1. MINERAL NUTRITION

1-1 INTRODUCTION

Plants take up mineral elements in the form of inorganic ions dissolved in soil solution. Out of 92 naturally occurring elements, only limited number of elements are essential to plants. Actually some 60 elements are found in plants. Most of the soil elements are not readily soluble in water. Roots exhibit selectivity in the uptake of mineral elements.

Carbon, hydrogen and oxygen are the most abundant elements present in the plant on weight basis. The Chemical composition of the plant is determined by Ash analysis. As carbon hydrogen and oxgen are given off as gases, the composition of the plant is determined by ash analysis. It revealed smaller amounts of Nitrogen followed by several other elements even in lesser concentrations. These mineral elements make up about 5% plants of dry weight. Out of them, 16 mineral elements are considered as essential elements.)

The list of essential elements has been built up over many years and perhaps even now not complete. By mid 18th century it was established that plants obtained minerals from the soil and natural waters.In the 19th century development of sand culture and water culture techniques led to recognition of most important elements. Sachs (1960) by means of water culture experiments showed that Nitrogen, Sulphur, Phosphorus, Calcium, Potassium, Magnesium, Iron are essential for a number of plants. The current list of essential elements for flowering plants stands at 17-20. However the precise number depends upon the species. Some elements appear to be essential for certain plants only.

1-2 ESSENTIAL AND NON - ESSENTIAL ELEMENTS

The essential elements are classified as **macro nutrients** and **micronutrients**. The macro nutrients are required in large concentrations (1000 μ.g g^{-1} of dry matter) while micro nutrients are required in small concentrations (100 μg. g^{-1} of dry matter). In addition to essential elements, beneficial elements are recognised. These are not necessary for survival but they do promote plant growth. eg. Cobalt, Vanadium, Sodium. Aluminium is beneficial to Tea. Rubdium and strontium can replace Potassium and Calcium upto some extent. Selenium is beneficial to some plants.eg. *Astragalus, Lupinus*. Non essential elements are taken up by plants. Any element present in the environment will be found in small amounts in plants. Aluminium, Silicon and Sodium are found in plants. Though non essential they influence the ionic balance and osmotic potential of cells. Many non essential elements are toxic in very low cocnentration. Their uptake is hazardous to plants and animals which feed on them.

1-3 CRITERIA OF ESENTIALITY

Plants contain about 60 elements. However only about 16 elements are necessary for the growth of the plant. The remaining elements are taken up because they happen to be present in the soil solution. The problem of esentially is approached by growing plants in complete absence of a given element. If the plant grows normally, the element is evidently non essential. If it fails to grow normally the element is considered as essential. Early workers could recognize a small range of elements due to difficulties in conducting experiments. They encountered impurities in culture medium, in the salts and even in the vessels. Sachs established the technique of water cultures of plants which eliminated many difficulties with impurities. In order to be certain that the elemenis truly essential, Arnon and Stout (1939) proposed the criteria of essentiality. The three requirements are

(1) The element must be essential for normal growth and reproduction.

(2) The element can not be substituted by another element.

(3) The concerned element should directly be involved in some function within the plant.

These criteria are rather strict and some liberality is required in their application. Plants show variation with reference to their composition and needs. Thus an element may be essential under certain circumstances but impossible to detect a requirement under other conditions It is extremely difficult to demonstrate the non essentiality of an element. Certain micro nutrients may be required in concentrations which the most careful analysis could not detect because of level of impurity in the culture solution. Unless the deficiency can be demonstrated and relieved by the addition of elements, its essentiality can not be proved. On the other hand its non essentiality can not be proved due to the inability to demonstrate a deficiency.

An element is considered as essential if deficiency symptoms appear on plants, when plants are grown without addition of the element to the nutrient solution (even though such plants form viable seeds). This criterion led to evidence that sodium and silicon are essential for some plants.

1-4 ESSENTIAL ELEMENTS

By applying the above criteria it is established that 16 elements are essential for plants. The essential elements are classified as Macronutrients and micro nutrients. 9 macro nutrients are required in large quantities where as 7 micro nutrients are required in small quantities. The macro elements are Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, Phosphorus, Calcium Potassium and Magnesium while the micro nutrients are Iron, Manganese, Boron, Copper, Zinc, Molybdenum and Chlorine.

1-5 NATURITIONAL DEFICIENCY SYMPTOMS

Essential elements, carryout specific functions in the plant. If any element is lacking in the plant, normal physiology of the plant is upset. The nutritional deficiency symptoms are :

(1) *Chlorosis* : A pale green or yellow colour develops due to failure of leaves to produce normal amount of chlorophyll.

(2) *Necrosis* : Death of localised tissues such as leaf tips or margins or formation of spots.

(3) *Stunted growth*

(4) *Mottling of leaves.*

(5) *Curling of leaves*

(6) *Premature drying* and *withering of leaves*

(7) *Premature fall* of *leaves, flowers and fruits.*

Generally symptoms are first noticed in older leaves and then in younger leaves. Potassium, Nitrogen, Magnesium are called *mobile elements* as their symptoms appear first in older leaves. Some elements are *immobile* and they are not translocated from older to younger leaves. Their deficiency causes symptoms of deficiency in younger leaves. Eg. Calcium. Sulphur and micro nutrients except Zinc.

The elements found in plants are divided into groups based on their function.

They are named as

(1) Frame work elements ; (2) Protoplasmic elements.

1. Frame work elements : Carbon, Hydrogen and Oxygen come under this category they constitute 90% or more of the dry matter of the majority of plants. They are present as major constituents of protoplasm, reserve foods Cellulose, lingnin etc.

2. Protoplasm elements : Nitrogen, phosphorus, Sulphur contribute to the protein and other compounds of the protoplasm. Calcium and Magnesium are also included in this group though they have other uses.

These protoplasmic elements are divided into two groups or types based on their functional aspects.

Type-I : Balancing elements : These are mainly concerned with ionic balance in the plant Examples are Mg, Ca, K, Na, Cl, Chlorine functions as "anion" in ionic balance

Type-II : Catalytic elements : Elements like, Cu, Zn. Mo, Mg, Fe, Cl, B act as Catalytic agents. They also may help in enzyme formations.

Classification of Plant Nutrients :

Generally, the classification depends on their

(a) mineral composition

(b) Concentration (macro 0.02 - 6.0%) and Micro (0.01-500 mg/kg)

(c) Physiological functions

Psychological Groups of Nutrients : Six groups are recognised. They are

Group-I : Constituents of various organic or in-organic compounds. This group includes N, P, S, Ca, B, Fe, and Mg.

Group-II : Activators of Enzymes. This group includes K, Mg, Ca, Fe, Zn, Mn, Cu, Mo, Na, and Cl.

Group-III : Includes components of Redox-systems and electron transport. P, S, Fe, Mn, Cu, Mo. are included in this group.

Group-IV : Includes osmotic regulators and ionic balancing elements They are K, Na, and Cl etc.

Group-V : Includes stimulating elements They are Co, Cr, Ni, Sn. Li, Fe, Se, Si etc.

Group-VI : Includes toxic heavy metals and other elements like Cd, Cr, Hg, Ni, Se, etc.

1-6 ESSENTIAL ELEMENTS - FUNCTIONS AND DEFICIENCY SYMPTOMS

A *Macro elements :*

1. Carbon, Hydrogen and oxygen : These elements are not mineral in origin. They enter into the composition of practically all organic compounds of the plant. Carbon is absorbed in the form of CO_2 from air. Oxygen is derived from water as well as air. Hydrogen is obtained from water. These elements constitute the major part of dry weight of the plant (Carbon 45%, oxygen 43%, Hydrogen 6%)

2. Nitrogen : After Carbon, hydrogen and oxygen, nitrogen is the fourth abundant element in plants (1·5%)

Source : Nitrogen is abundantly present in the atmosphere but plants obtain nitrogen from the soil in the form of nitrates and ammonium salts. Some bacteria and blue green algae can utilize atomospheric nitrogen.

Functions : Nitrogen is a component of proteins, amino acids, nucleic acids, enzymes, coenzymes, chlorophylls, alkaloids, and plant harmones. Some vitamins also contain nitrogen.

Deficiency : Nitrogen deficiency causes yellowing of leaves (chlorosis). Yellowing starts from older leaves and progresses to young leaves. Lower leaves fall off. Anthocyanin pigment develops in stem, leaf veins and peteoles which become red or purple(eg. Tomato). Flowering may be delayed and fruits are underdeveloped. Plants supplied with excess of nitrogen show dark green succulent leaves, weak stems and vigorous vegetative growth.

3. Sulphur : It is present 0·1% approximately in the makeup of the plant.

Source : It is absorbed from the soil in the form of sulphate. Little quantities sulphur dioxide enter through stomata when present in polluted air.

Functions : Sulphur is an important constituent of amino acids like cystine cysteine and methionine. It is found in vitamins like Thiamin and Biotin and coenzyme A. It is present in many enzymes as sulphahydryl groups. It imparts pungent odour to mustard family (Brassicaceae), onion and garlic. It favours root formation, chlorophyll formation, fruit formation and cell division.

Deficiency : Sulphur deficiency seldom occurs in natural conditions as SO_4^- is abundant and is taken up by the plant. The deficiency is known mainly from the solution culture experiments. The symptoms are characterised by yellowing of younger leaves. Stems become slender and roots are larger. *Tea yellows* is due to sulphur deficiency in Tea plants.

4. Phosphorus : Approximately phosphorus constitutes 0·2% in the composition of the plant

Source : Phosphorus is taken up by plants in the form of ions $H_2PO_4^-$ and HPO_4^-.

Function : It is a constituent of nucleic acids. Phospholipids, coenzymes like NAD, NADP and energy rich compound ATP. The highest percentage of phosphorus occurs in the meristematic regions.

Deficiency : The symptoms of phosphorus deficiency are not so marked as in the case of nitrogen deficiency. The phosphorus deficient plant is stunted in growth leaves are dark green in color, a tendency to develop purple or reddish anthocyamin pigments. These symptoms may be accompanied by the appearance of necrotic spots on leaves, petioles or fruits resulting in leaf fall.

5. Calcium : Calcium is approximately 0·5% in the chemical composition of plants.

Source : Calcium is absorbed as Ca^{2+} ions. It is abundantly present in the soil and soil is seldom deficient in it.

Functions : Calcium is important in the synthesis of middle lamella of cell wall It is associated with phospholipids of cell membrane as Ca^{2+} ions. It is necessary for maintenance of permeability of membranes. It functions as activator of some enzymes like amylase, ATP ase and phospholipase. It is necessary in small amount for mitosis.

Deficiency : Lack of calcium causes rapid death of growing regions of shoot and root in many plants Malformation of young leaves, chlorosis of young leaves along margins, stunted roots, reduced flowering and fruiting take place, Deficiency of symptoms appear in younger leaves. Hooking of leaf tips due to distortion detected in younger leaves.

6. Potassium : Potassium present in the plant is about 1% of the dry weight of the plant.

Source : Potassium is an exchangeable cation. Plants absorb K^+ ions in large amounts. It has no structural role in plants i.e., it does not enter the composition of any organic compound. However it is essential for functioning of about 40 enzymes as an activator. It is abundantly present in young parts like buds, root tips than in old parts. The specific function of potassium in plants is not clearly known. Potassium deficiency affects respiration, photosyntheses and chlorophyl development. The best known function of Potassium ions is its role in stomatal opening and closing.

Deficiency : Potassium deficiency results in yellowing of leaves (mottled chlorosis) starting in older leaves and spreading to younger leaves. This leads to development of necrotic areas along the margin and tips of leaves. As in all deficiencies growth is retarded and stems are weak so that plants are readily bending i.e., lodged - eg, cereals

7. Magnesium : Magnesium constitutes 0·2% of the dry weight of the plant

Source : Magnesium is absorbed as Mg^{2+} ions from the soil.

Functions : Magnesium is a component of chlorophyll without which photosynthesis would not occur. Magnesium pectate occurs in the middle lamella. The binding of two sub units of ribosomes during protein synthesis is controlled by Mg^{2+} ion concentration. It is an activator of enzymes involved in the synthesis of nucleic acids, ATP molecules and carbohydrate metabolism. It activates phosphate transfer enzymes.

Deficiency : Yellowing of leaves develops from the base of the plant to the younger leaves. It is referred to as interveinal chlorosis. After chlorosis, leaves become coloured due to anthocyanin pigment. Later necrotic spots develop resulting in death of the leaf.

Micro nutrients :

Mineral elements which are required in small quantities are called as trace elements or *micro nutrients*. Their requirement ranges in between 0·1 to 100 pm.

1. Micronutrients are specific and they can not be substituted by others.
2. They play a direct role in metabolism
3. Plants do not show normal growth in the absence of these elements.

The essential micro elements or *trace* elements are Iron, Manganese, Boron, Copper, Zinc, Molybdenum and Chlorine. The precise manner in which the micro nutrients affect the various metabolic processes is not known. But in all plants they are essential for normal growth and functioning .

1. Iron (Fe) : It is often considered as a macro-element because its requirement is relatively higher than any other micro-nutrient. It is present approximately 0.01% of total concentration in dry tissue of plant.

Source : It is absorbed as ferrous or ferric ions. The ferrous state (Fe^{2+}) is physiologically active in plants. It is abundant in acidic soils.

Functions : Iron is essential for the synthesis chlorophyll eventhough it is not one of its constituents. It is an important constituent of cytochromes, catalases and peroxidases which play an important role in respiraion. It is a component of ferredoxin and enzyme nitrogenase.

Deficiency : The characteristic symptom of deficiency of iron is extensive chlorosis in young leaves. The yellowing iron chlorosis sets in quite suddenly because iron unlike nitrogen is not mobile. So it can not be withdrawn from older leaves. The leaves show interveinal chlorosis. The chlorotic leaves do not die at once as in other deficiency induced chlorosis. They remain on the plant as a terminal cluster of white leaves.

2. Manganese : Manganese constitutes 0·005% of the plant.

Source : It is absorbed as Mn^{2+}. Mangenese is deficient in alkaline soil because it is converted as unavailable form.

Function : It is an activator of enzymes of respiration and nitrogen metabolism. For example malic dehydrogenase an enzyme of Kreb's cycle requires Manganese as an activator. It is involved in the photosynthetic split of water. Although it is not a constituent of chlorophyll, it appears to be connected with chlorophyll formation.

Deficiency : The symptoms of Manganese deficiency are chlorosis and necrotic spots on older leaves. Manganese deficiency occurs in alkaline soils but not in acidic soils. In leguminous plants seedlings show necrosis. *Grey speck* of oats, *marsh spot* of Peas, *speckled yellows* of sugar beet are due to Manganese deficiency.

3. Boron : The concentration of Boron constitutes 0·002% of the dry weight of the plant.

Source : Boron is abosorbed as borate ions ($H_2BO_3^-$). It is present in small amounts in the soil.

Function : The importance of Boron in plant metabolism is not fully understood. Boron is involved in translocation of sugars, in synthesis of DNA in meristems.

Deficiency : Boron deficiency causes death of shoot tips. The leaves show thick coppery texture and curling. Flowers do not form and root growth is stunted. In storage organs disintegration and browning of internal tissues results.

eg. *heart root of sugar beet, Corky core of apple,* In *water core of turnip and top sickness of tobacco* growth of plant is arrested due to non production of new leaves.

4. Copper : Copper constitutes 0·0006% of dry weight of the plant . Excess of copper is toxic to plants

Source : Copper is absorbed as cupric (Cu^{2+}) ions. Excessive application of phosphate fertilizer reduces the availability of copper to plants. Its deficiency is common in fruit orchards.

Function : Copper plays a catalytic role. It is a constituent of several oxidising enzymes such as ascorbic acid oxidase. Cytochrome oxidase, tyrosinase, phenolase. It is present in chloroplasts i.e., in plastocyanin an important electron carrier in photophos-phorylation.

Deficiency : Young leaves show withering of tips which leads to loss of leaves. Plants may wilt even when water is supplied. *Exanthema* is a disease of fruit trees in which gum exudates (gummosis) accompanied by die back and glossy brown blotches on leaves and fruits.

5. Zinc : In plants the dry weight of zinc constitutes about 0·002%.

Source : Zinc is widely available in the soil but if pH of soil increases, it becomes less available. As a result Zinc deficiency is common especially in citrus orchards and alkaline soils.

Function : Zinc is involved in the synthesis of Indole Acetic acid (IAA). It is an activator of several enzymes such as alcohol dehydrogenase, pyridine nucleotide dehydrogenase and hexo kinase.

Deficiency : The first sign of zinc deficiency is interveinal chlorosis of older leaves starting at tips and margins. In severe zinc deficiency leaves become small, internodes are shortened resulting in stunted growth. Leaves are distorted, smaller sized and cluster as rosettes. The zinc deficiency is known as *little leaf disease* eg. Little leaf and rosettes of apples, peaches. *White bud of* Maize is a zinc dificiency in Maize. It is characterised by stunted growth, reduced flowering and fruiting *Mottled leaf of Citrus, sickle leaf of Cocoa* are also due to zinc deficiency.

6. Molybdenum : It is present in minute quantity comprising 0·00001% of dry weight.

Source : It is readily absorbed from soils with high pH. It is available in the form of molybdate (MoO_4^-) in the soil. It is in short supply in acidic, sandy and granite soils.

Function : It has important role in Nitrogen fixation and nitrate reduction. It is an activator of nitrate reductase. Molybdenum deficiency leads to drop in the concentration of ascorbic acid. Hewitt (1963) observed that it causes chloroplast disorganisation leading to *whip tail disease.*

Deficiency : Chlorotic interveinal mottling of lower leaves, followed by necroses of margins leads to infolding of leaves. In *whip tail disease of cabbage* and cauliflower plants do not become chlorotic but develop severely twisted young leaves

7. Chlorine : Chlorine is about 0·01% in the dry weight of the plant tissue.

Source : Chlorine is available as chloride (Cl^-) ions in the soil.

Function : It remains in the form of Cl^- in the plant without becoming the structural part of the organic molecules. It stimulates the split of water during photosynthesis. It is essential for turgor control by being associated with Na^+ and K^+.

Deficiency : In the absence of chlorine roots are stunted, leaves wilt and fruiting reduced. Leaves show chlorotic and necrotic spots and bronze color (Bronzing).

In Recent times, plant physiologists, based on modern research and new techniques, making changes in the list of Micro-nutrients. On account of these modifications certain elements like sodium, Cobalt, Silicon and Nickel are included in the list of micro elements.

The details of these newly added elements and their composition, functional and deficiency symptoms in relation to plants are described below, element wise, though they are described in detail under *"Beneficial Elements"*.

1. Sodium (Na) : It is a trace element. Plants absorb it in the form of Na^+ ions.

Physiological functions :

(a) It can substitute for potassium in osmotic systems.

(b) It is required for Carbon fixation for C4 and CMP pathways.

(c) It regulates the transport of aminoacids.

Deficiency symptoms :

(a) Chlorosis and Necrosis

(b) Reduction in Cellsize.

(c) Failure of flower production.

2. Cobalt : It is a trace element. Plants absorb it in the form of CO^{2+} ions.

Physiological functions :

(a) plays important role in N_2 fixation

(b) Component of Vit. B_{12}.

(c)Enzyme activator (carboxylases and Pepstidases).

Deficiency symptoms :

(a) Yellowing of Leaves

(b) Inhibition of growth.

3. Silicon : It is a common element in a majority of plants and specifically present in Grasses, Diatoms.

Physiological functions :

(a) Component of cell walls.

(b) Growth activator (eg. Diatoms)

(c) Inhibits Toxicity.

Deficiency symptoms :

(a) Inhibition of Growth

(b) Fall in Transpirational rates

(c) Reduction in Reproductional rates

4. Nickel : It is a trace element. It is absorbed in the form Ni^{2+} Ions. Physiological role is limited. It acts as a cofactor for Uride metabolism in plants.

Deficiency symptoms :

(a) Leaf Tip Necrosis.

Useful (or) Beneficial elements :

In addition to essential elements, few other elements like Sodium, Aluminium, Cobalt, Selenium, Silicon, Vanadium etc are recognised as useful to certain plants. And they are described as "*Beneficial Elements*". These are, not necessary for survival plants but they do promote plant growth. Few of them and their activities in plant growth are described below.

1. Aluminium : It is beneficial to Tea plant. Manyplant species like Maize, Sunflower, peas, cereals, hydrophytes and grasses respond to the small quantities of Aluminium. It also acts as a catalyst in some reactions in plants.

2. Sodium (Na) : It can replace potassium in certain plants to some extent. It is useful for the growth of many crop plants . It exhibits specific requirement to certain xeroplytic plants.

(eg :Atriplex vesicaria), halophytes.

(eg :Halogeton glomeratus), CAM plants

(eg : Bryophyllum) and certain C_4 Plants

The deficiency of Na in these plants affects reproductive growth phase.

3. Cobalt : Its requirement to plants is very low. Cobalt helps Blue Green algae, Bacteria, Legumes in Nitrogen fixation. Beneficial effects of cobalt are specifically seen on Tomato and Rubber plants. Cobalt is a component of Vitamin - B_{12}. It is also related to compounds of Carbohydrate metabolism.

4. Selenium : Certain plants like Astragalus, Haplopapus, xylorhiza absorb and accumulate Selenium. This helps these plants to avoid or reverse the toxic effects phosphate. These plants grow well when grows in Selenium cultures. Also Selenium acts as a substitute for Sulphur in these plants.

Selenium in certain plant behaves as a substitute or as an alternative to elements like Strontium, Calcium, Venedium Molybdenum in their metabolic activities.

5. Silicon : It is a common element in majority of plants and mostly found in grasses, Diatoms. Deficiency of silicon affects growth in Diatoms and Crop plants like Rice, Tomato, Also silicon deficiency reduces transpirational rates and reproductive growth in Rice and Tomato plants. This element also protects plants from pathogen attacks like Rust, mildews etc by its deposition on the cell walls acting as extra covering.