Lesson 16

Plant nutrition

Learning outcomes

- The trainee knows the impact on growth, development and health of the following elements: Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulphur (S), Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), Molybdenum (Mo), Boron (B).

Instructions for the trainer

- The trainer shares theoretical knowledge through presentation.

Basic requirements: Projector, computer

Today, the close relationship between health and nutrition is increasing day by day. The Covid-19 pandemic, which has recently caused great deaths around the world, is a very good example of this. Because Covid-19, which has various effects on health and nutrition, is a respiratory disease and affects individuals with weak immune systems or chronic health problems more, health and nutrition measures have increased their importance. Therefore, it is known that the soil, which is the production environment, must first be recognized very well. It is a fact that plant nutrition, which affects plant development, yield, and quality, is very important in terms of plant and soil management. For this purpose, it has become a necessity to increase plant yield and reduce chemical inputs [93]. Plant nutrition is the sum of chemical elements and compounds necessary for plant growth and reproduction, and plant metabolism, in other words, plants need some plant nutrients for healthy growth. In their absence, the plant cannot complete a normal life cycle. Plants take a large number of nutrients from the environment in which they develop with their above- and below-ground organs. Seventy-four elements can be taken up by plants. However, only some of these elements are essential for plants. These mineral substances that plants need for their development are called absolute essential plant nutrients.

Necessary plant nutrients are divided into two. These are macro and micronutrients. **Macronutrients**: carbon (C), oxygen (O), hydrogen (H), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulfur (S), magnesium (Mg). **Micronutrients (or trace minerals)**: iron (Fe), boron (B), chlorine (Cl), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), nickel (Ni). In recent years, it is reported that sodium (Na), cobalt (Co), vanadium (V) and silicon (Si) have also been included in the classification of absolute essential elements [94].

The role of each plant nutrient element in the plant is different. Therefore, each element is necessary for the plant. So what are these benefits, what are the damages in case of excess, and what are the changes seen in the plant when it is deficient? Let's examine the most important ones one by one.

16.1. Nitrogen

Nitrogen is vital for plants and is an essential nutrient. Plants always need nitrogen for healthy reproduction, growth, and development [95].

Protein and Enzyme Production: Nitrogen is an essential component for protein synthesis in plants. Plants need protein to grow and develop, and this enables the formation of the plant's cellular structures and organelles. It also helps regulate metabolic reactions by taking part in the structure of enzymes.

Chlorophyll Synthesis: Chlorophyll is the green pigment found in chloroplasts, the cell organelles in plants where photosynthesis takes place. Photosynthesis is an important process in which plants use solar energy to convert carbon dioxide and water into glucose and oxygen. Chlorophyll contains nitrogen in its structure and therefore plants need nitrogen for photosynthesis.

Formation of Nucleic Acids: Nitrogen is found in the building blocks of nucleic acids (DNA and RNA) in plants. Nucleic acids store the hereditary information of plants and are vital for the synthesis and transmission of genetic material.

Formation of Amino Acids: Nitrogen is the building block of amino acids in plants. Amino acids are the basic building blocks for protein synthesis and are critical for the growth and development of plants.

Plant Growth and Productivity: Nitrogen supports the development and growth of root, leaf, and stem tissues of plants.

16.1.1. Deficiency and excess of nitrogen

Nitrogen deficiency is mostly seen in young leaves. Leaves develop light green color, in case of further progression, leaves turn yellow, and a lack of photosynthesis is observed. Chlorosis (yellowing) is first seen in old leaves and then in young leaves. Cell size and cell division decrease and plants become stunted. In excess nitrogen, premature aging of leaves is observed.

16.2. Phosphorus

Phosphorus is an essential nutrient element that is vital for plants. Plants need phosphorus for growth, energy transfer, cell structure, and formation of genetic materials [96]. The main functions of phosphorus in plants are as follows:

Energy Transfer: In plants, energy transfer takes place inside the cell through ATP (adenosine triphosphate) molecules. Phosphorus is one of the basic components of ATP molecules and plants need phosphorus where energy is required for their cellular activities and biochemical reactions.

DNA and RNA Synthesis: Phosphorus is one of the building blocks of DNA and RNA in plants. DNA and RNA store the genetic material of plants and are vital for protein synthesis and the transfer of genetic information.

Cell Membrane Structure: Phosphorus is involved in the basic structure of cell membranes in plants. Cell membranes are important structural components that separate the cell interior from the external environment and phosphorus plays an important role in the formation of these membranes.

Photosynthesis Phosphorus plays an important role in the regulation of photosynthetic reactions and energy transfer in plants. Photosynthesis is a critical process in which plants use solar energy to convert carbon dioxide and water into glucose and oxygen.

Plant Growth and Development: Phosphorus supports the development of the root, leaf, and stem tissues of plants. Phosphorus deficiency negatively affects root development in plants and slows down the growth of plants.

Reaction Catalyst: Phosphorus functions as a catalyst for biochemical reactions in plants. It regulates metabolic reactions by taking part in the structure of enzymes and provides physiological functions to plants.

Phosphorus deficiency or excess in the plant is one of the important problems that adversely affect plant health. Both can adversely affect plant

development and cause yield losses. Here are the effects of phosphorus deficiency and excess in the plant:

16.2.1. Phosphorus Deficiency

Problems in Root Development: Phosphorus deficiency negatively affects the root development of plants. Roots weaken and cannot get enough nutrients and water.

Slow Growth: The growth rate of plants slows down due to phosphorus deficiency. Plants may have smaller and weaker leaves.

Yield Loss: Phosphorus deficiency reduces the crop yield of plants. Especially fruit and seed formation can be affected.

Color Changes: Leaves may turn purple or dark green and leaf margins may be reddish.

Ripening Delay: Due to phosphorus deficiency, the ripening of fruits or seeds of plants may be delayed.

Seed Formation Problems: Phosphorus deficiency can affect the seed formation of plants and reduce seed quality.

16.2.2 Phosphorus Excess

Mineral Imbalance: Phosphorus excess can cause mineral imbalances in plants and inhibit the absorption of other nutrients.

Toxicity: Phosphorus excess can lead to plant toxicity and cause symptoms such as burns or chlorosis (yellowing of leaves).

Nutrient Poisoning: Phosphorus excess can reduce the bioavailability of other nutrients in the soil and damage plants.

Environmental Pollution: Excess phosphorus can cause environmental pollution in agricultural fields and irrigation water. The leaching of excess phosphorus into water bodies can adversely affect aquatic ecosystems and lead to algal blooms.

Therefore, it is important to ensure a balanced supply of phosphorus in the plant. In case of phosphorus deficiency, fertilizers containing appropriate phosphorus can be applied to the plants. In case of phosphorus excess, measures should be taken to improve the soil and to provide phosphorus in balance with other nutrients. It is important to carry out regular soil analyses and to ensure the balance of nutrients to protect plant health.

16.3. Potassium

Potassium is an important macronutrient for plants and is vital for plant growth, development, and metabolism [97]. The main functions of potassium in plants are as follows:

Water Balance and Osmoregulation: Potassium regulates the water balance in plant cells. Potassium ions inside the cell regulate the turgor pressure (tension) of the cell by controlling the entry of water into the cell. This allows plants to regulate the uptake and loss of water, ensuring a regular transport of water.

Photosynthesis and Respiration: Potassium affects the processes of photosynthesis and respiration in plants. In chloroplasts (the organelle where photosynthesis takes place), potassium is involved in the structure of chlorophyll molecules and photosynthetic enzymes. Therefore, it regulates photosynthesis processes and enables plants to produce food by using solar energy.

Protein Synthesis and Enzyme Activity: Potassium plays an important role in protein synthesis and activation of enzymes. It regulates the metabolic processes of plants by increasing the activity of enzymes.

Cell Division and Growth: Potassium affects cell division and growth processes in plants. It supports the development of root, leaf, and stem tissues of plants.

Disease Resistance: Potassium increases plant resistance to disease. It helps thicken and strengthen the walls of plant cells, thus preventing the entry of diseased organisms into the plant.

Ripening and Fruit Formation: Potassium affects the fruit formation of plants and the ripening of fruits. This increases crop yield and quality of plants.

Deficiency or excess of potassium in the plant is one of the important problems that adversely affect plant health. Both can negatively affect plant development and cause yield losses. Here are the effects of deficiency and excess potassium in the plant:

16.3.1. Potassium Deficiency

In potassium deficiency, the edges appear burnt on older leaves.

Slow Growth: Potassium deficiency negatively affects the growth rate of plants. Plants may have smaller and weaker leaves.

Leaf Yellowing: Due to potassium deficiency, yellowing (chlorosis) can be seen on the leaves. Yellowing leaves are first affected from the edges.

Susceptibility to Desiccation: Potassium deficiency weakens the ability of plants to regulate water balance and can cause plants to be more susceptible to desiccation.

Yield Loss: Potassium deficiency reduces crop yield in plants. Fruit and seed formation may be affected, thus yield may decrease.

Drying of Leaf Tips: Potassium deficiency can cause drying and burns on leaf tips.

Plants become susceptible to insects and disease.

16.3.2. Potassium Excess

Mineral Imbalance: An excess of potassium can cause mineral imbalances in plants and inhibit the absorption of other nutrients.

Toxicity: Excess potassium can lead to plant toxicity and cause symptoms such as burns or chlorosis (yellowing of leaves).

Nutrient Poisoning: An excess of potassium can reduce the bioavailability of other nutrients in the soil and damage plants.

16.4. Calcium

Calcium is an essential nutrient for plants and is vital for their growth, development, and healthy functioning [98]. The main functions of calcium in plants are:

Cell Wall Formation: Calcium plays an important role in the structure of the cell walls of plants. Cell walls provide the structural support of plants and determine the shape and rigidity of the cells.

Cell Division: Calcium regulates cell division in plants and supports the development of root, leaf, and stem tissues.

Ion Balancing: In plants, calcium regulates the ion balance inside and outside the cell. Calcium ions inside the cell regulate the functioning of the cell membrane and water movement.

Enzyme Activation: Calcium plays a critical role in the activation of many enzymes in plants. Enzymes are involved in the regulation of metabolic reactions in plants and calcium activates these reactions.

Cell Signalling: Calcium is an important part of cellular signaling in plants. Calcium levels within the cell can change in response to environmental stimuli and hormonal signals, allowing plants to respond.

Stomatal Control: Stomata are small holes in the leaves of plants that allow gas exchange and water vapor loss. Calcium is part of the mechanisms that regulate the opening and closing of stomata and controls water loss.

Disease Resistance: Calcium increases disease resistance in plants and activates plant defense mechanisms against pathogens (disease-causing organisms).

These functions of calcium in the plant are vital for the healthy growth and development of plants. Calcium deficiency can cause problems in plants such as weak cell walls, edge curling of leaves, and poor resistance to diseases. It is therefore important in agriculture and horticulture to provide plants with sufficient amounts of calcium. Plants are usually fed with calcium-containing fertilizers to meet their calcium needs. In addition,

calcium increases the fixation of atmospheric nitrogen by bacteria and increases the availability of molybdenum.

16.4.1. Calcium Deficiency

In calcium deficiency, the tips of the growing roots and leaves turn brown and die. The quality of the fruit is also affected and the fruits develop flower nose rot.

Problems in Root Development: Calcium deficiency negatively affects the root development of plants. Roots weaken and not enough water and nutrients can be taken.

Cell Wall Weakness: Calcium is involved in the structure of cell walls and therefore calcium deficiency causes the cell walls of plants to weaken. This reduces the structural support of the plants and collapse and sagging of the plants can occur.

Leaf Disturbances: Calcium deficiency can cause symptoms such as marginal curling, necrosis (tissue death), and curling of leaves.

Fruit Rot Calcium deficiency may cause rotting and deformation in fruits. There may be loss of quality especially in rind fruits.

Stomatal Control Disorder: Calcium deficiency prevents stomata (leaf holes) from functioning normally and can increase water loss in plants.

16.4.2. Calcium Excess

It can inhibit the absorption of other nutrients: An excess of calcium can reduce the absorption of other nutrients in the soil and cause nutrient deficiencies in plants.

Salinity and Toxicity: Calcium excess can cause salinity and high pH in the soil. This can cause toxicity in plants and negatively affect root development.

Nutrient Imbalance: An excess of calcium can disturb the balance of other nutrients and lead to mineral imbalances in plants.

16.5. Magnesium

Magnesium is a macronutrient element of vital importance for plants [99]. The main functions of magnesium in plants are as follows:

Chlorophyll Synthesis: Magnesium is an essential component of chlorophyll molecules in plants. Chlorophyll is the green pigment in which plants convert water and carbon dioxide into glucose and oxygen using solar energy in the process of photosynthesis. Without magnesium in the structure of chlorophyll, photosynthesis cannot take place and plants cannot produce nutrients.

Energy Transfer: Magnesium is an essential component of ATP (adenosine triphosphate) molecules in plants. ATP is the main molecule used for energy transfer of cellular activities in plants. Magnesium ensures efficient synthesis of ATP and cellular energy transfer.

Enzyme Activation: Magnesium plays a critical role in the activation of many enzymes in plants. Enzymes play an important role in the regulation of metabolic reactions and the synthesis of nutrients in plants. Magnesium is involved in the structure and function of these enzymes and helps many biochemical reactions to occur in plants.

Protein Synthesis: Magnesium plays an important role in protein synthesis in plants. Plants need proteins to grow, develop and fulfill their life functions. Magnesium plays an active role in ribosomes (structures of protein synthesis).

Synthesis of Nucleic Acids: Magnesium is involved in the synthesis of DNA and RNA (nucleic acids) in plants. Nucleic acids are critical for the storage and transfer of genetic material in plants. Magnesium plays an important role in the regulation of these processes.

Deficiency or excess of magnesium in the plant is one of the important problems that adversely affect plant health. Both can negatively affect plant development and cause yield losses. Here are the effects of deficiency and excess of magnesium in the plant:

16.5.2. Magnesium Deficiency

In magnesium deficiency, in old leaves of plants, interveinal veins turn yellow and veins remain green (Interveinal chlorosis).

Leaf Yellowing: Yellowing of leaves (chlorosis) can be seen due to magnesium deficiency. The yellowing leaves are first affected by the edges and may cover all leaves over time.

Slow Growth Magnesium deficiency negatively affects the growth rate of plants. Plants may have smaller and weaker leaves.

Decrease in Photosynthesis Efficiency: Since magnesium is present in the structure of chlorophyll molecules, its deficiency negatively affects the photosynthesis process. This reduces the ability of plants to produce nutrients using solar energy.

Decrease in Flower and Fruit Formation: Magnesium deficiency can affect the flower and fruit formation of plants and cause low yields.

Problems in Root Development: Magnesium deficiency can adversely affect the root development of plants and interfere with nutrient and water uptake.

16.5.2. Magnesium Excess

It may inhibit the absorption of other nutrients: Magnesium excess can inhibit the absorption and transport of other nutrients in plants. This can cause mineral imbalances in plants.

Cellular Disruptions: Magnesium excess can lead to deterioration and toxicity in plant cells. Disruption of cell membranes and organelle structures can be seen.

Decreased Photosynthesis: Magnesium excess can also negatively affect photosynthesis efficiency and reduce the nutrient production of plants.

Inhibiting Root Development: Magnesium excess can negatively affect the root development of plants and inhibit the growth of roots.

16.6. Sulphur

Sulphur is a micronutrient for plants and is essential for the healthy growth and development of plants [100]. The main functions of sulphur in plants are as follows:

Formation of Amino Acids and Proteins: One of the main functions of sulphur is to ensure the formation of amino acids and proteins in plants.

Chlorophyll Synthesis: Sulphur has an important role in the synthesis of chlorophyll in plants.

Synthesis of Plant Hormones: Sulphur is thought to be effective in the synthesis of some plant hormones in plants.

Participation in Cell Membrane Structure: Sulfur participates in the structure of the cell membrane in plants and supports the strength and functionality of the cell membrane.

Activates the Defense Mechanisms of Plants: Sulphur activates the defense mechanisms of plants against diseases and harmful organisms. It especially increases the resistance of plants against some diseases.

Deficiency or excess of sulphur in the plant is one of the important problems that adversely affect plant health. Both can adversely affect plant development and cause yield losses. Here are the effects of deficiency and excess sulphur in the plant:

16.6.1. Sulphur Deficiency

In case of sulphur deficiency, the interveinal yellow color between the veins and the veins remains green (Interveinal chlorosis).

Slow Growth: Sulfur deficiency negatively affects the growth rate of plants. Plants may have smaller leaves and their development may be slow.

Leaf Yellowing: Yellowing of leaves (chlorosis) may occur due to sulphur deficiency. The young parts of the leaves are affected, and the leaves may turn pale green or yellow.

Decreased Protein and Amino Acid Synthesis: Sulphur deficiency reduces protein and amino acid synthesis in plants. This situation negatively affects the normal growth and development of plants.

Problems in Chlorophyll Synthesis: Chlorophyll is the pigment that plants need for photosynthesis. Sulfur deficiency can reduce the photosynthesis efficiency of plants by affecting chlorophyll synthesis.

16.6.2. Sulfur Excess

May inhibit the **absorption of other nutrients**: An excess of sulphur can inhibit the absorption and transport of other nutrients in plants (such as calcium and potassium). This can cause mineral imbalances in plants and lead to deficiencies of other nutrients.

Toxicity: Excess sulphur can cause toxicity in plants. Symptoms such as burns on leaves, curling of leaf margins and plant death can be seen.

16.7. Iron

Iron is a micronutrient element of vital importance for plants [101]. The main functions of iron in plants are as follows:

Chlorophyll Synthesis: Iron is an essential component in the structure of chlorophyll molecules in plants.

Takes Part in Electron Transport Chain: Iron is involved in the structure of important proteins and enzymes such as cytochromes in the electron transport chain in plants. This chain ensures the transport of electrons in energy production processes such as photosynthesis and respiration.

Nitrate Reduction: Iron plays an important role in the conversion of nitrate to nitrite and then to ammonia in plants. This process is important for plants to take up nitrogen and form proteins and other compounds.

DNA and RNA Synthesis: Iron plays an important role in DNA and RNA synthesis in plants. DNA and RNA are critical for the storage and transfer of genetic material in plants.

Enzyme Activation: Iron plays a critical role in the activation of many enzymes in plants.

Deficiency or excess of iron in the plant is one of the important problems that adversely affect plant health. Both can negatively affect plant development and cause yield losses.

16.7.1. Iron Deficiency

Chlorosis (leaf yellowing): Iron deficiency affects chlorophyll synthesis in plants and causes yellowing of leaves (chlorosis). Yellowing of the leaves first appears on the young leaves and between the leaf veins. In severe cases, the whole plant may be light green.

Slow Growth: Iron deficiency negatively affects the growth rate of plants. Plants may have smaller leaves and less branched stems.

Restricted Photosynthesis and Nutrient Production: Iron deficiency reduces the photosynthetic efficiency of plants by reducing chlorophyll synthesis and restricts nutrient production.

Respiration Problems: Iron deficiency can affect the regulation of respiratory processes in plants and affect the energy production of plants, negatively affecting growth.

16.7.2. Iron Excess

Food Poisoning Iron excess can cause nutrient poisoning in plants. High iron levels can produce symptoms of toxicity in plants and cause spots, drying, and burns on leaves.

Mineral Imbalance: Iron excess can lead to mineral imbalances in plants by affecting the absorption and transport of other nutrients.

Negatively Affecting Root Development: Iron excess can negatively affect the root development of plants and prevent the roots from growing healthily.

In excess of iron, tanning, tiny brown spots appear on the leaves.

16.8. Manganese

Manganese is an important micronutrient for plants and has various functions in plants [102]. The main functions of manganese are as follows:

Chlorophyll Synthesis: Manganese is present in the structure of chlorophyll molecules in plants and plays an important role in chlorophyll synthesis. Chlorophyll is the green pigment that enables plants to produce nutrients by using solar energy in the process of photosynthesis.

Antioxidant Activity: Manganese is involved in the activation of antioxidant enzymes in plants. These enzymes help plants fight oxidative stress and prevent damage to cells.

Enzyme Activation: Manganese plays an important role in the activation of many enzymes in plants. It is especially involved in the structure of enzymes that catalyze redox reactions and regulates the metabolism of plants.

Nitrate Reduction: Manganese plays an important role in the reduction of nitrate to nitrite and then to ammonia in plants.

Phosphoric Acid Metabolism: Manganese plays an important role in phosphoric acid metabolism in plants and regulates phosphorus absorption and transport by plants.

Increases the availability of P and Ca in plants.

16.8.1. Manganese Deficiency

Chlorosis (Leaf Yellowing): Manganese deficiency, chlorosis (yellowish green) can be seen in the leaves of plants. Intermediate veins of leaves and young leaves are affected. Manganese deficiency is similar to iron deficiency in plants. Grey spots and streaks appear on the leaves. If severe, plants become stunted.

Decrease in Photosynthesis Efficiency: Manganese deficiency can reduce nutrient production by negatively affecting the photosynthesis process in plants.

Growth Retardation: Manganese deficiency adversely affects the normal growth and development of plants. Plants may have smaller leaves and poorly branched stems.

16.8.2. Manganese Excess

Toxicity: Excess manganese can cause toxicity to plants. High manganese levels can cause spotting, burns, and drying of leaves. Older leaves will show a chlorotic zone and brown spots surrounded by a circle.

It may inhibit the absorption of other nutrients: Manganese excess can lead to mineral imbalances in plants by inhibiting the absorption and transport of other nutrients.

16.9. Copper

Copper is one of the micronutrients required in trace amounts for plants and has various functions in plants [103]. The main functions of copper are:

Enzyme Activation: Copper plays an important role in the activation of many enzymes in plants. It is especially involved in the structure of enzymes that catalyze redox reactions and regulates the metabolism of plants.

Supporting Cell Wall and Tissue Structure: Copper helps support cell walls and tissue structure in plants. This is important for maintaining the structural integrity of plants.

Phosphorus Metabolism: Copper regulates phosphorus metabolism in plants, allowing plants to absorb and transport phosphorus.

Chlorophyll Synthesis: Copper is present in the structure of chlorophyll molecules in plants and contributes to chlorophyll synthesis. Chlorophyll is the green pigment that enables plants to produce nutrients by using solar energy in the photosynthesis process.

It is a catalyst for respiration. Provides balancing of water movement in the plant.

16.9.1. Copper Deficiency

In copper deficiency, plant growth slows down, and plants begin to deteriorate. Young leaves and the death of the growth point are experienced. Copper deficiency, chlorosis (yellowish green) can be seen in the leaves of plants. This is due to the effect of chlorophyll synthesis.

Slow Growth and Development: Copper deficiency can negatively affect the growth rate and development of plants. Plants may have smaller leaves and poorly branched stems.

16.9.2. Copper Excess

Toxicity: Excess copper can cause toxicity to plants. High copper levels can cause spotting, burns, and drying of leaves.

It may inhibit the absorption of other nutrients: Copper excess can lead to mineral imbalances in plants by inhibiting the absorption and transport of other nutrients (such as Fe).

16.10. Zinc

Zinc is one of the micronutrients required in trace amounts for plants and has several important functions in plants [104]. The main functions of zinc are as follows:

Enzyme Activation: Zinc plays an important role in the structure and activation of many enzymes in plants.

Hormone Regulation: Zinc plays an important role in the regulation of some hormones in plants. It regulates auxin hormone concentration.

Protein Synthesis: Zinc plays an important role in protein synthesis in plants.

Chlorophyll Synthesis: Zinc is present in the structure of chlorophyll molecules in plants and is an important component in chlorophyll synthesis.

Cell division promotes shoot elongation. It provides flower eye formation and proper development of fruits.

16.10.1. Zinc Deficiency

Chlorosis (leaf yellowing): Zinc deficiency, chlorosis (yellowish green) can be seen in the leaves of plants. Intermediate veins of leaves and young leaves are affected. If the deficiency progresses, the leaves turn white.

Short, Curled, and Narrow Leaves: Zinc deficiency can cause leaves to be shorter, curled, and narrower than normal in plants.

Problems in Root Development: Zinc deficiency can negatively affect the root development of plants and prevent healthy root growth.

16.10.2. Zinc Excess

Toxicity: Excess zinc can cause toxicity in plants. High zinc levels can cause spotting, burns and drying of leaves.

It may inhibit the absorption of other nutrients: Excess zinc can inhibit the absorption and transport of other nutrients, leading to mineral imbalances in plants.

16.11. Molybdenum

Molybdenum is a micronutrient required in trace amounts for plants and has important functions in the plant. The main function of molybdenum is to play a critical role in nitrogen conversion processes in plants [105]. The function of molybdenum in plants are:

Nitrogen Fixation: Molybdenum plays an important role in nitrogen fixation in plants. Molybdenum is involved in the structure of enzymes (nitrogenases) that are effective in nitrogen fixation and helps plants to utilize nitrogen in the atmosphere.

It helps nitrogen fixation by rhizobium bacteria. Root nodule bacteria also require Mo.

Reduction of **Nitrate**: Molybdenum is also involved in the conversion of nitrate to simpler compounds, e.g., ammonia, in plants.

Increases the availability of P and S in the soil. Takes part in vitamin synthesis.

16.11.1. Molybdenum Deficiency

Molybdenum deficiency symptoms are often similar to nitrogen deficiency. Older and middle leaves first undergo chlorosis. In some cases, leaf curling, growth, and flower formation are restricted.

Problems in Nitrogen Fixation and Nitrate Reduction: Molybdenum deficiency reduces the efficiency of nitrogen fixation and nitrate reduction in plants. Therefore, nitrogen uptake and protein synthesis of plants may be affected.

Slow Growth and Development: Molybdenum deficiency can cause slow growth and development in plants. Leaves of plants may be small and pale in color.

16.11.2. Molybdenum Excess

Toxicity: Excess molybdenum can cause toxicity in plants. High molybdenum levels can cause spotting and burns on leaves (chlorosis with orange color and pigmentation).

It may inhibit the absorption of other nutrients: Molybdenum excess can lead to mineral imbalances in plants by inhibiting the absorption and transport of other nutrients.

Molybdenum deficiency is usually seen when the soil pH is high or the soil in which the plants grow is deficient in molybdenum.

16.12. Boron

Boron is a micronutrient required in trace amounts for plants and has several important functions in plants [106]. The main functions of boron are:

Contribution to Cell Wall Structure: Boron contributes to the regulation of the permeability of the cell wall structure in plants.

Cell Division and Elongation: Boron plays an important role in the processes of cell division and elongation in plants.

Carbohydrate and Protein Metabolism: Boron is involved in carbohydrate and protein metabolism in plants and regulates the processes of energy production and nutrient synthesis.

Activation of Hormones: Boron can be effective in the activation of some hormones in plants. These hormones regulate processes such as the growth and flowering of plants.

It provides the **transport of photosynthesis** products from leaves.

16.12.1. Boron Deficiency

Abnormal development of growth points (meristematic tissue) occurs, and apical growth points are stunted and die in boron deficiency. Flower and fruit formation does not occur. For some cereals and fruits, yield and quality are significantly reduced.

Cell Wall Weakness: Boron deficiency can cause cell wall weakness and structural problems in plants. This can negatively affect the growth and development of plants.

Spot Formation on Leaves: Boron deficiency can cause brown spot formation on leaves in plants.

Slow Growth and Development: Boron deficiency can cause slow growth and development in plants. Plants may have smaller leaves and poorly branched stems.

16.12.2. Boron Excess

Boron excess can cause toxicity in plants. High boron levels can cause burns and drying of leaves. It may inhibit the absorption of other nutrients: Boron excess can lead to mineral imbalances in plants by inhibiting the absorption and transport of other nutrients.