Chapter - 8
Mineral Nutrition in Plants

All the living beings to complete their life cycle take some substances from outside to complete their life cycle which is called nutrition of the organism. On the basis of nutrition, organisms are divided in two classes -

(A) Heterotrophic :- Those organism, which depend on outside sources for both organic and inorganic substances are called Heterotrophic.

(B) Autotrophic :- Those organisms, which synthesis all the organic substances required for their needs themselves and depend on outside sources only for inorganic substances are called autotrophic.

All organisms that lack chlorophyll such as bacteria, fungi and animals are heterotrophic and photosynthetic bacteria all green plants that have chlorophyll are autotrophic. Green plants obtain their required organic substances by photosynthesis and most of the inorganic substances required are obtained from minerals present in the soil. Thus, the green plants nutrition is mainly by means of mineral nutrition. The dependence of plants on minerals was first proved by De Saussure in 1804 and later by Von Sachs in 1860.

Methods of study for necessity of mineral nutrients by plants : To know about the necessity of mineral elements for plants scientists have adopted many methods, most important of them are :

1. Analysis of plant ash : In this process, fresh plant is heated at 70-80^0 C in oven for one or two days due to which all water content in plant gets evaporated. The dry weight of the plantis identified by weighing the remaining portion. The main components of dry weight are cell wall, polysaccharidens, lignin, cytoplasmic contents and organic acids. To find the amount of inorganic substances in the dry matter of plant, it is heated upto 6000^{0}C in furnance. Due to this, the volatile organic substances present in it dissociate and evaporate as gases like CO_2, NH_3, O_2. The substance left after this process is called plant ash. It has mainly non volatile mineral elements of the plant. Analysis of plant ash only shows the presence of different elements in the plant. This method does not decide the utility or necessicity of the elements.

2. Sand culture experiment : In this method, plants are grown in sand to determine the utility of different elements in it. First of all, the sand is sterilized by washing in hydrochloric acid. Sterilized Soil does not has any minerals. It is then washed with water and dried. There after, according to the experiment many plants are grown. Out of these plants some are control plants which are given all nutrients by dissolving in water. Remaining plants are grown in separater containers with deficiency of one or more mineral elements. These plants are called deficient plants. The analysis of plant growth or deficiency symptoms as observed in different nutrient solution can be used to study importance elements.

In the above method various difficulties are them, so in place of sand other media such as quartz, plastic chips, Vermiculite or artificial sand etc. are

used vermiculite is a mineral substance which is found on earth in its natural state. Vermiculite is light in weight, chemically inert, has high water absorbing capacity and insulation, used extensively in the experiment. This method is called Vermiculoponics.

3. Water culture experiment : In this method, sand, soil etc are not used. Here, the plants roots are kept in nutrient solution. Because as the solution lacks oxygen, oxygen is supplied near the roots by aerator through a tube in the solution. This method is called hydroponics.

In this method, nutrient solution decided by Sachs (1860), Knop (1865) and Hoagland (1938) are used.

Essential elements of plants

Many mineral elements are essential for plants, these are called mineral nutrients. Out of 105 elements found on earth, 60 elements have been found in plants. But all these elements are not essential for plant. According to different studies, only 17 elements are important for the normal growth of plant. These are known as essential elements and the other remaining ones are called non essential elements. Many non essential elements are toxic to the plants.

The essentiality of 17 essential elements can be determined by the following facts :-

1. Elements that are needed for general growth and reproduction and in their absence, plant can not complete its life cycle.
2. Essentiality of the element must be specific. In other words, the deficiency of the element must be completed by the same element only.
3. Element that is involved in metabolic process of plant directly. On the basis of above parameters only essential elements have been identified.
4. Due to deficiency of each element specific synptoms are observed.

Macro and Micro nutrient elements

Essential nutrient elements are further grouped in to two series on the basis of their quantity present in plants.

1. Macro nutrient elements : They are also called major or prime elements. Such elements whose quantity is between 1-10 mg in 1 gm of dry weight of the plant or in excess of 10 m mole kg^{-1} of matter are called macro nutrient elements. These are 9 in number such as C, H, O, N, P, K, S, Mg and Ca

2. Micro nutrient elements : These are also called micro or minor elements. Such elements which are less than 1 mg in 1 gm of dry weight of the plant (or less than 10 m mole kg^{-1}) of dry weight are called micronutrients. These are 8 in number such as : Fe, B, Mn, Cu, Zn, Mo, Cl and Ni.

Sometimes Fe and B are also called intermediate nutrients.

N P and K are primary mega nutrients and Ca, Mg and S are secondary mega nutrients, Besides above mentioned 17 essential elements, few other elements are also useful to plants such as Na, Si, Co and Se etc. They are called useful or functional elements. Essential elemetns are also classified on the basis of their function in plants.

1. Structural elements: Different biochemicals of plants such as Carbohydrates, fats, proteins, DNA, RNA etc. have C, H, O and N as the structural components in them.

2. Energy related elements : Such elements that are useful in energy related compounds in plants, such as Phosphorus in ATP and Mg in chlorophyll.

3. Enzyme Activators : Such elements that are useful as activator or inhibitors of enzymes. Such as : Mn, Mg, Zn and Mo etc.

4. Those elements that balance the osmostic processes in plant cells such as K, Cl, etc.

For plants out of 17 essential elements which are often referred to as mineral nutrient elements four elements have their source atmosphere or water not soil. Therefore according to some authors these are called non mineral elements, like : C, H, O and N which are the main components of atmosphere but all higher plants obtain N from the soil. Thus the number of non mineral elements are 3 in number C, H and O. Rest of other 14 elements are mineral

elements plants obtain C and O as CO_2 and O_2 whereas H is obtained as H_2O.

Role of Macro and Micro nutrients in Plant nutrition

There is an important role of essential elements in physiological process of plants. For example functions like a component of different substances, permeability of cell membrane, regulation of osmotic pressure, electron transfer system, balance of biochemical reactions by enzymes, buffer action, storage of food in food storing organs etc. can not take place in the absence of nutrient elements. Here we will briefly study by about the availability, utility effects of deficiency or excess of elements on plants.

1, 2, 3, Carbon, Hydrogen and Oxygen:- Though these elements do not fall in the category of mineral elements but as these are essential elements therefore these are studied. Plants obtain C as and O as CO_2 and O_2 where as H is obtained from H_2O. Their functions have been already earlier. Generally these substances are not deficient in plant.

4. Nitrogen (N) : In plants, this element is needed in maximum amount. Plants obtain it from soil mostly as - NO_3^- (Nitrate) and Nitrite NO_2^- and least as NH_4^+ (ammonium) N is required in large quantities for developing and dividing tissue, buds and in general in all living cells. N is main component of amino acids, protein, nucleic, chlorophyll, vitamins and hormone. Urea is the main source of N in the form of chemical fertilizers.

Deficiency Symptoms

(I) Chlorosis (destruction of chlorophyll) is seen in plant leaves due to deficiency of N. First it occurs in old leaves then in young leaves.

(ii) Due to decomposition of chlorophyll, pink colour anthocynin pigment is visible due to which leaves turns pink.

(iii) Increased dormancy in lateral buds.

(iv) The whole plant shows less growth and it becomes stunted.

3. Phosphorus (P) : For plants, soil is the main source of phosporus. It is absorbed from soil through roots in the form of soluble inorganic phosphate ions as $H_2PO_4^-$ and HPO_4^- It is transported in the plant as inorganic form but found as organic compound in plants. Generally the amount of phosphorus in plants is 0.2 to 0.8% of dry weight.

Phosphorus is the main component of phospholipids, nucleic acid, coenzyme, NAD (Nicotinamide adenine dinucleotide), NADP (Nicotinamide adenine dinucleotide phosphate), ATP (Adenosine triphosphate) etc. Co enzyme NAD, NADP are needed for important reactions like oxidation reductions, photosynthesis, respiration, fatty acid synthesis etc.

Deficiency Symptoms

(i) Plants are stunted and dark green in color

(ii) Formation of anthocynin pigment in leaves and stem

(iii) Formation of necrotic regions in leaves and fruits due to excessive deficieney of phosphorus

(iv) Leaves become distorted

(v) Activity of cambium is reduced.

6. Calcium (Ca) :- It is found in the soil in the form of apetite, calcite, and dolomite ores. It is absorbed by the plants in the form of Ca^+ ions. Calcium is the main component of middle lamella of the cell wall. It affects the process such as cell division and cell elongation. It plays a vital role in combination of nucleic acids with proteins and transportation of carbohydrates and amino acids.

Deficiency Symptoms :

(1) The flexibility of the cell wall diminishes and cell elongation is affected.

(2) The shape of leaves gets distorted and the apex bends down. It is called tip burn.

(3) Leaves show chlorosis.

7. Potassium (K) :- Potassium is found in soil as soluble and exchangeable form. It is absorbed as K^+ ions. Though the requirement of potassium for plants is in large amount but it is a the component of any biochemical in plants i.e. it is not having any structural role. Potassium is mainly required in four biochemical processes: anion neutralisation,

transportation through membrane, enzyme activation and osmotic potential. Other than these, it is important for photosynthesis, opening and closing of stomata, normal growth of seeds and fruits. Potassium is the main component of cytoplasm. Potassium is found in excess quantity in root apex, shoot apex young leaxes and meristematic regions.

Deficiency symptoms :

(I) The deficiency symptoms of this element appears first on mature - leaves. Leaves become mottled and show chlorosis.

(ii) The growth of stem is stopped and it appears bushy.

(iii) Disease resistance of plant is reduced (Generally N, P, K are deficiency in the soil, because of their excessive use, these are also called critical elements. Chemical fertilizer NPK is their main source.)

(8) Magnesium (Mg) : It is mainly found in soil as carbonate ($MgCO_3$) and dolomite ($MgCO_3$ $CaCO_3$) . Magnesium is the main component of chlorophyll and it inhibits chlorosis. This elements helps the two sub units of RNA to bind together. It is found in excess amount in oil seeds thus probably it is useful in formation of oil in seeds. Mg acts as catalyst for enzymes associated with synthesis of DNA and RNA

Deficiency Symptoms

(i) Development of interveinal chlorosis.

(ii) Due to formation of anthocynin pigments red, yellow and orange spots are seen on leaves.

(9) Sulphur (S) : Sulphur is found as sulphate (SO_4^{2-}) in soil. Besides this as sulphur dioxide (SO_2) found in atmosphere is also the source of sulphur to plants. The strong smell of brassicacease family is due to the volatile substances having sulphur. Pea family plants that grow in sulphate rich soil have well developed root nodules. Sulphur is helpful for synthesis of amino acids essential for protein synthesis. It is present in Vitamin B and Co-A

Deficiency symptoms

(i) Chlorosis is seen in leaves

(ii) Deficiency of sulphur containing amino acids (cysteine and methionine)

(iii) Increase in thick walled tissues such as sclerenchyma, xylem and collenchyma

(iv) Plants remain stunted

10. Iron (Fe) : In plants it is absorbed as ferric ion(Fe^{+3}) but in metabolic processes it is functional as ferrous ion (Fe^{+2}). Iron mainly plays role in cell division, respiration and electron transport system at different stages. In leaves Fe is found as stable protein phytopheritin and in nucleus present in chromatin network. Iron is used as catalyst in structure of cytochrome pigments, kreb's cycle, aconitase, catalase, peroxidase enzymes.

Deficiency symptoms

(i) Chlorosis arises in young leaves widely.

(ii) Irregularity in photosynthesis, respiration and protein synthesis processes

(iii) Process of cell division stops.

(iv) Plant growth slows down

(11) Maganese (Mn) :- It is mainly found in soil as maganese oxide (MnO_2) and plants absorb in form of maganese ion (Mn^{++}). This element is a catalyst for respiration, nitrogen metabolism and many enzymes of photosynthesis. Maganese has an important role in the synthesis of chloroplasts. It is an important part of enzyme related to photolysis of water and release of O_2 in photosynthesis.

Deficiency Symptoms

(i) Characteristics of chlorosis are seen in young and mature leaves of plant

(ii) Limited development of roots.

(iii) Due to deficiency of maganese, specific plant disease developed are : grey speek of oat, marsh spot of pea etc.

(12) Boron (B) : This element is absorbed by roots as borate ion (BO_3^{3-}, $B_4O_7^{-2}$). It forms calcium borate with calcium present in soil which is not absorbed by roots. Thus, in soil having excess of calcium, boron becomes deficient to the plants. Boron has specific importance in transportation of carbohydrates, activity of cell membrane,

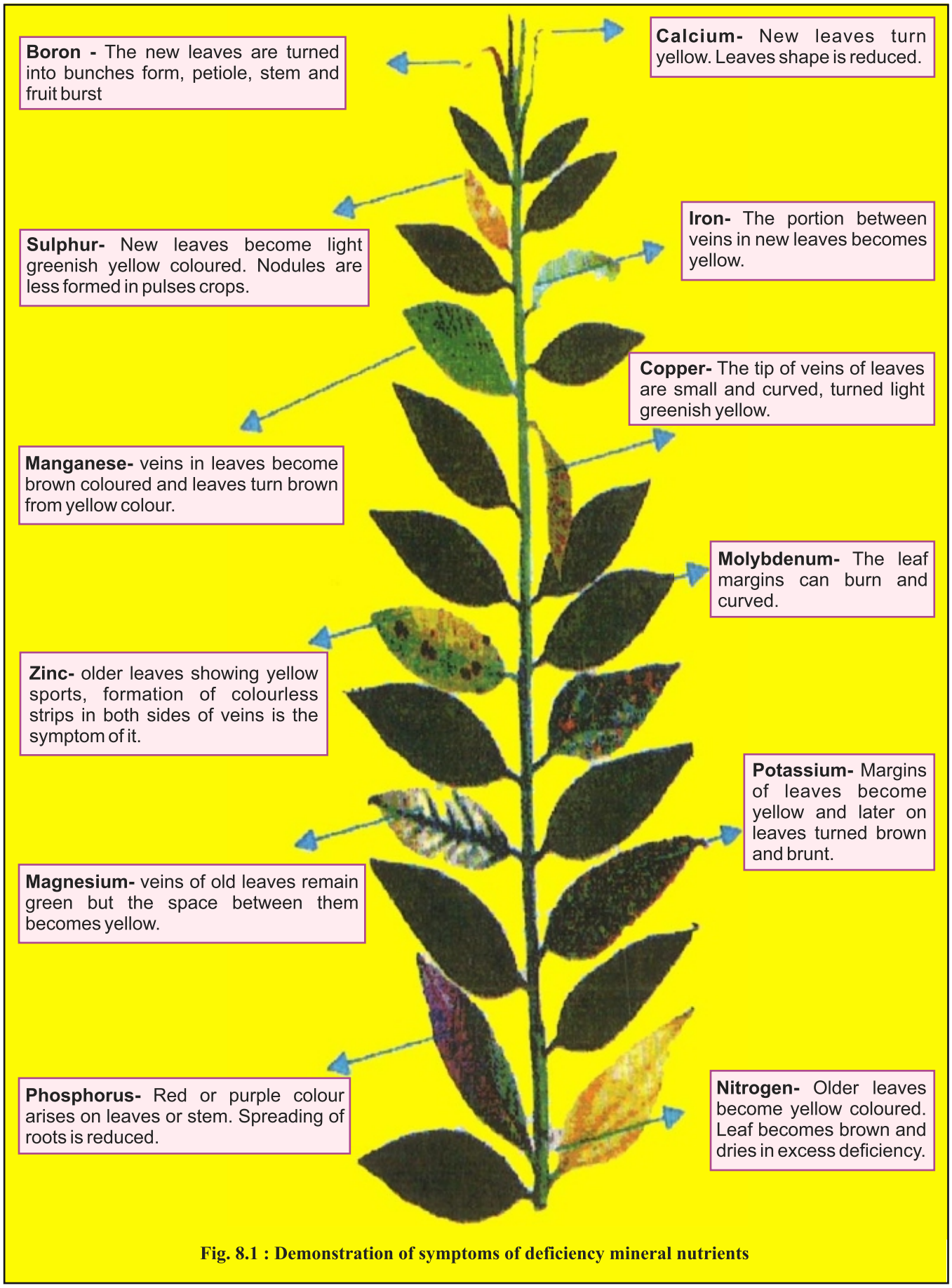

Fig. 8.1 : Demonstration of symptoms of deficiency mineral nutrients

germinations of pollen grains and cell division in plants.

Deficiency Symptoms

(I) Main symptom of boron deficiency is dark green thick leaves.

(ii) Degeneration of storage and succulent tissues.

(iii) Reduction in the number of flowers generally flowers are sterile

13. Zinc (Zn) : This element is absorbed as a bivalent Zn^{++}. This element is component of enzymes mainly carboxylase and also regulates the absorption of phosphorus. It plays a main role in synthesis of plant growth hormone auxin (IAA)

Deficiency Symptoms

(i) White necrotic area are seen in leaves.

(ii) Plants are stunted.

(iii) The perimeter of the leaf is reduced and they become distorted.

(iv) Malformation in phloem.

(v) Main deficiency disease of zinc is little leaf.

14. Cu - Copper : This element is absorbed by roots as bivalent cuperic (Cu^{++}) or univalent (Cu^{+}) cuperous ions. In oxidation reduction process, this element functions as an electron carrier. It is the main component of plastocyanin and cytochrome oxidase which acts as an electron carrier in photosynthesis.

Deficiency Symptoms

(i) Distortion of leaves and whitening of leaf tip.

(ii) Die back disease of citrus appear due to its deficiency.

15. Molybdenum (Mo): This element is often found less in the soil and plants absorb it as Molybdenum oxide (M_OO_2). It is the main factor of enzyme nitrogenase and nitrate reductase that fixes nitrogen.

Deficiency Symptoms

(i) Mottling of lower leaves of the plant is an important feature due to its deficiency

(ii) Chlorosis and reduced flowering

(iii) Due to deficiency of Molybdenum, whiptail disease is seen in cauliflower, in which the leaves become distorted.

16. Chlorine (Cl) : It is present in soil as Cl^- ions i.e. chlorides and it is soluble. Plants readily absorb it. This element is not a component of any biochemical form. As per the functional view, it is helpful in carbohydrate metabolism and balancing electrical charges. The deficiency of the element cause spotted chlorosis in leaves that degenerates the tissue. Later fruit formation is reduced.

17. Nickel (Ni) : Dalton in 1988 included it as an essential element. Nickel is neither the component of main biochemical nor its deficiency effects are known. However, it is the main component of urease enzyme. It is probably available to plants as Ni^{+2}

It is important to know that due to deficiency of mineral elements, deficiency symptoms may first appear on mature or older leaves and in some plants the symptoms may appear in new or young leaves. Element that are mobile, their deficiency symptoms appear first in mature or older leaves while deficiency symptoms for the immobile elements appear first in young/new leaves.

Here, the deficiency symptoms of elements are briefly comiled.

1. Appearance of deficiency symptom in terminal buds .....deficiency of Ca and B
2. Appearance of symptoms in young leaves first (Immobile element) .....

   Cu, S, Fe, Mn
3. Appearance of symptoms in mature leaves first (Mobile element)

   .....N, P, K, Mg, Zn, Mo,

Mechanism of Absorption of mineral salts

According to the diffusion theory the concentration of mineral elements beyond a limit is not possible in a cell. Due to the diffusion gradient, the entry of molecules of mineral substances in cell is possible upto that limit till the concentration in external solution and internal solution reach

equilibrium. Earlier it was believed that mineral substances were absorbed along with water but now it has been proved that these are two different processes. Mineral salts are absorbed from soil as ions by meristematic zone and elongation zone of the root. O1ften the absorption of mineral salt is by the use of metabolic energy thus it is an active process. Mineral salts are absorbed by two processes :-

(a) Passive absorption

(b) Active absorption

(a) Passive absorption :- In this type of absorption the ions on the basis of their electrochemical potential gradient enter the cell without using energy. In this context, three views are given -

(i) Mass flow hypothesis :- According to this hypothesis, due to the effect of transpirational pull, ions are also taken in by the roots along with the mass flow of water.

(ii) Ion exchange theory :- The exchange of cations and anions in definite numbers between the root surface and external solution is termed as ion exchange. Ion exchange takes place among the similar charged ions i.e. cation are exchange for cations and anions are exchanged for anions only. As a result of the exchange many types of cations are absorbed on the surface of root and their transfer in the cell is by passive diffusion.

(iii) Donnan equilibrium theory :- This theory was postulated by Donnan in 1927. It is based on the effect of indiffusible or fixed ions. Donnan equilibrium is also important because it meantions the accummulation of elements against concertration gradient.

(b) Active absorption :- The diffusion of ions against the electrochemical potential on expense of metabolic energy is called active absorption. In this process, ATP is required. There are three views presented for active absorption of ions -

(1) Carrier concept :- That part of cell or tissue in which absorption of ions is due to the expense of energy is termed as inner space. In this space, the absorbed ions are not exchanged but in the outer space the absorbed ions are freely diffused. The region between the outer space and inner space is not permeable for the ions. According to the propounder of this hypothesis Van Den Honert 1937, ions with the help of carriers, combine in outer space and dissociate in the internal space to cross this impermeable region. This process can be explained by the following equations -

1. Carrier + ATP ------> ADP + Activated carrier
2. Activated carrier + ion -------> carrier ion complex
3. Carrier ion complex .----------> passive carrier + ion

(2) Ion pump or cytochrome pump concept : According to Lundergardh and Burstrom 1933, there is a direct relation between respiration rate and anions absorbed. According to them, the process for anions and cations absorption are different. Anions are transferred by cytochromes through the barrier membrane from the outer to inner surface.

Outer surface	Barrier membrane	Internal surface
Anion (-) →	(-) cytochrome pump (-) →	(-) Anion
Cation (+) →	Inactive flow →	(+) cation

(1) Electro Chemical gradient hypothesis : According to the hypothesis postulated by Peter Micheal (1968) the transfer of anions between the outer and inner surfaces of barrier membrane is because of electrochemical potential. In this method ATPase enzyme has a main role.

Hydroponics

All those method in which plants are grown in nutrient solutions except soil are categorised as hydroponics or water culture. Hydroponics is a greek word which means - working with water. Initially sand, nutrient solutions were used but now a days, vermiculite medium is used.

Vermiculite is a mineral substance that is found an earth in natural state. This mineral is heated in special types of furnances upto 2000' F and the product obtained is used to grow the plants.

Features of Vermiculite

1. It is light weighted material
2. It is chemically inert
3. It is a sterile material in which insects and weeds do not grow.
4. It has more water absorption capacity than soil
5. It has loose texture i.e. it does not obstruct the growth of root system.
6. It does not dissociate. Thus, it can be used continously to grow crops. Thus, now a days vermiculite is used to grow plants and this technique is called Vermiculoponics.

Important Points

1. Plants need many substances from the environment to complete their life cycle, these substances are called nutrition of living being.
2. D. Sausar in 1804 was first to give evidence that plants are dependent on minerals for nutrition.
3. Plant ash analysis sand culture and water culture are main methods for the study of mineral nutrition.
4. Number of essential nutrients elements for plants are 17: out of those 9 are macro and 8 are micro nutrients elements.
5. Macro nutrients element are 9 : C, H, O, N, P, K, S, Mg and Ca and micronutrient element are 8 : Fe, B, Mn, Cu, Zu, Mo, Cl and Ni
6. In plant nutrition macro and micro elements play an important role.
7. Due to deficiency of nutrient elements in plants many symptoms are developed. Chlorosis, necrosis stunted growth etc are deficiency symptoms.
8. Cu, S, Fe, and Mn are immobile whereas N, P, K, Zn, Mg, Mo are mobile elements.
9. Mineral elements are usually absorbed by active absorption process by plants in which metobolic energy is spent, Some amount of absorption is also by passive absorption.
10. The active absorption process of minerals is explained by three methods- Carrier concept, Cytochrome pump concept and Electrochemical gradient hypothesis
11. The passive absorption process of minerals is also explained by three concepts :- Mass flow hypothesis, Ion - exchange theory, Donnan equilibrium theory.

Practice Questions

Multiple choice questions-

1. Which of the following elements are called micronutrients :
   (a) Mo, Cu, Zu, Ca
   (b) Mg, S, K, P
   (c) Mn, Zn, Ca, Mg
   (d) Mn, Mu, Cu, Zn
2. Chlorophyll has -
   (a) Fe (b) Mn
   (c) Mg (d) K
3. Main function of Mo is :
   (a) Flowering
   (b) Nitrogen fixation
   (c) Water absorption
   (d) Photosynthesis
4. Little leaf disease is due to deficiency of which element?
   (a) Zn (b) Mg
   (c) B (d) S
5. Which element is most important for carbohydrate transfer in plants :
   (a) Fe (b) Mn
   (c) B (d) Zn
6. The number of essential nutrient elements required by plants for normal growth and completion of their life cycle are -
   (a) 105 (b) 60
   (c) 27 (d) 17

7. Immobile nutrient element are :

(a) Cu, S, Fe, Mn

(b) Ca, B, Cu, S

(c) N, P, Fe, Mn

(d) P, K, Zn, Mo

Very short answer questions-

1. In which form do plants absorb nitrogen ?
2. Mention the name of primary macro nutrients.
3. Explain the terms : Verniculite and hydroponics.
4. Fe and Cl are absorbed from the soil in which form?
5. What do you understand by mineral salt absorption ?

Short answer questions-

1. Explain the plant ash analysis.
2. Describe the utility of nitrogen and its deficiency symptoms.
3. Differentiate between passive and active salt absorption
4. Explain chlorosis and necrosis

Essay answer questions-

1. Write short note on mineral nutrition in plants.
2. Mention the essential elements for plants and explain the function availability, form and deficiency symptoms of any four elements.
3. Explain in detail about the process of mineral salt absorption.
4. Write an essay on macro nutrient elements.
5. Write an essay on micro nutrient elements.

Answer Key-

1. (d) 2. (c) 3. (b) 4.(a) 5.(c) 6. (d) 7. (a)