Mineral Nutrition

Mineral nutrition in plants

Every living organisms need carbohydrates, proteins, fats, water, and minerals to live. Similarly, plants need nutrients for growth and development.

Methods to study the mineral requirement of plants

- **Hydroponics** is a technique in which plants are grown in nutrient solution instead of soil. This technique is used at the time of commercial production of vegetables. It is also used to study the mineral deficiency diseases in plants.
- **Aeroponics** is the technique in which nutrients are sprayed suspended in the air.

Essential mineral elements

Different plants have different mineral requirements. There is criterion for the essentiality of an element. It includes-

- The element must be necessary for normal growth and reproduction. In the absence of that element the plants will not be able to complete its life cycle.
- The requirement of the element must be specific, and it should not be replaceable by any another element.
- The element must be directly involved in the metabolism of the plant.

The mineral elements needed by the plant is divided into- macronutrients and micronutrients

Macronutrients:

These elements are needed by the plants in large quantities. It includes carbon, hydrogen, oxygen, nitrogen, phosphorous, sulphur, potassium, calcium and magnesium. Carbon, hydrogen and oxygen are obtained mainly from CO_2 and H_2O. Others are absorbed from the soil as mineral nutrition.

Micronutrients

These are the nutrients that are needed by the plants in small quantity. It includes iron, manganese, copper, molybdenum, zinc, boron, chlorine and nickel.

Essential elements are grouped in different categories based on their diverse functions such as-

- Essential elements such as carbon, hydrogen, oxygen and nitrogen serves as components of various biomolecules such as amino acids, lipids and hence structural elements of cells
- Essential elements are major components of chemical compounds related to energy such as magnesium ion in chlorophyll and phosphorous in ATP.
- Essential elements also influence enzyme action by acting as activator and inhibitor of certain enzymes. For example, Mg^{2+} activates both ribulose bisphosphate carboxylase oxygenase and

phosphoenol pyruvate carboxylase. Both of these are essential in carbon fixation. Zn^{2+} activates alcohol dehydrogenase and Mo is essential for nitrogenase activity during nitrogen metabolism.

- Some essential elements control osmolarity of a cell. Potassium ions control the opening and closing of stomata.

Role of macronutrients and micronutrients

The role of different macro and micronutrients are given below-

Nitrogen

- Essential element required by the plants in large quantities.
- It is absorbed by the plants in the form of **nitrate ions $(NO_3)^-$** and some plants also absorb in the form of **nitrite ions$(NO_2)^-$ or ammonium ions $(NH_4)^+$**
- Needed by the plants for actively growing tissues such as meristematic tissues.
- It is a necessary component of vitamins.
- Directly involved in photosynthesis.

Phosphorous

- It is absorbed by the plants in the form of **phosphate ions $(PO_4)^{3-}$**
- It is major component of cell membranes, proteins, nucleic acids and nucleotides.
- Promotes root formation and growth.
- Required for seed formation.
- Involved in energy storage and transfer.

Potassium

- It is absorbed by the plants in the form of **potassium ions**.
- It is abundant in actively growing tissues such as meristematic tissues, buds, leaves and root tips.
- It is required for maintaining osmotic potential in a cell which is responsible for **opening and closing of the stomata**.
- Increases the rate of photosynthesis
- Essential for protein synthesis

Calcium

- It is absorbed by the plants in the form of **calcium ions(Ca^{2+})**
- Required for continuous cell division and growth.
- Involved in nitrogen metabolism.
- It is present in the **middle lamella** in the form of **calcium pectate**.

- It is also required for the formation of mitotic spindle
- It is also required for the activation of the certain enzymes.

Magnesium

- It is absorbed by the plants in the form of **magnesium ions(Mg^{2+})**
- It is required for the activation of the enzymes involved in respiration, photosynthesis.
- It is involved in the synthesis of RNA and DNA.
- Key component of chlorophyll.
- It also maintains ribosome structure.

Sulphur

- Absorbed in the form of **sulphate ions(SO_4)$^{2-}$**
- Integral component of amino acids such as methionine.
- Component of several coenzymes vitamins such as **thiamine, biotin, and ferrodoxin**.
- Helps in seed production
- Required for chlorophyll formation

Iron

- Plants absorb iron mainly in the form of **ferric ions(Fe^{3+})**
- Important for cell division and growth.
- Participates in electron transfer during various metabolic reactions.
- It is important for the activation of an enzyme catalase that is required for chlorophyll formation.
- Serves as oxygen carrier.

Manganese

- It is absorbed in the form of **manganese ions (Mn^{2+}).**
- It is involved in photolysis of water during non-cyclic photophosphorylation.
- One of the component **of nitrogenase** enzyme required for nitrogen metabolism.

Zinc

- It is absorbed in the form of **zinc ions (Zn^{2+}).**
- Required for chlorophyll formation.
- Involved in activation of various enzymes such as carboxylases.
- Needed for carbohydrate formation.

Copper

- It is absorbed by the plants in the form of **cupric ions (Cu^{2+}).**
- It is involved in redox reactions during metabolic reactions.
- Works during photosynthesis and reproductive stages of the plants.
- Involved in flavor of fruits and vegetables.
- Increase the sugar content of the plants.

Boron

- It is absorbed by the plants in the form of **BO_3^{3-} or $B_4O_7^{2-}$.**
- Involved in the uptake of calcium by the plants.
- Functions in pollen tube formation.
- Carbohydrate translocation in plants.
- Involved in cell differentiation.

Molybdenum

- Plants obtain it in the form of **molybdate ions ($(MoO_2)^{2-}$).**
- Major component of nitrogenase enzyme. It forms a catalytic site of the enzyme along with iron.
- It is an important component of nitrate reductase. Nitrate reductase is an enzyme involved in nitrogen assimilation.
- Takes part in nodule formation

Chlorine

- Absorbed as **chloride ions (Cl^{1-}).**
- Maintains the osmotic potential of the cell.
- It is involved in photolysis of water for evolution of oxygen

Deficiency Symptoms of Essential Elements

- Nitrogen is one of the important essential elements. Deficiency of nitrogen leads to yellowing of leaves.
- Phosphorus is another element of which deficiency will lead to burnt leaf tips and yellowing of the tips.
- Potassium deficiency causes interveinal chlorosis and older leaves to wilt.
- Calcium deficiency leads to blossom end rot.
- Magnesium causes older leaves to become yellow, that is, chlorosis of leaf due to degradation of chlorophyll.

- Sulphur deficiency leads to yellowing of younger leaves compared to older leaves.
- Iron deficiency causes chlorosis of young leaves. Dieback disease is the characteristic disease of deficiency of iron in plants.
- Manganese causes yellowing in between the veins of the leaves and reduce plant parts with dead spots.
- Zinc causes rosette formation, yellowing between the veins as well as stunted growth of the plant.
- Copper is another mineral element, deficiency of which cause weakening of cell wall, dieback of stems and twigs.
- Boron affects the reproductive as well as vegetative growth of the plants and, death of the meristem.
- Molybdenum causes stunted growth. Leaves appear pale and there is necrosis in the tissues.
- Chlorine causes wilting, chlorosis, and highly branched root system.

Metabolism of nitrogen

Nitrogen exists as two nitrogen atoms joined by a triple covalent bond ($N \equiv N$). The process of conversion of nitrogen into ammonia is known as nitrogen fixation.

There are two methods for the conversion of nitrogen into ammonia. They are as follows-

- **Physical nitrogen fixation** occurs at the time of lightning. N_2 and O_2 present in the atmosphere reacts in presence of lightning to form nitric oxide (NO). NO then further gets oxidized to form nitrogen peroxide (NO_2).

  Formation of ammonia by the decomposition of dead plants and animals is known as **ammonification**. The process of conversion of ammonia in nitrite and then into nitrate is known as **nitrification**. The formation of nitrite occurs in presence of *Nitrosomonas* bacteria whereas nitrate formation occurs in presence of *Nitrobacter*.

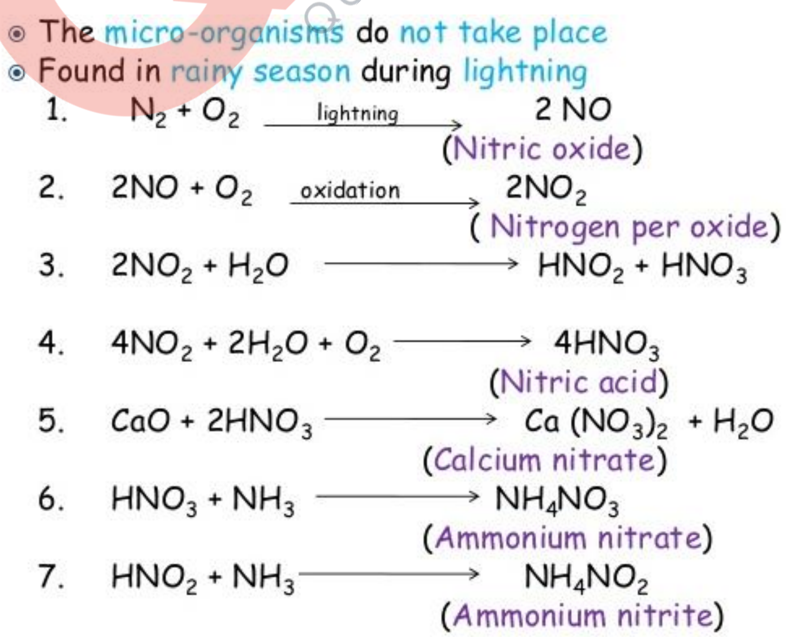

Fig.14. Steps of physical nitrogen fixation

- **Biological nitrogen fixation** occurs in presence of nitrogen fixing bacteria such as *Rhizobium*. The prokaryotes that fixes nitrogen biologically are known as **diazotrophs**. *Rhizobium* lives in symbiotic association with the roots of the leguminous plants. The enzyme that fixes nitrogen biologically is known as nitrogenase. Nitrogen fixing bacteria can be free living as well as symbiotic. Examples of free-living nitrogen-fixing aerobic microbes are *Azotobacter*, *Rhodospirillum*, *Anabaena* and *Nostoc* etc.

  Rhizobium lives in symbiotic association with the leguminous plants such as pea, beans, clover, alfalfa, etc. Nitrogen fixation involves characteristic nodule formation. Nodule formation begins with the interaction of *Rhizobium* with the roots of the plants. These plants release certain chemicals that attract the bacteria towards the roots of the plants. The *Rhizobium* secrets root hair curling factor that helps the bacteria to further invade the roots. Nitrogenase enzyme that catalyses nitrogen fixation is sensitive to oxygen. Oxygen is therefore scavenged by the enzyme leghemoglobin (belonging to hemoglobin family) during nitrogen fixation.

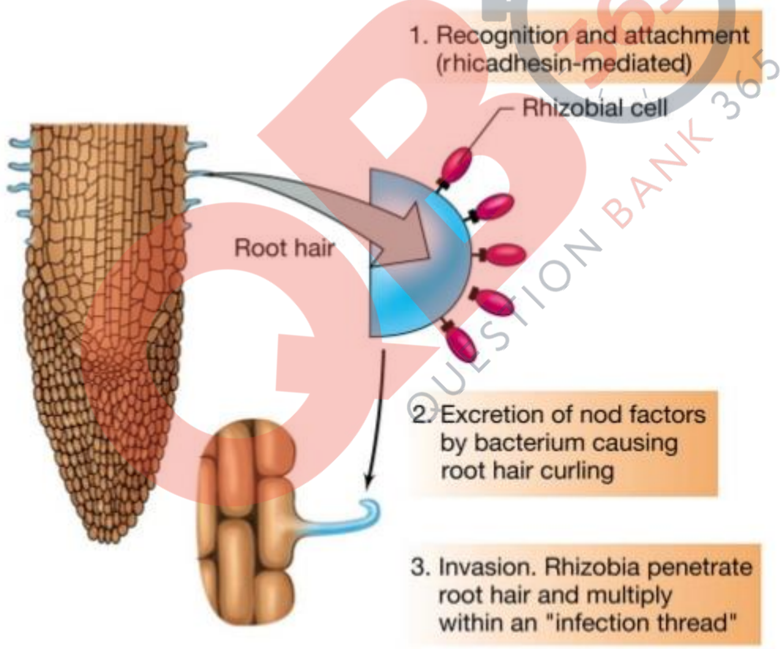

Fig.14. Steps of nodule formation during biological nitrogen fixation

The reaction catalyzed by the nitrogenase is as follows-

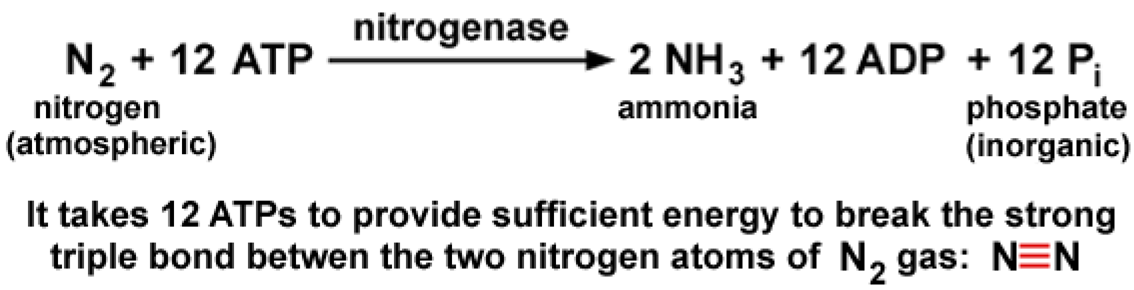

Fig.15. Nitrogenase reaction during biological nitrogen fixation

Nitrogen fixation is an energy intensive process. 16 ATP molecules are required to convert one molecule of nitrogen into two molecules of ammonia.

The ammonia formed as a result of nitrogen fixation is toxic to the plants. Thus, this ammonia undergoes further reactions-

- **Reductive amination**: The process in which ammonia reacts with alpha-ketoglutaric acid and forms glutamic acid or glutamate as shown below-

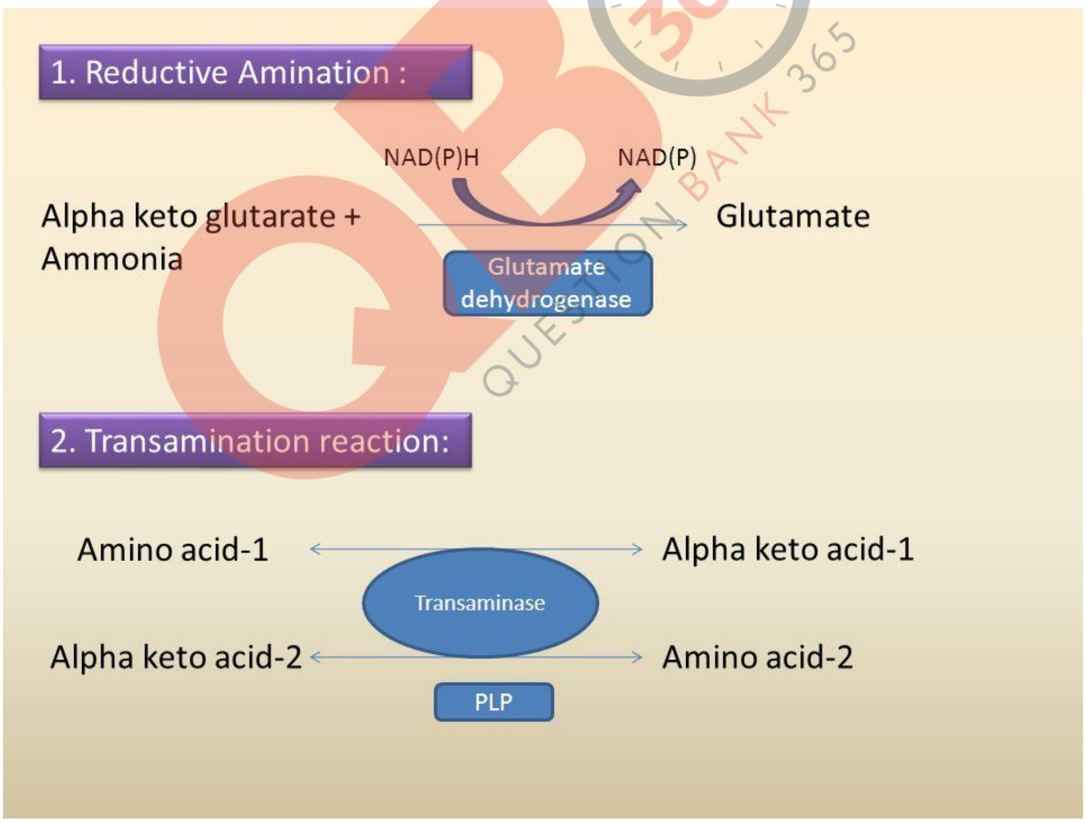

Fig.16. Reductive amination and Transamination

- **Transamination:** The transfer of amino group from one amino acid to keto acid. This reaction is catalyzed by enzymes known as transaminases. This forms asparagine amino acids.
  Thus, toxic ammonia is converted into amino acids that are essential for the plant growth and development.