes.

- Genetically engineered "smart plants" have been produced. These plants produce a blue pigment in their leaves to warn the farmer of impending nutrient deficiency.
- To fertilize judiciously, a farmer must maintain an appropriate soil pH. pH affects cation exchange and influences the chemical form of all minerals.
  - Even if an essential element is abundant in the soil, plants may starve for that element if it is bound too tightly to clay or is in a chemical form that the plant cannot absorb.
  - Adjustments to soil pH of soil may make one mineral more available but another mineral less available.
  - The pH of the soil must be matched to the specific mineral needs of the crop.
  - Sulfate lowers pH, while liming (addition of calcium carbonate or calcium hydroxide) increases pH.
- A major problem with acidic soils, particularly in tropical areas, is that aluminum dissolves in the soil at low pH and becomes toxic to roots.
  - Some plants cope with high aluminum levels in the soil by secreting organic ions that bind the aluminum and render it harmless.
- Water is the most common factor limiting plant growth.
  - Irrigation can transform a desert into a garden, but farming in arid regions is a huge drain on water resources.
  - Irrigation in an arid region can gradually make the soil so salty that it becomes completely infertile. Salts in the irrigation water accumulate in the soil as the water evaporates.
  - Eventually, the water potential of the soil solution becomes lower than that of root cells, which lose water to the soil instead of absorbing it.
- Valuable topsoil is lost to wind and water erosion each year.
  - This can be reduced by planting rows of trees between fields as a windbreak and terracing a hillside to prevent topsoil from washing away.
  - Some crops such as alfalfa and wheat provide good ground cover and protect soil better than corn and other crops that are usually planted in widely spaced rows.
- Soil is a renewable resource in which farmers can grow food for generations to come.
  - The goal is **sustainable agriculture,** a commitment embracing a variety of farming methods that are conservation-minded, environmentally safe, and profitable.
- Some areas have become unfit for agriculture or wildlife as the result of human activities that contaminate the soil or groundwater with toxic heavy metals or organic pollutants.
  - In place of costly and disruptive remediation technologies such as removal and storage of contaminated soils, **phytoremediation** takes advantage of the remarkable abilities of some plant species to extract heavy metals and other pollutants from the soil.
  - These pollutants are concentrated in plant tissues that can be harvested.
  - For example, alpine pennycress (*Thlaspi caerulescens*) can accumulate zinc in its shoots at concentrations that are 300 times the level most plants can tolerate.
  - Phytoremediation is part of a more general technology of bioremediation, which includes the use of prokaryotes and protists to detoxify polluted sites.

2.18 Metabolism of Nitrogen

- Apart from carbon, hydrogen and oxygen, nitrogen is the most prevalent element in living organisms.
- Nitrogen is a constituent of amino acids, proteins, hormones, chlorophylls and many of the vitamins.

- Plants compete with microbes for the limited nitrogen that is available in soil.
- Thus, nitrogen is a limiting nutrient for both natural and agricultural eco-systems. Nitrogen exists as two nitrogen atoms joined by a very strong triple covalent bond (N = N). The process of conversion of nitrogen (N_2) to ammonia is termed as In nature, lightning 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. Decomposition of organic nitrogen of dead plants and animals into ammonia is called Ammonification.
- Some of this ammonia volatilizes and re-enters the atmosphere but most of it is converted into nitrate by soil bacteria in the following steps:

$$2NH_3 + 3O_2 \rightarrow 2NO_2^- + 2H^+ + 2H_2O$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

- Ammonia is first oxidized to nitrite by the bacteria *Nitrosomonas* and/or *Nitrococcus*. The nitrite is further oxidized to nitrate with the help of the bacterium *Nitrobacter*
- These steps are called **nitrification**. These nitrifying bacteria are **chemoautotrophs**.
- The nitrate thus formed is absorbed by plants and is transported to the leaves; it is reduced to form ammonia that finally forms the amine group of amino group of amino acids.
- Nitrate present in the soil is also reduced to nitrogen by the process of Denitrification. Denitrification is carried by bacteria *Pseudomonas Thiobacillus.*

2.18.1 Nitrogen Cycle

- The **nitrogen cycle** is the process by which nitrogen in all its forms cycles through the earth, much in the same way the water cycle occurs. The majority of Earth's atmosphere (approximately 78-80%) is nitrogen, making it the largest pool of nitrogen.

2.18.2 Biological Nitrogen Fixation

- Biological nitrogen fixation (**BNF**) occurs when atmospheric nitrogen is converted to ammonia by an enzyme called nitrogenase. The formula for BNF is-

$$N_2 + 6\,H^+ + 6e^- \rightarrow 2NH_3$$

- The process is coupled to the hydrolysis of 16 equivalents of ATP and is accompanied by the co-formation of one molecule of H_2.
- In diazotrophs, ammonium is assimilated into glutamate through the glutamine synthetase /glutamate synthase pathway.
- Enzymes responsible for nitrogenase action are very susceptible to destruction by oxygen.
- Many nitrogen-fixing organisms exist only in anaerobic conditions, respiring to draw down oxygen levels, or binding the oxygen with a protein such as Leghaemoglobin.
- Plants that contribute to nitrogen fixation include the legume family – Fabaceae – with taxa such as clover, soybeans, alfalfa, lupines and peanuts.
- They contain symbiotic bacteria called *Rhizobia* within nodules in their root systems, producing nitrogen compounds.
- When the plant dies, the fixed nitrogen is released; making it available to other plants and this helps to fertilize the soil.
- The great majority of legumes have this association, but a few genera (example-*Styphnolobium*) do not.
- In crops, which usually includes one consisting mainly or entirely of clover or buckwheat (family *Polygonaceae*), which are called to as "green manure."

2.18.3 Symbiotic Biological Fixation

- Plant nutritional adaptations often involve relationships with other organisms.
- The roots of plants belong to subterranean communities that interact with a diversity of other organisms.
- Among these are certain species of bacteria and fungi that have coevolved with specific plants, forming symbiotic relationships with roots that enhance the nutrition of both partners.
- The two most important examples of mutualistic interactions are nitrogen fixation (symbiosis of plant roots and bacteria) and the formation of mycorrhizae (symbiosis of plant roots and fungi).

2.18.3.1 Nodule formation

- Symbiotic nitrogen fixation results from intricate interactions between roots and bacteria.
- Some plant species form symbiotic relationships with nitrogen-fixing bacteria.
  - This provides their roots with a built-in source of fixed nitrogen for assimilation into organic compounds.
  - Much of the research on this symbiosis has focused on the agriculturally important members of the legume family, including peas, beans, soybeans, peanuts, alfalfa, and clover.
- A legume's roots have swellings called **nodules,** composed of plant cells that contain nitrogen-fixing bacteria of the genus *Rhizobium*.
  - Inside the nodule, *Rhizobium* bacteria assume a form called **bacteroides,** which are contained within vesicles formed by the root cell.
  - Legume-*Rhizobium* symbioses produce more usable nitrogen for plants than all industrial fertilizers, at no cost to farmers. Subsequent crops can also benefit from the usable nitrogen left in the soil by a legume crop.
- Nitrogen fixation requires an anaerobic environment.
  - Lignified external layers of the nodule limit gas exchange.
  - Nodules produce Leghaemoglobin, an iron-containing protein that binds reversibly to oxygen. Leghaemoglobin provides oxygen for *Rhizobium*'s intense respiration, while protecting nitrogenase from free oxygen.
- The development of root nodules begins after bacteria enter the root through an infection thread.
  - Chemical signals from the root attract the Rhizobium bacteria, and chemical signals from the bacteria lead to the production of an infection thread.
  - The bacteria penetrate the root cortex within the infection thread.
  - Growth in cortex and pericycle cells which are "infected" with bacteria in vesicles continues until the two masses of dividing cells fuse, forming the nodule.
  - As the nodule continues to grow, vascular tissue connects the nodule to the xylem and phloem of the stele, providing nutrients to the nodule and carrying nitrogenous compounds to the rest of the plant.
- The symbiotic relationship between a legume and nitrogen-fixing bacteria is mutualistic, with both partners benefiting.
  - The bacteria supply the legume with fixed nitrogen.

  - Most of the ammonium produced by symbiotic nitrogen fixation is used by the nodules to make amino acids, which are then transported to the shoot and leaves via the xylem.
- The plant provides the bacteria with carbohydrates and other organic compounds and protects the nitrogenase from free oxygen.
- The common agricultural practice of **crop rotation** exploits symbiotic nitrogen fixation.
  - One year, a nonlegume crop such as corn is planted. The following year, alfalfa or another legume is planted to restore the concentration of fixed soil nitrogen.
  - Often, the legume crop is not harvested but is plowed under to decompose as "green manure."
  - To ensure the formation of nodules, the legume seeds may be soaked in a culture of the correct *Rhizobium* bacteria or dusted with bacterial spores before sowing.
- Species from many other plant families also benefit from symbiotic nitrogen fixation.
  - For example, alder trees and certain tropical grasses host nitrogen-fixing bacteria of the actinomycetes group.
  - Rice benefits indirectly from symbiotic nitrogen fixation because it is often cultivated in paddies with the water fern *Azolla*, which has symbiotic nitrogen-fixing cyanobacteria.
    - This increases the fertility of the rice paddy through the activity of the cyanobacteria.
    - The growing rice eventually shades and kills the *Azolla*.
    - The decomposition of water fern adds more nitrogenous compounds to the paddy.
- The specific recognition between legume and bacteria and the development of the nodule is the result of a chemical dialogue between the bacteria and the root.
  - Each partner responds to the chemical signals of the other by expressing certain genes whose products contribute to nodule formation.
  - The plant initiates the communication when its roots secrete molecules called flavonoids, which enter *Rhizobium* cells living in the vicinity of the roots.
  - Each particular legume species secretes a type of flavonoid that only a certain *Rhizobium* species can detect and absorb.
- A specific flavonoid signal travels from the root to the plant's *Rhizobium* partner.
- The flavonoid activates a gene-regulating protein in the bacterium, which switches on a cluster of bacterial genes called *nod* (for nodulation genes).
- The *nod* genes produce enzymes that catalyze production of species-specific molecules called Nod factors.
- Nod factors signal the root to initiate the infection process, enabling *Rhizobium* to enter the root and begin forming the root nodule.
- The plant's responses require activation of early nodulin genes by a signal transduction pathway involving Ca^{2+} as second messengers.
  - It may be possible in the future to induce *Rhizobium* uptake and nodule formation in crop plants that do not normally form such nitrogen-fixing symbioses.
  - In the short term, research is focused on improving the efficiency of nitrogen fixation and protein production.

2.18.3.2 Mycorrhizae

- Mycorrhizae are symbiotic associations of roots and fungi that enhance plant nutrition*.*
- **Mycorrhizae** ("fungus roots") are modified roots, consisting of mutualistic associations of fungi and roots.
  - The fungus benefits from a hospitable environment and a steady supply of sugar donated by the host plant.
- The fungus provides several potential benefits to the host plant.
  - First, the fungi increase the surface area for water uptake and selectively absorb phosphate and other minerals in the soil and supply them to the plant.
  - The fungi also secrete growth factors that stimulate roots to grow and branch.
  - The fungi produce antibiotics that may help protect the plant from pathogenic bacteria and fungi in the soil.
- Almost all plant species produce mycorrhizae.
  - This plant-fungus symbiosis may have been one of the evolutionary adaptations that made it possible for plants to colonize land in the first place.
    - Fossilized roots from some of the earliest land plants include mycorrhizae.
  - Mycorrhizal fungi are more efficient at absorbing minerals than roots, which may have helped nourish pioneering plants, especially in the nutrient-poor soils present when terrestrial ecosystems were young.
  - Today, the first plants to become established on nutrient-poor soils are usually well endowed with mycorrhizae.
- Mycorrhizae take two major forms: **ectomycorrhizae** and **endomycorrhizae.**
  - In ectomycorrhizae, the mycelium forms a dense sheath over the surface of the root.
  - Some hyphae grow into the cortex in extracellular spaces between root cells. Hyphae do not penetrate root cells but form a network in the extracellular spaces to facilitate nutrient exchange.
  - The mycelium of ectomycorrhizae extends from the mantle surrounding the root into the soil, greatly increasing the surface area for water and mineral absorption.
  - Compared with "uninfected" roots, ectomycorrhizae are generally thicker, shorter, more branched, and lack root hairs.
  - Ten percent of plant families have species that form ectomycorrhizae. Ectomycorrhizae are especially common in woody plants, including trees of the pine, spruce, oak, walnut, birch, willow, and eucalyptus families.
- Endomycorrhizae have fine fungal hyphae that extend from the root into the soil.
  - Hyphae also extend inward by digesting small patches of the root cell walls, forming tubes by invagination of the root cell's membrane.
  - Some fungal hyphae within these invaginations may form dense knot like structures called arbuscles that are important sites of nutrient transfer.
  - Roots with endomycorrhizae look like "normal" roots with root hairs, but the microscopic symbiotic connections are very important.
  - Endomycorrhizae are found in more than 85% of plant species, including important crop plants such as corn, wheat, and legumes.
- Roots can be transformed into mycorrhizae only if they are exposed to the appropriate fungal species.
  - In most natural systems, these fungi are present in the soil, and seedlings develop mycorrhizae.
  - However, seeds planted in foreign soil may develop into plants that show signs of malnutrition because of the absence of the plant's mycorrhizal partners.
  - Researchers observe similar results in experiments in which soil fungi are poisoned.
  - Farmers and foresters are already applying the lessons learned from this research by inoculating plants with the spores from the appropriate fungal partner to ensure development of mycorrhizae.

- An epiphyte is an autotrophic plant that nourishes itself but grows on the surface of another plant, usually on the branches or trunks of trees.
- Epiphytes absorb water and minerals from rain, mostly through their leaves.
- Examples of epiphytes are staghorn ferns, some mosses, Spanish moss, and many species of bromeliads and orchids.
- A variety of plants parasitize other plants to extract nutrients to supplement or even replace the production of organic molecules by photosynthesis by the parasitic plant.
- Many species have roots that function as haustoria, nutrient-absorbing roots that enter the host plant.
- Mistletoe supplements its photosynthesis by using projections called haustoria to siphon xylem sap from the vascular tissue of the host tree.
- Both dodder and Indian pipe are parasitic plants that do not perform photosynthesis at all.
    - The haustoria (modified roots) of dodder tap into the host's vascular tissue for water and nutrients.
    - Indian pipe obtains its nutrition indirectly via its association with fungal hyphae of the host tree's mycorrhizae.
- Carnivorous plants are photosynthetic but obtain some nitrogen and minerals by killing and digesting insects and other small animals.
- Such plants live in acid bogs and other habitats where soil conditions are poor in nitrogen and other minerals.
- Various types of insect traps have evolved by the modification of leaves.
- The traps are usually equipped with glands that secrete digestive juices.
- Examples are the Venus flytrap, pitcher plant, and sundew.

2.18.4 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, the latter is quite toxic to plants and hence cannot accumulate in them.
- There are two main process in which this can take place:-
    - **Reductive Amination**: In these processes, ammonia reacts with α-ketoglutaric acid and forms glutamic acid as indicated in the equation given below-

$$\alpha\text{ - Ketoglutaric acid} + NH_4^+ + \text{NADPH} \xrightarrow[\text{Dehydrogenase}]{\text{Glutamate}} \text{Gulutamate} + H_2O + \text{NADP}$$

- **Transamination**

- It involves the transfer of amino group from one amino acid to the keto group of a keto acid.
    - Glutamic acid is the main amino acid from which the transfer of NH_2, the amino group takes place and other amino acids are formed through Transamination.
    - The enzyme transaminase catalyses all such reactions.
    - The two most important amides- asparagine and glutamine found in plants are a structural part of proteins.
    - They are formed from two amino acids, i.e. aspartic acid and glutamic acid respectively, by addition of another amino group to each.
    - The hydroxyl part of the acid is replaced by another NH_2^- radicle.
    - 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 particularly high nitrogen to carbon ratio.

2.19 Points to Remember

- Plants obtain their inorganic nutrients from air**.**
- Plants absorb a wide variety of mineral elements.
- Out of 105 element found in nature only 21 are essential elements.
- The elements required in large quantities are called Macronutrients.
- The elements required in fewer quantities or in traces are called Micronutrients.
- These elements take part in various metabolic processes or are main part of proteins, carbohydrates, fats, nucleic acid etc.
- Micronutrients are always required in low amounts while their moderate decrease causes the deficiency symptoms and a moderate increase cause toxicity.
- Mineral ion concentration in tissues that reduces the dry weight of tissues by about 10 % is considered toxic.
- Plants absorb minerals through roots by either passive or active processes.
- Nitrogen is very essential for the sustenance of life.
- Plants cannot directly use the atmospheric nitrogen.
- Some plants having root nodules or in association with N_2-fixing bacteria, can fix the atmospheric nitrogen.
- This is mainly done with the help of nitrogen-fixing microbes, *Rhizobium*.
- The enzyme nitrogenase which plays an important role in biological N_2 fixation is very sensitive to oxygen.
- Most of the Biological Nitrogen fixation process takes place in anaerobic environment.
- Ammonia produced following N_2fixation is incorporated into amino acids as the amino group.