Mineral Nutrition in Plants

DISCLAIMER

Mineral Nutrition in Plants

INTRODUCTION

- Three elements carbon, hydrogen and oxygen play important role in the formation of carbohydrates, fats and proteins.
- In addition to carbon, hydrogen and oxygen, plants need a variety of elements for their normal growth and development.
- Plants absorb minerals through their roots from the soils, where they are primarily present in the form of inorganic ions.

MINERAL NUTRITION

The process that involves absorption and utilization of mineral elements by the plants for their growth and development.

SOILLESS CULTURE OR HYDROPONICS.

- The technique of cultivation of plants by placing their roots directly in nutrient solution
- **Julius Sachs** (1860) a prominent German botanist, for the first time, demonstrated that plants could be grown to maturity to defined nutrient solution in complete absence of soil.
- During experiments an element was added or removed or given in varied concentrations. Thus, a mineral solution suitable for the plant growth was obtained.
- In this method purification of water and nutrient salts is done regularly. Nutrient solutions need to be adequately aerated to obtain optimum growth.

Significance

- Essential elements were identified and their deficiency systems discovered.
- Hydroponics has been successfully employed as a technique for commercial production of vegetables such as tomato, seedless cucumber and lettuce in some countries.
- Vegetables and flowers are cultivated round the year.

Previous Year's Question

Roots can not absorb minerals from the soil, when they are in:
(1) Solid state
(2) Liquid state
(3) Gaseous state
(4) Both 1 and 3

Definition

Hydroponics: The method of cultivating plants in nutrient rich solution without soil.

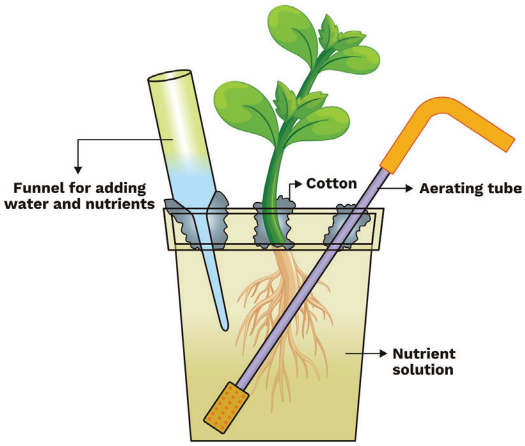


FIG. DIAGRAM OF A TYPICAL SET-UP FOR NUTRIENT SOLUTION CULTURE

Gray Matter Alert!!!

Gericke, 1940 developed hydroponics.

CRITERIA TO DETERMINE THE ESSENTIALITY OF AN ELEMENT

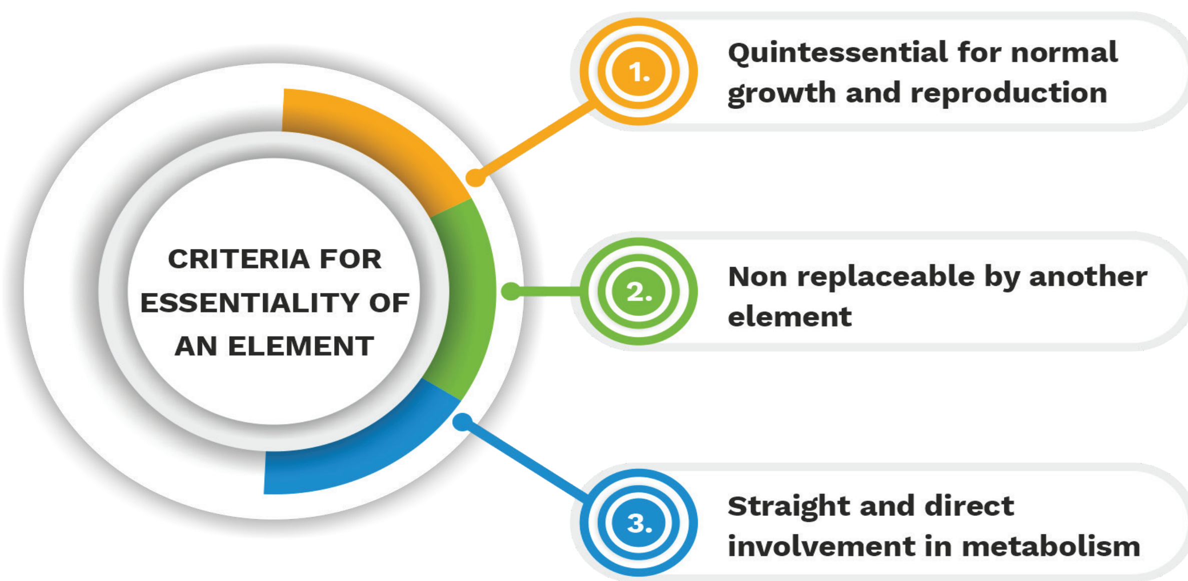
- Plants can absorb most of the minerals present in the soil. More than sixty elements of the 105 discovered so far are found in different plants.
- The essentiality of an element is determined on the basis of water culture experiments proposed by **Arnon** and **Stout** (1939)
  - o The elements must be absolutely necessary for supporting normal growth and reproduction.
  - o The requirement of the element must be specific and not replaceable by another element.
  - o The element must be directly involved in the metabolism or biological processes of the plant.

Definitions

Essential element: If the lack of the element results in the inability of the plant to complete its life cycle then it is termed as essential element.

Rack Your Brain

How can we find out that an element is non-essential for the plants?



- Examples-
  - o **Magnesium** is an essential element and cannot be replaced by any other element because it is-
    - ◆ constituent of chlorophyll, essential for photosynthesis.
    - ◆ required as a cofactor by many enzymes involved in cellular respiration and other metabolic pathways

Previous Year's Question

Which one of the following elements is almost non-essential for plants

(1) Zn	(2) Ca
(3) Mo	(4) Na

- **Iron** is an essential element and cannot be replaced by any other element
  - It is a constituent of cytochromes

Note:
If an element satisfies all three criteria, it is considered to be an **essential element**.
If it fails to satisfy any of the above criteria, it is considered to be inert or **non-essential element**.

Previous Year's Question

Which group of the plants can grow in nitrogen deficient soil?
(1) Gymnosperms
(2) Lichens
(3) Bryophytes
(4) Insectivorous plants

ESSENTIAL AND NON-ESSENTIAL ELEMENTS

Essential Elements

About 20 elements have been found to be essential, out of these 17 are given

- Carbon (c)
- Hydrogen (H)
- Oxygen (O)
- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)
- Magnesium (Mg)
- Sulphur (S)
- Calcium (Ca)
- Iron (Fe)
- Copper (Cu)
- Zinc (Zn)
- Boron (B)
- Manganese (Mn)
- Molybdenum (Mo)
- Chlorine (Cl)
- Nickel (Ni)

Non-Essential Elements

Apart from essential elements, some more elements have been found to be essential for some plants.

- Cobalt (Co)
- Sodium (Na)
- Aluminium (Al)
- Silicon (Si)
- Vanadium (V)
- Selenium (Se) etc.

Note:
Silicon is required by most grasses and cereals Sodium seems to be involved in membrane permeability such elements are often called **functional elements or non-essential functional elements.**
Sodium (Na) and **iodine (I)** are essential for animals but are not needed by the majority of plants..

Previous Year's Question

Carbon becomes available to crop plants in the form of
(1) Amino acids
(2) Carbonates
(3) Carbon-di-oxide
(4) Carbon

MACRO-ELEMENTS AND MICRO-ELEMENTS

- On the basis of the relative amount (quantitative requirement) of the elements found in plants, essential elements are differentiated into two categories –
  - Macroelements
  - Microelements.

Definition

Macronutrients: The essential elements present in plant tissues in easily detectable quantity.

Macroelements (Macronutrients)	**Microelements** (Micronutrients)
• Essential elements, which are present in easily detectable quantity, (in excess of 10 m mole kg^{-1} of dry matter). • They are **9** in number o Carbon o Hydrogen o Nitrogen o Oxygen o Phosphorous o Sulphur o Potassium o Calcium o Magnesium	• Essential elements which are found in plants in traces only (*i.e.*, less than 10 m mole kg^{-1} of dry matter). • They are **8** in number o Iron o Manganese o Zinc o Copper o Molybdenum o Boron o Chlorine o Nickle

- Macroelements are usually involved in the synthesis of organic molecules and development of osmotic potential of the cells.
- About 96% of the dry matter of the plants is formed of carbon, hydrogen and oxygen only
- Microelements are mostly involved in the functioning of enzymes as cofactors or metal activators.

Note:
In addition to the 17 essential elements listed above, there are a few more beneficial elements viz. sodium, silicon, cobalt and selenium that are specially required by higher plants.

Rack Your Brain

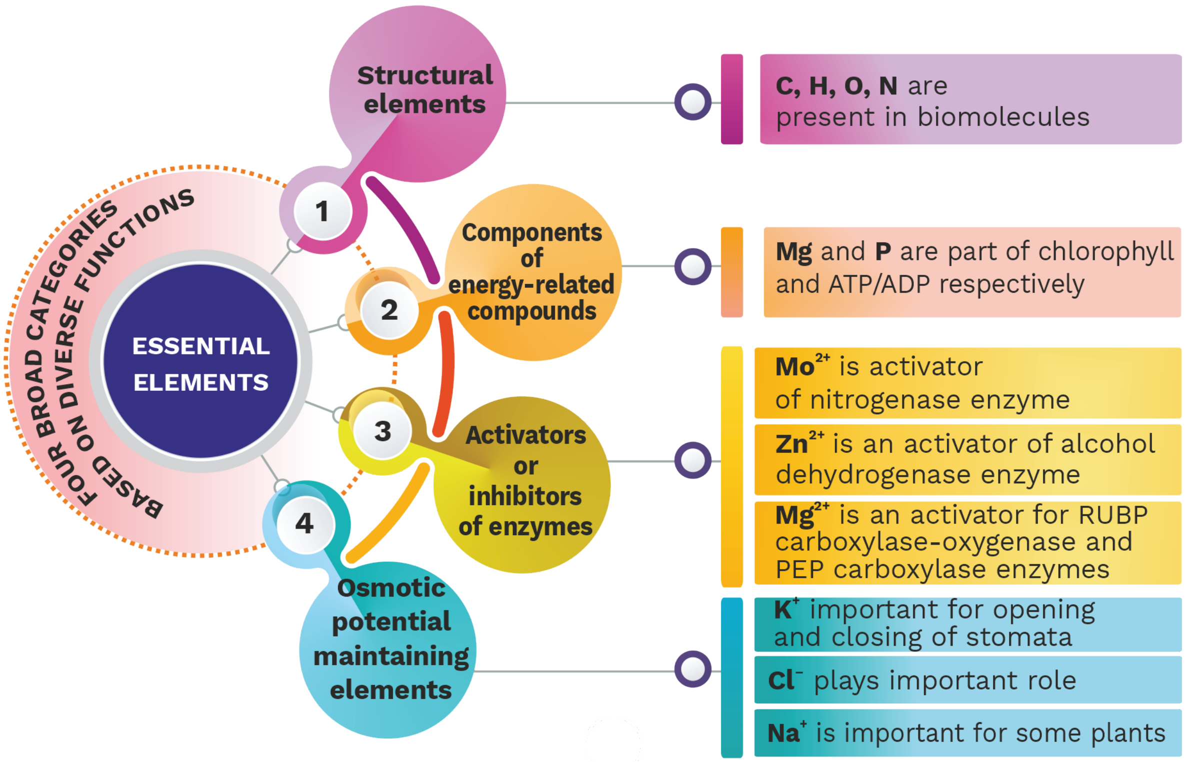
What is the criteria for placing the essential element into the category of micronutrient or macro-nutrient?

Definition

Micronutrients: The essential elements present in plant tissues in traces.

TYPES OF ESSENTIAL ELEMENTS

Grouped into four broad categories on the basis of their diverse functions.



SOURCES OF ESSENTIAL ELEMENTS FOR PLANTS

- All elements which enter into plants are derived from the atmosphere, water and soil.
- Soil a reservoir of essential elements and is rich in ions, inorganic salts, air, water and useful microbes.
- Carbon enters the plants from atmosphere as carbon dioxide.
- Hydrogen is obtained mainly from water.
- Oxygen comes from the air or water and often in the form of inorganic ions.
- Plants absorb nitrogen in compound state from the soil.
- All other elements needed by the plants, are absorbed from the soil, which are derived from the parent rocks by disintegration and weathering.

Rack Your Brain

Name the mineral element that acts as an activator for RUBISCO.

Gray Matter Alert!!!

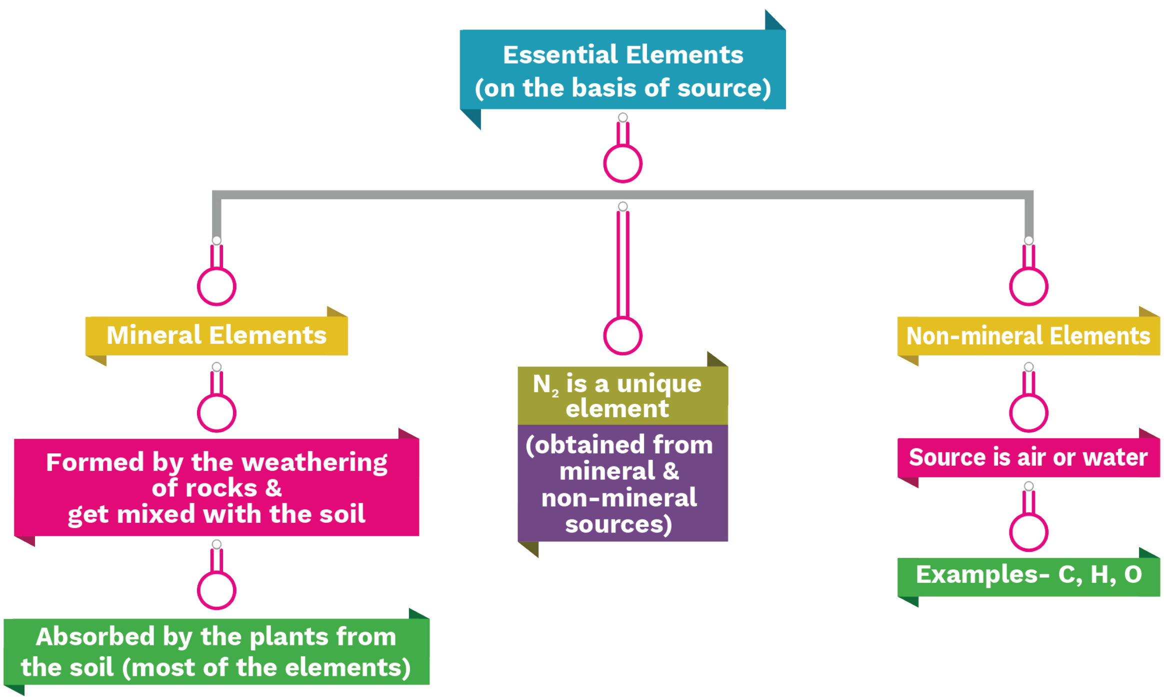
Most free ion is potassium (K^+). It is one of the essential element that is helpful in determining the water potential of a cell.

NON-MINERAL AND MINERAL ELEMENTS

- The essential elements, obtained by the plants from the soil are called **mineral elements.** Most of the elements are mineral elements.
- The essential elements (such as carbon, hydrogen and oxygen), obtained by the plants from air or water are known as **non-mineral elements.**
- Nitrogen is considered a unique element, as it is derived from both **mineral and non-mineral sources.**

Definition

Non-mineral elements: The essential elements obtained from by the plants from air or water.



Note: The elements that are required for various metabolic activities like regulation of cell membrane permeability, osmotic pressure of cell sap and are part of nucleic acids, enzymes and proteins get depleted from soils that are under continuous cultivation of plants and are replenished by fertilizers. For example nitrogen, phosphorous and potassium fertilizers.

Rack Your Brain

Name the structural elements of a plant cell.

Definition

Mineral elements: The essential elements derived from rocks.

CRITICAL CONCENTRATION

- The concentration of the essential element below which growth in plant is retarded is termed as critical concentration.
- Element at this or lower than this concentration, becomes deficient.

MINERAL DEFICIENCY IN PLANTS

- The abnormalities or deformities caused in plants due to deficiency of essential elements are called deficiency symptoms or hunger signs.
- The deficiency symptoms disappear when the deficient mineral nutrient is provided to the plant.
- If the deficiency prolongs, the plant may eventually die.

ROLE AND DEFICIENCY OF MACRO NUTRIENTS IN PLANTS

NITROGEN (N_2)

Absorbed as : Mainly as NO_3^- also taken up as $NO_2^-$and NH_4^+

Functions : Part of proteins, chlorophyll, cytochromes, phytochromes, hormones (auxins, cytokinins), nucleic acids (DNA, RNA), NAD etc; serves as enzymes, promotes vegetative growth.

Deficiency Symptoms : Stunted growth, Chlorosis, dormancy of causal buds.

PHOSPHORUS (P)

Absorbed as: Phosphate ions ($H_2PO_4^-$or HPO_4^{2-})

Functions: Part of RNA, DNA, NADP, ATP, phospholipids, etc. Important in energy transfer reactions in cell metabolism. Constituent of cell membrane.

Deficiency Symptoms of Phosphorus : Poor growth, leaves dull green, delay in seed germination purple or red spots on leaves, premature leaf fall.

Definition

Critical Concentration: The concentration of essential element below which growth of the plant is retarded.

Previous Year's Question

One of the following is not essential for the plants?
(1) Sodium
(2) Potassium
(3) Iron
(4) Zinc

Rack Your Brain

Deficiency of which mineral elements appear, first at younger parts of the plants?

Gray Matter Alert!!!

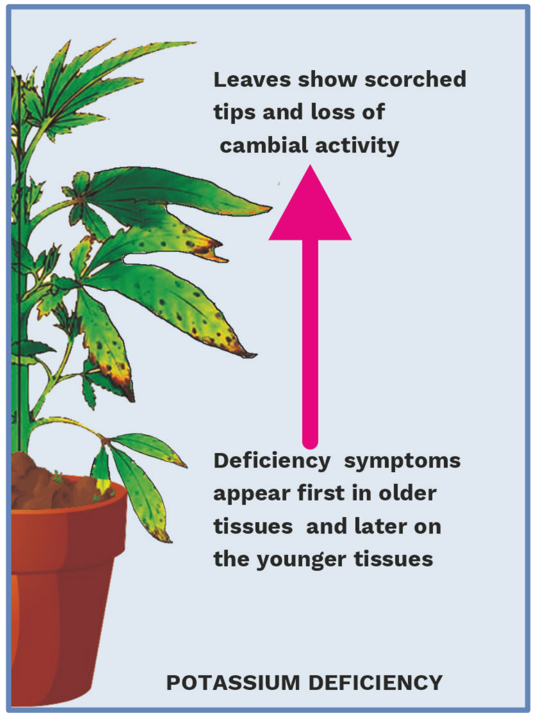
Potassium is most effective cofactor of enzymes.
Potassium and boron are involved in the translocation of organic substances in the phloem.

SULPHUR (S)

Absorbed as: Sulphate (SO_4^{2-})

Functions: Part of proteins (amino acids- cysteine, methionine), vitamins (biotin, thiamine, Coenzyme A) and ferredoxin.

Deficiency Symptoms: Chlorosis of younger leaves, stunted growth



POTASSIUM DEFICIENCY

POTASSIUM (K)

Absorbed as: Potassium ions (K^+)

Functions: Helps to maintain an anion-cation balance in cells. Involved in protein synthesis, in opening and closing of stomata; activation of enzymes; maintenance of turgidity of cells. Electro-osmotic flow of sucrose across sieve plates, common in cell sap.

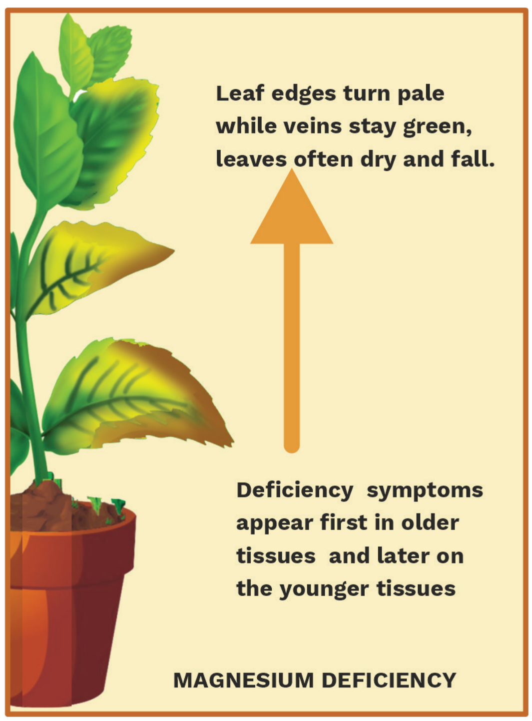
Deficiency Symptoms: Stunted growth; yellow leaves edges of leaves; mottled appearance of leaves. Premature death.

CALCIUM (Ca)

Absorbed as: Calcium ions (Ca^{2+})

Functions: Participate in synthesis of cell wall (middle lamella); activator of amylase, ATPase, phospholipase, used in mitotic spindle during cell division. Involved in normal functioning of cell membranes.

Deficiency Symptoms: Stunted growth, chlorosis of young leaves.



MAGNESIUM DEFICIENCY

MAGNESIUM (Mg)

Absorbed as: Divalent (Mg^{2+})

Functions: Activates enzymes in phosphate metabolism, constituent of chlorophyll; maintains ribosome structure.

Deficiency Symptoms: Chlorosis between the leaf veins narcosis purple colours spots on older leaves.

ROLE AND DEFICIENCY OF MICRO NUTRIENTS IN PLANTS

Element	Obtained as	Functions	Deficiency symptoms
Iron (Fe)	Ferric ions (Fe^{3+})	Constituent of Ferredoxin and cytochrome; needed for synthesis of chlorophyll.	Chlorosis of leaves
Manganese (Mn)	Manganous ions (Mn^{2+})	Activates certain enzymes involved in photosynthesis, respiration and nitrogen metabolism. Photolysis of water in photosynthesis (i.e., splitting of water to liberate oxygen).	Chlorosis, grey spots on leaves.
Zinc (Zn)	Zn^{2+}	Activates various enzymes like carboxylases. Required for synthesis of auxins.	Malformation of leaves
Copper (Cu)	Cu^{2+}	Activates certain enzymes. Essential for overall metabolism	Stunted growth, inter-veinal chlorosis in leaves. Necrosis of the tip of young leaves, die back of shoot.
Boron (B)	BO_3^{3-}, $B_4O_7^{2-}$	Required for uptake of water and Ca, for membrane functioning, pollen germination, cell elongation carbohydrate translocation.	Death of stem and root apex, loss of a foical dominance, abscission of flowers, small size of fruits

Element	Obtained as	Functions	Deficiency symptoms
Molybdenum (Mo)	MoO_2^{2+} (molybdate ions)	Activates certain metabolism.	Nitrogen deficiency interveinal chlorosis retardation of growth
Chlorine (Cl)	Cl^-	Maintains solute concentration along with Na+ & K+; maintain anion-cation balance in cells; essential for oxygen evolution in photosynthesis.	Wilted leaves; stunted root growth and reduced fruiting.

APPEARANCE OF DEFICIENCY SYMPTOMS IN PLANTS DEPENDING ON THE MOBILITY OF THE ELEMENTS

The deficiency symptoms may affect the whole plant or be restricted to particular organ or part of an organ. The symptoms also depend on the mobility of the elements in the plants.

- **Actively Mobilized Elements:** When the elements keep moving along with the water to different parts (growing parts and younger parts) of the plants then the symptoms first appear on the older parts e.g. deficiency symptoms of nitrogen, potassium and magnesium.
- **Immobile Elements:** The deficiency symptoms appear first in young tissue if the elements are comparatively immobile and do not get transported to younger parts in case of deficiency e.g. deficiency symptoms of sulphur and calcium.

Previous Year's Question

Fall of immature leaf is due to deficiency of
(1) Sodium
(2) Sulphur
(3) Phosphorus
(4) Zinc

Definition

Primary deficiency: Deficiency caused by critical elements like N, P or K.

SYMPTOMS CAUSED BY THE DEFICIENCY OF MINERALS AT A GLANCE

Deficiency Symptoms	Mineral Elements Responsible
Chlorosis (yellowing of leaves)	N, K, Mg, S, Fe, Mn, Zn, Mo
Stunted growth	N, K, Ca, S, Zn, B, Mo, Cl
Interveinal chlorosis	Fe
Purple coloration(short axis & leaves)	N, P, S, Mg, Mo
Necrosis	Ca, Cu, K, Mg
Premature leaf fall and bud fall	P, Mg, Cu
Inhibition of cell division	N, S, Mo, K
Wrinkling of cereal grains	N, S, Mo
Dormancy of lateral buds	N, S, Mo
Delayed flowering	N, S, Mo
Dieback of stem and leaves	K, Cu
Wilted leaves	Cl
Death of shoot and root tip	B
Bushy habit of stem	K
Scorched leaf tips	K

TOXICITY OF MICRONUTRIENTS

- Excessive amount of a mineral element is often toxic to plants.
- All most all the minerals have a narrow range of requirements and become toxic at relatively low concentrations.
- In any tissue, if concentration of a mineral that reduces the dry weight of tissue by about 10 percent is considered toxic.
- The critical concentration of toxicity varies for different micronutrients in different plants.
- For example, beyond 600 μg g^{-1} manganese is toxic for soya bean while for sunflower its concentration for being toxic has to exceed 5300 μg g^{-1}
- Manganese also competes for uptake with iron and magnesium and for binding with enzymes, it competes with magnesium
- Manganese also inhibits calcium translocation towards shoot.

Rack Your Brain

Iron deficiency leads to interveinal chlorosis. (True / false).

Previous Year's Question

A trace element is an element which is

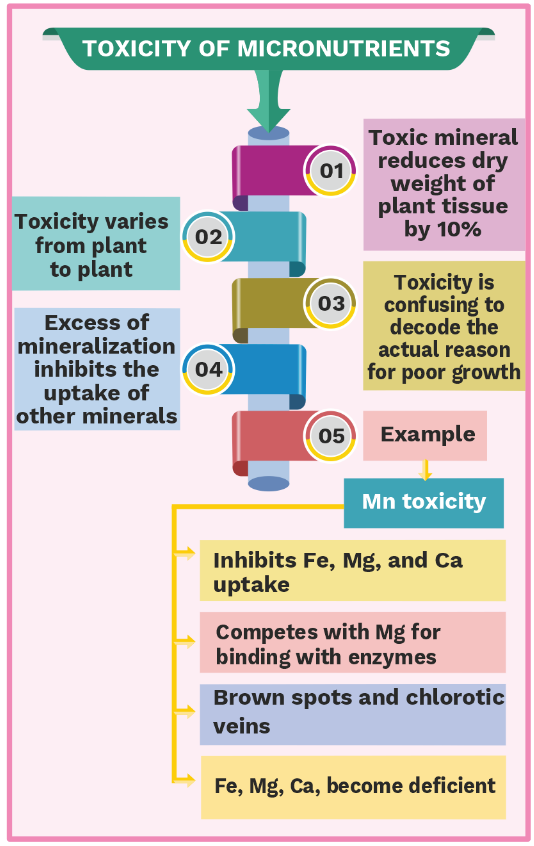
(1) Radioactive and can be detected by Geiger-counter method

(2) Required in very minute quantities

(3) Known to remove other element out of protoplast

(4) One of the first to be discovered in protoplasm

- Prominent symptoms of manganese toxicity appear as brown spots surrounded by chlorotic veins.
- Thus, excessive manganese results in the deficiency of iron, magnesium and calcium.



MECHANISM OF ABSORPTION OF MINERAL ELEMENTS

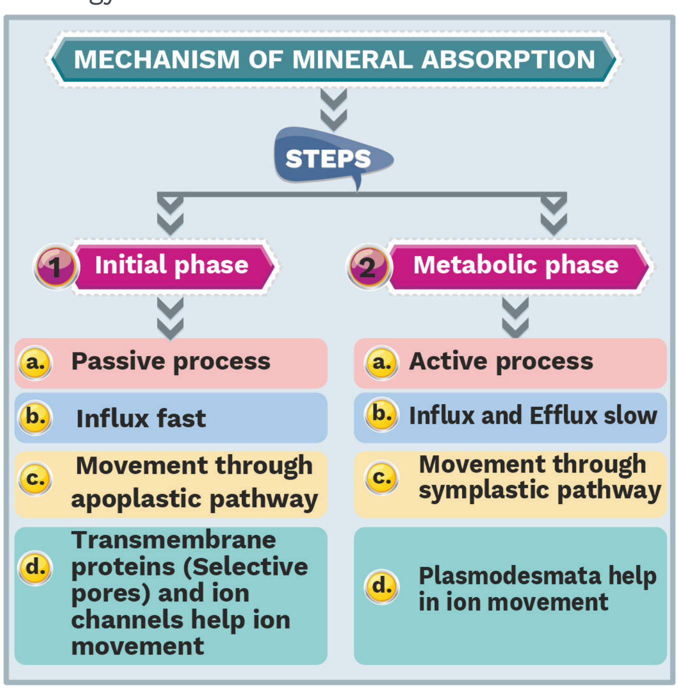
It occurs in two phases : Initial phase and metabolic phase

Initial Phase

- Rapid uptake of ions from the soil into the intracellular spaces of cells or outer space of cells or free space of cells (the apoplast) occurs.
- The uptake of ions is passive.

Metabolic Phase

- The movement of ions is slow as these move into the cell cytoplasm and vacuole (symplast) then move to other cell.
- It is an active process that requires the metabolic energy.



Rack Your Brain

Why is the movement of ions in metabolic phase slow in comparison to initial phase of ion uptake?

Previous Year's Question

The nitrifying bacteria are:

(a) Autotrophic
(b) Chemosynthetic
(c) Saprophytic
(d) Parasitic

Note :
The movement of mineral ions – **flux**.
The inward movement of mineral ions –**influx**.
The outward movement of mineral ions- **efflux**.

TRANSLOCATION OF SOLUTE

- The transportation of mineral salts is through the xylem along with the ascending water.
- Transpiration pull plays a major role in the movement of mineral salts.

METABOLISM OF NITROGEN

NITROGEN CYCLE

- The molecular nitrogen is not utilized directly by the plants. It has to be fixed i.e., combined with the elements such as carbon, hydrogen or oxygen to form compounds prior to utilization.
- Nitrogen exists as two nitrogen atoms joined by a very strong triple covalent bond ($N \equiv N$) in nature. Nitrogen cycle can be expalined under the following headings.
  - Nitrogen fixation
  - Ammonification
  - Nitrification
  - Denitrification

Nitrogen Fixation

- The process of conversion of nitrogen (N_2) to ammonia is termed as nitrogen fixation.

Methods of Fixation of Nitrogen

- Physical nitrogen fixation.
- Biological nitrogen fixation.

Physical Nitrogen Fixation

- It takes place by two ways: Natural and Industrial

Natural Nitrogen Fixation

- Atmospheric nitrogen combines with oxygen under the effect of lightening (i.e., electric discharge) and thunder in the clouds to form

Previous Year's Question

Assertion: If you burn a plant, its nitrogen component is given off as ammonia and other gases.
Reason: Hydroponics does not allow plants to grow well if they are supplied with all the mineral nutrients they need.

(a) Both Assertion and Reason are true, and the Reason is the correct explanation of the Assertion.
(b) Both Assertion and Reason are true, but the Reason is not the correct explanation of the Assertion.
(c) Assertion is true statement, but Reason is false.
(d) Both Assertion and Reason are false statements.

Gray Matter Alert!!!

Winogradsky, in 1891 discovered biological nitrogen fixation.

Previous Year's Question

Which of the following is the most limiting factor for nitrification in the soil?
(a) Soil reaction (pH)
(b) Moisture
(c) Tillage
(d) Temperature

nitric oxide (NO).

- Nitric oxide is then oxidized to form nitrogen peroxide (NO_2)

$$2NO + O_2 \xrightarrow{\text{Oxidation}} \underset{\text{(Nitrogen peroxide)}}{2NO}$$

$$N_2 + O_2 \xrightarrow{\text{Electric discharge and thunder}} \underset{\text{(Nitric oxide)}}{2NO}$$

$$2NO_2 + H_2O \xrightarrow{\text{Rainwater}} \underset{\text{(Nitrous acid)}}{HNO_2} + \underset{\text{(Nitric acid)}}{HNO_3}$$

- During rains the nitrogen peroxide combines with water to form nitrous acid and nitric acid which come to ground along with the rains.
- On the ground, the acids react with the alkaline radicals to form water soluble nitrates(NO_3^-) and nitrites(NO_2^-).The water soluble nitrates and nitrites are directly absorbed by the plants.

$$2NO_2 + H_2O \xrightarrow{\text{Rainwater}} \underset{\text{(Nitrous acid)}}{HNO_2} + \underset{\text{(Nitric acid)}}{HNO_3}$$

$$HNO_3 + \text{Ca or K Salts} \longrightarrow \text{Ca nitrates or K nitrates}$$

Industrial Nitrogen Fixation

- Ammonia is produced industrially by the direct combination of nitrogen with hydrogen (obtained from water) at high temperature and pressure. Later, it is converted into various types of fertilizers like urea.

Ammonification

- Decomposition of organic nitrogen of dead plants and animals into ammonia is called ammonification.
- Ammonification is carried by ammonifying bacteria that are found in the soil e.g., *Bacillus ramosus*, *Bacillus vulgaris* and *Bacillus mycoides*.

Nitrification

- Some of this ammonia volatilises and re-enters the atmosphere but most of it is converted into nitrate by soil bacteria in the following steps:

Definition

Ammonification: The process by which proteins and amino acids of dead organisms are converted to ammonia by microbes.

Previous Year's Question

Which one of the following is an aerobic, free living nitrogen fixing soil bacterium?
(a) *Klebsiella*
(b) *Rhizobium*
(c) *Clostridium*
(d) *Azotobacter*.

Gray Matter Alert!!!

Foliar Fertilizers or foliar nutrition: Spraying of deficient micro nutrients over the cultivated plants.

Definition

Nitrification: The process of conversion of ammonia into nitrates.

$$2NH_3 + 3O_2 \longrightarrow 2NO_2^- + 2H^+ + 2H_2O \quad \text{-----(i)}$$
$$2NO_2^- + O_2 \longrightarrow 2NO_3^- \quad \text{----(ii)}$$

- Ammonia is first oxidised to nitrite by the bacteria **Nitrosomonas** and/or **Nitrococcus**.
- The nitrite is further oxidised to nitrate with the help of the bacterium *Nitrobacter*.
- *Nitrosomonas*, *Nitrococcus* and *Nitrobacter* are called nitrifying bacteria and are chemoautotrophs.
- The nitrate formed during nitrification is absorbed by plants and is transported to the leaves. In leaves, it is reduced to form ammonia that finally forms the amine group of amino acids.

Definition

Chemoautotrophs: Organisms that synthesize organic substances by utilizing chemical energy by performing exothermic

Rack Your Brain

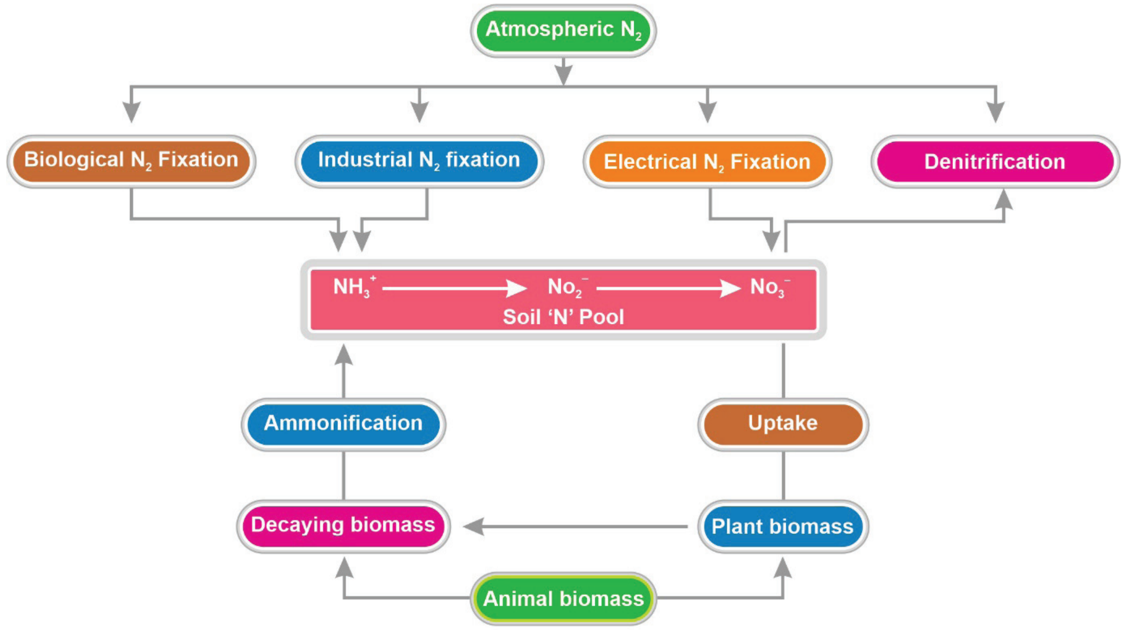
Which pigment is essential for nitrogen fixation by leguminous plants?

Denitrification

- Nitrate present in the soil is also reduced to nitrogen by the process of denitrification that is mixed into the soil and is released into the atmosphere..
- Denitrification is carried by bacteria **Pseudomonas** and **Thiobacillus**.

Definition

Denitrification: The process of conversion of nitrate into elemental nitrogen.



The nitrogen cycle showing relationship between the three main nitrogen pools–atmospheric soil, and biomass

Note :
Nitrogen is the fourth most prevalent element in living organisms. Plants compete with microbes for the limited nitrogen that is available in soil. Thus, nitrogen is a limiting nutrient for both natural and agricultural ecosystems.

Gray Matter Alert!!!

Some vascular plants possess nodules on stem (*Sesbania*) and even leaves (*Ardisia* etc.) which contain nitrogen fixing microbes.

BIOLOGICAL NITROGEN FIXATION

- Reduction of nitrogen to ammonia by living organisms is called biological nitrogen fixation.
- The enzyme capable of nitrogen reduction is present exclusively in prokaryotes and such microbes are called N_2-fixers.
- In the soil numerous nitrogen fixing microbes are present and **Molybdenum** is required by the microbes to fix the nitrogen.

Previous Year's Question

Which one of the following elements plays an important role in biological nitrogen fixation?
(a) Molybdenum
(b) Manganese
(c) Copper
(d) Zinc

Type of Biological Nitrogen Fixation

- Asymbiotic nitrogen fixation:
- symbiotic nitrogen fixation.

Asymbiotic Nitrogen Fixers	Symbiotic Nitrogen Fixer
• Aerobic and free-living nitrogen fixing bacteria e.g., **Azotobacter, Beijerinckia, Derxia** • Anaerobic and free-living nitrogen-fixing bacteria e.g., **Rhodospirillum, Clostridium, Bacillus** *etc.* • Cyanobacteria-e.g., *Nostoc, Anabaena, Aulosira, Cylindrospermum, Trichodesmium* etc. Few Fungi-e.g., *Pullularia*, yeasts • Photosynthetic Nitrogen-Fixing Bacteria-e.g., **Rhodopseudomonas, Chlorobium, Rhodospirillum** etc. • Chemosynthetic Nitrogen-fixing bacteria-e.g., **Desulfovibrio** etc.	• Symbiotic nitrogen fixing bacteria like **Frankia** produces nitrogen fixing root nodules in the roots of certain non-leguminous angiosperms (e.g., *Casuarina*, *Alnus*) and gymnosperms (e.g., *Cycas*, *Podocarpus*) • Certain cyanobacteria also establish symbiotic association with plants for example **Nostoc** is symbiont with liverwort *Anthoceros* and *Anabaena* with the fronds of water fern *Azolla*. • Coralloid roots of *Cycas* harbour blue-green algae like *Nostoc, Anabaena* etc.

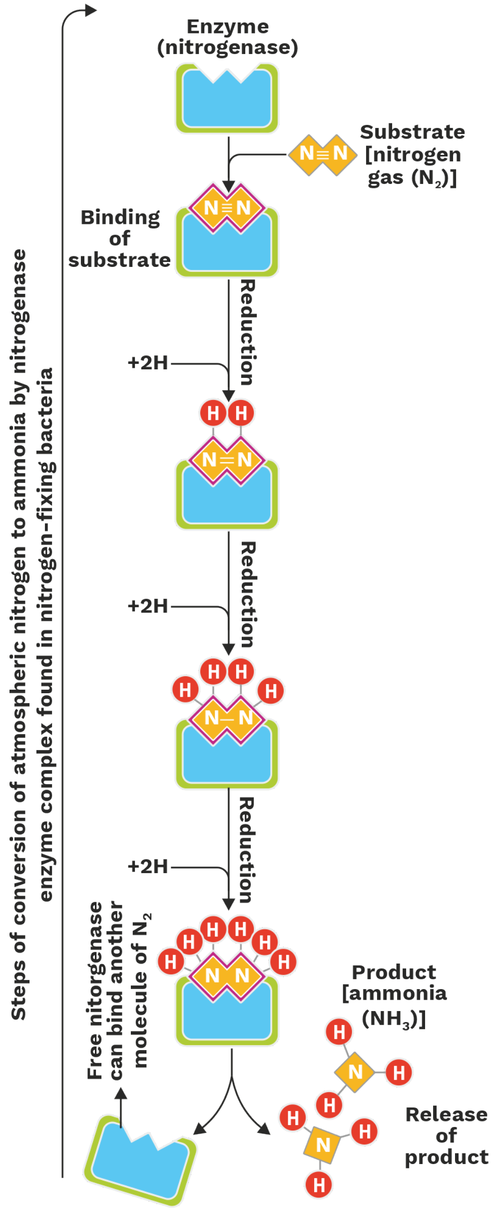
Note : Rhizobium leguminosarum, bacterium lives in soil to form root nodules in plants belonging to the family Leguminosae such as alfalfa, sweet clover, sweet pea, lentils, garden pea, broad bean, clover beans, gram, groundnut, soyabean etc.
Both **Rhizobia** and **Frankia** are free living bacteria but as symbionts, these can fix nitrogen into its compounds.

MECHANISM OF BIOLOGICAL NITROGEN FIXATION

- Progressive reduction of dinitrogen(N_2) molecule by the addition of pairs of hydrogen atoms.
- Three bonds between the two nitrogen atoms are cleaved and ammonia is formed. The process requires-
  - A strong reducing agent like $NADPH_2$, $FMNH_2$
  - A source of energy like ATP
  - An enzyme nitrogenase (**Mo-Fe protein**)
  - Compounds for trapping ammonia formed by the reduction of dinitrogen.
- Depending upon the type of nitrogen fixer, ATP and reducing agents are provided by either respiration or photosynthetic metabolism.
- Enzyme **nitrogenase** has **molybdenum** (Mo^{+4}) and **iron** (Fe^{+3}).Both of them take part in attachment of a dinitrogen molecule and weaken the bonds between the two atoms of the latter. The weakened molecule of nitrogen is reduced by the reducing agent (NADPH, $FMNH_2$). It produces Diazene (N_2H_2), hydrazine and then ammonia ($2NH_3$).

$$N_2 + 8e^- + 8H^+ + 16ATP \longrightarrow 2NH_3 + H_2 + 16ADP + 16Pi$$

- The ammonia formed in the biological nitrogen fixation is not liberated. It is highly toxic even in small quantities. The nitrogen fixers protect themselves from ammonia by providing organic acids. The organic acids react with ammonia and give rise to amino acids.



Rack Your Brain

For conversion of atmospheric nitrogen to ammonia, how many ATP molecules are required?

> **Note :**
> The nitrifying bacteria are chemoautotrophs and use energy liberated during nitrification in the synthesis of organic substances from carbon-di-oxide and a hydrogen donor other than water.

ROOT NODULE FORMATION

- Root nodules are small irregular outgrowths on the roots of leguminous plants.
- Rhizobium bacteria multiply and colonise in the surroundings of root hair and get attached to them as well as the root epiblema.
- Specific chemical substances are secreted by the bacteria that cause the curling of the root hair. At the site of curling or deformation of the root hair, *Rhizobia* invade the root tissue.
- An infection thread is produced which carries the Rhizobia to the cortex of the root.
- The cells of the root nodules are large and tetraploid. These contain irregular polyhedral bacteria called bacteroids.
- Bacteroids cannot divide and remain untransformed which facilitate the infection to spread.
- Cell division is stimulated in the infected cells of cortex and pericycle, more bacteria invade the newly formed tissues.
- The combination of cytokinin produced by the invading bacteria and auxin produced by the plant cells promotes cell division and extension, leading to nodule formation.
- The nodule thus formed establishes a direct vascular connection with the host for the exchange of nutrients.
- Fixation of nitrogen is under the control of plant **nod genes** and bacterial **nod**, **nif** and **fix genes** cluster.

ROOT NODULE FORMATION

Root hair secretes flavonoids to attract bacteria + activation of *nod* genes in bacteria

↓ *Rhizobium* multiply

Curling of root hair (deforming of root hair)

↓

Cell division in infected tissue

↓

Infection thread forms (a small tube)

↓

entry of more *Rhizobia* inside the root hair

↓

Cytokinin secretion by bacteria + auxin secretion by root hair cell

↓

Inner cortical cells (tetraploid) enlarge + set connection with vascular bundle

↓

Nodule formed

↓

Rhizobia convert into rod-shaped bacteroids and occupy enlarged cells

Previous Year's Question

Which of the following bacterium is associated with the roots of legumes?

(1) *Clostridium* (2) *Rhizobium*

(3) *Nostoc* (4) *Spirogyra*

Root Nodule

- The root nodules are red or pinkish internally due to the presence of pigment called **leghaemoglobin**.
- Leghaemoglobin pigment is closely related to haemoglobin (found in human blood) as it has the ability to combine with oxygen.
- Leghaemoglobin is present between bacteroids and the surrounding host membrane. Leghaemoglobin combines with oxygen rapidly thus, acts as efficient **oxygen scavenger**.
- The nitrogen fixing enzyme nitrogenase of the bacteroids function under anaerobic conditions. Thus, leghaemoglobin protects this enzyme from combining with oxygen and so maintains its activity.

Note: Bacteroid-The symbiotic bacteria which become enlarged, rod shaped and membrane bound in the root nodules of leguminous plants.

Gray Matter Alert!!!

Nitrosococcus oceani, is omnipresent in the world's oceans and is important to the global nitrogen cycle.

Previous Year's Question

Which pigment is essential for the nitrogen fixation by leguminous plants?
(1) Phycoerythrin
(2) Anthocyanin
(3) Phycocyanin
(4) Leg-haemoglobin

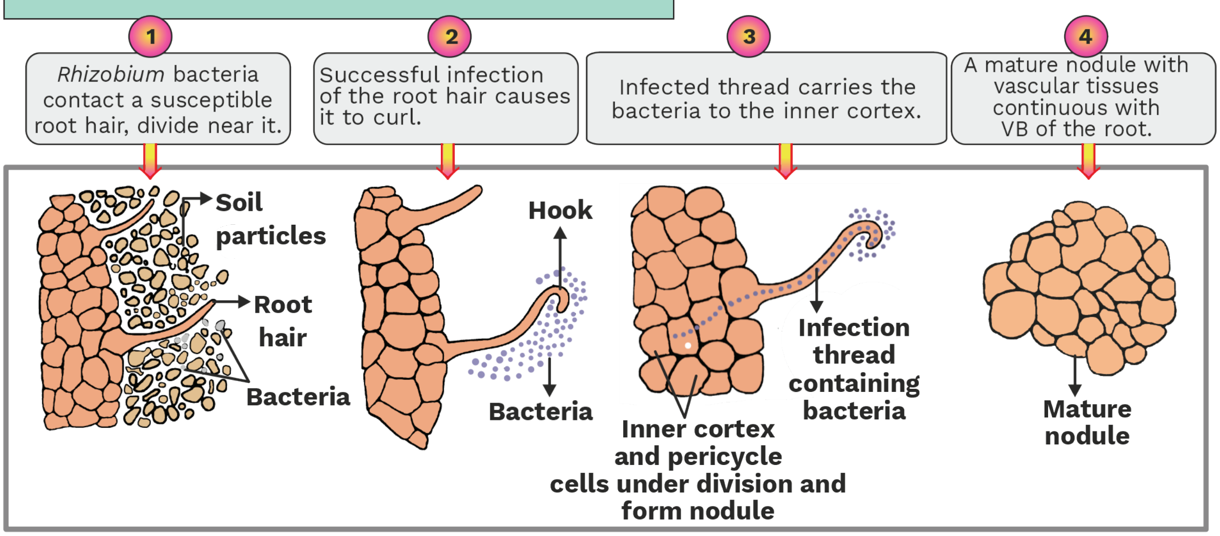


FIG. DEVELOPMENT OF ROOT NODULES IN SOYABEAN

NITRATE ASSIMILATION IN PLANTS

- Nitrate is the most important source of nitrogen for plants.

Rack Your Brain

How is anaerobic condition maintained in root nodule?

- It cannot be used as such by the plants in the synthesis of organic compounds. It is first reduced to ammonia before being incorporated into organic compounds.
- Steps of nitrate reduction to ammonia (mediated by a specific enzyme)–
  - Reduction of Nitrate to Nitrite
    - First the nitrate is reduced to nitrite by an enzyme called **nitrate reductase**.
  - Reduction of Nitrite
    - The nitrite ions are then reduced to ammonia by an enzyme called nitrite reductase.
    - Nitrite reductase does not require molybdenum but requires copper and iron for its activity.
    - The enzyme nitrate reductase occurs inside chloroplasts in the leaf cells and leucoplasts of other cells. Nitrite ions formed in other parts of the plants are transported to leaves for their reduction to ammonia.

Fate of Ammonia

- At physiological pH, ammonia is protonated to form ammonium (NH_4^+) ions. Ammonium ions are quite toxic to plants,hence cannot accumulate in plants.
- Ammonium iones combines with some organic acids to produce amino acids.

Synthesis of Amino Acids

- There are two main processes by which majority of amino acids are synthesized in plants.
  - Reductive Amination
    - In this process, ammonia reacts with carboxylic acids such as α-ketoglutaric acid and forms glutamic acid

$$\alpha\text{-ketoglutaric acid} + NH_4^+ + NADPH \xrightarrow[\text{Dehydrogenase}]{\text{Glutamate}} \text{Glutamate} + H_2O + NADP$$

  - Transamination

Previous Year's Question

Which of the following is not caused by the deficiency of mineral nutrition?

(1) Shortening of internode
(2) Necrosis
(3) Etiolation
(4) Chlorosis

Rack Your Brain

Name the primary amino acid from which other 17 amino acids are formed through the process of transamination.

Previous Year's Question

In nitrogen cycle the bacteria which change proteins to ammonia are known as:

(a) Bacteria of decay
(b) Denitrifying bacteria
(c) Nitrifying bacteria
(d) Nitrogen fixing bacteria.

- Transfer of amino group from one amino acid to the keto group of keto acid. Glutamic acid is the main amino acid from which other amino acids are formed through transamination.

Amino-donor Amino-acceptor

- Transamination process is catalysed by the enzyme transaminase.

AMIDES

- Amides contain more nitrogen than amino acids and are structural part of most proteins.
- Two most important amides found in plants are asparagines and glutamine, formed from two amino acids namely glutamic acid and aspartic acid respectively. In this process, hydroxyl part of the amino acid is replaced by another $-NH_2$ radicle.
- The reaction is catalysed by the enzyme *glutamine synthetase* or *asparagine synthetase.*
  Amides are transported to other parts via xylem vessels.

Previous Year's Question

Assertion: Deficiency of sulphur causes chlorosis in plants.
Reason: Sulphur is a constitutent of chlorophyll, proteins and nucleic acid.
(a) Both Assertion and Reason are true, and the Reason is the correct explanation of the Assertion.
(b) Both Assertion and Reason are true, but the Reason is not the correct explanation of the Assertion.
(c) Assertion is true statement, but Reason is false.
(d) Both Assertion and Reason are false statements.

Gray Matter Alert!!!

In soyabean the fixed nitrogen is exported out of the root nodules in the form of ureides. These have more nitrogen then carbon.

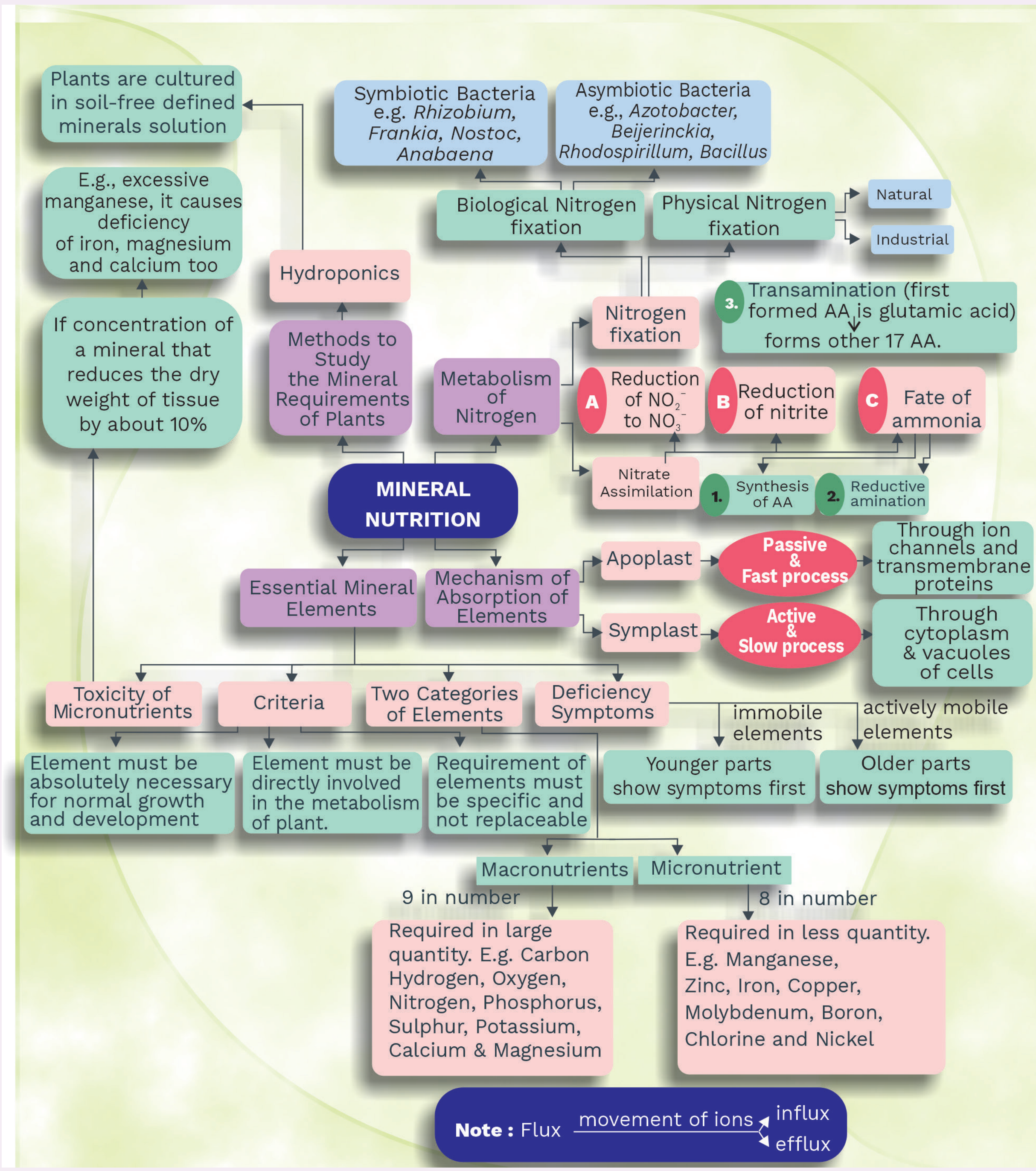
Previous Year's Question

Most of the plants obtain nitrogen from the soil in the form of
(a) Free nitrogen gas
(b) Nitrates
(c) Nitrites
(d) Ammonia.

Gray Matter Alert!!!

Monovalent cations (such as sodium) commonly increase the cell membrane permeability
Divalent cations (such as calcium) decrease the cell membrane permeability.

Chapter Summary



Chapter Summary

HUNGER SIGNS/DEFICIENCY SYMPTOMS FOR ELEMENTS IN PLANTS, OLDER LEAVES AFFECTED

Effect localised, leaves (light or dark green, leaves dry up or curl)

PHOSPHORUS

(i) Plant dark green/red/purple

(ii) Dry leaves brown-black

(iii) Poor root growth

(iv) Stunted growth in acute condition

(v) Localised chlorosis and mottling

(vi) Lower leaves do not shrivel

(vi) Small spots or dead tissue at the tip and between veins

NITROGEN

(i) Plant light green

(ii) Leaves yellow, dry brown leaves

(iii) Stunted growth in acute condition

(iv) In excess, causes foliar hypertrophy and suppressed fruit production

Effect systemic, mottling or chlorosis with or without sports of dead tissue, lower leaves do not dry up

MAGNESIUM

(I) Mottling or chlorosis

(ii) Leaves may have spots of dead tissue

(iii) Tip and margin turned upward

(iv) Slender stalk

(v) Delayed flowering

POTASSIUM

(I) Mottling or chlorosis

(ii) Necrotic spots small

(iii) Spots more marked near margin

(iv) Stalk slender

ZINC

(I) Large necrotic spots near tips and between veins (both primary and secondary)

(ii) Leaves thick and small

(iii) Stunted stem and internodes

Chapter Summary

YOUNGER LEAVES/BUD AFFECTED WITH LOCALISED SYMPTOMS

- Terminal bud remains alive. Veins light green in colour. Wilting or chlorisis of younger leaves. Necrotic spots present or absent
  - (i) Young leaves wilt permanently
    (ii) No chlorosis
    (iii) Stalk unable to stand erect
    - **COPPER**
      - (i) Chlorosis may not be confined to veins
      - (ii) Necrotic spots not present
        - **IRON**
          - (i) Chlorosis in young leaves
          - (ii) Intervenial chlorosis confined to youngest leaves
          - (iii) Stalk short and slender
        - **SULPHUR**
          - (i) Tissue between veins light green
          - (ii) Poor root development
  - (I) No wilting
    (ii) Chlorosis present
    (iii) Necrotic spots may be present
    - **MANGANESE**
      - (I) Necrotic sports scattered over leaf
      - (ii) Leaf mottled
- Terminal bud dies, distortion of tip and bases of young leaves
  - **BORON**
    - (i) Slow root tip elongation
    - (ii) Growth, abnormalities and malfuncitons e.g., heart root of beet and stem cracks of celery
    - (iii) Abnormal dark foliage
    - (iv) Leaves twisted
    - (v) Stalk die back at the terminal bud
  - **CALCIUM**
    - (i) Young leaves of terminal bud are hooked and later die back at tips and margins
    - (ii) Stalk dies at terminal bud

SOLVED EXERCISE

Q1 **A trace element is an element which**

(1) Is a radioactive element and can be traced by Geiger counter

(2) Is required in very minute amounts

(3) Draws other elements out of protoplasm

(4) Was one of the first to be discovered

A1 **(2)**

Trace elements are those elements that are required in minute amounts for carrying out various physiological and biochemical processes in plants.

Q2 **Deficiency of phosphorous**

(1) Brings about healthy root growth **(2) Promotes fruit ripening**

(3) Retards protein formation **(4) None**

A2 **(3)**

Phosphorous is a constituent for certain proteins. So, its deficiency affects proteins synthesis adversely.

Q3 **In plants a common symptom caused by deficiencies of P, K, Ca and Mg is**

(1) Bending of leaf tip

(2) Formation of anthocyanin

(3) Poor development of vasculature

(4) Appearance of dead necrotic areas

A3 **(4)**

Necrosis means death of tissue of leaves or any other part of plant. It happens if middle lamella chlorophyll formation does not occur.

Q4 **Which pigment is essential for the nitrogen fixation by leguminous plants?**

(1) Anthocyanin **(2) Leghaemoglobin**

(3) Phycocyanin **(4) Phycoerythrin**

A4 **(2)**

For the activity of enzyme nitrogenase anaerobic conditions are required. So, leghaemoglobin is ideal as it acts as oxygen scavenger in root nodules thus, create anaerobic condition.

Q5 **Interveinal necrosis in lemon leaves is caused by the deficiency of**

(1) Molybdenum **(2) Boron**

(3) Zinc **(4) Copper**

A5 **(3)**

Death of leaf tissues between veins occur.

Q6 **Which is not an essential element for plants?**

(1) Iron **(2) Boron**

(3) Sulphur **(4) Cadmium**

A6 **(4)**

Cadmium is not essential for all the plants.

Q7 **Roots can absorb minerals from the soil when they are in-**

(1) Solid state **(2) Liquid state**

(3) Ionic state **(4) Gaseous state**

A7 **(3)**

Special carrier proteins are present in the plasma membrane which help mineral ions to move across the cells.

Q8 **The mineral constituent of cell wall is**

(1) Iron **(2) Magnesium**

(3) Potassium **(4) Calcium**

A8 **(4)**

Calcium is important for middle lamella formation.

Q9 **The enzyme responsible for the reduction of molecular nitrogen to the level of ammonia in the leguminous root nodule is**

(1) Nitrogenase **(2) Nitrate reductase**

(3) Nitrite reductase **(4) All the above**

A9 **(1)**

The Mo-Fe cofactor of nitrogenase enzyme act as a site for N_2 fixation and converts it into NH_3.

Q10 **Which of the following is the most limiting factor for nitrification in the soil**

(1) Soil reaction (pH) **(2) Moisture**

(3) Tillage **(4) Temperature**

A10 **(1)**

In general nitrifying bacteria need pH 7.0 to 8.0 and if this pH fluctuates the number of bacteria reduces.