6.3. ESSENTIAL AND NON-ESSENTIAL ELEMENTS

All the 40 elements obtained by the analysis of plant ash are not essential for the nutrition of plants but a few are essential for the growth and development of plants. Other elements are non-essential. It is known since ancient times that C, H and O are essential elements for plants. It has been confirmed by water-culture and sand-culture experiments that N, S, P, K, Ca, Mg and Fe are also essential elements in addition to C, H, O, elements. Their deficiencies produce many diseased symptoms. B, Zn, Mn, Cu, Mo and chlorine are also essential elements although they are required in very small amounts in plants. C, H, O, N, S, P, K, Ca, Mg, Fe, B, Mn, Zn, Cu, Mo and Cl are sixteen essential

elements discovered so far and others which are not required for the growth and development of plants are called *non-essential elements.*

Essential elements are divided into following two groups depending upon their requirement.

(1) *Macronutrients = Macroelements = Major elements*

Those elements which are required in large quantities (more than 100 mg/litre of water) are called *macronutrients* or *macro-elements*. They usually participate in body construction and are ten in number (C,H, O, N, S, P, K, Mg, Ca and Fe).

(2) *Micronutrients = Micro elements = Minor elements =Trace elements*

Those elements which are required in smaller quantities (100 or less mg/litre of water) are called *microelements* or *trace elements*. They usually participate in various metabolisms and are six in number (B, Mn, Zn, Cu, Mo and Cl).

6.9. OCCURRENCE AND FUNCTIONS OF ESSENTIAL ELEMENTS

(1) **Carbon (C):** It is obtained from the air in the form of CO_2.

(2) ***Hydrogen*** **(H):** It is obtained from the soil in the form of H_2O.

(3) **Oxygen (O):** It is obtained from air and soil in the form of O_2 and H_2O respectively. C, H and O mainly participate in the formation of protoplasm and cell-wall of plants. Without them, the life is impossible.

(4) **Nitrogen (N):** It is obtained from the soil in the form of nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH_4^+) salts. Insectivorous plants use molecular nitrogen.

(*i*) **Occurrence:** It is found in entire plant body, seeds and food storing regions in both organic and inorganic forms.

(*ii*) **Functions:** (*i*) Protein synthesis, (*ii*) Formation of protoplasm, nucleic acids, purine and pyrimidine bases, chlorophyll, alkaloids, NAD and NADP coenzymes etc.

Deficiency Symptoms

(A) *External Symptoms*:

(*i*) The leaves become yellow. This phenomenon is called *chlorosis*.

(*ii*) Lowering of respiratory rates and reduction in growth.

(*iii*) Poor development of foliage and roots.

(*iv*) Late and less or no flowering.

(*v*) Development of anthocyanin pigment in the stems and petiole and veins of leaves due to which they become red.

(*vi*) Production of erect leaves in grasses, potato, tomato cereals and *Linum* etc.

(*vii*) Necrosis (death) of tissues at advanced stage.

(B) *Anatomical Symptoms*:

(*i*) Deposition of excess amount of lignin on the cell-walls.

(*ii*) Increase in starch contents and decrease in protein contents.

(*iii*) Cells become smaller and thick walled.

(*iv*) Reduction in the size of nuclei and cell-lumen.

(5) **Sulphur (S)**

(*a*) *Source*: It is obtained either from soil solution in the form of sulphate (SO_4^{--}) ions or through the activity of micro-organisms by biological oxidation.

(*b*) *Occurrence*: Sulphur is found in all the parts of plants in both organic and inorganic forms. In organic forms it is present in amino-acids like *Cysteine*, *Cystine* and *Methionine*, in respiratory pigment as *glutathione*; in *glucosides* and also in mustard oil. In inorganic form, it is present in the form of sulphate ions.

(*c*) *Functions of Sulphur*

(*i*) Formation of sulphur-containing amino-acids like cystine, cysteine and methionine.

(*ii*) Synthesis of sulpur-containing vitamins like *biotin thiamine* and *coenzyme-A*.

(*iii*) It imparts distinctive odour and flavour to garlic, onion and mustard oil.

(*iv*) Increases growth, cell-division and fruiting.

(1) *External deficiency Symptoms*: These symptoms resemble to that of nitrogen. The main among them are :

(*i*) Creates hindrance in chlorophyll formation resulting in chlorosis.

(*ii*) Retards cell division and growth.

(*iii*) Development of anthocyanin pigment in the stem and leaves.

(*iv*) Suppression of fruit formation and delaying in ripening.

(2) *Anatomical and Chemical Changes Symptoms*

(*i*) Reduction in the number of stroma lamellae and increase in number of grana lamellae in chloroplasts (*Hall et. al.*, 1972).

(*ii*) Accumulation of starch, sucrose and soluble nitrogen in tomato and sunflower plants (*Eaton,* 1942, 51).

Other symptoms resemble with nitrogen.

(6) Phosphorus (P)

(1) *Source*: It is obtained from soil solution in the form of phosphate ions ($H_2PO_4^-$ and HPO_4^{--}).

Occurrence: Phosphorus is more abundantly found in the meristematic tissues and storage regions as fruits and seeds. In inorganic form, it is found in the form of $H_2PO_4^-$ and HPO_4^{--} while in organic forms, it is present in nucleic acids (RNA, DNA), in phospholipids, hexose phosphates, coenzymes NADP, NAD and ATP, GTP, CTP etc.

Functions: (*i*) Synthesis of nucleoproteins.

(*ii*) Formation of ATP, NAD and NADP which are involved in photosynthesis, respiration, synthesis of fatty acids and proteins etc.

External Deficiency Symptoms: The deficiency symptoms of phosphorus resemble with nitrogen but they are comparatively less developed. The main deficiency symptoms of phosphorus are :

(*i*) Plants show stunted growth due to abnormal cell-division.

(*ii*) Favours healthy root growth by helping the translocation of solutes.

(*iii*) Development of dead necrotic spots on the leaves, petioles and fruits which ultimately cause falling of the leaves.

(*iv*) Promotes fruit ripening.

(*v*) Reduction of nitrates is checked resulting in slow down of protein synthesis.

(*vi*) Development of anthocyanin pigmentation.

Internal Deficiency Symptoms

(*i*) Hinders cambial activity.

(*ii*) Lignification.

(*iii*) More development of pith and reduction of vascular tissues.

(*iv*) Elements of xylem and phloem become thin-walled.

(*v*) Accumulation of carbohydrates.

(*vi*) Production of large-sized intercellular spaces in the stem due to necrosis of pith cells.

(7) Potassium (K)

(1) *Source*: It is found in soil solution in non-exchangeable or fixed form and in the cell in free ionic form.

(2) *Occurrence*: It is found mostly in all cells except cork-cells. It is most common in

cytoplasm and vacuoles, more abundant in apical meristems of roots and shoots, and absent from nucleolus and nucleus.

(3) *Functions*: It is supposed that potassium does not participate directly in the formation of organic compounds present in plants but plays important roles in respiration, photosynthesis, development of chlorophyll and acts as inorganic catalyst in various processes. It plays following important roles:

(*i*) Maintains water-balance and hydration of protoplasm and controls permeability of cytoplasm.

(*ii*) Controls enzymatic activities of various enzymes like diastase, catalase, reductase and invertase.

(*iii*) Antagonises the toxic effects of calcium.

(*iv*) Plants become fleshy and succulent in its proper supply.

(*v*) Affects the synthesis of sugars, starches, fats and proteins.

(*vi*) Adds in enzymatic hydrolysis of starch and hence essential for manufacture and translocation of carbohydrates (*White*, 1936).

(*vii*) Neutralises the effects of organic acids.

(*viii*) Enhance meristematic activity.

(4) *External Deficiency Symptoms*

(*i*) Foliage leaves become yellow at the margins and roll inward and their tips curve downward (mottled chlorosis).

(*ii*) Plants become less resistant to pathological diseases.

(*iii*) Growth become stunted and internodes become very much short.

(*iv*) Occurrence of leaf wilting and abscission.

(*v*) At early stage, the leaves become slender and light-green.

(5) *Internal Deficiency symptoms*

(*i*) Mechanical tissues remain poorly developed.

(*ii*) Phloem elements degenerate.

(*iii*) More lignification of cells.

(*iv*) Reduction in the activity of secondary meristematic and cambial meristematic tissues.

(*v*) Cell walls of pericycle and collenchyma become thick.

(*vi*) Accumulation of starch grains in cortex, phloem, medullary rays and pith as in tomato stem.

(*vii*) Exessive proteolysis (*Malavolte et al.*, 1955).

(*viii*) Xylem becomes parenchymatous.

(8) Calcium (Ca)

(1) *Source*: In soil, it is present in the form of cations or in mineral salts like anorthite ($CaAl_2Si_2O_8$) and calcite ($CaCO_3$).

(2) *Occurrence*: It is abundantly found in leaves, fruits and seed-coats. In middle lamella of cell-wall, it is found in the form of calcium pectate and in the leaves of **Ficus** sp. and other plants it is present in the form of calcium carbonate and calcium oxalate respectively. Leguminous plants contain higher percentage of calcium while grasses contain comparatively lower percentage.

(3) *Functions*

(*i*) It is the main constituent of middle lamella of cell-wall in the form of calcium pectate.

(*ii*) Maintains the semipermeable nature of plasma membrane.

(*iii*) Initiates the development of root hairs.

(*iv*) Neutralises the organic acids like oxalic acid.

(v) Ca antagonises the toxic effect of certain mineral salts like NaCl in acidic soil.
(vi) Formation of lipids and cell-membrane.
(vii) Helps in the binding of nucleic acids with protein.
(viii) Activate phospholipase, arginine kinase and ATP.
(ix) Helps in the metabolism of fats.
(x) Transportation of carbohydrates and amino-acids.
(xi) Helps in the formation of chromosomes.

(4) *External Deficiency Symptoms*

(i) Poor development of root hairs.
(ii) Chlorosis occurs at the leaf tips and necrosis at the margins.
(iii) The roots become short, stubby and brown.
(iv) Absorption of nitrate is reduced and as such the rate of protein synthesis is retarded.
(v) More absorption of Mg takes place resulting in toxic effect and dying of plant.
(vi) Cell-walls remain weaker due to decrease in the cell-cytoplasm.
(vii) Hooking of leaf tip and leaf-apex killed.

(5) *Internal Deficiency Symptoms*

(i) Incomplete separation and lumping of chromosomes during cell-division.
(ii) Cell-walls become rigid or brittle with the break down of middle lamella.
(iii) Decrease in the cytoplasm of cells occurs resulting in weakening of cell-wall.
(iv) Protoplasm becomes more granulated.
(v) Cells of the shoot apex become enlarged and vacuolated.

(a) Magnesium (Mg)

(1) *Source*: It is present in the soil solution in the form of magnesite ($MgCO_3$), dolomite ($MgCO_3$. $CaCO_3$), and olivine [$(MgFe)_2$ SiO_4].

(2) *Occurrence*: It is mainly found in the leaves, seeds, fruits and meristematic cells. The oily seeds (castor) contain more Mg as compared to starchy seeds (wheat and barley). Leguminous plants contain a higher percentage of Mg than grasses. In organic form, it is present in chlorophyll while in inorganic form it is present in cytoplasm.

(3) *Functions*

(i) Chief role is the formation of chlorophyll.
(ii) Activates the enzymes of carbohydrate metabolism.
(iii) Helps in the binding of ribosomal subunits during protein synthesis.
(iv) Helps in fat synthesis and nucleoprotein synthesis.
(v) Activates the enzymes participating in phosphate transfer processes.

(4) *External Deficiency Symptoms*

(i) *Interveinal chlorosis*: The chlorosis develops from the base of the leaves and then proceeds upward.
(ii) Development of anthocyanin pigment and necrotic spots in the leaves.
(iii) Reduction or ceasing of protein synthesis.
(iv) Reduction in carbohydrate and fat synthesis.

(5) *Internal Deficiency Symptoms*

(i) Cells size is reduced.
(ii) Number of chloroplasts in cells is very much increased.
(iii) Pith cells become smaller.

(10) Iron (Fe)

(1) *Source*: It is absorbed in the form of ferrous ions (Fe^{++}) from the soil solution. In neutral and alkaline soil, it is present in insoluble form while in acidic soil in soluble form.

(2) *Occurrence*: It is found in all the parts of plant and protoplasm but in very small quantities. Its greatest concentration is found inside the vacuoles.

(3) *Functions*

(*i*) Acts as catalytic agent in chlorophyll synthesis.

(*ii*) Helps in the formation of important respiratory enzymes and coenzymes like flavoprotein, iron porphyrin, cytochrome peroxidase and catalase etc.

(*iii*) Formation of ferridoxin which plays important role in biological nitrogen fixation and primary photochemical reaction.

(4) *External Deficiency Symptoms*

(*i*) Occurrence of excessive interveinal chlorosis.

(*ii*) Reduces respiration rate.

(5) *Internal Deficiency Symptoms*

(*i*) Chloroplast formation is checked.

(*ii*) Protein synthesis is stopped.

(*iii*) Accumulation of large quantities of free amino acids and amides.

(11) Manganese (Mn)

(1) *Source*: It is found in the soil in the form of bi-, tri-, or tetravalent ions. Of these ions only bivalent ions are found in soluble state in soil solution.

(2) *Occurrence*: It is found in the plant ash especially in the leaves.

(3) *Functions*

(*i*) It helps in the formation of chlorophyll (*Eyster et al.*, 1958).

(*ii*) Oxidises indole 3-acetic acid (IAA) (*Goldacre*, 1961).

(*iii*) Activates the enzymes of Krebs cycle like malic dehydrogenase and oxalosuccinic decarboxylase and the enzymes of nitrogen metabolism like nitrate reductase and hydroxylamine reductase (*Nason*, 1956; *McElroy et al.*, 1957).

(*iv*) Participates in primary photochemical reaction of photosynthesis (*Arnon*, 1954).

(*v*) Acts as a cofactor in oxidative phosphorylation (*Lindberg* and *Ernster*, 1954).

(4) *External Deficiency Symptoms*

(*i*) Retardation in chlorophyll formation (*Hopkins*, 1934).

(*ii*) Causes interveinal chlorosis and necrosis of leaves.

(*iii*) Retardation in growth as in Pea (*Piper*, 1941).

(*iv*) Formation of seeds slowed down (*Piper*, 1941).

(*v*) Respiratory rate is lowered due to reduction in oxygen carrying power of oxidase.

(*vi*) Retardation in nitrogen assimilation.

(5) *Internal Deficiency Symptoms*

(*i*) Chloroplasts lose chlorophyll (*Eltinge*, 1941).

(*ii*) Disintegration of starch grains as in tomato (*Eltinge*, 1941).

(6) *Effect of Mn when present in excess*

(*i*) Browning of roots and leaves as in barley, wheat, lettuce and tomato (*Williams* and *Velamis*, 1957).

(*ii*) Causes Chlorosis in Pine apple and Citrus (*Haas*, 1932).

(12) Zinc (Zn)

(1) *Source*: It is present in the soil in the form of divalent ions which are released by the weathering of minerals like magnetite, biotite and hornblende.

(2) *Occurrence*: It is usually found in the seeds.

(3) *Functions*

(*i*) Participates in the synthesis of tryptophan and auxins-IAA (*Tsui*, 1948).

(*ii*) Activates the metabolism of enzyme alcohol dehydrogenase (*Vassel*, 1951).

(*iii*) Enhances the production of cytochrome a and b and cytochrome oxidase (*Grim* and *Allen*, 1953).

(*iv*) Involved in the formation of enzyme carbonic anhydrase (*Keilin* and *Mann*, 1940).

(*v*) Participates in protein synthesis (*Possingham*, 1956).

(4) *External Deficiency Symptoms*

(*i*) Depression in chlorophyll formation and development of interveinal chlorosis followed by necrotic spots as in cotton (*Brown* and *Wilson*, 1952).

(*ii*) Results in an increase in the amide and free amino acids, particularly asparagine and glutamine (*Possingham*, 1956, 57).

(*iii*) Decrease in protein synthesis.

(*iv*) Creates hindrance in seed formation.

(*v*) Causes diseases like rosette disease of walnut, mottled leaf disease of walnut and apple, and white bud disease of maize.

(*vi*) Checks growth of vegetative parts particularly size of inter-nodes and leaves is reduced.

(*vii*) Interveinal chlorosis which starts from tips and margins of leaves.

(5) *Symptoms when Zn present in excess*

(*i*) Promotes antibiotic production in **Fusarium** (*Kalyansundarum* and *Saraswathi Devi*, 1955).

(*ii*) Promotes nicotine production in tobacco plants (*Steinberg* and *Jeffery*, 1956).

(13) Boron (B)

(1) *Source*: It is present in the soil in the form of boric acid, calcium and manganese borate and silicates. It is always absorbed in the form of borate anions or tetraborate ions.

(2) *Occurrence*: The percentage of boron is higher in woody plants than herbs.

(3) *Functions*

(*i*) Boron helps in easy transport of sugar in phloem which ultimately implicates in various metabolic activities of plants.

(*ii*) Changes the concentration of vitamin C.

(*iii*) Helps in the metabolism of nitrogen, phosphorus, fats and hormones.

(*iv*) Helps in the absorption of salts and in photosynthesis.

(4) *External Deficiency Symptoms*

(*i*) Causes death of shoot and root apex.

(*ii*) Checks flowering.

(*iii*) Leaf veins become copper coloured.

(*iv*) Accumulates carbohydrates and amino acids in leaves.

(*v*) Causes shortening of roots.

(*vi*) Causes *"top sickness"* disease in tabacco.

(*vii*) Retards formation of root nodules in leguminous plants.

(*viii*) Occurrence of brittleness in stems and leaf petioles as in *Vicia faba*.

(5) *Internal Deficiency Symptoms*

(*i*) Causes disintegration and browning of internal tissues in sugarbeet, called "*heart rot disease of sugarbeet*".

(*ii*) Similar disease of cauliflower is called "*browning disease*" where watery areas are produced.

(*iii*) Results in browning of cork cambium in apples, called internal cork of apples.

(*iv*) Results is breaking down of conducting tissues in tomato.

(*v*) Size of root cells is reduced.

(14) Copper (Cu)

(1) *Source*: In soil, the copper is mainly present as chalcopyrite ($CuFeS_2$) and copper sulphide. It is absorbed in the form of divalent copper cations.

(2) *Functions*

(*i*) Participates in the formation of phenolase lactase and ascorbic acid oxidase enzymes.

(*ii*) Helps in the biosynthesis of chlorophyll (*Stiles*, 1951).

(*iii*) Helps in absorption of CO_2 and photosynthesis.

(*iv*) Acts as catalyst in oxidation processes.

(*v*) Imparts black pigmentation to the spores of *Aspergillus niger.*

(*vi*) Acts as fungicide to prevent various diseases as 'late blight of potato'.

(3) *External Deficiency Symptoms*

(*i*) Produces necrotic spots at the tips of young leaves.

(*ii*) Causes 'exanthema' disease where erruptions are produced on the stem and branches.

(*iii*) Causes 'reclamation' or 'Moor sickness' disease in fruit trees, cereals and leguminous plants. Here the growth of plants in spring is vigour and leaves become abnormally large but later on become chlorotic.

(15) Molybdenum (Mo)

(1) *Source*: It is absorbed from the soil solution in the form of molybdate ions (MoO_4^{--} or $HMoO_4^{-}$). In exchangeable form it is found adsorbed on soil particles while in non-exchangeable form it is present as constituent of soil minerals and organic matter.

(2) *Functions*

(*i*) The chief role of molybdenum is to activate nitrate reductase enzyme during nitrogen metabolism, (*Possingham*, 1956, 57).

(*ii*) Controls ascorbic acid synthesis (*Hewitt et al.*, 1950).

(*iii*) Increases carbohydrate metabolism (*Agarwal* and *Hewitt*, 1955).

(*iv*) Helps in the formation of pectic substances (*Agarwal*, 1952).

(3) *External Deficiency Symptoms*

(*i*) Chlorotic interveinal mottling of lower leaves followed by a marginal necrosis and infolding of the leaves.

(*ii*) Inhibition of flowering.

(*iii*) Causes "whiptail" disease of cauliflower.

(*iv*) Under more severe conditions, mottled areas of lower leaves become necrotic resulting in wilting of leaves.

(4) *Internal Deficiency Symptoms*

(*i*) Depression of ascorbic acid (*Hewitt et al.*, 1950).

(*ii*) Reduction in sugar content of plants (*Agarwal* and *Hewitt*, 1955).

(*iii*) Formation of poorly developed middle lamella as in cauliflower (*Agarwal*, 1952).

(*iv*) Marked depression in soluble nitrogenous compounds (*Hewitt et al.*, 1957 ; *Possingham*, 1956 and 57).

(*v*) Accumulation of amino acids and protein synthesis is stopped.

(16) **Chlorine:** It is absorbed from the soil solution in the form chloride ions (Cl^-). Chlorine is an essential factor in photophosphorylation (*Arnon*, 1959). It helps in transfer of electrons during photosynthesis (*Vernon* and *Ke*, 1966).

(17) **Vanadium:** *Arnon* (1959) emphasized the importance of this element in *Scenedesmus*. In its deficiency, chlorophyll synthesis is depressed and photosynthetic oxygen evolution is inhibited. These processes can be restored by supplying vanadium element to the deficient cells.