MINERAL NUTRITION

*The process of absorption and utilisation of various mineral ions by plant for their growth and development is called **Mineral nutrition**.*

Mineral nutrients (mineral elements): Nutrients obtained from soil.

Non mineral nutrients: Carbon, Hydrogen and Oxygen (*mainly obtained from air and water*)

Hydroponics (*Soilless culture, Solution culture, Water culture*)

It is a technique of growing plants in nutrient solution .

- By this method essential elements and their deficiency symptoms could be identified.
- This method was first demonstrated by ***Julius Von Sachs*** in 1860 (German botanist).
- Commercially developed by ***William F Gericke*** in 1930 (University of California).
- These methods require purified water and mineral nutrient salts

Defined (balanced) nutrient solution

- Solution containing various mineral elements in the proper proportion is called Definied nutrient solution.

Example:

1. Knop's solution
2. Sasch's solution
3. Hoagland's solution. *It is widely used and it contains all the nutrients needed for plant growth.*

- Nutrient solution must be aerated to obtain optimum growth.

Economic Importance

Commercial production of Tomato, seedless Cucumber and Lettuce

Advantages of Hydroponics

1) High yield

2) Out of season vegetables and flowers can be obtained

3) To study about Toxicity, Deficiency symptoms etc.

Disadvantage of Hydroponics

1) Costly

2) Need the help of an expert to prepare nutrient solution

Aeroponics

In this technique roots are supplied with nutrient mist .

Developed by Weathers and Zobel (1976)

In aeroponics plant show a very good growth of root hair. It is used for research purposes .

Example: Citrus and Olive

ESSENTIAL MINERAL ELEMENTS

More than 60 elements are found in plants

Example

Selenium → *Astragalus,*

Gold → *Phacelia*

Radioactive Strontium → *Plants growing near Nuclear Test Site*

There are techniques that are able to detect the low concentration of mineral ions (10^{-8} g/mL)

ESSENTIAL ELEMENTS

Essential elements: They are essential for normal growth, development and metabolism.

CRITERIA FOR ESSENTIALITY

Proposed by Arnon and Stout

1) 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.
2) The element must be specific and is not replaceable by other element . *(Deficiency of any one element cannot be met by supplying some other element.)*
3) It must be directly involved in the metabolism of the plant.

Beneficial (functional) elements

Some plants require certain elements other than essential elements. They have some special role in plants.

- Silicon (Si) → Grass, Diatoms and Equisetum
- Sodium (Na)→ C_4 plants and Halophytes
- Cobalt (Co) → Wheat
- Selenium (Se) →Astragalus and Atriplex
- Aluminium (Al)→ Ferns
- Gallium (Ga) → Apergillus
- Gold (Au) → Equisetum
- Vanadium (V) → Scenedesmus (a green algae)

Classification of Essential elements

I) Based on Quantitative requirement (Hoagland)

1) Macro Nutrients (Macro Elements or Major Elements)**:** *Require more than 10mmole Kg^{-1}* of dry matter. Macronutrients are Carbon, Oxygen, Hydrogen, Nitrogen, Potassium, Calcium, Magnesium, Phosphorous and Sulphur.

2) Micro Nutrients (Micro nutrients, Micro elements ,Trace elements)**:** *Require less than 10 m mole Kg^{-1}* of dry matter.

Micronutrients are Iron, Chlorine, Boron, Manganese, Zinc, Copper, Nickel and Molybdenum.

II) Based on Function

1) Component of biomolecules (structural element of cell) : C,H,O and N

2) Component of energy related chemical compound: Example: Magnesium in Chlorophyll and Phosphorous in ATP.

3) Activate or inhibit enzymes :

Magnesium is an activator for both Ribulose biphosphate carboxylase-oxygenase (RuBisCO) and Phosphoenol pyruvate carboxylase (PEPcase).

Zn^{2+} is an activator of alcohol dehydrogenase.

Mo activates Nitrogenase during nitogen metabolism.

4) Alter osmotic potential: Potassium → opening and closing of stomata.

- Critical elements: N,P and K. They are deficient in agricultural soil due to leaching and withdrawal by plants.
- Balancing elements : Ca, Mg and K
- Tracer elements: These are radioactive isotope of elements which are used to detect various metabolic pathway in plants.
- Electron transport elements : Fe and Cu
- Osmotic concentration of cell sap : K and Cl
- Buffering action: Phosphate
- Framework elements : C,H and O

ROLE OF MACRO NUTRIENTS

Nitrogen:

Required in the greatest amount.

It is absorbed mainly as NO_3^- though some are also taken up as NO_2^- or NH_4^+.

Required : All parts of a plant, particularly the meristematic tissues and the metabolically active cells.

Functions:

1) Major constituents of proteins, nucleic acids, vitamins, hormones and chlorophyll.

2) Nitrogen is a limiting nutrient for both natural and agricultural eco-systems because plants compete with microbes for the limited nitrogen that is available in soil.

3) Insectivorous plants overcome nitrogen deficiency of its body by catching and digesting small insects.

Potassium:

It is absorbed as potassium ion (K^+).

Most abundant intracellular cation

Required: More abundant quantities in the meristematic tissues, buds, leaves and root tips.

Functions:

1) Maintain anion-cation balance in cells,

2) Protein synthesis,

3) Opening and closing of stomata,

4) Activation of enzymes

5) Maintenance of the turgidity of cells.

Phosphorus:

Absorbed in the form of phosphate ions (either as $\mathbf{H_2PO_4^-}$ or $\mathbf{HPO_4^{2-}}$).

Functions:

1) Phosphorus is a constituent of cell membranes, certain proteins, nucleic acids and nucleotides.

2) It is required for all phosphorylation reactions.

Glomus helps in absortion of phosphorus from soil.

Calcium:

Plant absorbs in the form of calcium ions (Ca^{2+})

Required : meristematic and differentiating tissues. It accumulates in older leaves.

Functions:

1) Calcium is used in the synthesis of cell wall, particularly as calcium in the middle lamella. (Ca and Mg pectates)

2) It is also needed during the formation of mitotic spindle.

3) It is involved in the normal functioning of the cell membranes.

4) It activates certain enzymes.

5) Regulating metabolic activities

Magnesium:

Absorbed in the form of divalent Mg^{2+}.

Functions:

1) Constituent of the ring structure of chlorophyll.

2) Helps to maintain the ribosome structure.

3) It activates the enzymes of respiration and photosynthesis .

4) Synthesis of DNA and RNA.

5) Middle lamella is made up of Ca and Mg pectates.

Sulphur:

Plants obtain sulphur in the form of sulphate (SO_4^{2-})

Functions:

1) Sulphur is present in two amino acids – cysteine and methionine

2) Main constituent of several coenzymes, vitamins (thiamine and biotin), Coenzyme A , Lipoic acid and ferredoxin(Fe and S containing protein).

3) Presence of Sinigrin causes pungent smell of Crucicers (*plants of the family Cruciferae or Brassicaceae*) such as Mustard, Cabbage etc.

4) The characteristic odour of Onion and Garlic is due to the presence of Sulphur containing compounds.

<u>ROLE OF MICRO NUTRIENTS</u>

Iron:

Plants obtain iron in the form of ferric ions (Fe^{3+}).

It is required in larger amounts in comparison to other micronutrients.

Functions:

1) It is an important constituent of proteins involved in the transfer of electrons like ferredoxin and cytochromes.

2) It is reversibly oxidised from Fe^{2+} to Fe^{3+} during electron transfer.

3) It activates catalase enzyme.

4) It is essential for the formation of chlorophyll.

Manganese:

It is absorbed in the form of manganous ions (Mn^{2+}).

Functions:

1) Activation of enzymes in photosynthesis, respiration and nitrogen metabolism.

2) The best defined function of manganese is in the splitting of water (Photolysis) to liberate oxygen during photosynthesis

Zinc:

Plants absorb zinc in the form of Zn^{2+} ions.

Functions:

1) It activates various enzymes, especially carboxylases.

2) It is also needed in the synthesis of auxin.

3) Synthesis of amino acid *Trypotophan* and it can serve as precursor for Auxin biosynthesis.

4) Activation of Alcohol dehydrogenase

Copper:

It is absorbed as cupric ions (Cu^{2+}).

Functions:

1) It is essential for the overall metabolism in plants.

2) Like iron, it is associated with certain enzymes involved in redox reactions

3) It is reversibly oxidised from Cu^{+} to Cu^{2+}

4) Copper is present in cytochrome oxidase (in respiration) and plastocyanin (in photosynthesis)

Boron :

It is absorbed as $BO_3{}^{3-}$ or $B_4O_7{}^{2-}$.

Functions:

1) Pollen germination

2) Cell elongation

3) Cell differentiation.

4) Carbohydrate translocation.

5) Boron is required for uptake and utilisation of Calcium,

6) Membrane functioning

7) Helps to increase fruit size.

Molybdenum:

Plants obtain it in the form of $MoO_2{}^{2+}$ (molybdate ions).

It is required in least quantity.

Functions:

1) It is a component of several enzymes, including nitrogenase and nitrate reductase both of which participate in nitrogen metabolism.

Chlorine:

It is absorbed in the form of chloride anion (Cl^-).

Functions:

1) It helps in determining the solute concentration and the anion cation balance in cells. (Along with Na^+ and K^+)

2) It is essential for the water-splitting reaction in photosynthesis(Photolysis), a reaction that leads to oxygen evolution.

Nickel

Plants absorb Nickel in the form of Ni^{2+}

Functions:

1) It is the component of enzymes such as urease and hydrogenase.

Critical concentration

The concentration of Essential elements below which the plant growth is retarded termed as Critical concentration.

The concentration of the essential element above the critical concentration causes **Toxicity** and below courses **Deficiency symptom (Hunger sign)**

DEFICIENCY SYMPTOMS

1) Chlorosis: Loss of chlorophyll leading to yellowing in leaves. It is caused by the deficiency of **N, K, Mg, S, Fe, Mn, Zn and Mo.**

2) Inhibition of cell division. Due to Lack or low level of **N, K, S and Mo**.

3) Delay flowering : Low concentration of **N, S and Mo** in plants

4) Necrosis: Death of tissue, particularly leaf tissue. It is due to the deficiency of **Ca, Mg, Cu and K.**

- **Premature leaf fall → P**
- **Die back disease → Cu and K**
- **Wilting → Cl**
- **Exanthema (Rough and split bark disease) → Cu**
- **Death of root and shoot tip, Small size of fruit, Internal cork disease (in Apple), Stout axis → B**
- **Bushy habit of shoot, Shortening of internode → K**
- **Little leaf disease, Khaira disease in Paddy → Zn**
- **Grey speck disease → Mn**
- **Whip tail disease → Deficiency of Mo in Crucifers**
- **Leaf tip necrosis → Ni**

- **Toxicity of Micronutrients**
- Any mineral Ion concentration that reduces the dry weight of tissue by about 10 percentage is considered as toxic .
- Toxicity symptoms are difficult to identify and toxicity levels for any element vary for different plants.
- Example: ***Manganese toxicity:*** Manganese competes with iron and magnesium for uptake .
- Manganese compete with magnesium for binding with enzymes .
- Manganese also inhibits calcium translocation into shoot apex.
- ***Symptom of Manganese toxicity*** : Brown spots surrounded by chlorotic veins

MOBILE ELEMENTS: N,K and Mg. Deficiency symptom first appear in senescent leaves.

IMMOBILE ELEMENT : Ca. Deficiency symptom first appear in younger part.

RELATEVLY LESS MOBILE: S

MECHANISM OF ABSORPTION OF ELEMENTS

- Mineral absorption of elements occurs in two phases
- 1) Rapid and passive absorption of ions into the outer space or free space (cell wall or intercellular spaces)***- Apoplast pathway.***
  It does not involve crossing the cell membrane.
- 2) Active uptake of Ions into the inner space (cytoplasm) -***Symplast pathway.***
  Neighbouring cells are connected (intercellular movement) through Plasmodesmata .Water has to enter the cells through the cell membrane, hence the movement is relatively slower.
- The trans-membrane proteins that function as selective pores.

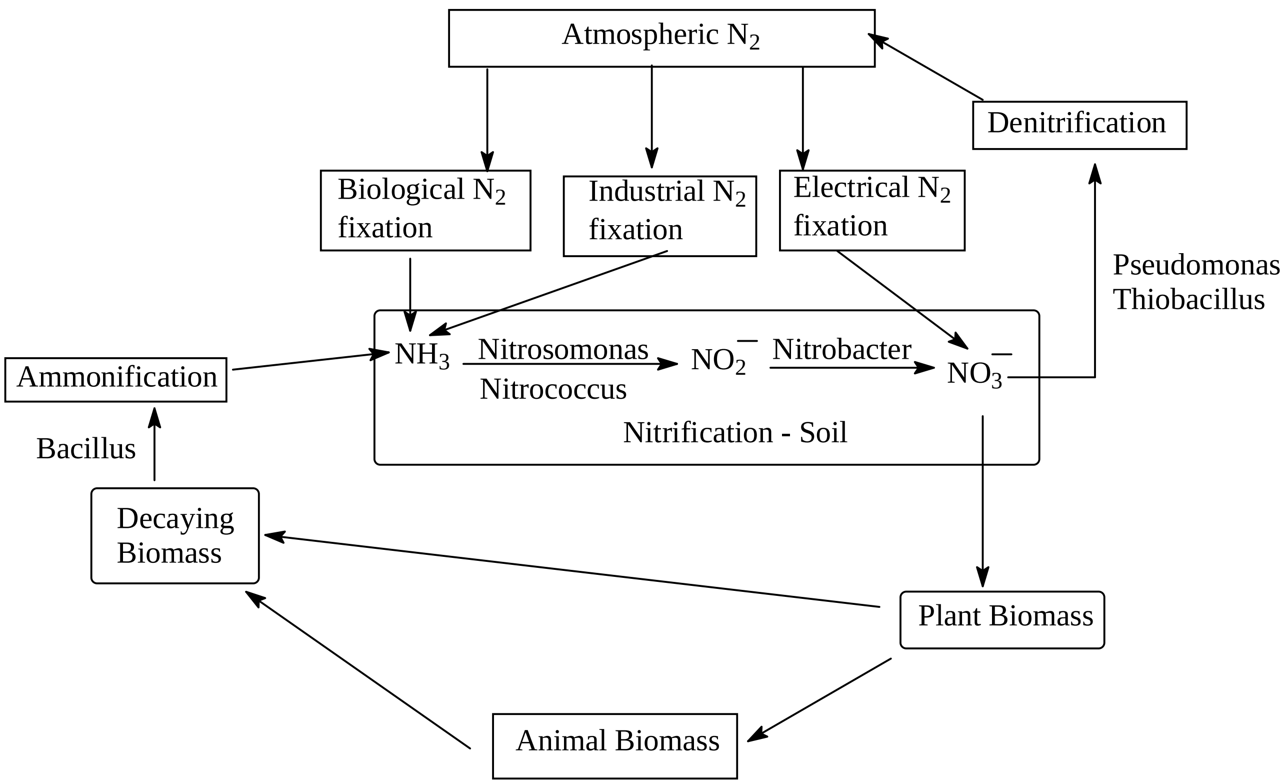
FLUX

Movement of ions is called of ***flux*** . Inward movement is called ***influx*** and outward movement is called ***efflux*** .

SOIL AS RESERVOIR OF ESSENTIAL ELEMENTS

- Weathering of rocks enriches the soil with dissolved ions and inorganic salts.
- Mineral salts are translocated through the xylem along with ascending stream of water by transpiration pull.
- Soil not only supplies minerals but also harbours nitrogen-fixing bacteria and other microbes.
- Soil holds water, supplies air to the roots and acts as a matrix that stabilises the plant.

NITROGEN CYCLE



- Nitrogen is a limiting nutrient for both natural and agricultural eco-systems.
- The process of conversion of nitrogen (N_2) to ammonia is called **nitrogen fixation**.
- Lightning and ultraviolet radiation convert nitrogen to nitrogen oxides (NO, NO_2 , N_2O).

Ammonification: Decomposition of organic nitrogen of dead plants and animals into ammonia is called Ammonification.

Some of this ammonia volatilises and re-enters the atmosphere but most of it is converted into nitrate by *Nitrifying bacteria*.

Nitrification: ***Conversion of ammonia into nitrate*** **.** This process consists of 2 steps

1) Ammonia is first oxidised to nitrite by the bacteria *Nitrosomonas* and/or *Nitrococcus.*

$$2NH_3 + 3O_2 \rightarrow 2NO_2^- + 2H^+ + 2H_2O$$

2) The nitrite is further oxidised to nitrate with the help of the bacterium *Nitrobacter.*

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

Nitrifying bacteria are chemoautotrophs.

Denitification : Nitrate present in the soil is reduced to Nitrogen. This process is carried out by *Pseudomonas* and *Thiobacillus*.

N2 Fixers

I. **Free Living**

- **Aerobic** : *Azotobacter, Beijernikia, Azospirillum*
- **Anaerobic** : *Rhodospirillium, Clostridium*
- **Facultative Aerobic :** Some Bacillus species
- **Facultative Anaerobic** : Some other Bacillus species
- **Blue Green Algae** : *Nostoc, Anabaena, Oscillatoria, Aulosira, Cylindrospermum, Trichodesmium*

II. **Symbiotic**

- Bactera
  - *Rhizobium leguminosarum* = *Pisum sativum*
  - *Rhizobium japonicum* = Soyabean (*Glycine max*)
- Blue Green Algae
  - *Nostoc* = *Cycas*
  - *Anabaena* = *Azolla*
- Filamentous Bacteria (Actinomycetes) → Frankia
  - *Alnus (Alder)*
  - *Casuarina*
  - *Myrica*

  Non legumes

III. **Fungi** – *Yeast, Pullaria (Pullularia*)

a. **Chemosynthetic** – *Desulphovibrio*

b. **Photosynthetic** – *Chlorobium*, *Chromatium, Rhodospirillum*

Nitrogen fixing microbes are called Diazotrophs.

Symbolic N_2 Fixation

- Rhizobium is Free living, Aerobic, (during nitrogen – fixing events, they become anaerobic) Gram negative and Rod shaped bacterium.
- Root Nodules acts as a site for symbiotic N_2 fixation.
- It contains Nitrogenase enzyme and Leghaemoglobin

1. Nitrogenase enzyme

- It catalyses the conversion of atmospheric N_2 into NH_3
- Ammonia is the first stable product of N_2 fixation
- Nitrogenase enzyme is sensitive to oxygen

$$N_2 + 8e^- + 8H^+ + 16ATP \xrightarrow{\text{Nitrogenase}} 2NH_3 + H_2 + 16ADP + 16Pi$$

It is made up of 2 sub units

1) Fe-protein . It is a dimer

2) Mo-Fe protein: It is a tetramer. N_2 gets attached to MoFe component

2. Leghaemoglobin (Leguminous haemoglobin)

- It is a pink coloured pigment present in root nodule

Functions

1) Oxygen scavenger
2) Provides oxygen to the Bacteria

- In leghaemoglobin **Globin** part is provided by the plant and **Haem** is provided by bacteria
- In Rhizobium there are 3 types of genes in organizing N_2 fixing apparatus.

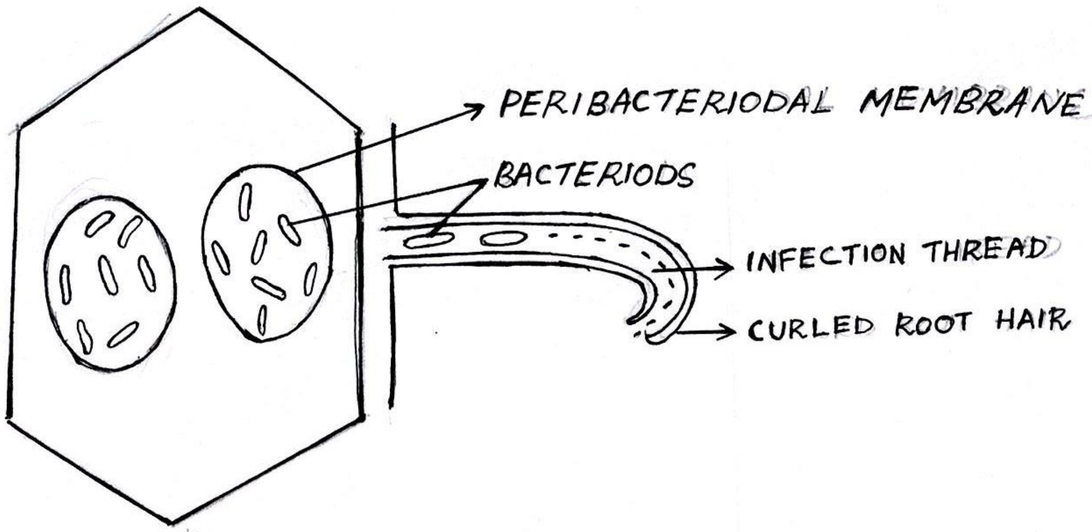
1) **nif – gene** – formation of Nitrogenase enzyme
2) **nod-genes** – Nodule formation
3) **fix – gene** – Nitrogen fixation

These genes are located on a Plasmid in the fast growing Rhizobia and on chromosome in slow growing Rhizobia.

NODULE FORMATION

- Leguminous root secrete certain chemical substance called **growth factor** into the soil.
- Rhizobia multiply and colonise surroundings of the root.
- Bacteria produce Nod (Nodulation) factor which help in the production of **Lectin** by root hair.
- Lectins help them to attach the root hair.
- When the bacteria aggregate at the tip of the root hair curling occurs.
- Cell wall disintegrate and plasma membrane invaginate and grow into tube like structure towards cortex known as **infection thread**.
- Bacteria in the infection thread enlarge and are covered by an extracellular polysaccharide – **Bacteriod**.
- Inside the cortex bacteriod is again surrounded by another membrane known as **Peribacterial (Peribacteriodal) membrane** which is in plant origin.

- Leg haemoglobin is synthesized and it is localized within the Peribacteriodal membrane.
- Bacteria produce **Cytokinin** and plant cell produces **Auxin**. These hormones stimulate the cell division of inner cells and pericycle cells. It leads to the formation of knob like root nodule.
- A mature nodule establishes direct vascular connection with the root for the exchange of nutrients.



Nitrate Assimilation

Plants absorb nitrate from the soil and is transported to leaves. In leaves , it is reduced to form Ammonia and the ammonia is protonated to form NH_4^+ (ammonium) ion.

Reduction of nitrate occurs in two steps

1) Reduction of Nitrate to Nitrite

It is carried out by nitrate reducatse enzyme. The enzyme is a molybdoflavoprotein

$$NO_3^- \xrightarrow[\text{NADPH}]{\text{Nitrate reductase}} NO_2^-$$

2) Reduction of Nitrite

This process is carried out by enzyme Nitrite reducatse. The enzyme is a metalloflavoprotein which contains copper and iron.

$$NO_2^- \xrightarrow[\text{Ferredoxin}]{\text{Nitrite reductase}} NH_3$$

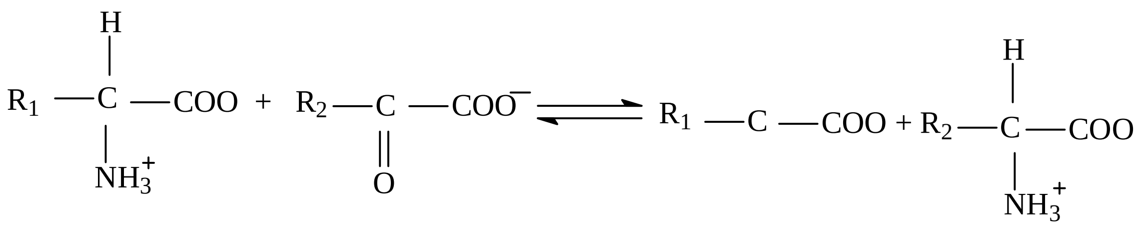
SYNTHESIS OF AMINO ACID

Ammonia is protonated to from ammonium ions.
Ammonium ion is toxic to plants and hence cannot accumulate in them.
Ammonium ion is used to synthesise amino acids in plants.

1) Reductive Amination

$$\alpha\text{ Ketoglutaric acid} + NH_4^+ + \text{NADPH} \xrightarrow{\text{Glutamate dehydrogenase}} \text{Glutamic acid (Glutamate)} + H_2O + \text{NADP}$$

2) Transamination



Amino - donor   Amino - acceptor

Glutamic acid is the main aminoacid in which other aminoacids are formed through Transamination.

Eg. Oxalo acetic acid + Glutamic acid $\longrightarrow$ α Ketoglutaric acid + Aspartic acid

AMIDES

Derivatives of aminoacids in which hydroxyl group (OH) is replaced by amino group (NH_2).
They contain more Nitrogen than aminoacids and are structural part of most proteins.

Eg:**1)** **Asparagine** is formed from Aspartic acid.

2) **Glutamine** is formed from Glutamic acid.

UREIDES

It's form of fixed nitrogen present in Soyabean. These compounds have particularly high Nitrogen to Carbon ratio.