**ESSENTIAL AND OTHER MINERAL ELEMENTS**

The presence of an element in a plant does not in itself signify that the element plays an essential role in the life of that plant. The soil contains numerous chemical elements. With sufficiently sensitive methods, a majority of the elements in the periodic table could be detected in any soil sample. Thus, a plant grown on such soil when analyzed would be found to contain at least traces of most of the elements those essential for its growth as well as others taken up because the absorption mechanism does not make absolute selection between essential and other elements.

**Criteria for essential**

Arnon and Stout, 1937 and Epstein, 1965, developed the four (4) criteria.

i) Deficiency of the element makes it impossible for the plant to complete the vegetative and reproductive phases of its life cycle (i.e. form viable seeds) e.g. N for vegetative growth

ii) The deficiency symptoms must be specific for the element in question and must be prevented and corrected by only supplying that element i.e. it cannot be replaced by any other element e.g. P for flowering, rooting and fruiting.

iii) The element must be directly involved in metabolism or it must be part of the molecule of an essential plant constituent e.g. Mg – Chlorophyll, N in proteins

iv) The deficiency symptoms described for the element must be observed in a representative number of plant families N deficiency in several plant families

**Macronutrients/major elements**

At present, there are seven mineral elements referred to as macro elements N, P, K, C, Mg, S and Fe. The elements are referred to as macronutrients because they are required in large quantities ≥ 1000 mg/g dry matter.

**Micro/minor/trace nutrients**

In addition to Fe, six other elements have been identified to be taken up by plants in relatively small amounts and they have been found to be essential. They are Mn, Cu, Zn, Bo, Mo and Cl. They are needed in quantities ≤ 100 µg/g dry matter.

Mn is essential for oat, soybeans, tomatoes and cowpea.

Zn is essential for barley, sunflower and several types of beans.

Mo is essential for N-fixing bacteria.

**Elements Essential for Specific Plants under Specific Conditions**

**Co:** General requirement for higher green plants has not been established, however, Co has been found to be essential for blue-green algae. It is also essential for legumes relying on N fixation as source of N. Therefore, Co is an indirectly essential element in N-fixation by microorganism in root nodules on legumes and many non legumes.

**Vanadium (Vd):** it was found to be essential for green algae and no higher green plants has shown requirement for Vanadium.

**Na:** It has been shown to be essential for blue-green algae and angiosperms. Sugar beet needs Na.

**Si:** Plant grown in Si rich soil invariably contain appreciable amount of Si. But experiments with plants grown in nutrient solution in which Si was omitted have generally failed to show that Si is important. Rice fails to grow normally in solutions lacking Si but its essentiality has not been shown for rice.

**I:** It has been shown to be essential for marine red algae.

Some elements can partially substitute for essential elements e.g. Rb = K, Sr = Ca in some algae and bacteria. Va = Mo in some nitrogen fixing microorganisms. Na = K in sugar beet.

Concerning essentiality of elements, it is incorrect to make an absolute statement that an element is not essential for plant growth. It is better to say that such an element is not proven essential.

**Essential elements for most higher plants**

| **Element** | **Chemical symbol** | **Available form** |
|---|---|---|
| Molybdenum | Mo | $MoO_4^{=}$ |
| Copper | Cu | $Cu^{+}$, $Cu^{2+}$ |
| Zinc | Zn | $Zn^{+2}$ |
| Manganese | Mn | $Mn^{+2}$ |
| Boron | B | $H_3BO^{-}_3$ |
| Iron | Fe | $Fe^{+3}$; $Fe^{+2}$ |
| Chlorine | Cl | $Cl^{-}$ |
| Sulfur | S | $SO_4^{=2}$ |
| Phosphorus | P | $H2PO_4^{-}$; $HPO_4^{=}$ |
| Magnesium | Mg | $Mg^{+2}$ |

| | | |
|---|---|---|
| Calcium | Ca | $CA^{+2}$ |
| Potassium | K | $K^{+}$ |
| Nitrogen | N | $NO^{-}_{3;}$ $NH_4^{+}$ |
| Oxygen | O | $O_{2:}$ $H_2O$ |
| Carbon | C | $CO_2$ |
| Hydrogen | H | $H_2O$ |

**HYDROPONICS**

Hydroponic cultute is growing plants by immersing their roots in an aqueous nutrient solution with known concentration of nutrients.

**Disadvantages**

i. Need for aeration

ii. Frequent replacement of solution every day or two for maximum growth because certain ions are absorbed more rapidly than others thus resulting in change in pH

Many plants grow well in solutions having concentrations of essential nutrients as low as those dissolved in the soil solution, provided the solutions are replenished enough to maintain such solutions.

**Growth as a function of the concentration of any element in plant tissue**

When the concentration of a nutrient is in the **deficient zone** and the element is provided such that its concentration is increased in the plant, the growth rate is stimulated dramatically. After the **critical**

**concentration** (minimal tissue concentration giving almost maximal growth), increases in concentration (fertilization) do not appreciably affect the growth rate (**adequate zone**). The adequate zone represents luxury consumption of the element. The zone is fairly wide for most elements but narrow for micro nutrients. Continued increases of these elements usually lead to toxicities and a reduced growth rate (toxic zone)

## ROLES AND FUNCTIONS OF MINERAL ELEMENTS

a) Constituents of metabolites or complexes

b) Activators, cofactors, or regulators of enzymes.

c) Elements involved in physiological processes.

### A. Constituents of metabolites

1. **Nitrogen:** N is the abundant after C, H and O. Protein contains about 16-18% N. N is normally absorbed as Nitrate $NO^{3-}$ and it is reduced and incorporated into organic compounds. N is a constituent of amino acids, nucleotides and co-enzymes. About 70% of the total leaf N is found in the chloroplast. N is also found in peptide bonds, nicotine, morphine, caffeine.

2. **Phosphorus:** Is largely absorbed as $H^2PO^{4-}$, $HPO^{4=}$ and as phosphate $PO_4^{3-}$. P is one of the three (3) elements that are absorbed as complex anions; the other two are nitrate and sulphate. Unlike N and S in $NO^{3-}$ and $SO_4^{2-}$, the P atom of the biphosphate is not reduced in the cell to any lower oxidation state. $PO_4^{3-}$ plays a key role in element metabolism incorporated into ATP. It is part of the universal element

currency of all living cells of whatever specie. $PO_4^{3-}$ occurs in phospholipids including those of membranes. It also occurs in sugar phosphate in various nucleotides as co-enzymes. In seeds, $PO_4^{3-}$ is stored as phytic acid or as phytin.

3. **Sulphur:** It is absorbed mainly in the form of $SO_4^{2-}$ ion. It is incorporated into organic compounds. It is a constituent of Sulphur containing amino acids (methionine, cystine and cysteine). Therefore, S is a constituent of protein containing these amino acids. Vitamins and co-enzymes also contain S. the pyridoxines which are non-heme proteins involved in photosynthesis and other element transfer processes contain S. volatile compounds containing S contribute to the characteristic odour given off by onions, mustard and other plants.

4. **Magnesium:** Chlorophyll is the major stable compounds of plants, which contain an atom of Mg as a fixed constituent (constant). The compounds bearing this chlorophyll molecule is Mg-porphyrins**.** Mg represents 2.75% of molecular weight of chlorophyll. Since half or more leaf Mg may be present in the chloroplast, these plastids therefore contain more Mg in addition to that which is part of chlorophyll. Element conversion and conservation are the major functions of the chloroplast. In addition to its role in the chlorophyll, Mg is the most common activator of enzymes that are involved in element metabolism.

5. **Iron:** There are many metabolites containing atoms of Fe as fixed constituents of their molecules. Fe is an integral part of protein. It is part of the Fe-porphyrins called *heme.* They function prominently in element transfer. The role of heamoglobin in symbiotic N fixation is not well-understood i.e. very complex process. The other Fe-porphyrin enzymes include peredoxases and dehyrogenases. They are non-heme Fe proteins.

6. **Manganese:** It is a constituent of many enzymes but only one enzyme has been isolated called mangaloprotein (manganin).

7. **Zinc:** It is a metal component of a number of metallo-enzymes. These enzymes include alcoholdehydrogenase and lactic dehydrogenase.

8. **Copper:** It is a component of different enzymes including ascorbic acid oxidase, phenolases and others. It is also a constituent of cytochrome auxins.

9. **Calcium: I**t is a metal component of metallo-enzymes called amylase in animal tissues and microbial tissues. Ca is commonly the major cation of the middle lamella of cell wall.

10. **Molybdenum (Mo):** It is the metal of several enzymes involved in N fixation and N reduction.

11. **Cobalt:** It is a constituent of Vit. $B_{12}$ (Cyano-cobalamine enzyme). All N fixing systems require Co.

12. **Potassium, Chlorine and Boron:** No enzyme has been isolated containing these elements.

**B. Nutrients as co-factors, activators or regulator of enzymes**

1. **Nitrogen:** Certain enzyme activities cannot be demonstrated if the organism has been grown in the absence of the substrate of such enzymes, but their activities become apparent when the organism is exposed to the substrate. Factors other than the substrate may also be instrumental in inducing the enzyme. $NO^{3-}$ reductase enzyme (NR) is such an inducible enzyme in plants being induced by $NO^{3-}$ ion.

This process of induction represents enzyme synthesis. $NH^{4+}$ activates some enzymes for which $K^+$ is the main activator.

2. **Phosphorus:** P regulates many enzymic processes. Phosphorylation of ADP to ATP and its dependence on the concentration of $PO_4^{3-}$ is important and is dependent on the presence of the $PO_4^{3-}$ .

3. **Magnesium:** Is an activator of more enzymes than any other elements. It is a co-factor of nearly all enzymes acting on phosphorylated substrate. It is therefore of great importance in energy metabolism. Activation by Mg is not highly specific, Mn can frequently substitute for Mg. Mg also activates some enzymes not concerned with $PO_4^{3-}$ transfer.

4. **Manganese:** Mn is often substituted for Mg as an activator of $PO_4^{3-}$ transferring enzymes e.g. Agenase. Mn is prominent as an activator of enzymes involved in reactions of Krebs cycle.

5. **Molybdenum:** Functions mainly as a component of metalloenzymes rather than activator of enzymes. It plays a major role in the induction of nitrate reductase (NR).

6. **Chlorine:** Acts in conjunction with other enzymes in photosystem II (photolysis of water).

7. **Boron:** Plays a regulatory role in carbohydrate metabolism.

8. **Potassium:** It is the only monovalent cation essential for higher plants. It is an activator of numerous enzymes.

## C. Roles of nutrients in physiological processes

Numerous processes are governed by nutrient elements as substrates' component of metabolites, activators and inhibitors; they affect the rate of many enzymes catalyzed reactions. Highly integrated sequences of enzyme-catalyzed reactions are recognized as metabolic or physiological processes. The common method of investigating physiological functions of a given nutrient is to study the biochemical effects of its deficiency. When an essential element is efficient, growth is inhibited. When the element is re-supplied, there are two (2) obvious consequences:

i) The content of that element in the plant will increase because of renewed absorption of it.

ii) Growth will resume if no other factor is inhibitory.

1. **Nitrogen:** An early dramatic symptom of N deficiency is a general yellowing of leaves – chlorosis due to an inhibition of chlorophyll synthesis. The internal appearance of the plastids is altered considerably. The resulting slow down of photosynthesis causing an N deficient plant to lack not only essential amino acids and also the machinery for the synthesis of necessary carbohydrate and Carbon skeleton for all manner of organic synthesis. Before chlorosis sets in, carbohydrate including starch may accumulate since they are not utilized for protein synthesis because of the deficiency in amino acids. Plant absorb N in $NO_3^-$ or $NH_4^+$. Absorption of $NH_4^+$ results in the reduction of the $P^H$ of the medium, whereas the absorption of $NO3^-$ has the opposite effect. In most well aerated soils, $NO_3^-$ is the principal form of available N. some plants can also utilize ammonium N. low $P^H$ reduces availability of some microelements e.g. Cu, Mn, Fe. The structure of the chloroplast is affected under the condition of $NH_4^+$ toxicity.

2. **Phosphorus:** Plays a major role in element metabolism i.e. it is necessary for ATP synthesis and phosphorilated compounds. The deficiency of P causes immediate and severe disruptions of metabolism and development. P promotes the absorption of Molybdate by plants. The chloroplast of P deficient plants show various abnormalities but the obvious and most common deficiency of P is purple colouration of leaves.

3. **Sulphur:** The consequences of S deficiency are low level of carbohydrate and build up of soluble N fractions including nitrate. In S deficiency, there are fewer cytoplasmic inclusions and their appearance are abnormal.

4. **Magnesium:** As a constituent of chlorophyll and as an activator of numerous enzymes, its deficiency affects every facets of metabolism in plants. Chlorosis is an early symptom followed by diminished photosynthesis. In Mg deficient plant, the fine structure of the chloroplast becomes abnormal.

5. **Iron:** It is essential for chlorophyll synthesis. The appearance of chloroplast is changed if Fe is deficient i.e. the no and the size of grana are much reduced. Element relation is also disrupted when Fe is deficient because Fe contains element carriers.

6. **Manganese:** It is also a prominent component of chloroplast because it is involved in photolysis of water (light reaction) and it participates in the reaction leading to the evolution (giving up) of $O_2$.

7. **Zinc:** Zn deficiency is termed 'little leaf' or resetting. Rosetting is the failure of internodes to elongate causing the leaves of several nodes to lie together in a plane. The masked Zn deficiency on growth results from its influence on the auxin level. The concentration of IAA in Zn deficient tissue drops well before visible symptoms become apparent and upon resupplying Zn, it rises. Protein synthesis, which is mediated by RNA, is regulated by the concentration of Zn.

8. **Copper:** Cu deficiency interferes with protein synthesis and causes an increase in soluble N compound.

9. **Molybdenum:** Mo deficient plants have lower level of sugar and ascorbic acid. Concentrations of most amino acids are usually low in Mo deficient plants.

10. **Chlorine:** Cl is required in the evolution of $O^2$ by photosystem II in photosynthesis. Cl deficient plants have the tendency to wilt.

11. **Boron:** Growing points of both shoot and root stops elongation when Bo is deficient, and if severe deficiency continues, they become discoloured, disorganized and die.