

OCCURRENCE AVAILABILITY AND SPECIFIC ROLES OF MACRONUTRIENT MINERAL ELEMENTS

NITROGEN

After oxygen, hydrogen and carbon, nitrogen is the fourth most abundant element in plants.

Occurrence

The ultimate source of nitrogen is atmospheric nitrogen present in the form of gas. The nitrogen is fixed in usable forms by several biological and nonbiological agencies. Nitrogen is also present in the soil in the form of nitrates and ammonium salts.

Availability

Green plants cannot utilize atmospheric free nitrogen directly, It is fixed into nitrate and ammonical nitrogen before it is absorbed by the plants. The absorbed nitrogen is made available to plants by the nitrogen fixing enzyme known as "nitrogenase."

Physiological role

Approximate amount of nitrogen present in the whole plant is 1 – 3%. It is present in almost all the living matter ; chiefly macromolecules like proteins, nucleic acids (RNA and DNA) and thus it is an important element in various metabolic processes. It is also found in aminoacids, purines, pyrimidines, porphyrins and coenzymes. It plays an important role in protein synthesis, photosynthesis, respiration, growth and in almost all the metabolic reactions.

Deficiency symptoms

Most of the soils are more commonly deficient in nitrogen than any other element. Its deficiency in plants shows the following symptoms :

- (i) An early symptom of nitrogen deficiency is yellowing of leaves and development of chlorosis which starts from older leaves and gradually progresses towards younger leaves.
- (ii) Some plants exhibit a purplish coloration of stems, petioles and lower leaf surfaces caused due to accumulation of the phenolic pigment anthocyanin.
- (iii) Lower leaves turn light brown in colour and gradually dry. The stalks become short and slender.
- (iv) Flowering is delayed or completely suppressed. The fruits and seeds formed from them remain small and less viable.
- (v) Deficiency of nitrogen interferes with protein synthesis and hence all forms of growth are affected.

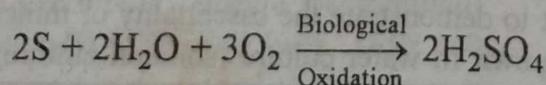
SULPHUR

It is well distributed in plants, present approximately 0.05 – 1.5% in the whole plant.

Occurrence

Inorganic fraction of soil sulphur is found in minerals such as pyrite, cobaltite, gypsum, epsomite and in the soluble form as sulphate ions (SO_4^-). Plants readily utilize soluble sulphate from the soil.

Organic sulphur is made available to the plant through "biological oxidation". Certain micro-organisms convert organic sulphur to sulphate ions.



Availability

Sulphate ions are weakly adsorbed. The adsorption increases with the decrease in soil pH. It is also favoured by the presence of hydrated oxides of iron and aluminium.

Sulphur is absorbed by plants in the form of sulphate ions. These ions are reduced in plants via an activation step involving the compounds 3-phosphoadenosine-5-phospho sulphate (PAPS) and ATP.

Physiological role

Sulphur is absorbed by plants as sulphate ions and then reduced to sulphhydryl group ($-SH$) in the formation of various amino acids (*viz.*, cystine, cysteine and methionine). Finally it enters into protein structure. Sulphur is essential for the synthesis of some vitamins like biotin, thiamine and coenzyme A, which are involved in various metabolic activities.

Sulphur is essential for the synthesis of allyl oils of mustard (*i.e.*, sinigrin), which gives odors and flavours to mustard, onions and garlic.

Sulphur is an important element because :

1. It plays a role in the synthesis of chlorophyll.
2. It is a constituent of ferredoxin and some lipids found in the chloroplast ;
3. It is essential for nodulation in legumes ;
4. It determines the structure of protein ;
5. It plays a role as a part of active centre of some enzymes and affects various metabolic processes.

Deficiency symptoms

Deficiency symptoms first appear in young leaves in the form of general chlorosis (including the veins). Sometimes both young and old leaves develop chlorosis at about the same time, or even first in older leaves. In some species the chlorosis is followed by anthocyanin pigmentation. Root system becomes extensive and stems become hard and woody. Deficiency of sulphur brings about reduction in juice content of citrus fruit. The disease **Tea yellow** is caused due to sulphur deficiency. Deficiency of sulphur inhibits nodule formation in leguminous plants.

PHOSPHORUS

Approximate amount of phosphorus present in the whole plant is 0.05 – 1.0%

Occurrence

The usable inorganic fraction of soil phosphorus is found in the form of dihydrogen phosphate ($H_2PO_4^-$) and HPO_4^- ions (Wiklander, 1958).

Availability

Phosphorus is absorbed as complex anions, (like nitrogen and sulphur), but it is not reduced in the cell to a lower oxidation state. The availability of phosphorus to the plants depend upon – (i) pH of soil solution ; (ii) dissolved aluminium and iron ; available calcium ; (iii) anion exchange and (iv) presence of micro organisms in the soil.

Physiological role

A large amount of phosphorus accumulates in storage tissues of fruits and seeds and during active growth in meristematic tissues. It is a component of the nucleic acids and proteins (which together form nucleoproteins), phytin, phospholipid, sugar phosphates, ATP, NADP⁺ and a number of phosphorylated compounds.

Phosphate plays a key role in energy metabolism. Incorporated into ATP, it is part and parcel of the universal “energy currency” of all types of living systems. Phosphorus is actively involved in the

synthesis of protein, photosynthesis, respiration and other metabolic processes. It also acts as an activator of some enzymes.

Deficiency symptoms

The deficiency of phosphorus is less disastrous than nitrogen. Its deficiency causes:— (1) Disruption of general metabolism particularly at the level of energy generation; (2) Abnormalities in the shape and size of chloroplasts; (3) Stunted growth of plants followed by anthocyanin pigmentation, yellowing and drying of lower leaves; (4) Root and shoot become short and slender and (5) Deficiency of phosphorus promotes leaf fall and delays flowering. Maturity is also delayed.

CALCIUM

Approximately 0.1–3.5% calcium is present in the whole plant. It is an extremely essential element in maintaining structure and metabolism of plants.

Occurrence.

Calcium is made available for the plants by weathering of *anorthite* ($\text{Ca Al}_2 \text{Si}_2 \text{O}_8$) in the soil. Other forms of calcium present in the soil are calcium carbonate (CaCO_2) derived from lime stone or chalk rocks and insoluble calcium phosphate.

Availability

Calcium is an exchangeable cation. Much of it remains adsorbed on soil micelles which are commonly disc shaped with a surface enveloping layer of negative charges which attract strongly H^+ and Ca^+ cations. If pH is raised, Ca^+ ions will be released and the H^+ ions will take their place. The phenomenon is known as cation exchange.

Physiological role

Calcium plays following important roles in plants:

- (i) It is a chief constituent of cell wall, present in the form of calcium pectate in middle lamella.
- (ii) It controls cell permeability.
- (iii) It is important in the formation of cell membranes.
- (iv) It is essential for continued growth of the apical meristem. Calcium in small amounts is necessary for normal mitosis as it is important in chromatin or mitotic spindle organization.
- (v) It is a potent activator of the enzyme- phospholipase, arginine kinase, adenosine triphosphatase (ATPase), adenyl kinase and amylase.
- (vi) It is responsible to reduce toxicity by forming calcium salts of organic acids.
- (vii) It helps in translocation of carbohydrates and aminoacids.
- (viii) It encourages root development.
- (ix) In many plants it is also found as insoluble crystals of calcium oxalate.

Deficiency symptoms

Calcium deficiency brings about the following symptoms:

- (i) Meristematic zones of roots, stems and leaves degenerate and die, perhaps because calcium is required to form a new middle lamella in the cell plate.
- (ii) Calcium deficiency results in the twisting and deformation of tissues. Twig or stalk just below the tip and seed-head are often unable to stand erect.
- (iii) Roots are first to show deficiency symptoms. They become translucent or mucous due to decomposition of root epidermis. The lateral roots rapidly die off.

(iv) Margins of young leaves show chlorosis followed by necrosis.

(v) Younger leaves become permanently wilted (wither-tip effect) without spotting or marked chlorosis.

POTASSIUM

Approximate amount of potassium present in the whole plant is 0.3- 6.0%

Occurrence

Potassium is made available to plants by withering of minerals such as—biotite, muscovite and illite. Some times it also occurs as soluble organic salts.

Availability

Potassium is exchangeable cation. It remains adsorbed to the surface of clay micelles and absorbed by plants through cation exchange.

Physiological role

Potassium is rich in actively dividing cells of buds, young leaves and root tips. It is present in fairly less amount in seeds and other mature tissues. It has the following physiological roles.

(i) It is needed for proper growth and development.

(ii) A high amount of potassium is required in the process of protein synthesis.

(iii) It is essential as activator of several enzymes. It is needed in the enzyme system in the change of sugar to starch, aminoacids to protein, citric acid synthesis, DNA polymerase and interacts with iron enzymes.

(iv) It is required in maintaining cellular organization, permeability and hydration.

(v) It regulates movement of stomata.

(vi) It is needed in photosynthesis, respiration, translocation, reduction of nitrate and chlorophyll formation.

Deficiency symptoms

Deficiency symptoms are first observed on the older, lower leaves. Spots of dead tissue on older leaves are seen which are small, usually at tips, between veins and more marked at margins. The effects are localized. Potassium deficiency in cereal crops develop weak stalk. These plants easily bent to the ground by wind or rain.

MAGNESIUM

Approximately 0.05 – 0.7% magnesium is present in the whole plant.

Occurrence.

Magnesium is an exchangeable cation. It is fixed in minerals such as magnesite, dolomite ($\text{Mg} \cdot \text{CO}_3 \cdot \text{CaCO}_3$) and olivine $(\text{MgFe})_2\text{SiO}_4$.

Availability

In nature it is present in low concentration and hence it is low in availability to plants : it is present in the form of magnesium silicates which on withering releases the available form of magnesium to plants.

Physiological role

Magnesium is present in tetrapyrrolic chlorophyll. Thus, it is found in all the green parts of plants and helps in photosynthesis. It also acts as an activator of several enzymes viz., hexokinase, phosphorylase,

carboxylase, dehydrogenase and peptidase etc., and hence it plays important role in various metabolic processes including respiration.

Magnesium is an important binding agent in microsomal particles where protein synthesis takes place.

Deficiency symptoms

Deficiency of magnesium results

- (i) Extensive interveinal chlorosis of the leaves resulting in defoliation ;
- (ii) Yellowing of the leaves start from basal to younger ones ;
- (iii) Development of anthocyanin pigment with dead spots ;
- (iv) Tips and margins of leaves turn upward ;
- (v) Stalk become slender.

OCCURRENCE, AVAILABILITY AND SPECIFIC ROLES OF MICRONUTRIENTS OR TRACE ELEMENTS

IRON

Approximate amount of iron present in the whole plant is 10-1500 ppm (mg/L).

Occurrence

Iron is found in minerals in the form of oxides (such as limonite), pyrite and sulfides.

Availability

Iron is absorbed in ferrous form although some ferric ions may also be absorbed by plants. The soil pH controls the iron availability to plants. It is readily available to the plants in acidic soil.

Physiological role

It plays an important role in electron transport systems in photosynthesis and respiration and helps in energy generation. It is essential in chlorophyll synthesis. Iron is a component of flavoproteins active in biological oxidation. It functions in iron-porphyrin proteins which include peroxidases and catalases. It is present in ferredoxin, ferredoxin reducing substance and cytochromes.

Deficiency symptoms

Deficiency of iron causes.

- (i) Marked chlorosis particularly in younger leaves, the mature leaves remain unaffected ;
- (ii) Characteristic interveinal chlorotic spots develop and the principal veins remain typically green showing fine network of reticulate venation ;
- (iii) Inhibits chloroplast formation ;
- (iv) Stalks become short and slender.

On removal of iron deficiency there is invariably an incomplete recovery from chlorosis.

BORON

Approximate amount present in the whole plant is 2-75 ppm (mg/L).

Occurrence

Boron is abundant in rocks and marine sediments. In general it exists in three forms viz., exchangeable, soluble and non-exchangeable forms *i.e.*, as boric acid (H_3BO_3), Calcium or manganese borate and as a constituent of silicates. The dissolved boron content in the soil solution is very low.

Boron is absorbed by plants as anion *i.e.*, borate or tetraborate. Availability of boron decreases with increasing pH.

Physiological role

Boron plays following physiological roles :

- (1) It regulates carbohydrate metabolism specially pentose phosphate shunt.
- (2) It regulates many growth phenomenon such as regeneration, fruiting and cell division.
- (3) It facilitates the translocation of sugars in plants.
- (4) It forms complex at cell membrane which facilitate its passage across the membrane.
- (5) It regulates cellular differentiation and development.
- (6) Boron also regulates water relations, active salt absorption, nodulation in legumes, fat metabolism, hormone metabolism, fertilization, phosphorus metabolism and photosynthesis.

Deficiency symptoms

Deformation, discolouration and disorganisation of meristematic tissue and finally death of growing point in severe boron deficiency have been noted. It causes abscission of flowers, increased fruit drop, inhibition of flower formation and retards root growth. Its deficiency causes curling and twisting of leaves which become quite brittle. Its deficiency causes an abrupt growth of lateral shoots but tips of such shoots soon die. Boron deficiency causes heart rot of sugar beet, internal cork formation in apples and the development of watercore is inhibited in the turnip.

MANGANESE

Approximate amount of manganese present in the whole plant is 5-1500 ppm (mg/L).

Occurrence

The major amount of manganese is found in the soil as tetravalent and trivalent oxides. It exists in very little amount as a bivalent. Tetravalent and trivalent forms usually present in soil in an insoluble form whereas bivalent form is soluble and it is significant in manganese nutrition. Organic form is also unavailable to plants. Poorly aerated, acid soils favour the availability of manganese whereas it is not available above the soil pH of 6.5.

Physiological role

Manganese primarily functions as activator of several enzymes such as (i) Malic dehydrogenase and oxalosuccinic dehydrogenase — the enzymes of Kreb's cycle ; (ii) nitrate reductase and hydroxylamine reductase— thus play important role in nitrogen metabolism ; (iii) arginase and (iv) carboxylase etc.

Manganese plays a role in the photo oxidation of H_2O and release of molecular O_2 in photosynthesis. It is also involved in the synthesis of chlorophyll and oxidation of auxin (indole-3-acetic acid).

Deficiency symptoms

Deficiency of manganese causes chlorosis and necrosis in the interveinal areas of leaves. However, the veins remain green, producing a checkered or reticulating effect. The chloroplasts are devoid of chlorophyll and starch grains become yellow green in colour, vacuolated and finally disintegrate.

COPPER

Approximate amount of copper present in the whole plant is 2-75 ppm (mg/L). It is toxic when present in larger amount.

Occurrence

The major portion of copper is found as natural deposit of copper sulphate called chalcopyrite (CuFeS_2). The soil is generally toxic near its deposits. A very little amount (nearly 1%) is found dissolved in the soil solution.

Physiological role

Copper is a component of plastocyanin and therefore, acts as a key role in the electron transport chain in photosynthesis. It acts as an activator of several enzymes such as polyphenol oxidase, lactase and oxidase. It is a component of enzyme involved in the synthesis of ascorbic acid (vitamin-C).

Deficiency symptoms

Deficiency of copper causes distortion and chlorosis in leaves followed by necrosis of the tips of young leaves that proceeds along the margin of the leaf. Under severe conditions the whole plant may appear wilted and the leaves may be lost.

ZINC

Approximate amount of zinc present in the whole plant is 3-350 ppm (mg/L).

Occurrence

Zinc occurs in nature in the form of minerals such as ferromagnesium minerals, magnitite, biolite and hornblende. Withering of these minerals releases divalent form of zinc which is adsorbed on to soil and organic matter in exchangeable form. The availability of zinc to the plants decreases with the corresponding increase in the pH value.

Physiological role

Zinc plays an important role in the synthesis of tryptophan which is a precursor of a plant growth hormone-auxin (Indol-3-acetic acid). It acts in the metabolism as an activator of several enzymes, such as (i) carbonic anhydrase – catalyze the decomposition of carbonic acid to carbon dioxide ; (ii) alcohol dehydrogenase ; (iii) pyridine nucleotide dehydrogenase ; (iv) hexose kinase and (v) phosphorylation enzymes.

Deficiency symptoms

Deficiency of zinc causes (i) shortening of internodes with the result plants become stunted ; (ii) reduction in the size of leaves so that the leaves become very small ; (iii) interveinal chlorosis of older leaves starting at tip and extending to the margins ; (iv) interveinal necrosis, the spots of dead tissues enlarge in the areas between veins, (v) suppression of seeds formation.

MOLYBDENUM

It is required by plants in very minute amount.

Occurrence

Molybdenum is widely distributed in soil mainly in three forms— (i) dissolved in the soil solution as molybdate ions ; (ii) adsorbed to soil particles as exchangeable form and (iii) in non-exchangeable form of soil mineral and organic matter. It is available to the plants in higher pH.

Physiological role

Molybdenum is required for nodulation in legumes, synthesis of tannins and reduction of nitrates to nitrites. It regulates the amino acid concentration in plant systems. It is also required in ascorbic acid metabolism. It has a protective role in the chloroplasts.

Deficiency symptoms

Deficiency of molybdenum develops chlorosis coupled with poor leaf growth. Nitrogen fixation is reduced in symbiotic plants. Its deficiency causes shoot growth die back. Flower formation is also inhibited.

CHLORINE

Approximate amount of chlorine present in the whole plant is 100-300 ppm (mg/L).

Occurrence

In nature it occurs as chlorine gas but its chlorides in the mineral matter of the soil are common. Chiefly it is in available form.

Physiological role

Chlorine plays an important role in photosystem II in photosynthesis. It is essential in the transfer of electrons from water to photooxidized chlorophyll in photosystem II. It also plays a role in transpiration.

Deficiency symptoms

Its deficiency in nature can not be encountered because of the prevalence of the cyclic salts of chloride. The deficiency symptoms consists of wilted leaves, which then become chlorotic and necrotic. Roots become short, thick and club-shaped near the tip.

NICKEL

There are sufficient evidences that Nickel (Ni^{++}) is an essential micronutrient required by the plants (Dalton et al., 1988)

Physiological role

Nickel is an essential part of an enzyme called **Urease**, which catalyzes hydrolysis of urea to CO_2 and NH_4^+ . Urea is formed in most or all plants and needs the enzyme urease for its hydrolysis. Many legumes form ureides in root nodules during nitrogen fixation which are transported to leaves along with xylem sap. Utilization of ureides requires the activity of enzyme urease and nickel, without which, the toxic level of urea accumulates in leaves.

Deficiency symptoms :Deficiency of nickel causes accumulation of so much urea in leaves that they develop necrotic spots in their tips. Nickel deficiency in barley plants results in the production of nonviable seeds which show various anatomical abnormalities.

SOME OTHER MICRONUTRIENTS

Besides the above mentioned essential elements, certain elements are essential for some specific plants. For example, (i) **Silica** (Si) is essential for cell walls of diatoms, grasses and some other higher plants ; (ii) **Aluminium** (Al) is accumulated in ferns; (iii) **Vanadium** (V) is required by *Scenedesmus*; (iv) **Selenium** (Se) is essential for *Atriplex* and *Astragalus* species (v) **Iodine** is required by marine algae *Polysiphonia*. and (vi) **Sodium** is also listed among the essential trace elements. It regulates the transport of amino acids to the nucleus.

DEFICIENCY DISEASES

The plants require various mineral elements for their normal growth development and metabolism. They fulfil their mineral requirement usually from the soil. That means all the essential elements must be present in the soil where a plant grows. Now suppose a particular element or a group of elements are