MINERAL NUTRITION

INTRODUCTION

The basic needs of all living organisms are essentially the same. They require macro-molecules such as carbohydrates, proteins, fats and water and minerals for their growth and development.

Methods to Study the Mineral Requirements of Plants

In 1860, Julius Von Sachs, a prominent German botanist demonstrated, for the first time, that plants could be grown to maturity in a defined nutrient solution in complete absence of soil. This technique of growing plants in a nutrient solution is known as hydroponics. By this method, essential elements were Identified and their deficiency symptoms were discovered.

Criteria for essentiality

- The element must be absolutely necessary for supporting normal growth and reproduction.
- The requirement must be specific and not replaceable by another element.
- The element must be directly involved in the metabolism of the plant.

Based upon the above criteria only a few elements have been found to be absolutely essential for plant growth and metabolism. These elements are further divided into two broad categories based on their quantitative requirements, macronutrients and micronutrients

Macronutrients

- They are generally present in plant tissues in large amounts (in excess of 10 m mole/kg of dry matter) These include C, H, O.
- N, P, S, K, Ca, Mg

Micronutrients

- Also called trace elements, are needed in very small amount (less than 10 m mole kg−1 of dry matter)
- These include Fe, Mn, Cu, Mo, Zn, B, Cl, Ni

Essential elements can also be grouped into four broad categories on the basis of their functions These categories are:

(i) Components of biomolecules and structural elements of cells (C. H, O and N)

(ii) Components of energy related chemical compounds in plants (Mg in chlorophyll and P in ATP)

(iii) Activate or inhibit certain enzymes (Mg^{2+} activates RuBisco and PEPcase, Zn^{2+} activate alcohol dehydrogenase and Mo activate nitrogenase)

(iv) Essential elements which alter osmotic potential (K).

Apart from 17 essential elements there are 4 beneficial elements - Na, Si, Co, Se required by higher plants.

Role of Macro and Micronutrients

Essential elements perform several functions. They participate in various metabolic processes in the plant cells. Various forms and functions of essential nutrient elements are given below.

S. No	Mineral element	Absorbed as	Required in	Functions
1	Nitrogen	NO_3^-, NO_2^- or NH_4^+	All parts of the plants, particularly meristems.	Major constituents of proteins, nucleic acids, vitamins and hormones.
2	Phosphorus	$H_2PO_4^-$ or HPO_4^{2-}	Developing fruits, seeds storage organs, young meristems.	Constituent of cell membrane, certain proteins, all nucleic acids.
3	Potassium	K^+	Meristems, buds leaves & root tips.	Maintain turgidity of cells, required for opening and closing of stomata.
4	Calcium	Ca^{2+}	Meristems and differentiating tissues.	Required for formation of middle lamella, mitotic spindle and for activating of certain enzymes Accumulates in older leaves.
5	Magnesium	Mg^{2+}	Seeds leaves, growing areas of root and stem.	Constituent at the center of ring structure of chlorophyll and helps to maintain ribosome structure.
6	Sulphur	SO_4^{2-}	Young leaves and meristems.	Constituent of two amino acids cysteine and methionine; main constituents of several coenzymes and vitamins.

7	Iron	Fe^{3+}	All parts of plants	Main constituents of ferredoxin and cytochromes. It activates catalase enzyme and is essential for the formation of chlorophyll
8	Manganese	Mn^{2+}	Leaves and seeds	The best defined function of manganese is in the splitting of water to liberate oxygen during photosynthesis
9	Zinc	Zn^{2+}	All parts of the plants	Activates various enzymes especially carboxylase, also needed for auxin synthesis
10	Copper	Cu^{2+}	All parts of the plants	Associated with certain enzymes involved in redox reactions
11	Boron	BO_3^{2-} or $B^4O_7^{2-}$	Leaves and seeds	Required for uptake and utilisation of Ca^{2+}, membrane functioning, pollen germination, cell elongation and carbohydrate translocation
12	Molybdenum	MoO^{2+}	All parts of plants and commonly in roots	Component of nitrogenase and nitrate reductase
13	Chlorine	Cl^-	All parts of the plants	Essentai for water splitting reaction in photosynthesis and for anion and cation balance in cells

Deficiency Symptoms of Essential Elements

The concentration of the essential element below which plant growth is retarded is termed as critical concentration. The element is said to be deficient when present below the critical concentration. Due to deficiency of critical elements plants show deficiency |symptoms. The parts of the plants that show the deficiency symptoms also depend on the mobility of the element in the plant.

Deficiency symptoms in plants include

(a) Chlorosis : Due to deficiency of N, K, Mg, S, Fe, Mn, Zn and Mo

(b) Necrosis: Due to deficiency of Ca, Mg, Cu, K

(c) Inhibition of cell division: Due to deficiency of N, K, S, Mo

(d) Delay in flowering: Due to deficiency of N, S, Mo

(e) Stunted plant growth

Mobile Elements

- Transported from older leaves to younger leaves
- Deficiency symptoms first appear in older/senescent leaves. Example N, K, Mg

Immobile Elements

- Not transported out of the mature leaves.
- Deficiency symptoms tend to appear first in the young leaves. Example: Ca

Toxicity of micronutrients

The requirements of micronutrients is always in low amounts while their moderate decrease causes the deficiency symptoms and a moderate increase cause toxicity. Any mineral ion concentration in tissues that reduces the dry weight of tissues by about 10 percent is considered toxic. Many times, excess of an element may inhibit the uptake of another element.

For example, manganese competes with iron and Mg for uptake and with Mg for binding with enzymes. Mn also inhibits calcium translocation in shoot apex.

Mechanism of absorption of elements

Process of absorption can be demarcated into two phases.

In the first, the rapid uptake of ions is into apoplast. It is passive.

In the second phase the ions move into symplast. It require energy; so it active.

The movement of ions is called flux, the inward movement is influx and the outward movement is efflux.

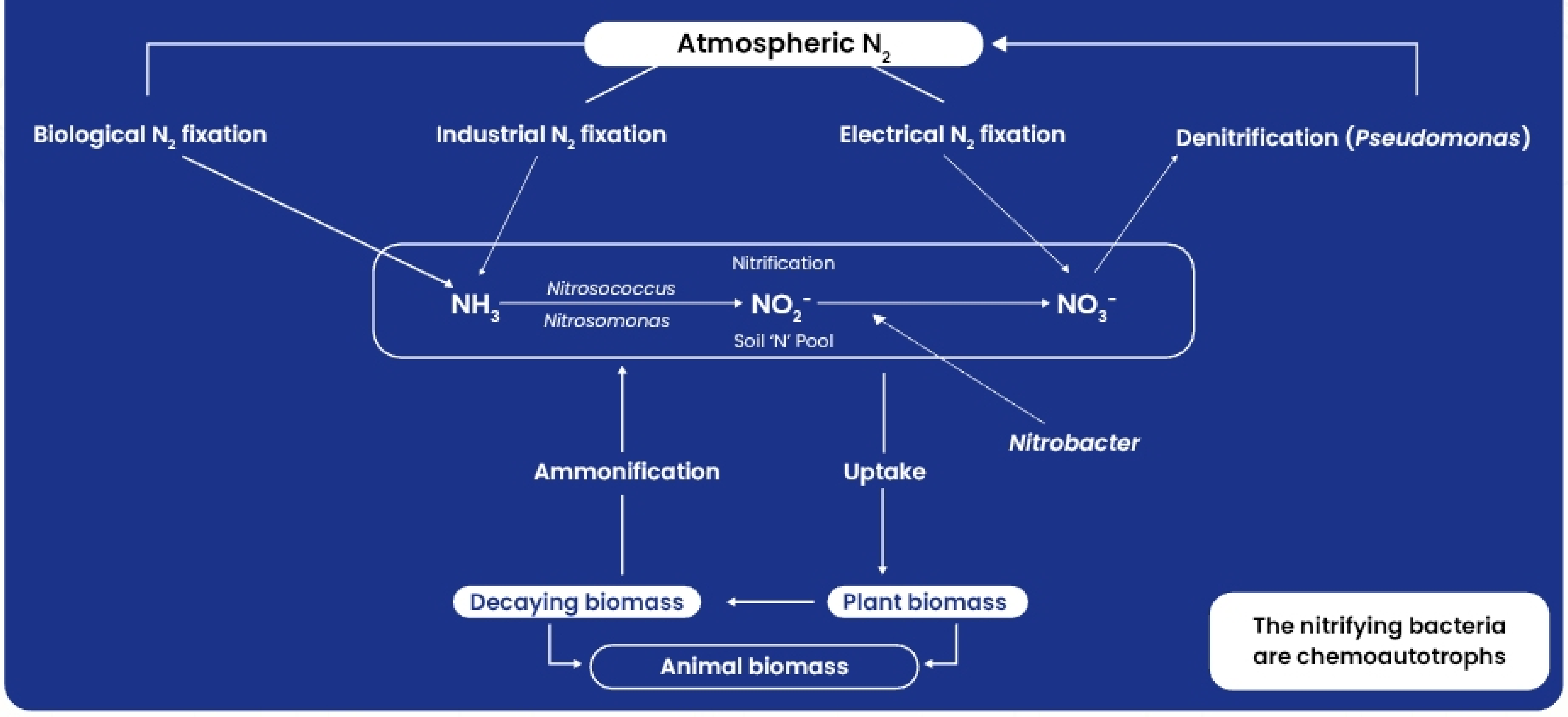
Translocation of solutes

Mineral salts are translocated through xylem along with the ascending stream of water, which is pulled up through plant by transpiration pull.

Soil as Reservoir of Essential Elements

Soil consists of a wide variety of substances. Soil not only supplies minerals but also harbours nitrogen fixing bacteria.

METABOLISM OF NITROGEN: Nitrogen Cycle



The nitrifying bacteria are chemoautotrophs

BIOLOGICAL NITROGEN FIXATION

Only certain prokaryotic species are capable of fixing nitrogen. Reduction of nitrogen to ammonia by living organisms is called biological nitrogen fixation. Enzyme nitrogenase is exclusively present in prokaryotes

$$N \equiv N \xrightarrow{\text{Nitrogenase}} 2NH_3$$

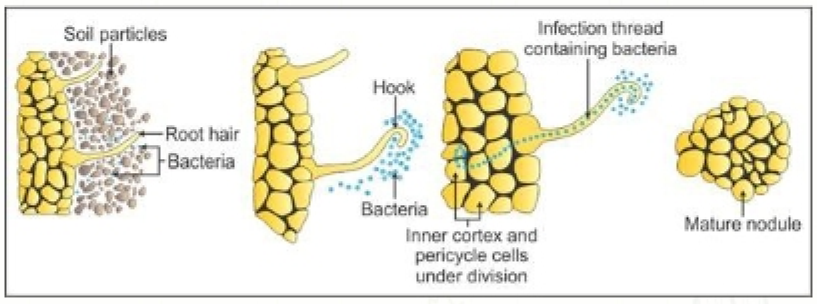
Bacteria	Nitrogen fixation	Aerobic/ anaerobic
Azotobacter	Free living	Aerobic
Beijerinckia	Free living	Aerobic
Bacillus	Free living	Anaerobic
Clostridium	Free living	Anaerobic
Rhodospirillum	Free living	Anaerobic
Anabaena	Symbiotic or free	----
Nostoc	Symbiotic or free	----
Rhizobium	Symbiotic	----
Frankia	Symbiotic	----

Rhizobium fixes nitrogen in legumes whereas *Frankia* in non-leguminous plants such a *Alnus*.

NODULE FORMATION

Nodule formation involves a sequence of multiple interactions between Rhizobium and roots of host plant. Principal steps in the nodule formation are as follows:

- Rhizobia multiply, colonise the surroundings of the roots and get attached to epidermal and root hair cells Root hair curls and bacteria invade the root hair.
- An infection thread is produced carrying the bacteria into the cortex of the root where they initiate nodule formation in the cortex.
- The nodule thus formed establishes a direct vascular connection with the host for exchange of nutrients.



Nodule contains nitrogenase and leg-haemoglobin

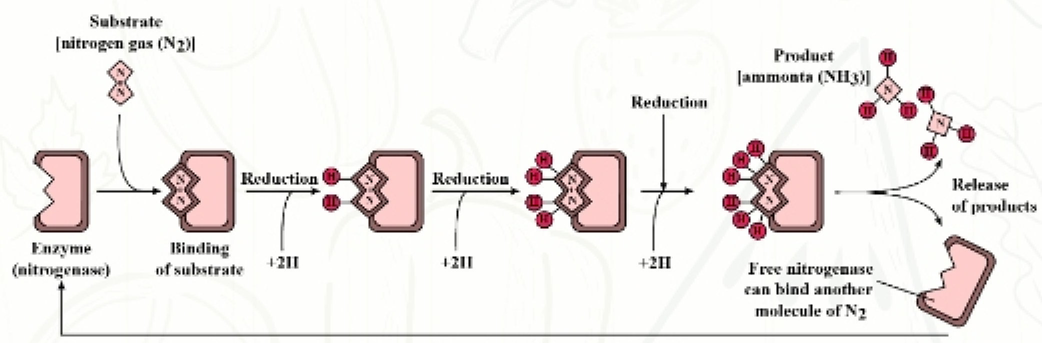
Nitrogenase is Mo-Fe protein and highly sensitive to the molecular oxygen, thus requires anaerobic conditions

To protect nitrogenase nodule contains an oxygen scavenger called laghaemoglobin

***Rhizobium* and *Frankia* live as aerobes under free living condition but as symbionts during nitrogen fixing events they become anaerobic.**

SUBSTRATE [NITROGEN GAS (N_2)]

The ammonia synthesis by nitrogenase requires a very high input of energy 8 ATP for each NH produced. The energy required thus, is obtained from the respiration of the host cells. Substrate [nitrogen gas(N_2)]



Steps of conversion of atmospheric nitrogen to ammonia by nitrogenase enzyme complex found found in nitrogen - fixing bacteria

FATE OF AMMONIA

At physiological pH the ammonia is protonated to form NH_4^+ ions while most of the plants can assimilate nitrate as well as ammonia ions, the latter is quite toxic to plants and hence cannot accumulate in them

REDUCTIVE AMINATION

In this process, ammonia reacts with α-ketoglutaric acid and forms glutamic acid

α-ketoglutaric acid + NADPH ⟶ Glutamate

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

TRANSAMINATION

It involves transfer of amino group from one amino acid to the keto group of a keto acid. Glutamic acid is the main amino acid from which the transfer of amino group takes place and other amino acids are formed through transamination. The enzyme transaminase catalyses this reaction.

The two most important amides Asparagine and glutamine found in plants are a structural part of proteins. They are formed from two amino acids namely aspartic and glutamic acid respectively.

Amides contain more nitrogen than amino acids, they are transported to other parts of the plant via xylem vessels. Nodules of some plants like soyabean export fixed nitrogen as ureides (High N : C ratio).