Unit-IV

Mineral nutrition: Essential micro and macro elements and their role, mineral uptake, deficiency and toxicity symptoms. Nitrogen metabolism: Biology of nitrogen fixation – *nif* genes – mechanism of nitrogen fixation and assimilation of ammonia.

Introduction

- Living organism- Macromolecules (Carbohydrates, proteins & fat), water and minerals for growth and development.
- ***Def.***- A mineral is a chemical element which naturally occurs as inorganic nutrients in the food and soil, and are essential for the proper functioning of the plant and animal body.
- Other than carbon, hydrogen, oxygen & sulphur- organic molecules

- Based on quantitative requirement by plants:

1) Macronutrients
2) Micronutrients

MACRONUTIENTS

- Large amounts in plant tissues (in excess of 10 mmole Kg^{-1} of dry matter)
- Carbon, hydrogen, oxygen, nitrogen, phosphorous, sulphur, potassium, calcium and magnesium- CO_2, H_2O & soil

MICRONUTRIENTS

- Trace elements, less than 10 mmole Kg^{-1} of dry matter
- iron, manganese, copper, molybdenum, zinc, boron, chlorine and nickel
- Higher plants- sodium, silicon, cobalt and selenium

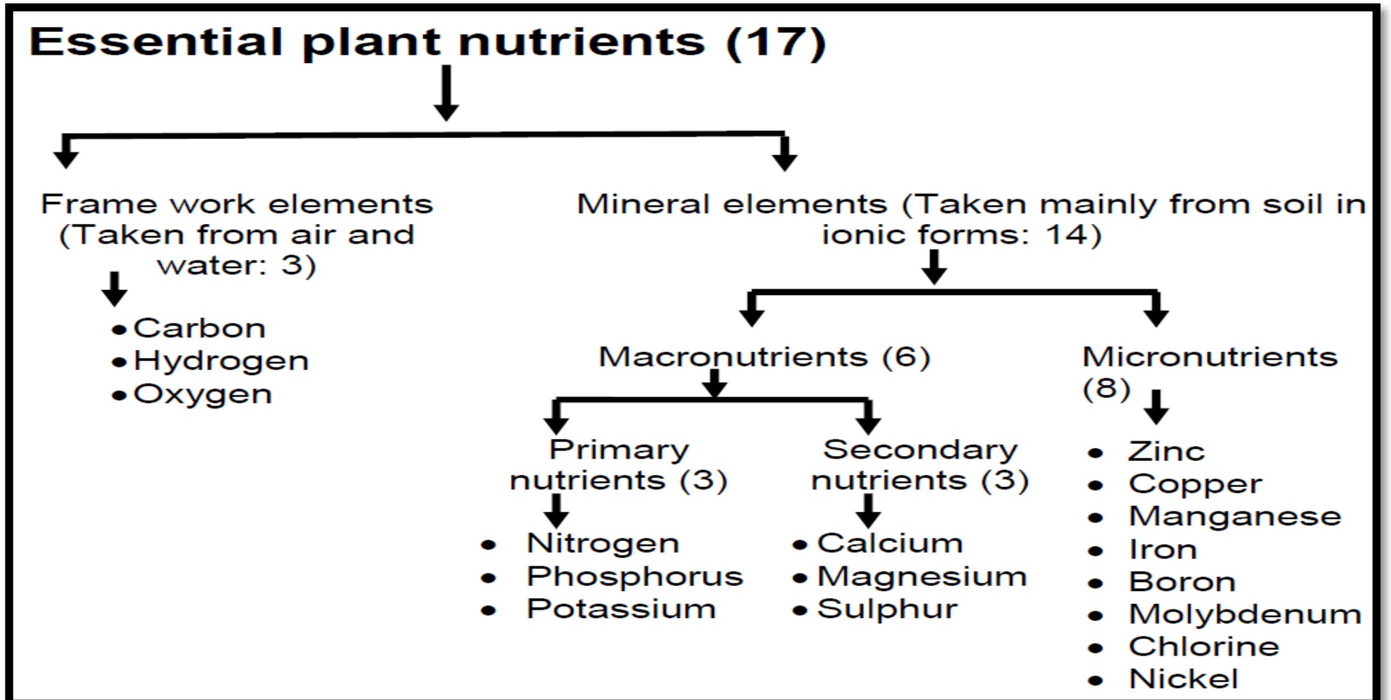
Criteria for Essentiality of minerals

- Minerals present in soil enters plant- roots
- Criteria for essentiality of mineral elements:

a) The element must be absolutely necessary for supporting normal growth and reproduction. In the absence of the element the plants do not complete their life cycle or set the seeds.

b) The requirement of the element must be specific and not replaceable by another element. In other words, deficiency of any one element cannot be met by supplying some other element.

c) The element must be directly involved in the metabolism of the plant.



Classification of essential elements

The essential elements can be classified based on the amount required, their mobility in the plant and soil, their chemical nature and their function inside the plant.

1. **Amount of Nutrients:** Depending on the quantity of nutrients present in plants, they can be grouped into three: basic nutrients, macronutrients and micronutrients.

a) **Basic Nutrients:** carbon, hydrogen, oxygen, which constitute 96 % of total dry matter of plants are basic nutrients. Among them, carbon and Oxygen constitute 45 % each.

Eg. The total dry matter produced by rice crop in one season is about 12 t/ha. In this 5.4 t is carbon, 5.4 t is oxygen and 0.7 t is hydrogen.

b). **Macronutrients:** the nutrients required in large quantities are known as macronutrients. They are N, P, K, Ca, Mg, and S. Among these, N, P and K are called primary nutrients and Ca, Mg and S are known as secondary nutrients. The latter are known as secondary nutrients as they are inadvertently applied to the soils through N,P and K fertilisers which contain these nutrients.

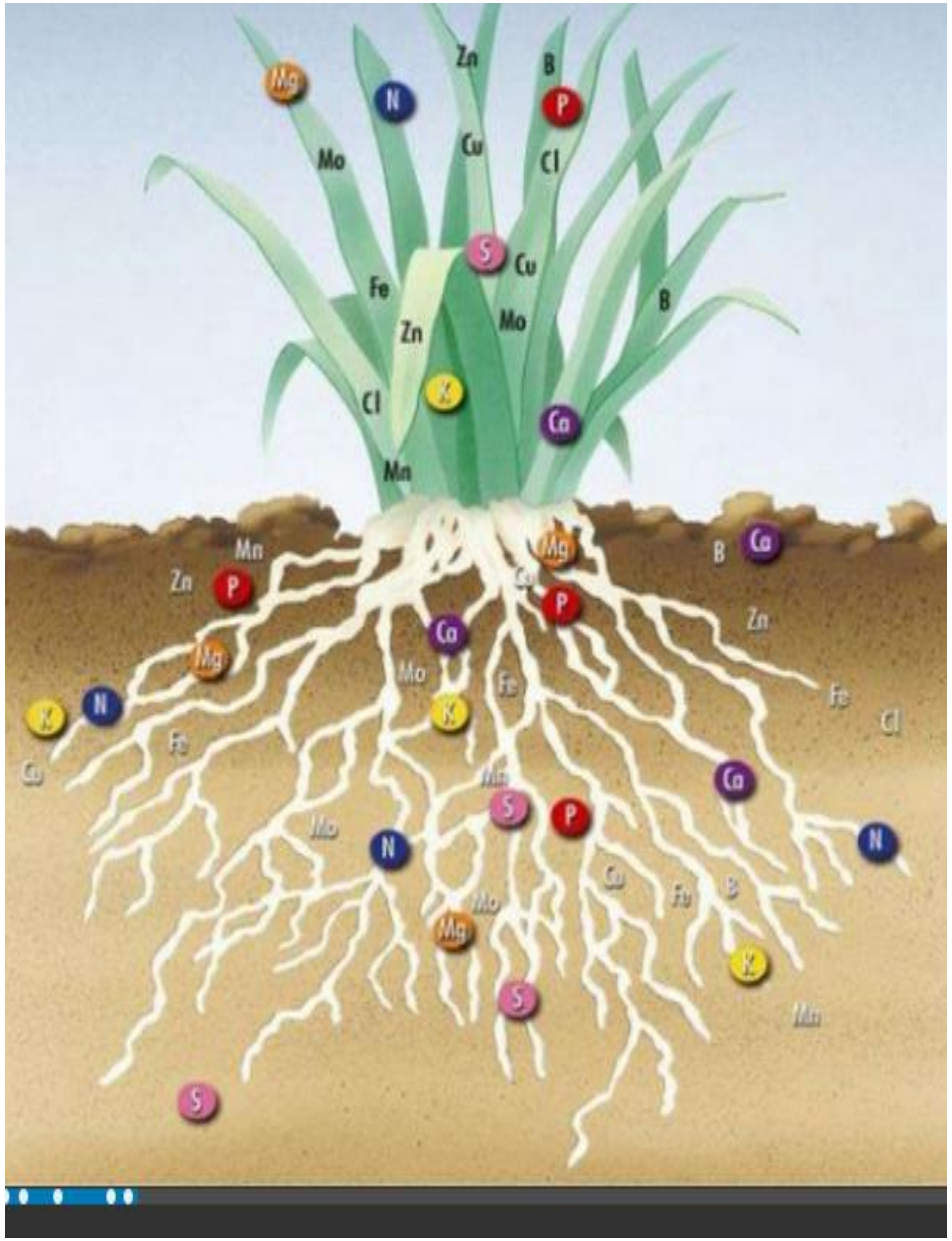
c). **Micronutrients :** the nutrients which are required in small quantities are known as micronutrients or **trace elements**. They are Fe, Zn, Cu, B, Mo and Cl, Mo, Ni. These elements are very efficient and minute quantities produce optimum effects. On the other hand, even a slight deficiency or excess is harmful to the plants.

Plants, like all other living things, need food for theirgrowth and development.

Plants require 17 essen-tial elements. Carbon, hydrogen, and oxygen are de-rived from the atmosphere and soil water.

The remain-ing 13 essential elements (nitrogen, phosphorus, po-tassium, calcium, magnesium, sulfur, iron, zinc, man-ganese, copper, boron, molybdenum, and chlorine) are supplied either from soil minerals and soil organic matter or by organic or inorganic fertilizers.

- For plants to utilize these nutrients efficiently, light,heat, and water must be adequately supplied.
- Each type of plant is unique and has an optimum nutrient range as well as a minimum requirement level.
- Below this minimum level, plants start to show nutri-ent deficiency symptoms.
- Excessive nutrient uptake can also cause poor growth because of toxicity. Therefore, the proper amount of application and the placement of nutrients is important.
- In addition to the levels of plant-available nutri-ents in soils, the soil pH plays an important role in nutrient availability and elemental toxicity



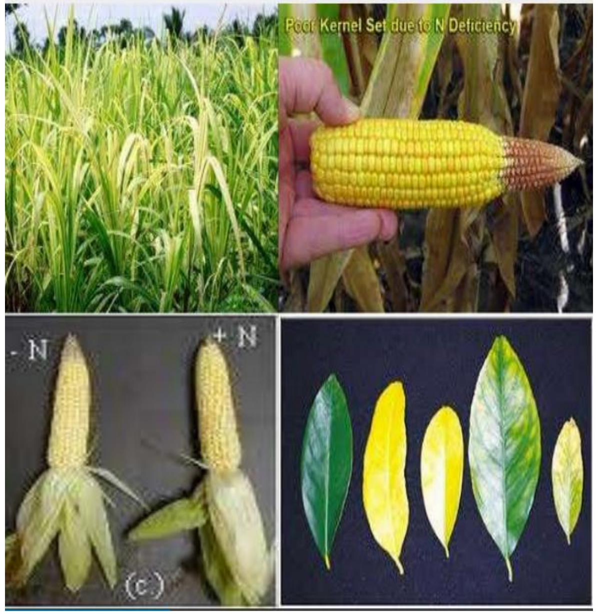
NITROGEN

- Major component of plant cells and cell wall. Cell cytoplasm and organelles contain nitrogen in combination with C, H, O, P and S.
- Necessary for **formation of amino acids**, the building blocks of protein.
- Essential for plant cell division, vital for plant vegetative growth.
- **Integral part of chlorophyll**
- Necessary component of vitamins
- **Improves the quality of leafy vegetables**
- Affects energy reactions in the plant

<u>Deficiency symptoms</u> :

- Lower leaves become yellow firstly and dries
- Tillering is poor in cereals
- Stunted growth
- In case of cabbage, there is no formation of heads
- ‘V’ shaped chlorosis on older leaves

Nitrogen deficiency



PHOSPHORUS

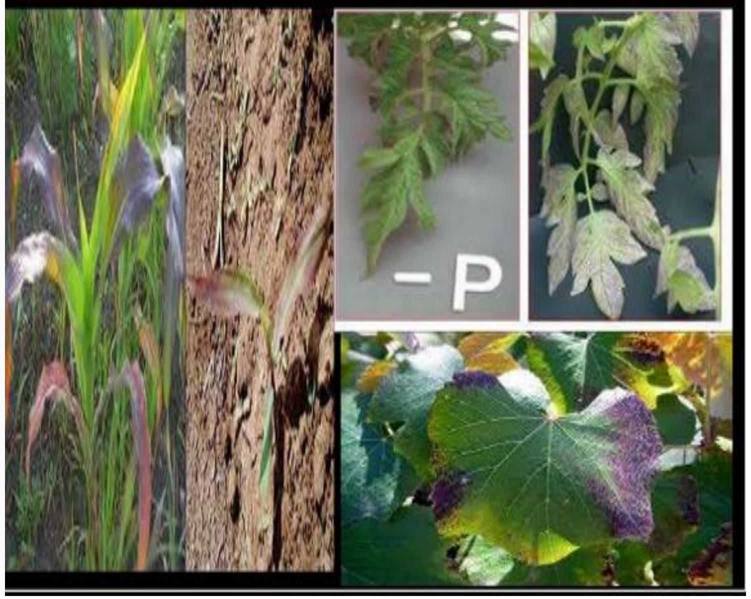
- Great role in energy storage and transfer in the form of ATP and ADP. So it is also called as "**Energy currency**"
- Essential constituent of nucleic acid, phytin and phospho-lipids
- Involved in photosynthesis, respiration, cell division and enlargement
- Promotes early root formation and growth
- Improves quality of fruits, vegetables, and grains
- **Vital to seed formation**
- Excess of P can cause deficiency of certain micro-nutrient like Zn and Fe

<u>Deficiency symptoms</u> :

- Deficiency symptoms are appears first on older leaves
- Deficiency imparts dark green colour in leaves
- Bronzing or **red purple coloration** on leaves due to synthesis of anthocyanin
- development of lateral buds is suppressed

Phosphorus Deficiency

Phosphorus Deficiency

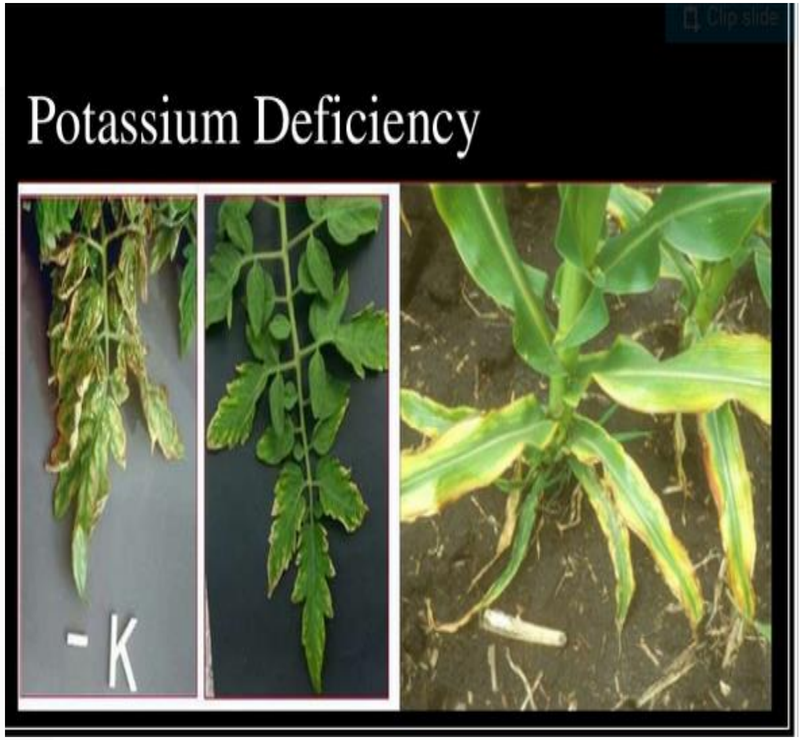


POTASSIUM

- Most essential function of potassium is **stomata regulation**
- Increases water-use efficiency
- Provides disease resistance
- Formation and **translocation of sugars**
- Increases photosynthesis
- Activates enzymes and controls their reaction rates
- **Improves quality of seeds and fruit**
- Improves winter hardiness
- In plants K+ also reduced the transpiration rate and increase photosynthetic rate

<u>Deficiency symptoms</u> :

- Scorching or burning of margins of older leaves
- Weakning of straw in grain crops
- reduction in turgidity of cells
- Spots of dead tissues at tips
- Keeping quality of fruits and vegetables is reduced



CALCIUM

- Constituent of cell wall (as Ca-pectate)
- Helps to maintain membrane permeability and stability
- Retards abscission and senescence of leaves
- Important for growth of meristems and functioning of root tips
- Neutralizes the charge on acidic molecules of phosphoric acid and other organic acids i.e. citric acid, malic acid, oxalic acid which are injurious to plant growth

Deficiency symptoms :

- Deficiency symptoms first appear on younger leaves.
- Its deficiency is manifested by failure of terminal buds and apical roots to develop. Thus the growth of plant ceases.
- **Deficiency of Ca leads to-**
  - Tip burn of cabbage, cauliflower
  - Black heart of celery
  - Blossom end rot of tomato and ber
  - Bitter pit of apple

Calcium Deficiency

Blossom end rot of Tomato

Bitter pit of Apple

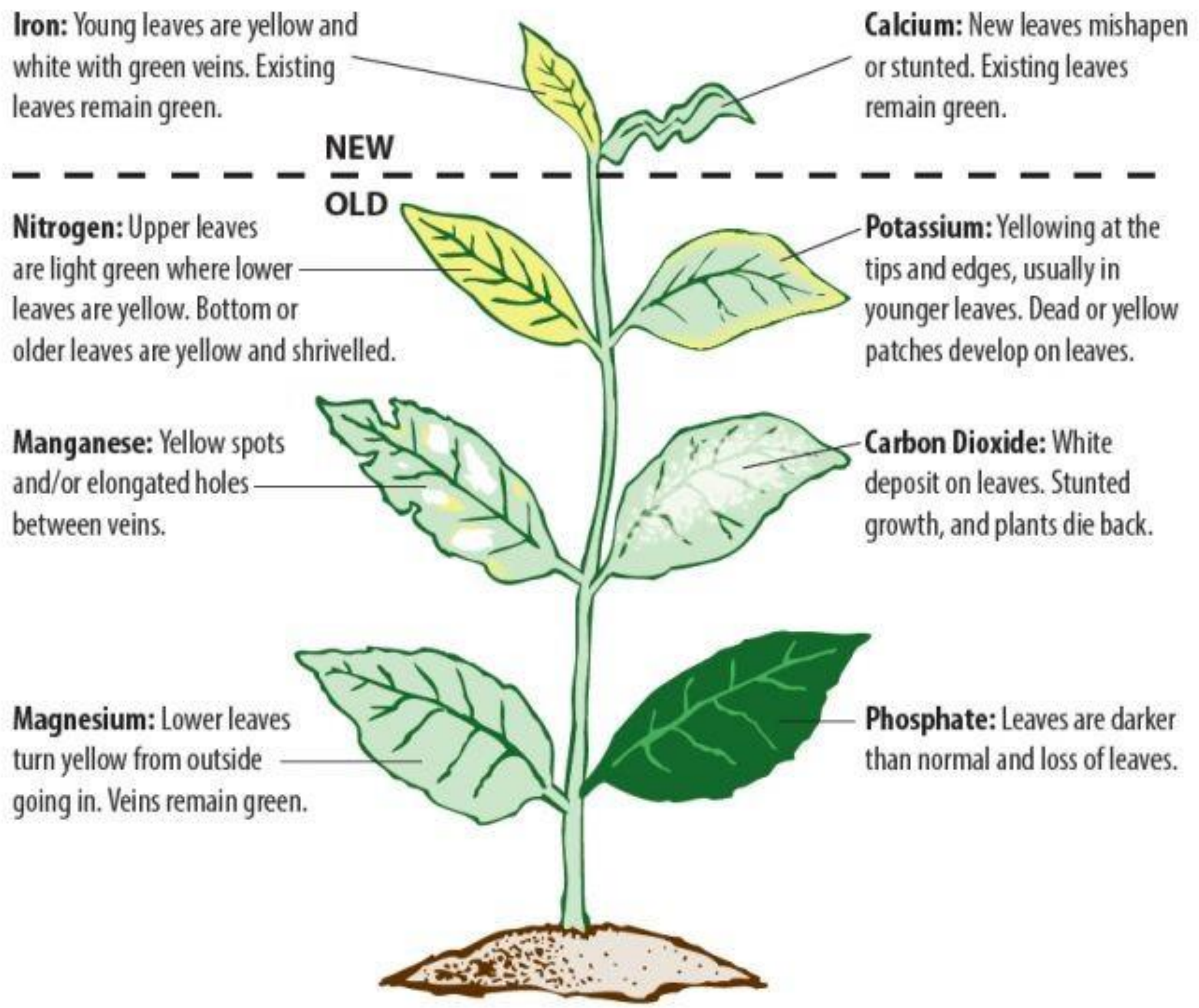
- **Magnesium –** Magnesium is absorbed in the form of divalent Mg^{2+}. It is responsible for activating the enzymes of photosynthesis, respiration and is involved in synthesis of nucleic acid (RNA and DNA). Magnesium is important constituent of ring structure of chlorophyll and helps in regulating metabolic activities. It also helps in the formation of fruits and nuts and in germination of seeds as well. Deficiency of magnesium results in extensive interveinal chlorosis that initiates with basal leaves and progresses to younger leaves.
- **Sulphur –** Sulphur is obtained by plants in the form of sulphate ion SO_4^{2-}. It is present in two amino acids and is the main constituent of several coenzymes like methionine and cysteine. Sulphur is also taken by leaves in gaseous form SO_2. Deficiency of sulphur results in general chlorosis of leaves, including vascular bundles.
- **Iron –** Iron is obtained in the form of ferric ions (Fe^{3+}) and plenty of ferric ions are required by plants as compared to other micronutrients. It is an important constituent of protein which is involved in transference of electrons such as cytochromes and ferredoxin. It is reversibly oxidized from Fe^{2+} to Fe^{3+} during the transfer of electron, activates catalase enzyme and is important for the formation of chlorophyll. Deficiency symptoms are larger amount of interveinal chlorosis, starting with younger leaves.
- **Manganese –** Manganese is absorbed in the form of manganous ions Mn^{2+} and helps in activating enzymes required in respiration, nitrogen metabolism and photosynthesis. Its main role is in splitting of water to release oxygen during the process of photosynthesis. The deficiency of this nutrient results in disorganization of chloroplast thylakoid membrane.
- **Zinc –** Zinc is obtained as Zn^{2+} ions and activates enzymes like carboxylase. Zinc is important in the synthesis of auxin and absence or deficiency of zinc results in interveinal chlorosis of upper leaves. Absence of zinc results in slowing down of shoot, resulting in rosette like appearance of plants.

•**Copper –** Copper is absorbed in the form of cupric ions (Cu^{2+}) and is important for the overall metabolism of plant. Copper is associated with the enzymes involved in redox reactions as iron and is irreversibly oxidized from Cu^{+} to Cu^{2+}. More than half of the copper is present in chloroplast and plays an integral role in photosynthesis. Absence of copper results in dieback of shoots.

•**Boron –** Boron is absorbed as BO_3^{3-} or $B_4O_7^{2-}$ and is required for uptake and utilization of Ca^{2+}, pollen germination, functioning of membrane, cell differentiation, cell elongation and translocation of carbohydrate. In case of deficiency of Boron, terminal buds are damaged, resulting in rosette effect on leaves. Fruits, roots and tubers are discolored, cracked and flecked with brown spots.

•**Molybdenum –** Molybdenum is obtained as molybdate ions (MoO_2^{2+}). It is a component of various enzymes like nitrogenase and nitrogen reductase, enzymes which participate in the metabolism of nitrogen. Absence of molybdenum results in pale green leaves with cupped or rolled margins.

•**Chlorine –** Chlorine is absorbed in the form of chloride ions (Cl^{-}) and adding with Na^{+} and K^{+} it helps in determining solute concentration and anion – cation balance in cells. Chlorine is important in water splitting reaction in photosynthesis and as a result of this; it leads the evolution of oxygen. Absence of chlorine results in reduced growth, interveinal chlorosis, reduced growth and nonsucculent tissue.

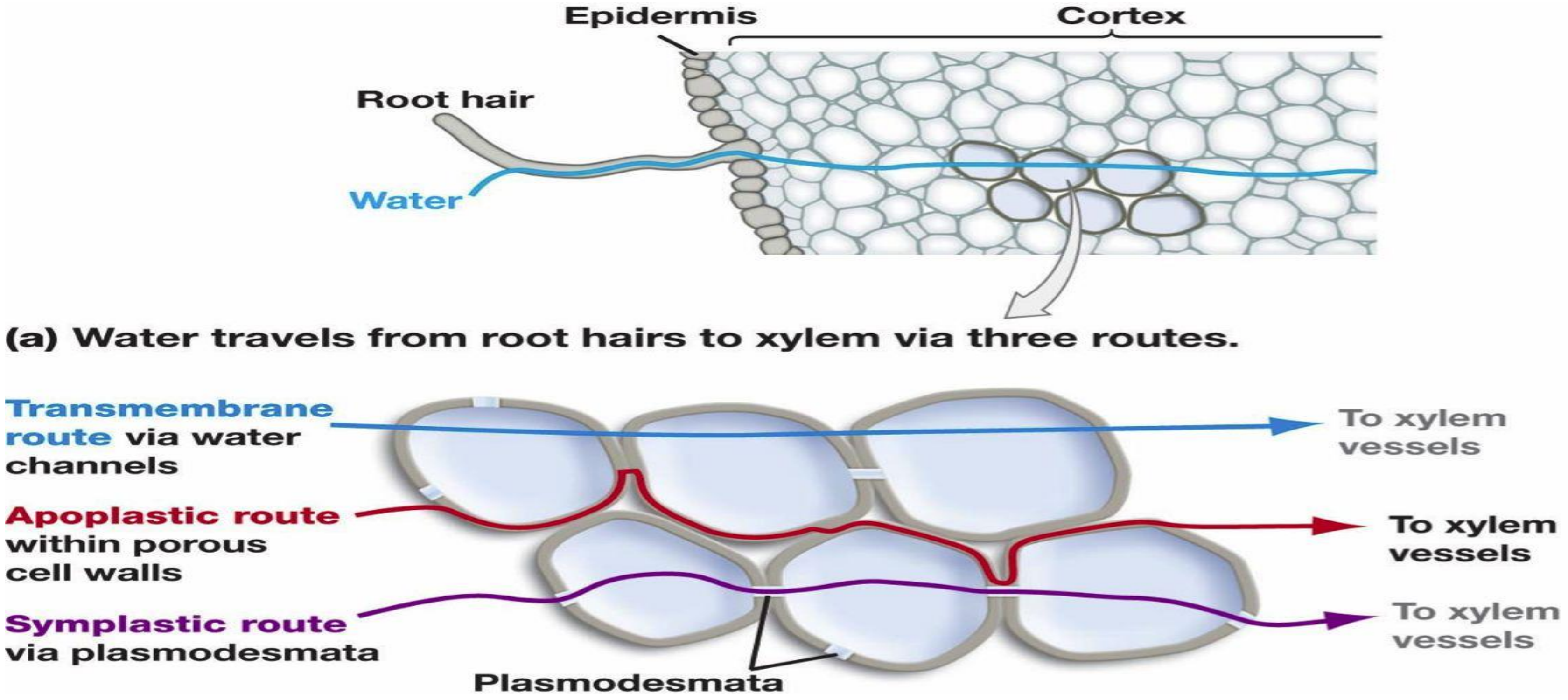


Toxicity of Micronutrients

The micronutrients are the nutrients that are required in very less amounts and therefore, even their little deficiency results in deficiency symptoms. On the other hand, even the moderate increase of nutrient causes toxicity. Thus, it can be said that plants have the optimum requirement of nutrition. The symptoms of toxicity are difficult to identify because level of toxicity varies from plants to plants. There are several cases where an excess of an element may prevent the uptake of another element. For instance, in case of toxicity of manganese, the plants show prominent symptom, i.e. appearance of brown spots all over chlorotic vein. It, on the other hand, inhibits translocation of calcium in the apex of shoots. Moreover, Manganese competes with magnesium and iron for uptake and with magnesium for binding with enzymes. Thus, the toxicity of manganese results in Deficiency Symptoms of Magnesium, Calcium and Iron.

Absorption of Elements in plants are carried on isolated organs of it like tissues and cells. According to these studies, two main phases are included in the absorption of elements. In the initial phase, the passive uptake of ions takes place in outer space or free space of cells - **Apoplast**. In the latter phase of uptake, ions are slowly absorbed in inner space referred as the symplast of the cells. The passive movement of ions into the apoplast is carried out via ion – channels, the trans-membrane proteins that act as selective pores. Added to this, the entry and exit of ions to and from symplast need metabolic energy and thus, it is an active process. This movement of ions is referred as **Flux**, whereby inward movement into the cells is influx and vice versa, i.e. outward movement is **Efflux**.

Following diagram shows the mechanism of absorption in plants. For instance, water travels with the help of root hairs to xylem via three routes, i.e. transmembrane route, apoplastic route and symplastic route.



Biological Nitrogen Fixation

Agricultural systems

Crop

Plant-associated
- legume-rhizobia (symbiotic)
- *Azolla*-cyanobacteria (symbiotic)
- cereal-associative bacteria
- cereal-endophytic bacteria

Free-living
- cyanobacteria
- heterophic bacteria
- autotrophic bacteria

Pastures & Fodder

Plant-associated
- legume-rhizobia (symbiotic)
- cereal-associative bacteria
- cereal-endophytic bacteria

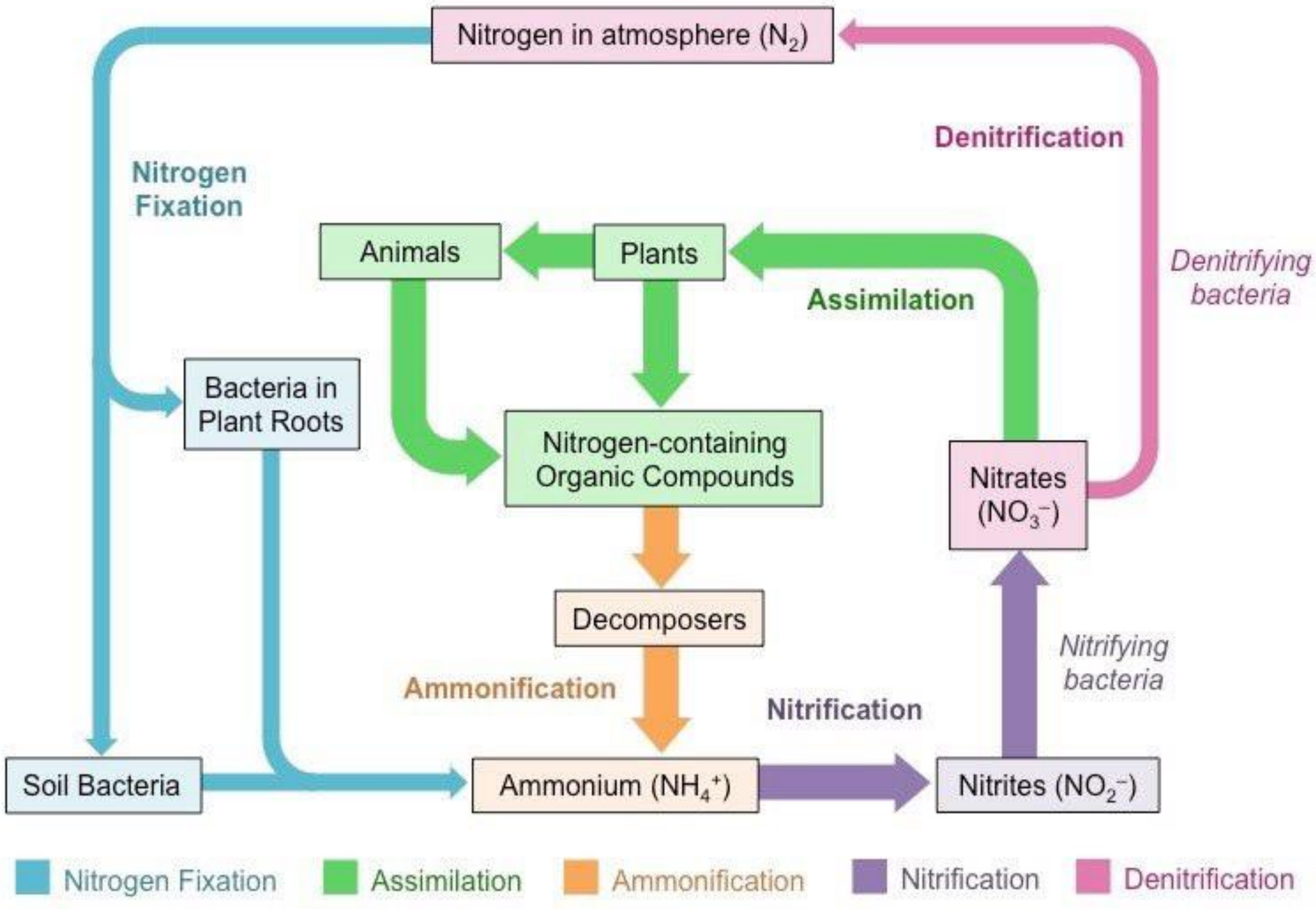
Free-living
- cyanobacteria
- heterophic bacteria
- autotrophic bacteria

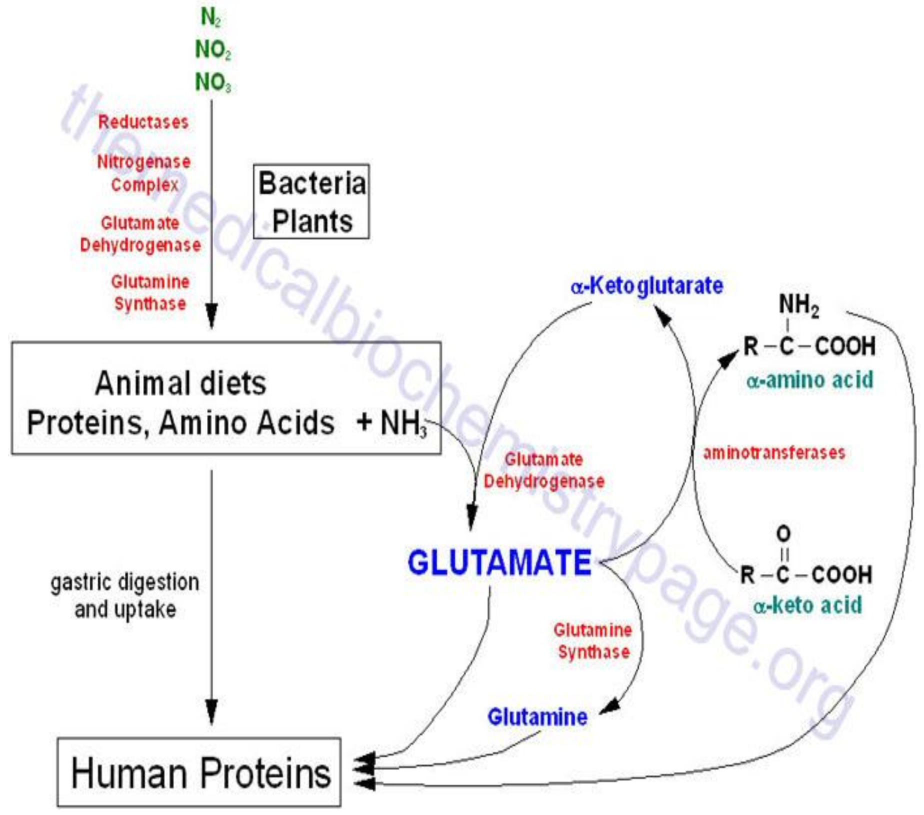
Natural systems

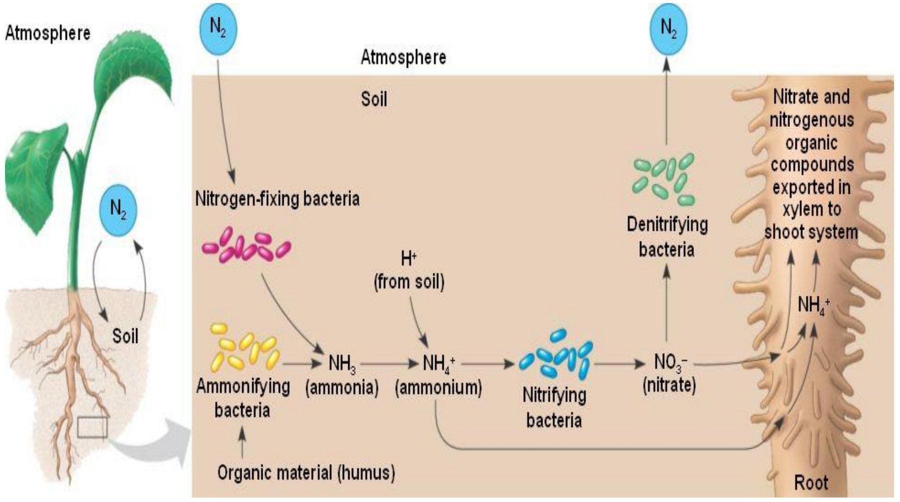
Plant-associated
- legume-rhizobia (symbiotic)
- nonlegume-*Frankia* (symbiotic)
- *Azolla*-cyanobacteria (symbiotic)
- cycad-cyanobacteria (symbiotic)
- cereal-associative bacteria
- cereal-endophytic bacteria

Free-living
- cyanobacteria
- heterophic bacteria
- autotrophic bacteria

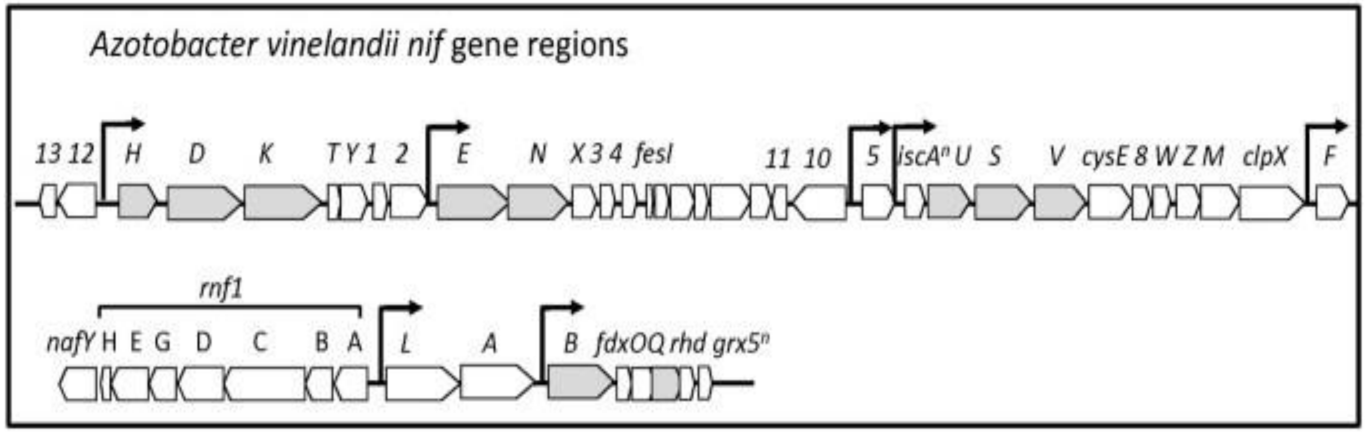
Biological nitrogen fixation Chemically, this process is same as abiological. Biological nitrogen fixation is reduction of molecular nitrogen to ammonia by a living cell in the presence of enzymes called nitrogenases.

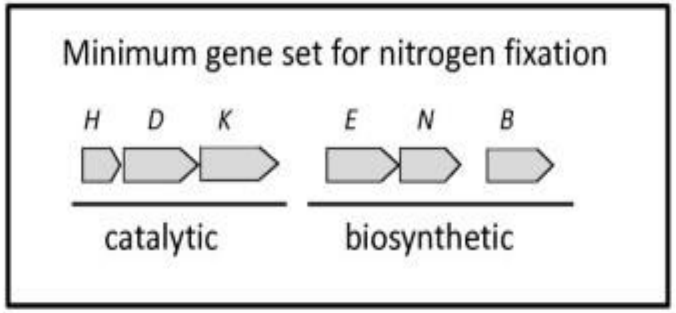


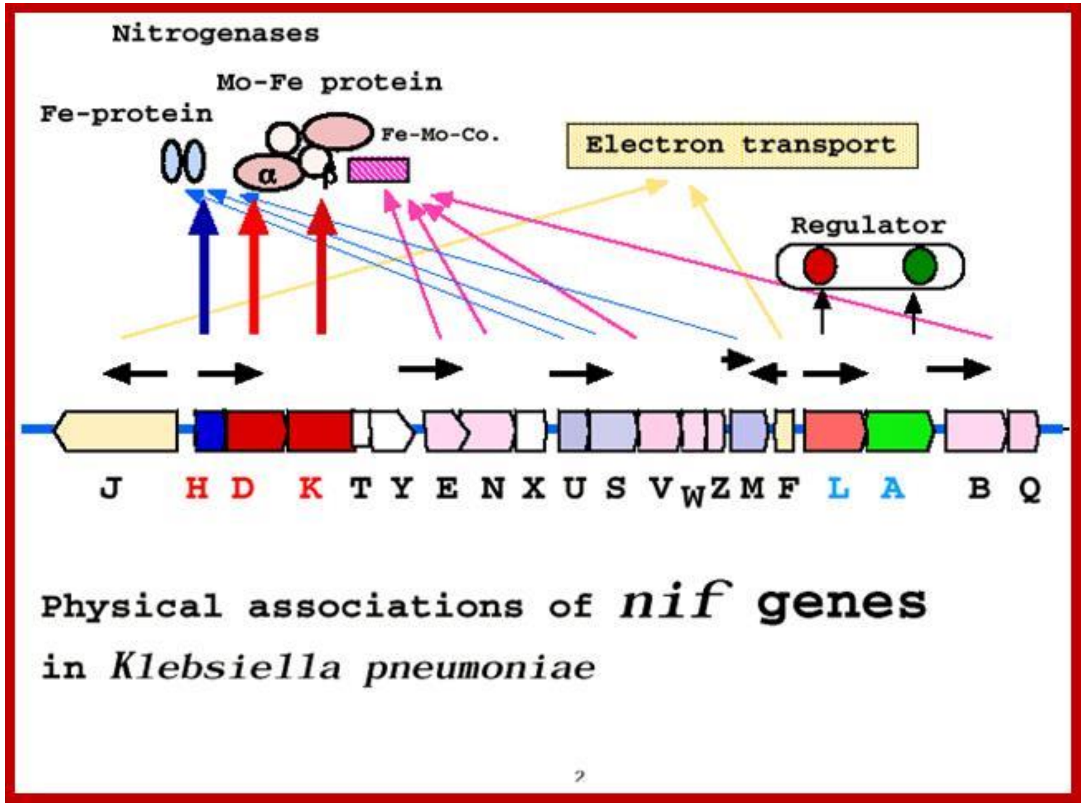




The ***nif* genes** are genes encoding enzymes involved in the fixation of atmospheric into a form of nitrogen available to living organisms. The primary enzyme encoded by the *nif* genes is the nitrogenase complex which is in charge of converting atmospheric nitrogen (N_2) to other nitrogen forms such as ammonia which the organism can use for various purposes. Besides the nitrogenase enzyme, the *nif* genes also encode a number of regulatory proteins involved in nitrogen fixation. The *nif* genes are found in both free living nitrogen – fixing bacteria and in symbiotic bacteria associated with various plants. The expression of the *nif* genes is induced as a response to low concentrations of fixed nitrogen and oxygen concentrations (the low oxygen concentrations are actively maintained in the root environment of host plants).





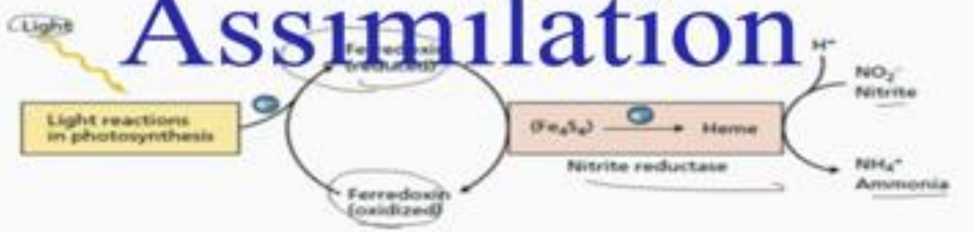


Physical associations of *nif* genes in *Klebsiella pneumoniae*

Ammonium Assimilation

- Plants cells avoid ammonium toxicity by rapidly converting the ammonium generated from nitrate assimilation or photorespiration into amino acids
- This requires the action of two enzymes
  - *Glutamine synthetase* - combines ammonium with glutamate to form glutamine
  - *Glutamate synthase* - stimulated by elevated levels of glutamine synthetase
  - Transfers the amino group of glutamine to an intermediate yielding two molecules of glutamate

Nitrogen Assimilation



Model for coupling of photosynthetic electron flow, via ferredoxin, to the reduction of nitrite by nitrite reductase. The enzyme contains two prosthetic groups, Fe454 (iron—sulfur cluster) and heme, which participate in the reduction of nitrite to ammonium.