PLANT PHYSIOLOGY - MINERAL NUTRITION OF PLANTS

When any plant material is burnt in air, the organic matter is destroyed and the residue of inorganic salts remain, which is called as the ash. A complete analysis of the ash reveals the presence of at least traces of nearly half the elements in the periodic table, but all of them are not required by the plant as nutrients. After they have been absorbed, the elements are never present in the plant in the free state. They are generally in ionic form or as constituents of organic compounds. It was later established by further studies that some elements are indispensable for the plant growth and metabolism. In the absence of these elements, the growth of the roots or the shoots was found to be stunted. Besides C, H and O, these elements were grouped together as the 'essential elements' and were required in large quantities by plants. Therefore these were termed as 'macronutrients'. The importance of some other such elements were realized later and were found to be required in small concentrations, therefore variously termed as minor elements, rare elements, trace elements or micronutrients. The functions of some such elements from physiological point of view and the symptoms that the plants show in their absence or deficiency are described as follows:

ESSENTIAL ELEMENTS / MACRONUTRIENTS

I. Nitrogen (N): -

Functions -

1. Nitrogen is absolutely essential for the synthesis of protein.
2. In addition, nitrogen is found in such important molecules as purines and pyrimidines, which are found in nucleic acids.
3. Nitrogen is a component of porphyrin molecule, which is present in the structure of chlorophylls and the cytochrome enzymes. These two compounds play very important role in photosynthesis and respiration respectively.
4. Nitrogen is essentially a part of all amino acids that make up various proteins in plants.
5. The energy currency of the cell, ATP, requires nitrogen for its formation.
6. Various plant hormones are molecules that contain nitrogen in them.
7. Molecules like NAD+, NADP+, FMN, FAD, which act as co-factors, require nitrogen for their formation.

Deficiency symptoms –

1. Nitrogen is rapidly translocated to the older leaves. Therefore the deficiency symptoms first appear in the older leaves. Chlorosis first appears in the older leaves.
2. As chlorophyll fades, xanthophylls and carotenes are unmasked exposing areas of orange and red tints first in the older leaves and then in the younger leaves.
3. Shortage of nitrogen results in acceleration in the rate of formation of purple pigment anthocyanin in the leaves which become purplish in colour.

4. Stems and twigs also become reddish – yellows, with numerous red and brown spots.
5. Because of small leaves, early defoliation and suppressed shoot growth, nitrogen – deficient plants are conspicuously thin, sparse – foliaged and weak.
6. The flowering is delayed or completely suppressed.
7. The plants have woody stems because of surplus of carbohydrates particularly in the absence of amino acid and protein synthesis.

II. Phosphorus (P): -

Functions –

1. Phosphorus is absorbed by plants in the form of phosphate ions. It is a vital structural component of nucleic acids, nucleoproteins, phytin, phospholipids, sugar phosphates, ATP, NADP+ and numerous phosphorylated compounds.
2. Highest amount of phosphorus is found in meristematic parts, maturing seeds and fruits.
3. Phosphorus is a component of DNA, RNA, phospholipids of the membranes, AMP, ADP, GDP, GTP, etc.
4. Phosphorus is present in all the phosphorylated compounds of glycolysis, pentose-phosphate pathway and Calvin cycle.
5. Phosphorus is actively involved in the synthesis of nucleoprotein – firstly by being present in the nucleic acids and secondly by activating the amino acids for protein synthesis.
6. The roles of the coenzymes NAD+ and NADP+ and ATP which contain phosphorus in processes like photosynthesis and respiration are well-known.

Deficiency symptoms –

1. Phosphorus deficiency causes decrease in the rate of protein synthesis.
2. It also results in the accumulation of carbohydrates and soluble nitrogenous compounds.
3. Phosphorus deficiency may also cause premature leaf fall and purple anthocyanin pigmentation, similar to nitrogen deficiency.
4. The leaves do not show chlorosis. Instead, the leaves show dark greenish purple colouration.
5. Older leaves die and maturation of the plant may also be delayed.
6. The anthocyanin is found to be present in excessive amount.
7. The leaves become dark blue green in colour, and brown necrotic areas are developed on leaves and petioles.
8. The growth of the root and the shoot is extremely restricted.
9. Branching becomes sparse.
10. Flowering is delayed.

III. Potassium (K): -

Functions –

1. Potassium is the only monovalent cation essential for plant growth. It is found in large amounts in rapidly growing tissues. It acts as an activator of over 40 enzymes including the enzymes of photosynthesis, respiration, phosphorylations and protein synthesis.
2. Potassium is essential for activating the enzymes concerned in the synthesis of polypeptides from amino acids, according to Webster (1953).
3. It is needed by the enzyme DNA polymerase and also by the mitochondrion.
4. Being the most common free ion in the cell, it helps to keep the cell electrically neutral and perhaps stabilizes emulsions.
5. Potassium is essential for the formation of sugar and starch and also for their translocation throughout the plant.
6. It is also needed in cell division, reduction of nitrate, development of chlorophyll, stomatal movements, etc.
7. Potassium is believed to be essential in maintaining the cellular organization, permeability, osmotic potential of plant cells as well as the turgor.

Deficiency symptoms –

1. Potassium deficiency inhibits the synthesis of protein, which results in the accumulation of organic nitrogenous compounds in the plant cells.
2. Carbohydrate metabolism is checked and the rate of respiration increases.
3. The deficiency symptoms occur first in the older leaves. The typical symptoms are mottled or marginal chlorosis, necrosis on the leaf margins and leaf tips.
4. The stems become thin and weak and the leaves exhibit curling.
5. Scorching of older leaves is the most important symptom on fruit trees. The leaves are discolourized.
6. The storage of large amounts of carbohydrates in the underground stems of sugarbeets and potatoes, etc is very much decreased due to inhibition of the enzymatic hydrolysis of starch into soluble sugar in the leaves probably.

IV. Calcium (Ca): -

Functions –

1. Calcium has many roles in the structure and metabolism of plants. An important role of calcium in the plant is to provide strength. It is a constituent of the middle lamella, in which it is present in the form of calcium pectate.
2. It is essential for the continued growth of the apical meristems.
3. Maintenance of Na+, K+ and Ca+2 ions within fairly narrow limits would appear to be essential for maintaining the differential permeability of the cell membranes.

4. Calcium affects the hydration of colloids.
5. Toxic soluble organic acids like oxalic acid are converted into harmless insoluble calcium oxalate.
6. It is also suggested that calcium helps in the translocation of carbohydrates and amino acids and encourages root development.
7. Calcium reduces the toxicity of such inorganic elements as sodium and magnesium.
8. Calcium is believed to be important in the formation of cell membranes and also their normal functioning.
9. Calcium is required in the formation of spindle fibres during mitosis.
10. The structure and stability of chromosomes is dependent on calcium, according to Hewitt (1963).

Deficiency symptoms –

1. Meristematic regions found in stem, leaf and root tips are greatly affected by the absence of calcium because it is not rapidly translocated to these regions. They die ultimately and thereby the growth of these organs is stopped.
2. Chlorosis generally occurs along the margins of younger leaves.
3. Calcium deficiency causes malformation of the younger leaves.
4. Calcium deficiency results in necrosis of young leaves and root tips because of inhibition of cell division and cell wall formation.
5. The plants may be stunted.

V. Magnesium (Mg): -

Functions –

1. Magnesium is indispensable for the formation of chlorophyll since it is the one and the only mineral constituent of the chlorophyll molecule.
2. Magnesium is intimately associated with the phosphorus metabolism and is particularly essential for the enzymes involved in the phosphate transfer reaction.
3. It plays an important role in synthesis of ATP from ADP and inorganic phosphate.
4. Magnesium is an activator for many of the enzymes involved in carbohydrate metabolism such as those participating in glycolysis, pentose phosphate pathway and Calvin cycle.
5. Magnesium acts an activator of the enzymes concerned in the synthesis of nucleic acids.
6. It is also believed to be an important binding agent in ribosomes where protein synthesis takes place.

Deficiency symptoms –

1. Deficiency of magnesium invariably results in extensive interveinal chlorosis of the leaves.
2. The older leaves are affected first and the younger leaves are affected later on.
3. Ultimately leaves develop anthocyanin pigment and necrotic spots.
4. The leaves show premature leaf abscission.

NON - ESSENTIAL ELEMENTS / MICRONUTRIENTS

I. Iron (Fe): -

Functions -

Iron is normally absorbed in the ferric form, though it can be absorbed in the ferrous form as well. It is required in larger amounts as compared to the micronutrients.

1. Iron is essential for the synthesis of chlorophyll.
2. It is found in ferredoxin, FRS, flavoproteins and iron-porphyrin proteins, which include cytochromes, peroxidases and catalases.
3. Iron plays an important role in respiratory mechanism.
4. Iron is also a component of several electron carriers.
5. According to Gauch (1957), iron is primarily concerned in the formation of chloroplast protein in the leaves.

Deficiency symptoms –

1. Iron deficient plants develop pronounced interveinal chlorosis similar to that caused by magnesium deficiency.
2. The young leaves may become yellow or white with prominent green veins.
3. Sometimes the chlorotic patches in a leaf are due to presence of iron in the unavailable form (ferric) in such spots only.
4. Its deficiency seriously impairs aerobic respiration and other related processes. Fruit trees are particularly sensitive to it.

II. Manganese (Mn): -

Functions –

1. Primarily manganese functions as an enzyme activator in several reactions of respiration and nitrogen metabolism.
2. Manganese also plays some role in the synthesis of chlorophyll and in the transfer of electrons from H_2O to photo-oxidized chlorophyll in photosynthesis.
3. Manganese also has a role in photolysis of water and evolution of oxygen, according to Marschner (1995).
4. Maintenance of chloroplast membrane structure requires manganese ions.
5. Functioning of the enzymes like RNA polymerase requires manganese in ionic forms.

Deficiency symptoms –

1. Deficiency symptoms can occur on both older and younger leaves. Interveinal chlorosis and small necrotic spots are typical deficiency symptoms. Chlorosis caused by manganese deficiency is distinct from that of magnesium or iron deficiency.
2. Leaves take a mottled appearance.

3. The chloroplasts lose chlorophyll as well as starch grains, become vacuolated and granular and finally disintegrate.
4. Grey spots appear on the leaves and in the grains of oats.
5. Plants become more vulnerable to diseases like pahla blight of sugarcane and marsh spot of pea.

III. Boron (B): -

Functions –

Boron differs from other micronutrients in that it is absorbed as an anion i.e. borate or tetraborate rather than as a cation like other metallic nutrients.

1. It is believed to promote synthesis of nucleic acids.
2. It plays a role in the elongation of the cell and its differentiation.
3. It also plays an important role in the functioning of the membranes.
4. Boron facilitates the translocation of sugar in plants.
5. Boron is also believed to affect flowering and fruiting, cell division, metabolism, active salt absorption, photosynthesis, etc.
6. Uptake and utilization of calcium ions requires the presence of boron.
7. Boron is an important factor during germination of pollen tube in plants.
8. Boron is also involved in RNA metabolism, phenol metabolism, GA and α-amylase activity, etc.

Deficiency symptoms –

1. Boron deficiency inhibits cell division and results in the death of root and shoot tips. The root tips die and the shoot growth is stunted.
2. Flowers are not formed.
3. The leaves have a coppery texture.
4. Internally, carbohydrates and amino acids accumulate in the leaves.
5. Necrosis of the apices, fruits, fleshy roots, tuber, young leaves and terminal buds is very common.
6. The plants become bushy and highly branched due to loss of apical dominance.
7. Boron deficiency tends to shift metabolism from glycolysis to pentose phosphate pathway.
8. Physiological diseases like internal cork of apples, top rot of tobacco, cracked stem of celery, browning of cauliflower and heart rot of sugarbeet are developed as a result of boron deficiency.

IV. Sulphur (S): -

Functions –

1. Sulphur, which is absorbed as sulphate ions, is used in the formation of sulphur – bearing amino acids eg., cysteine, methionine, etc.
2. Besides, sulphur is essential for the synthesis of sulphur – bearing vitamins, eg. Biotin, thiamine and coenzyme A.

3. Sulphur aids in the synthesis of oils.
4. It is also associated with chlorophyll synthesis.
5. Sulphur is a constituent of ferredoxin and some lipids found in chloroplasts.
6. Sulphur bridges (-S-S-) have an important role in determining protein structure and sulphydryl groups (-SH) are often part of the active centres of many enzymes.

Deficiency symptoms –

1. Sulphur is relatively immobile and therefore deficiency symptoms appear first in young leaves.
2. Sulphur starvation results in shortage of protein.
3. Similar to a nitrogen – deficient plant, there is reduced leaf, stunted growth, general chlorosis, followed by production of anthocyanin pigments in some species.
4. Root system becomes highly extensive and stem becomes hard and woody.
5. There is some accumulation of nitrates and carbohydrates in different parts of the plants.

Sulphur deficiency is more likely in plants growing in acidic soils.

V. Zinc (Zn): -

Functions –

1. Zinc functions as an activator of certain enzymes, eg. Carbonic anhydrase, alcohol dehydrogenase, etc.
2. Zinc is essential for the biosynthesis of indole – 3 – acetic acid.
3. It is also believed to be concerned with protein metabolism and chlorophyll synthesis.
4. Zinc is required for the formation of tryptophan amino acid, which is a pre-cursor for auxin manufacture.
5. Zinc promotes the synthesis of cytochromes.
6. Zinc also stabilizes the ribosomal fractions.

Deficiency symptoms –

1. Zinc deficiency first occurs in the older leaves. The leaves become distorted.
2. It causes reduced stem growth due to decreased synthesis of auxin.
3. It results in stunted vegetative growth.
4. Chlorosis in the interveinal region of leaves takes place.
5. Leaves also show white necrotic spots.
6. The internodes are reduced in size and the effect is sometimes referred to as ‘little leaf’ disease.
7. Other deficiency diseases are white bud of maize, mottle leaf disease of apples and walnut, etc.
8. The absence of zinc also suppresses seed formation and causes malformation in fruiting trees.

VI. Molybdenum (Mo): -

Functions –

1. Molybdenum is required in very small quantities in plants. The main role is seen in nitrogen metabolism.

2. Molybdenum ions are activators of several enzymes. It plays an important role in the production of nitrite from nitrate and in nitrogen fixation since it is a part of the enzyme nitrate Reductase and Nitrogenase.
3. Ion absorption and translocation takes place with the help of molybdenum.

Deficiency symptoms –

1. Its deficiency results in the chlorotic interveinal mottling of the lower leaves.
2. The older leaves exhibit interveinal chlorosis and necrosis.
3. The leaves become twisted and ultimately die. It is commonly known as the 'whiptail disease' such as in cauliflower.
4. Molybdenum deficiency also results in suppression of flowers.

****