



# Aakash



## BYJU'S NOTES

### Mineral Nutrition

## Key Takeaway

**Mineral requirement by plants**

1

2

**Hydroponics**

**Essential elements**

3

Criteria of essentiality

Functions of minerals

4

**Role of macronutrients**

**Role of micronutrients**

5



**Critical concentration**

6

Manganese (Mn) toxicity

7

**Types of essential elements**

**Common deficiency symptoms**

8

9

**Absorption of minerals**

**Journey of the elements**

10



11

**Nitrogen: An essential element**

12

**Nitrogen cycle**

Nitrogen fixation

Nitrification

Assimilation

Denitrification

Ammonification

**Summary**





# Mineral Requirements by Plants



- Plants require water, sunlight, gases, and minerals for their survival.



- Different minerals are required in different amounts.

Large amounts	Small amounts
<ul style="list-style-type: none"><li>Carbon</li><li>Hydrogen</li><li>Oxygen</li><li>Nitrogen</li><li>Phosphorus</li><li>Sulphur</li><li>Potassium</li><li>Calcium</li><li>Magnesium</li></ul>	<ul style="list-style-type: none"><li>Copper</li><li>Manganese</li><li>Molybdenum</li><li>Zinc</li><li>Boron</li><li>Chlorine</li><li>Nickel</li><li>Iron</li></ul>



# Phytomining and Phytoremediation

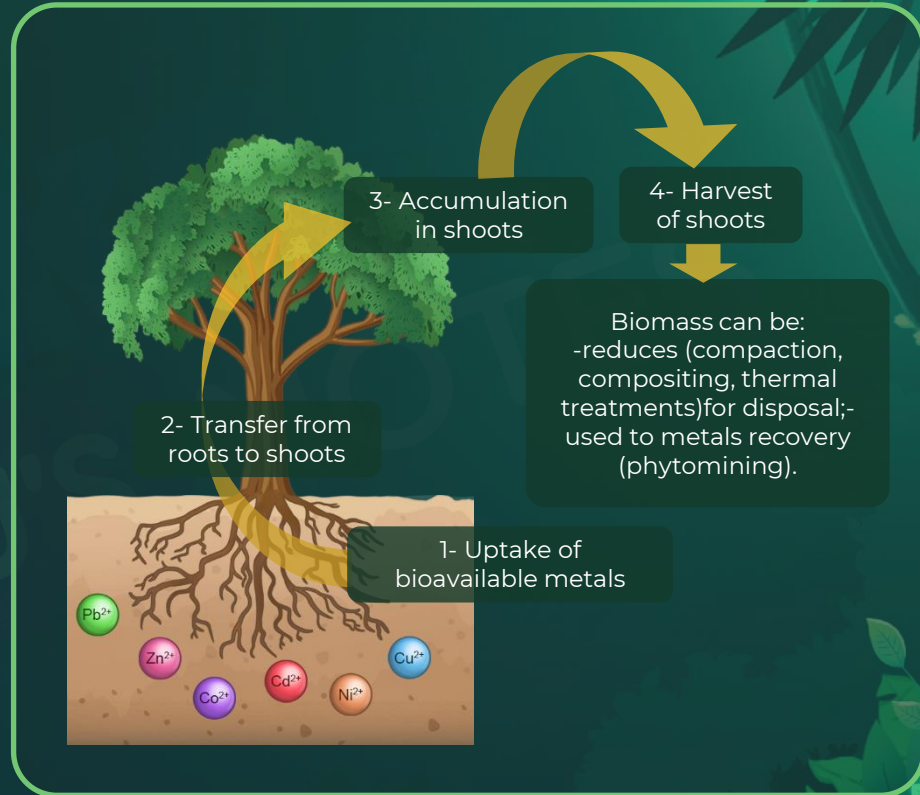


## Phytomining

- It is the process of **growing plants on ores** and obtaining minerals from these plants.
- Minerals like selenium can be extracted from plants by this process.

## Phytoremediation

- Phytoremediation refers to the technologies, which **use plants to clean up the soil, air, and water** that have been contaminated by chemicals.
- Many plants such as mustard plants, alpine **pennycress**, **hemp** and pigweed have proven to be successful at hyperaccumulating contaminants at toxic waste sites.





# Hydroponics



**Julius von Sachs**

- It is a technique of growing plants without soil in a **nutrient medium**.
- It was first demonstrated in 1860 by the German botanist, **Julius von Sachs**.
- In this method, **purified water and mineral nutrient salts** are used.
- Contaminated water is avoided since it may infect the plants.
- **Aeration** is required for oxygenation and nutrient circulation to the roots.



# Types of Hydroponics



## Types of hydroponics

### Tank system

- In this system, the roots are immersed in a nutrient medium.
- Air is bubbled through the nutrient solution to provide aeration.

Funnel for  
adding water  
and nutrients

Cotton

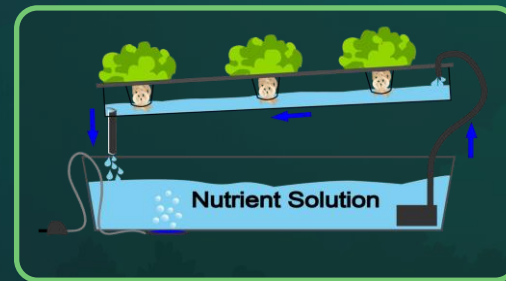


Aerating tube

Nutrient  
solution

### Nutrient film system

- In this system, plants are grown in a tube.
- The tube has a thin film of recirculated nutrient solution that provides nutrients to the roots of the plant.







# Significance of Hydroponics



- **Efficient usage of water:** Wastage of water can be reduced when compared to conventional farming methods.
- **Protection of plants** from soil-borne diseases.
  - Pest control or chemical insecticides and weedicides are not required.
- Labour intensive procedures like ploughing, etc., are not required.
- **Production of plants is higher** in the same amount of land or space
  - It can be practised in feasible locations like terrace and balcony, a proper land is not required.
- **Production of off season plants** continuously.
  - Indoor farming is done in a controlled climate conditions.
- **Essential elements** can be identified.
- **Deficient elements** can also be discovered.



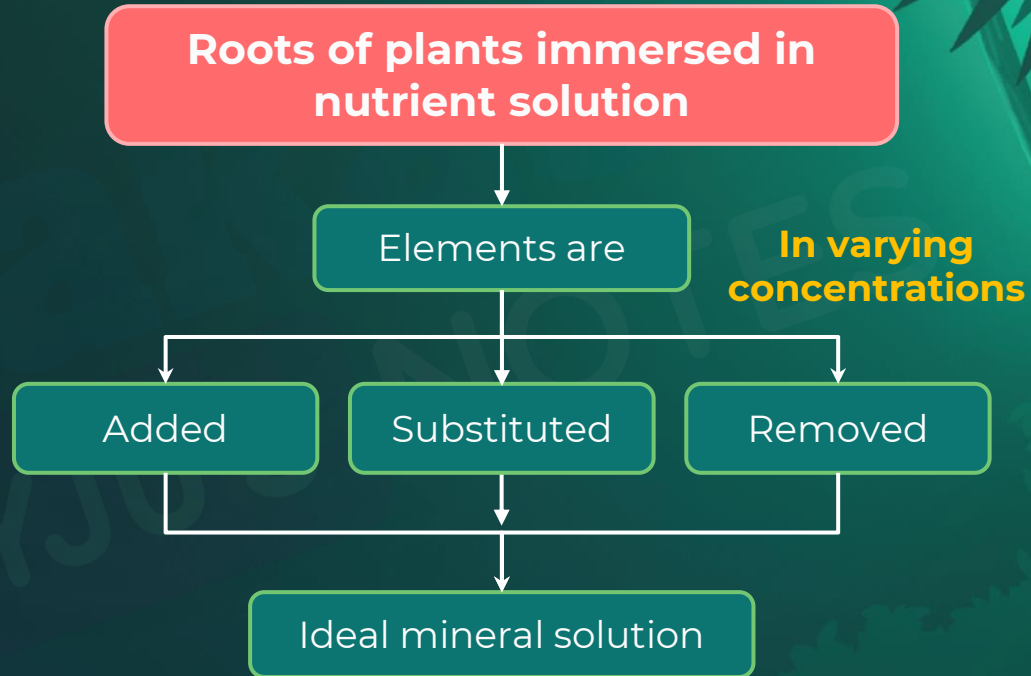
Hydroponics in closed room (a) and outside (b)



# Ideal Mineral Solution



- Series of experiments are conducted for hydroponics to confirm the suitable mineral solution to grow a particular plant.
- Essential and deficient elements are confirmed by this method.





# Essential Mineral Elements



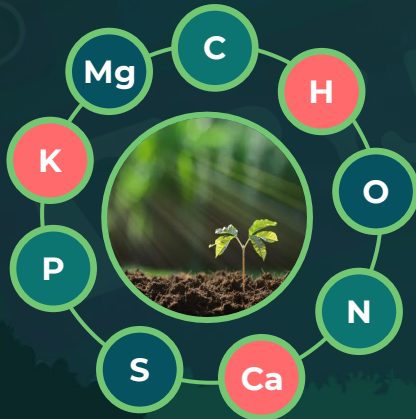
- Elements required for the growth and development of plants are known as essential elements.

## Essential elements

### Macronutrients

Present in large amounts (excess of **10 mmol Kg<sup>-1</sup>** of dry matter)

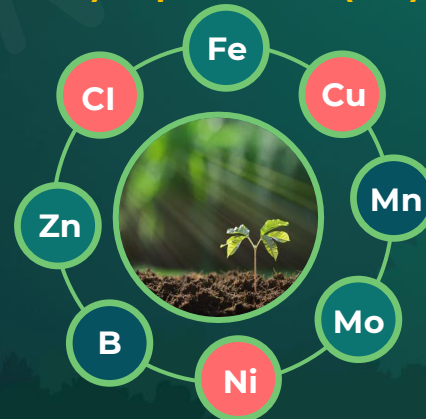
**Maggie CHOPS Carrots (iN a) Pot**



### Micronutrients

Present in small amounts (less than **10 mmol Kg<sup>-1</sup>** of dry matter)

**Nick & Zayn Managed (to) Board (the) Ferry (as the) Cops Cleared (the) Mob**





# Criteria for Essentiality



## Not replaceable

- The requirement of the element must be specific and **non-replaceable**.
- In other words, deficiency of any one element cannot be met by supplying some other element.

## Necessary for survival

- 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**.



## Involved in metabolism

- The element must be **directly involved** in the **metabolism** of the plant.



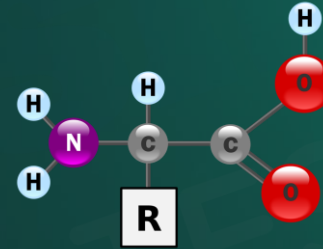


# Functions of Minerals



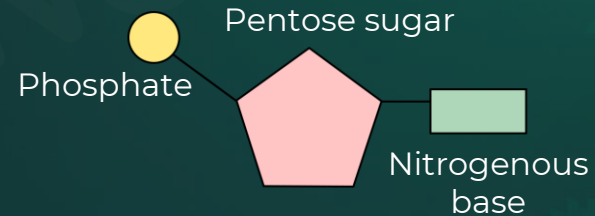
## 1. Forms structural elements of cell

- Essential elements are the components of biomolecules such as **amino acids** and **nucleic acids** that form structural elements of the cell.
  - Elements like carbon, hydrogen, oxygen, nitrogen, and sometimes sulphur make up the **amino acids to form proteins**.



## 2. Components of energy related chemical compounds

- Essential elements are the components of energy related chemical compounds in plants.
  - **Mg** is an essential part of **chlorophyll** which is important for photosynthesis.
  - **ATP** is the energy currency of the cell and has **three phosphate molecules** along with carbon, hydrogen, nitrogen, and oxygen.





# Functions of Minerals



## 3. Activator or inhibitor of enzymes

- **Mg<sup>2+</sup>**
  - Activates **enzymes** that play an important role in carbon fixation
    - **RuBisCo** (Ribulose biphosphate carboxylase/oxygenase)
    - **Phosphoenolpyruvate carboxylase**
    - **Carbon fixation** is an incorporation of carbon into organic compounds by the process known as photosynthesis in green plants.
- **Zn<sup>2+</sup>**
  - Activates **alcohol dehydrogenase**
    - Converts alcohol to aldehyde or ketone by oxidation
- **Mo**
  - Activates **nitrogenase**
    - Converts nitrogen to ammonia
    - Helps in nitrogen fixation

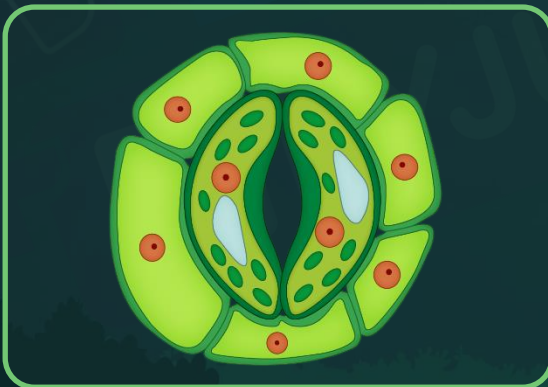


# Functions of Minerals



## 4. Change in osmotic potential and permeability of the cell membrane

- Nutrients like potassium can alter the **osmotic potential** of cells.
- Potassium plays an important role in **opening and closing of stomata**.
- Minerals play a role in controlling what goes in and out of the cell.



Increased ionic concentration ( $K^+$ )



Rise in osmotic pressure



Water potential decreases in guard cell (GC)



Water enters GC through subsidiary cells



GC becomes turgid (Stomata opens)



# Role of Macronutrients



**N<sup>7</sup>**  
Nitrogen

- It is required in the greatest amount by the whole plant.
- It is absorbed as **NO<sup>3-</sup>** (nitrate), **NO<sup>2-</sup>** (nitrite), and **NH<sup>4+</sup>** (ammonium ion).
- It is specifically needed by meristematic cells and metabolically active cells.
- It is major constituent of proteins, nucleic acids, vitamins, minerals

**Ca<sup>20</sup>**  
Calcium

- It is absorbed in the form of **Ca<sup>2+</sup>** from the soil.
- It is used in **synthesis of cell wall** as calcium pectate.
- It is involved in the **formation of mitotic spindle**.
- It is needed by the **meristematic tissue** and differentiating parts.
- It gets accumulated in older leaves.

**S<sup>16</sup>**  
Sulphur

- It is absorbed by plants in the form of **SO<sub>4</sub><sup>2-</sup>** (sulphate).
  - It is present in amino acids, **cysteine, and methionine**.
  - It is the constituent of **coenzyme A** and vitamins like **thiamine and biotin**.
- Ferredoxins are small proteins containing S and Fe that are used in photosynthesis for electron transfer.





# Role of Macronutrients



**P**<sup>15</sup>

Phosphorus

- It is absorbed by plants in the form of (phosphate ions)  $\text{H}_2\text{PO}_4^-$  /  $\text{HPO}_4^{2-}$  from the soil.
- It is present in the cell membrane, proteins, nucleic acids, and is required in the phosphorylation reactions.
  - Part of ATP
  - Part of NAD and NADP

**K**<sup>19</sup>

Potassium

- It is absorbed by plants in the form of  $\text{K}^+$ .
- It is needed by meristematic tissues, leaves, buds, and root tips in abundant quantities.
- It helps to maintain **anion-cation balance**.



# Role of Micronutrients



**Mg<sup>12</sup>**  
Magnesium

- It is absorbed by plants in the form of **Mg<sup>2+</sup>**.
- It constitutes the **ring structure of chlorophyll**.
- It maintains the **structure of the ribosome**.
- It activates enzymes related to,
  - Respiration
  - Photosynthesis
  - Synthesis of DNA and RNA

**Fe<sup>26</sup>**  
Iron

- It is absorbed in the form of **Fe<sup>3+</sup>**.
- The requirement of iron is more than the requirement of other micronutrients.
- It is reversibly oxidised from **Fe<sup>2+</sup>** to **Fe<sup>3+</sup>**.
- It **activates the catalase enzyme**.
- It is essential for the **formation of chlorophyll**.

**Cu<sup>29</sup>**  
Copper

- It is absorbed in the form of cupric ions (**Cu<sup>2+</sup>**).
- It is essential for the overall metabolism in plants.
- It is **essential for the redox reaction**, where it is reversibly oxidised from **Cu<sup>+</sup>** to **Cu<sup>2+</sup>**.



# Role of Micronutrients



**Mn<sup>25</sup>**  
Manganese

- It is absorbed in the form of  $\text{Mn}^{2+}$ .
- It plays an important role in photosynthesis, i.e., it is involved in the **splitting of water to liberate oxygen**.
- It activates many enzymes involved in photosynthesis, respiration, and nitrogen metabolism.

**Mo<sup>42</sup>**  
Molybdenum

- It is obtained by the plants in the form of molybdate ions  $\text{MoO}_4^{2-}$ .
- It is the **component of several enzymes**, including nitrogenase and nitrate reductase, both of which participate in the nitrogen metabolism.

**Ni<sup>28</sup>**  
Nickel

- It is absorbed in the form of  $\text{Ni}^{2+}$ .
- The component of some plant enzymes, most notably urease, metabolises urea nitrogen into usable ammonia within the plant.
- The **toxic levels of urea can accumulate in the absence of nickel**.



# Role of Micronutrients



**B**<sup>5</sup>  
Boron

- It is absorbed as  $\text{BO}_3^{3-}$  or  $\text{B}_4\text{O}_7^{2-}$ .
- Boron is required for the **uptake and utilisation of  $\text{Ca}^{2+}$** , membrane functioning, **pollen germination**, cell elongation, cell differentiation, and **carbohydrate translocation**.

**Zn**<sup>30</sup>  
Zinc

- It is obtained by plants as  $\text{Zn}^{2+}$  ions.
- It **activates various enzymes**, especially **carboxylases**.
- It is also needed in the synthesis of auxin.
  - Auxin is a growth hormone responsible for the growth and development of plants.

**Cl**<sup>17</sup>  
Chlorine

- It is absorbed in the form of chloride anion ( $\text{Cl}^-$ ) along with  $\text{Na}^+$  and  $\text{K}^+$ .
- It helps in determining the solute concentration and the **cation-anion balance** in the cells. It is essential for the **water splitting reaction in photosynthesis**, which is a reaction that leads to the evolution of oxygen.





# Critical Concentration



The concentration of the essential elements below which the growth of the plant is retarded is termed as critical concentration.

## Below critical concentration

- Plants exhibit **deficiency symptoms**
  - **Morphological changes** in the plant induced by the reduced availability of a particular nutrient are termed as deficiency symptoms.
  - The growth of the plant is retarded.

## Above critical concentration

- **The moderate increase** in the critical concentration of essential elements may become toxic to plants.
- Toxicity levels are different for different micronutrients and also varies across the plants.
- Excess of one nutrient may **inhibit the intake of other elements**.
- **It reduces the dry weight of tissues** by about 10 %.

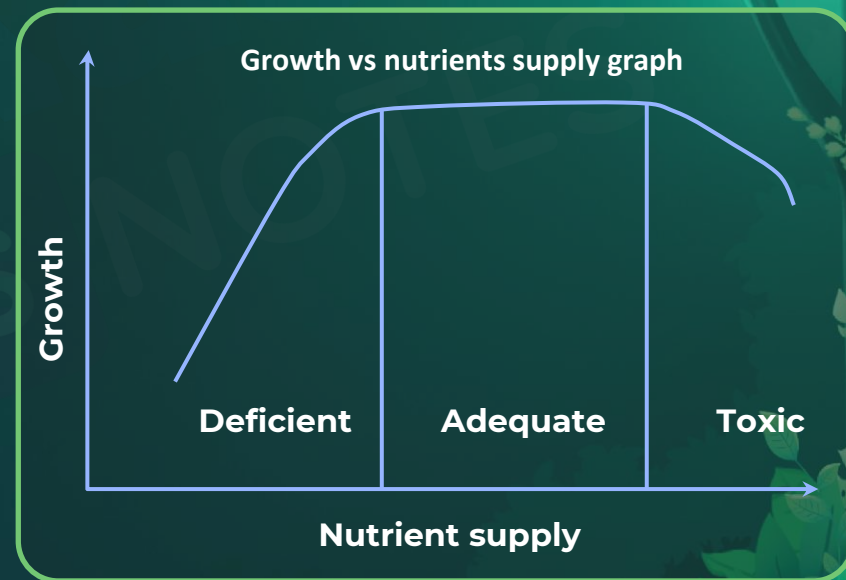
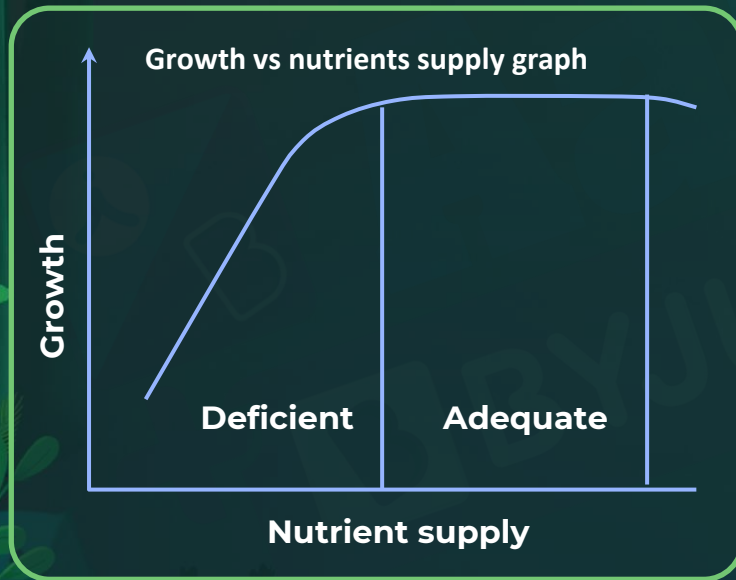


# Critical Concentration



**Below critical concentration**

**Above critical concentration**





## Example for Above Critical Concentration : Manganese (Mn) Toxicity

- Mn competes with Fe and Mg leading to the reduction in the uptake of Fe and Mg.
- The binding of magnesium with enzymes is inhibited as Mn competes with Mg for binding with enzymes.
- Manganese also **inhibits calcium translocation** in shoot apex. Therefore, excess of manganese may induce deficiencies of iron, magnesium, and calcium.
- Thus, what appears as the symptoms of manganese toxicity may actually be the **symptoms of deficiency of iron, magnesium, and calcium.**
- Symptoms: **Brown spots with chlorotic vein** in leaves.





# Types of Essential Elements



## Mobile elements

- Elements/ nutrients that are **transported to the growing regions of plants** are known as mobile elements.
- Based on the mobility of nutrients
  - Nutrients in the older leaves are broken down and transported to younger leaves to keep them healthy.
  - Older leaves exhibit deficiency symptoms.
- Examples: Nitrogen, phosphorus, magnesium, and potassium.



Old leaf



New leaf

## Immobile elements

- Elements that are **not transported to the growing regions of plants** are known as immobile elements.
- These are associated with the structural component of the cell wall and hence are locked in a place.
- Younger leaves exhibit deficiency symptoms.
- Examples: Calcium and sulphur



Old leaf



New leaf





# Common Deficiency Symptoms



## Chlorosis

- **Loss of chlorophyll** or normal green colouration
- Elements responsible for chlorosis
  - Deficiency of S, K, Mn, Mg, Zn, N, Fe, Mo



## Necrosis

- Death of tissue
- Due to the deficiency of Ca, Mg, Cu, K





# Common Deficiency Symptoms



## Cell division inhibition

- Due to the deficiency of Mo, K, S, N



## Delayed flowering

- Flowers take longer time to bloom
- Due to the deficiency of Mo, S, N





# Absorption of Minerals



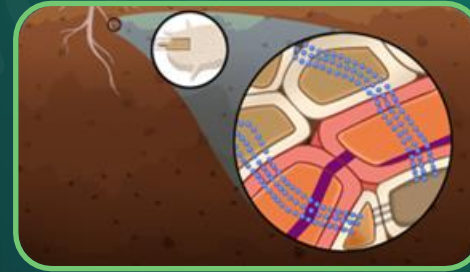
## Absorption of minerals

### Phase 1: Apoplastic movement

- Molecules travel through free spaces of cells
- Movement is passive as transfer does not require energy
- Intake of minerals is rapid

### Phase 2: Symplastic movement

- Molecules move through cells
- Movement is active as transfer requires energy
- Intake of minerals is slow





# Absorption of Minerals



## Absorption of minerals

### Flux

- The movement of ions to and from the cells is known as **flux**.

Influx

Efflux

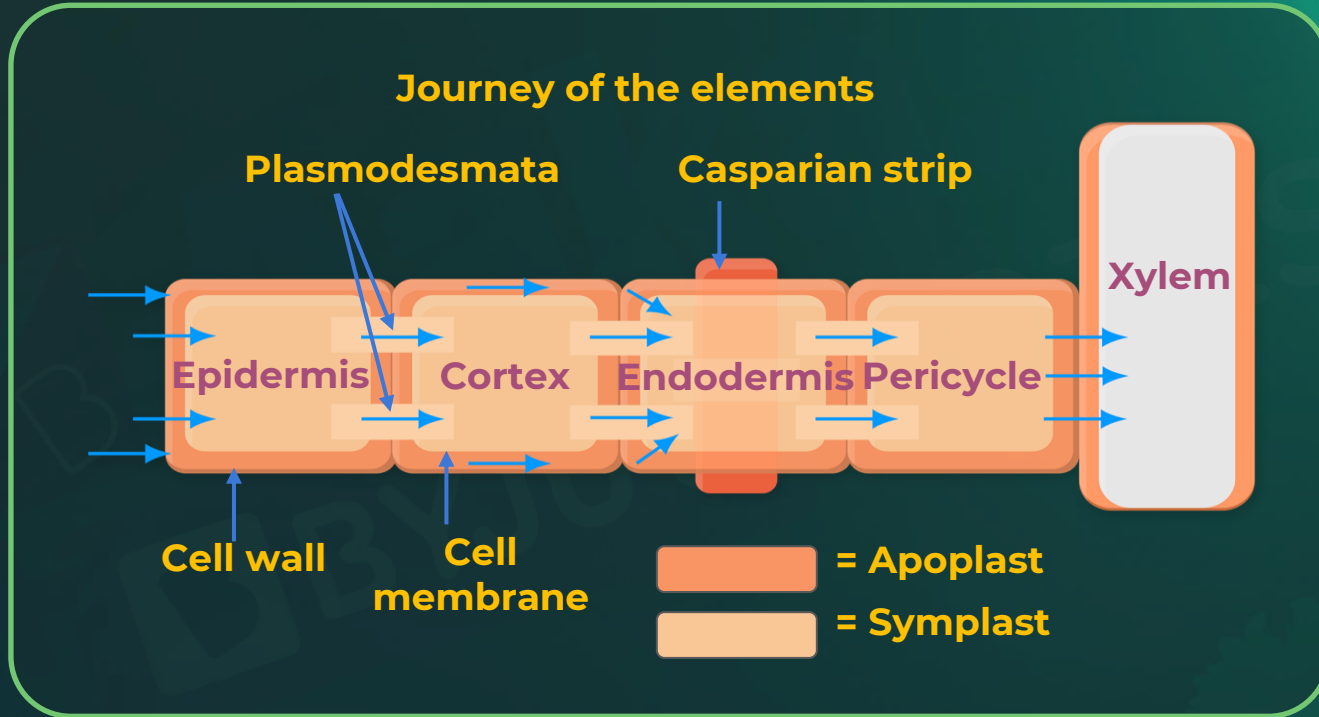
Entry

Exit



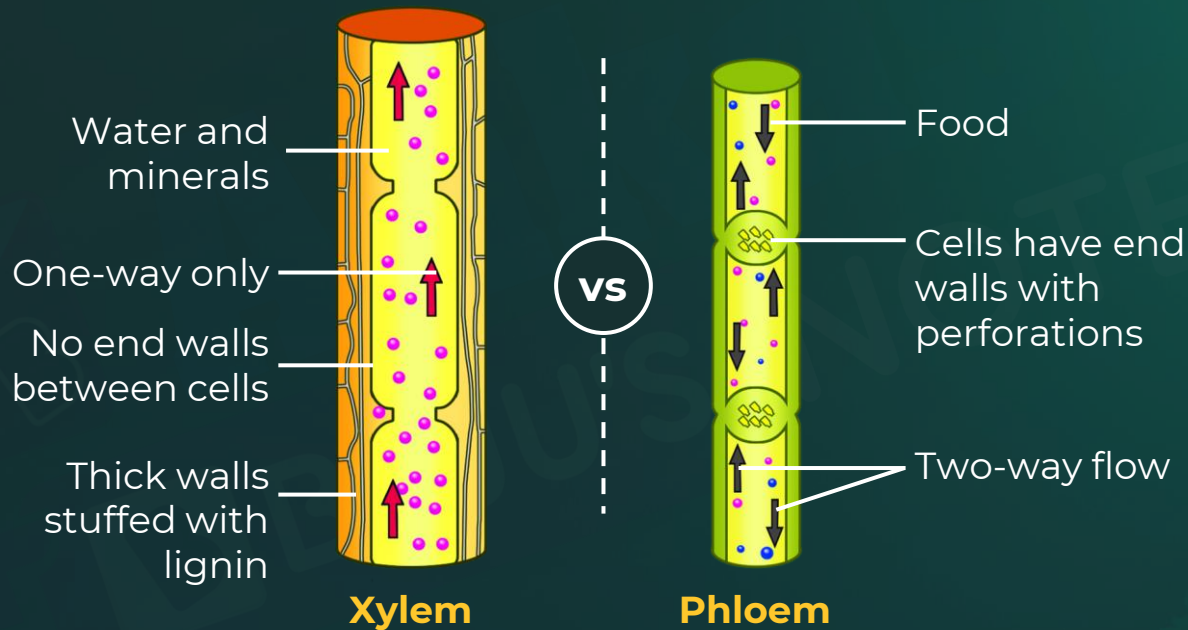


# Journey of the Elements





# Transporters of Cell: Xylem and Phloem





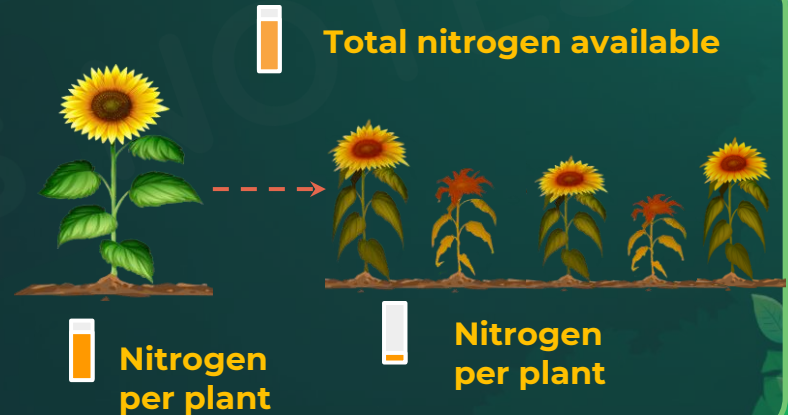
# Nitrogen: An Essential Element



- Nitrogen exists as a **diatomic molecule** with **triple bonds** between the nitrogen atoms in the atmosphere.
- Plants obtain nitrogen from the soil. However, the source of nitrogen remains the same for **microbes** as well, which makes nitrogen **a limiting nutrient** for plants.



The competition with microbes makes it tougher for plants to get nitrogen derivatives.



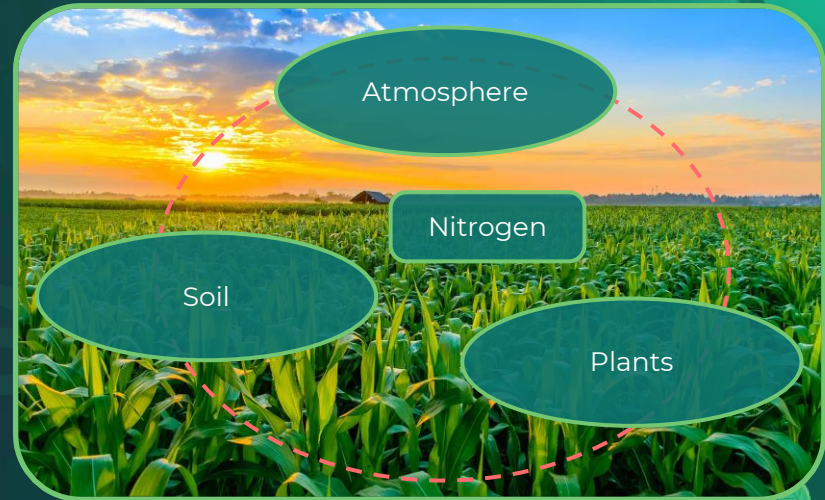
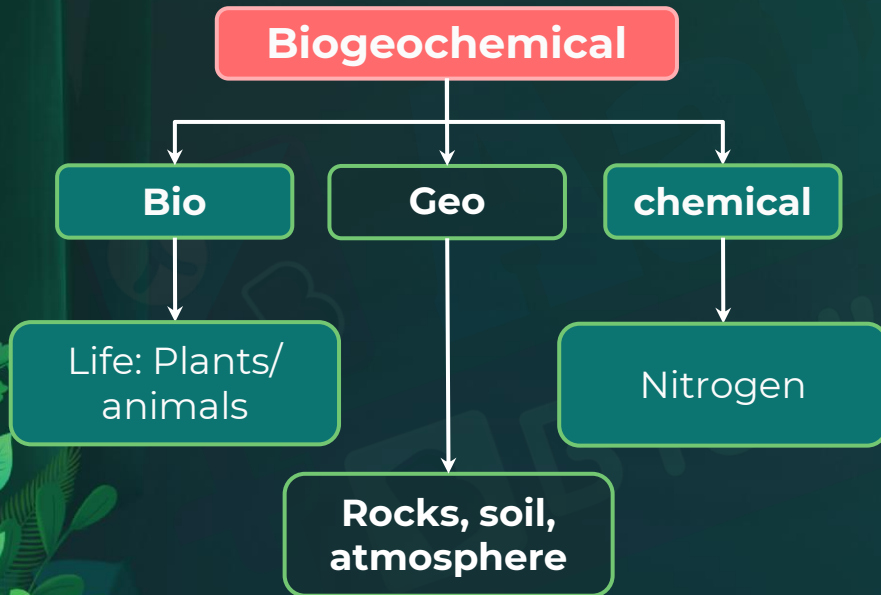
Too many plants on a plot reduce the amount of nitrogen derivatives available per plant.



# Nitrogen Cycle



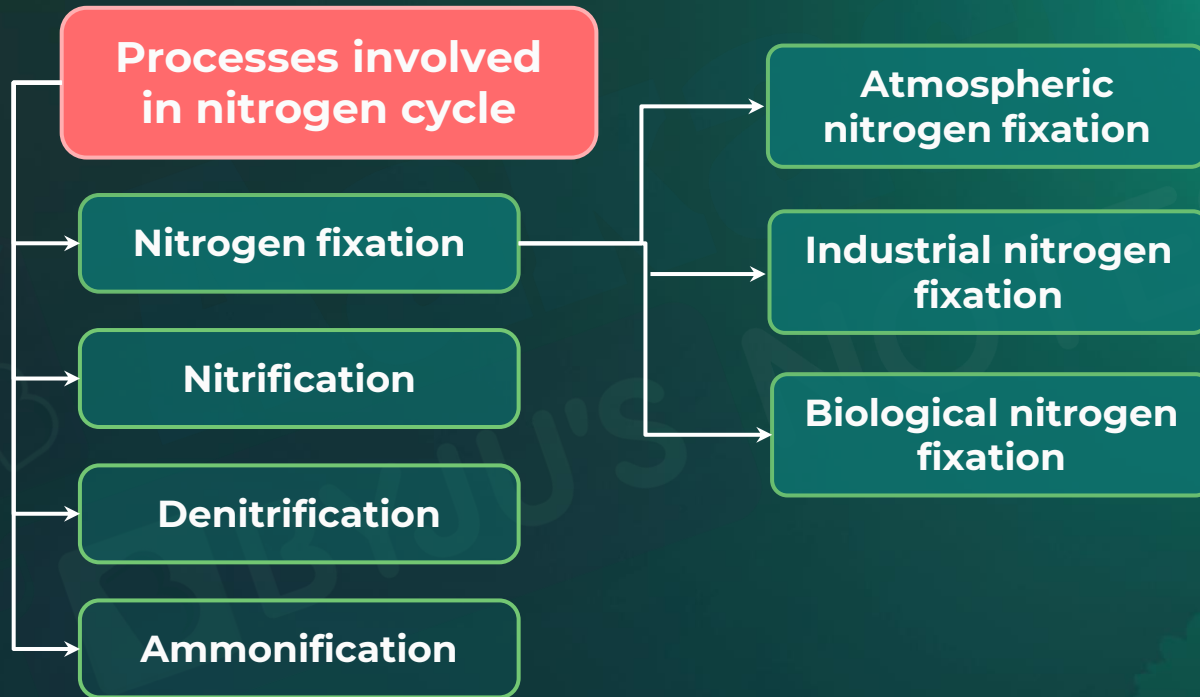
- It is a **biogeochemical process** that helps in the **regular recycling** of **nitrogen** between atmosphere, lithosphere, and biosphere.







# Processes Involved in Nitrogen Cycle

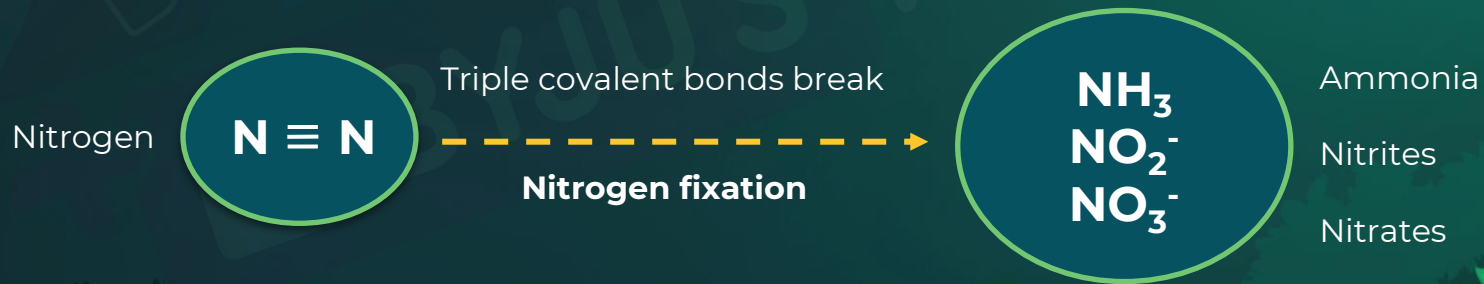




# Nitrogen Fixation



- Nitrogen fixation is the process by which **molecular nitrogen ( $N_2$ )** is converted into biologically available forms of nitrogen like **ammonia**.
- Apart from ammonia, **oxides of nitrogen, nitrates**, and **nitrites** can also be formed.
- The **breakdown of triple covalent bonds** linking two nitrogen atoms in a molecule, which needs to be done to get biologically active derivatives, requires a lot of energy. Plants cannot accomplish this step.
- Nitrogen fixation involves processes that help in the breakdown of the triple bonds and thereby help in the **formation of biologically utilisable forms of nitrogen**.

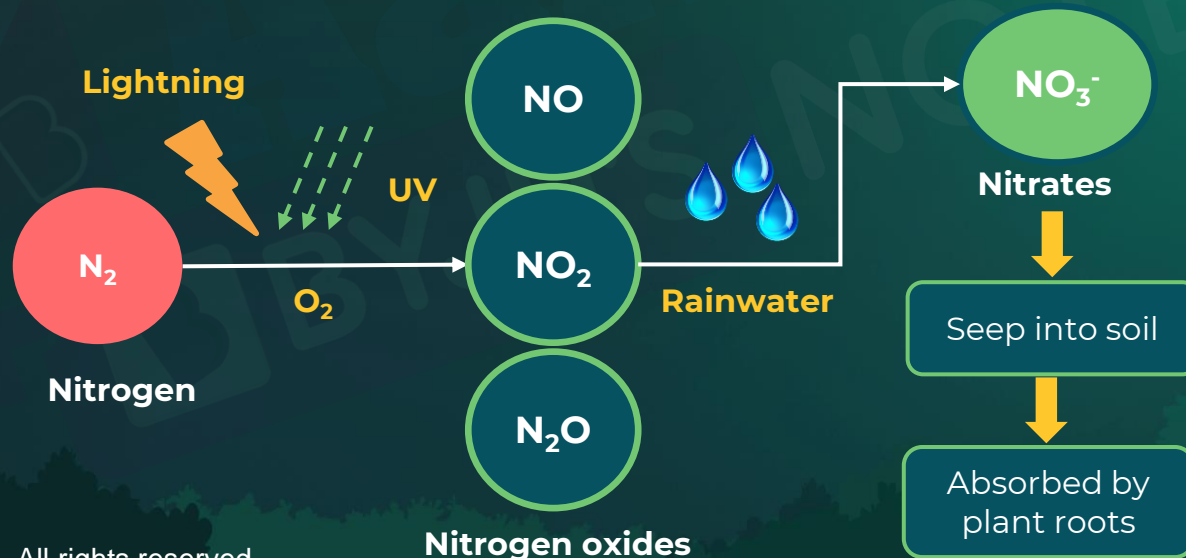




# Atmospheric Nitrogen Fixation



- The process of fixation of **atmospheric nitrogen** into oxides of nitrogen, nitrates, or nitrites by the **atmospheric processes** that involves **high energy phenomena** like lightning, UV exposure is known as atmospheric nitrogen fixation.
- These oxides of nitrogen then react with water to form corresponding acids which then **liberate nitrites** and **nitrates** that seep into the soil.





# Industrial Nitrogen Fixation

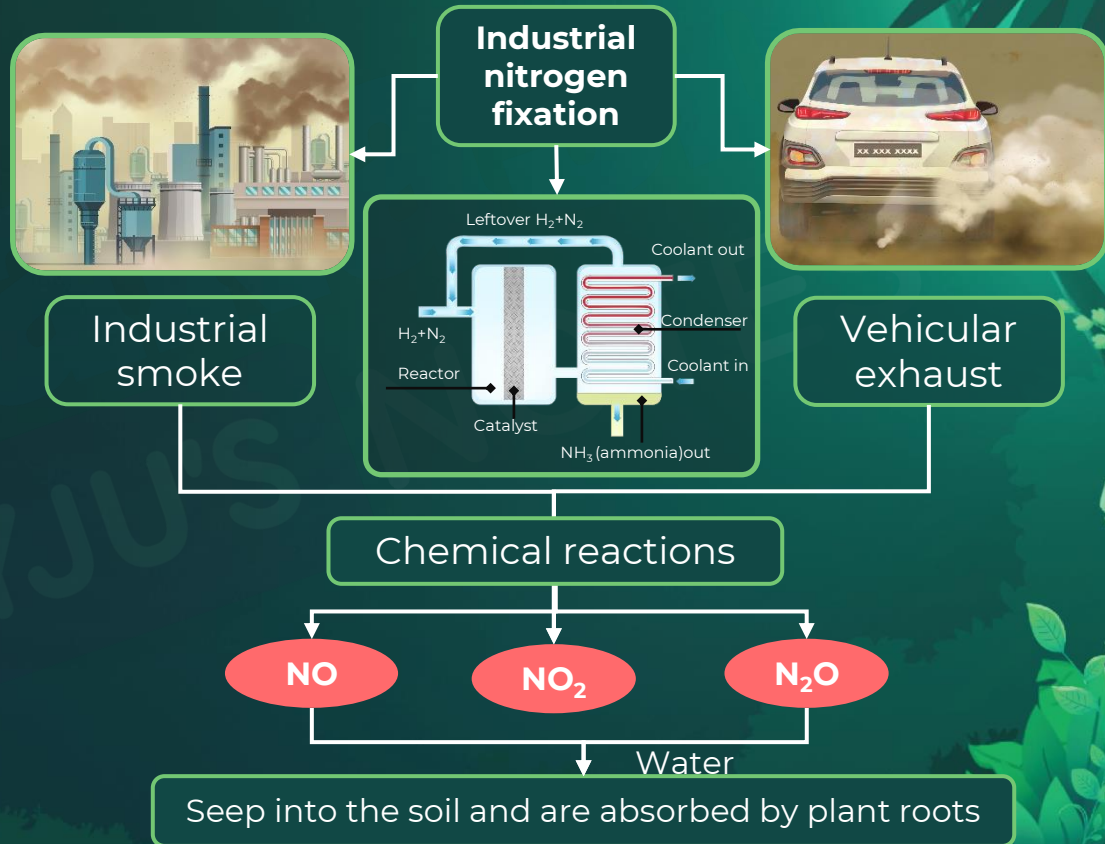


- Industrial nitrogen fixation is the process of **fixation of atmospheric nitrogen** into ammonia, oxides of nitrogen, nitrites, or nitrates by **industrial** means under **artificial reaction conditions** like

- high temperatures
- high pressures
- catalysts

- Sources** of industrial nitrogen fixation include:

- Industrial smoke
- Vehicular exhaust
- Chemical reactions in industries







# Biological Nitrogen Fixation



- The process of fixation of atmospheric nitrogen into ammonia by **biological agents (living organisms)** is known as **biological nitrogen fixation**.
- This is a major contributor to the **replenishment of nitrogen pools in the soil** that plants can suitably uptake and utilise.

## Nitrogen-fixing organisms

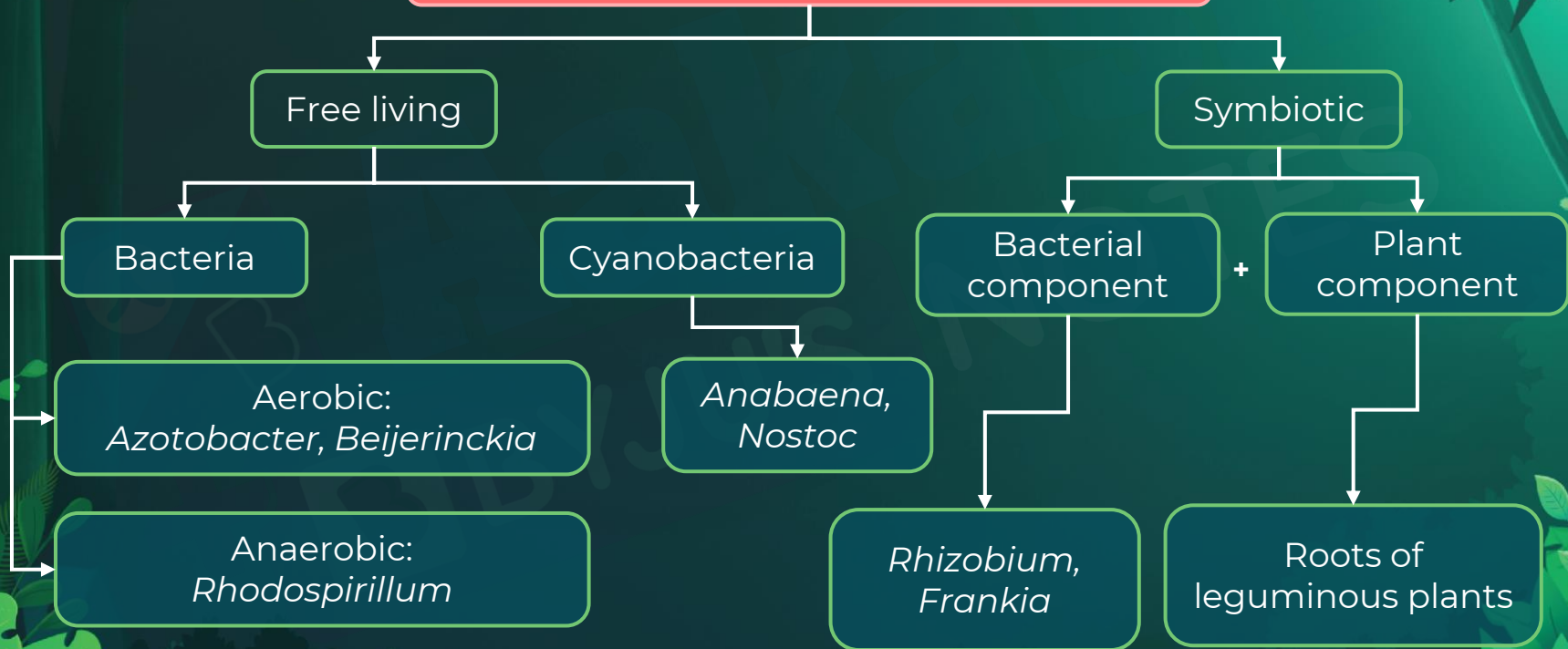
- The nitrogen-fixing microbes (**prokaryotes**) are known as **diazotrophs** (diazo = dinitrogen).
- They can be **free-living** or **symbiotic**.



# Biological Nitrogen Fixation



## Biological nitrogen-fixing microbes





# Biological Nitrogen Fixation



Symbiotic nitrogen fixation

- It is **a biological nitrogen fixation**, which is accomplished due to the symbiotic association between **bacterial components and roots of leguminous plants**.
- The bacteria have the special ability to **induce nodule formation** in the legumes where nitrogen fixation occurs.

## Symbiotic nitrogen fixation



### Rhizobium

- Rod-shaped
- Gram negative
- Motile
- Anaerobic when symbiotic
- Non-sporulating



### Leguminous plants

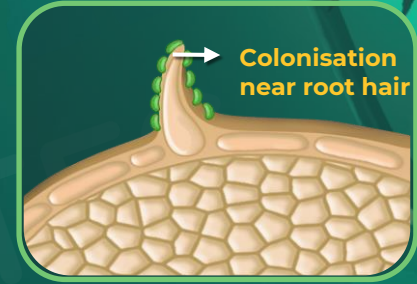
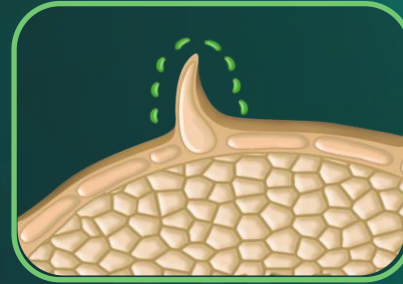
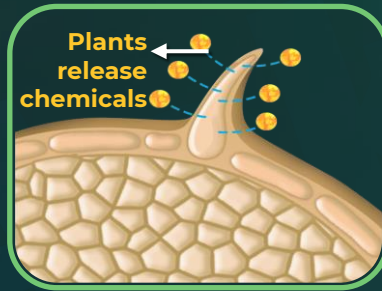
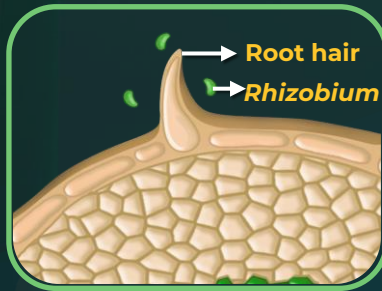
- Belong to legume family
- Have seeds enclosed in pods



# Steps of Nodule Formation



## Stage 1: Multiplication of *Rhizobium*



- The root hair of the leguminous plants are surrounded by *Rhizobium*.
- The bacteria get stimulated to multiply as plant roots start secreting certain **chemical signals** like **flavonoids**.

After multiplication, the bacteria surround the root hair completely and **colonise** near them.

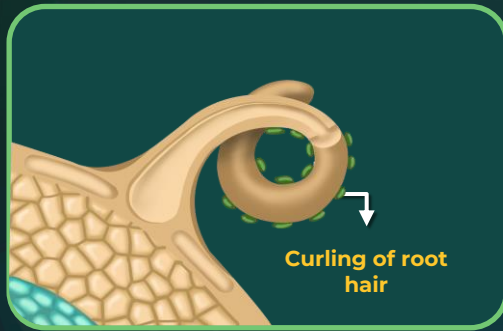




# Steps of Nodule Formation

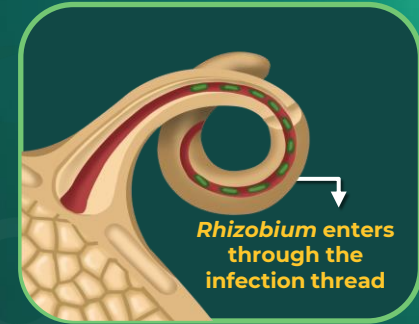
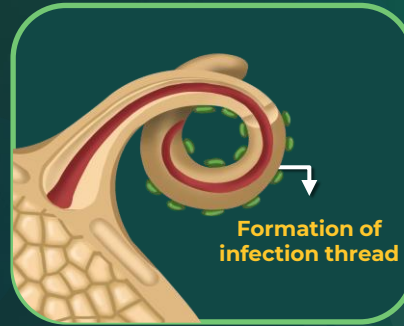


## Stage 2: Curling of root hair



After colonisation, the root hair get **curled**.

## Stage 3: Formation of infection thread



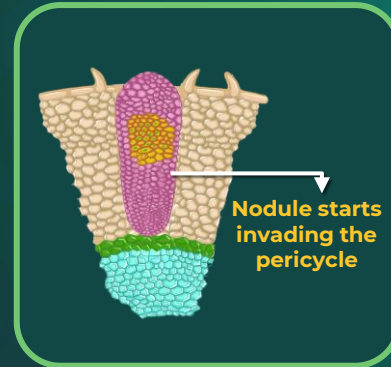
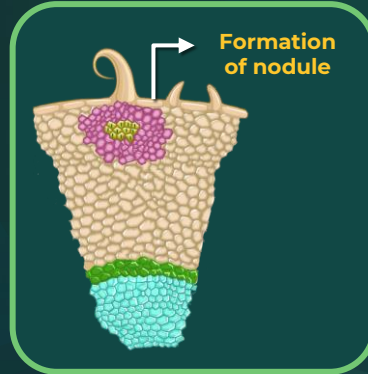
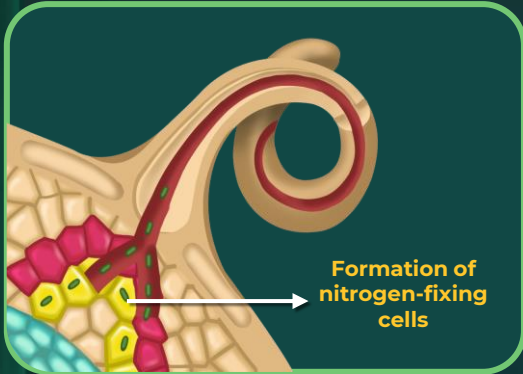
An **infection thread** is formed which extends up to the cortex through which *Rhizobium* enters and invades into the cortex.



# Steps of Nodule Formation



## Stage 4: Formation of nitrogen-fixing cells



- The invasion of the cortex by the *Rhizobium* leads to the differentiation of the cortical cells into **specialised nitrogen-fixing cells**.
- This leads to the appearance of the **nodules**.

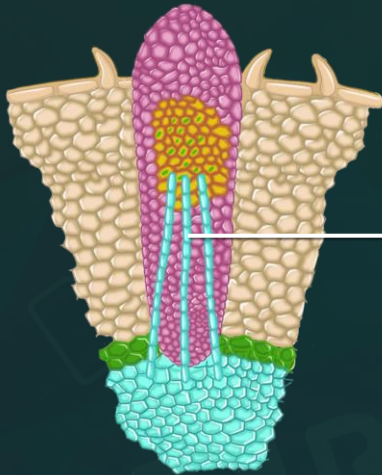
- The **nodule** starts enlarging and extending, thereby **invading the pericycle**.
- Additionally, it also protrudes outwards to form a **bulging/swelling**.



# Steps of Nodule Formation



## Stage 5: Formation of vascular connections



Formation  
of vascular  
connections

- The bacteria that inhabit the nodules perform nitrogen fixation and allow these nitrogen derivatives to get discharged into the **vascular system** and get transported throughout the plant through **xylem**.



## Underlying Catalysis

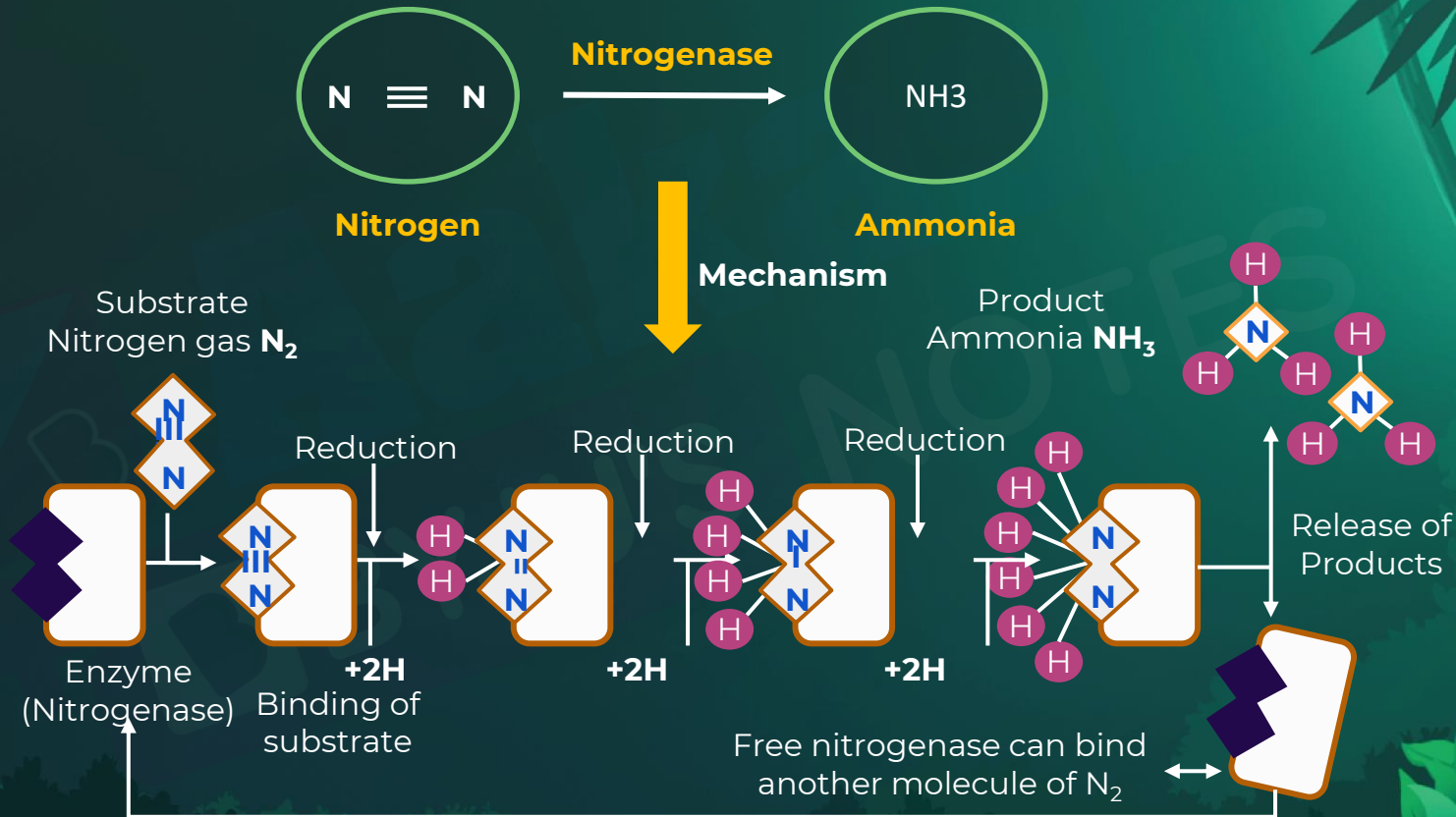


- These microbes possess special **enzymes (nitrogenase)** to catalyse the conversion of atmospheric nitrogen into ammonia.
- Nitrogenase is a special protein containing non-protein counterparts (**co-factors**), i.e., **Mo-Fe** protein which helps in the catalysis.





# Underlying Catalysis





# Underlying Catalysis



- This requires a lot of energy e.g., **16 ATP** molecules)



- The enzyme nitrogenase is highly sensitive to the molecular oxygen, as it requires **anaerobic conditions**.
- During symbiotic nitrogen fixation, a special **red-coloured pigment** known as **leghemoglobin** is associated with nitrogenase in the **root nodules** of leguminous plants.
- Characteristics of leghemoglobin:
  - Acts as an **oxygen scavenger** (binds to oxygen)
  - **Prevents** the **oxidation** and **inactivation of nitrogenase** even in the **aerobic environment** of the root nodules
  - Allows smooth running of nitrogen fixation



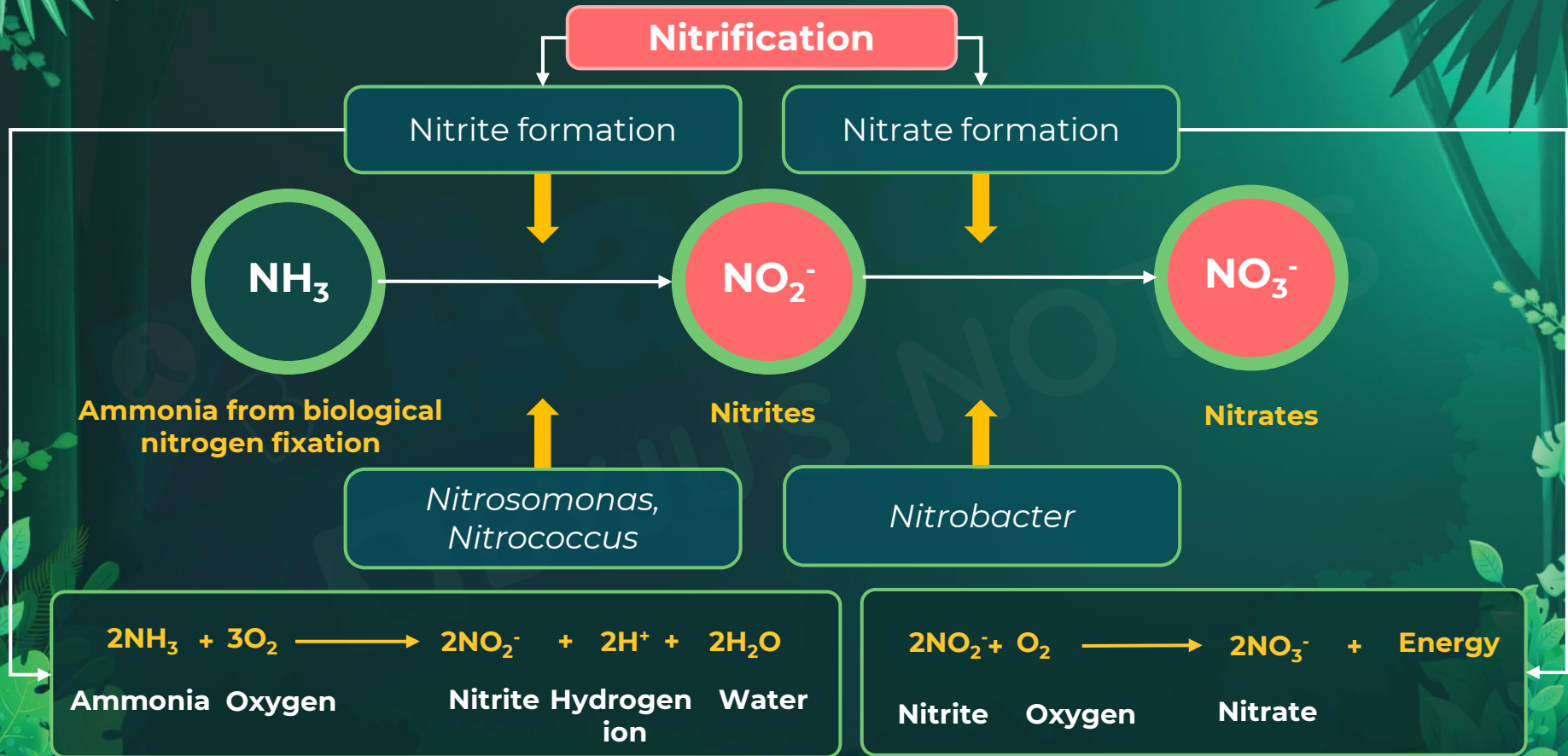
# Nitrification



- The process of **oxidation** of ammonia (formed due to nitrogen fixation) into **nitrites** and then **nitrates** is known as **nitrification**.
- It is a **two-step process**:
  - **Nitrite formation**
  - **Nitrate formation**
- The microorganisms catalysing this conversion are the **free-living chemoautotrophs** (organisms that derive energy from the oxidation of inorganic compounds).
- Nitrification is required for the **conversion of the ammonia** formed as a result of the biological nitrogen fixation **into nitrites or nitrates** so that it can be easily taken up by the plants.



# Nitrification







# Assimilation



- It refers to the **uptake of the nitrates** from soil through roots and its **transportation** to various parts of plants.
- This assimilated nitrogen accumulates inside animals when they feed on plants.



Nitrates transported from  
the roots to the leaves

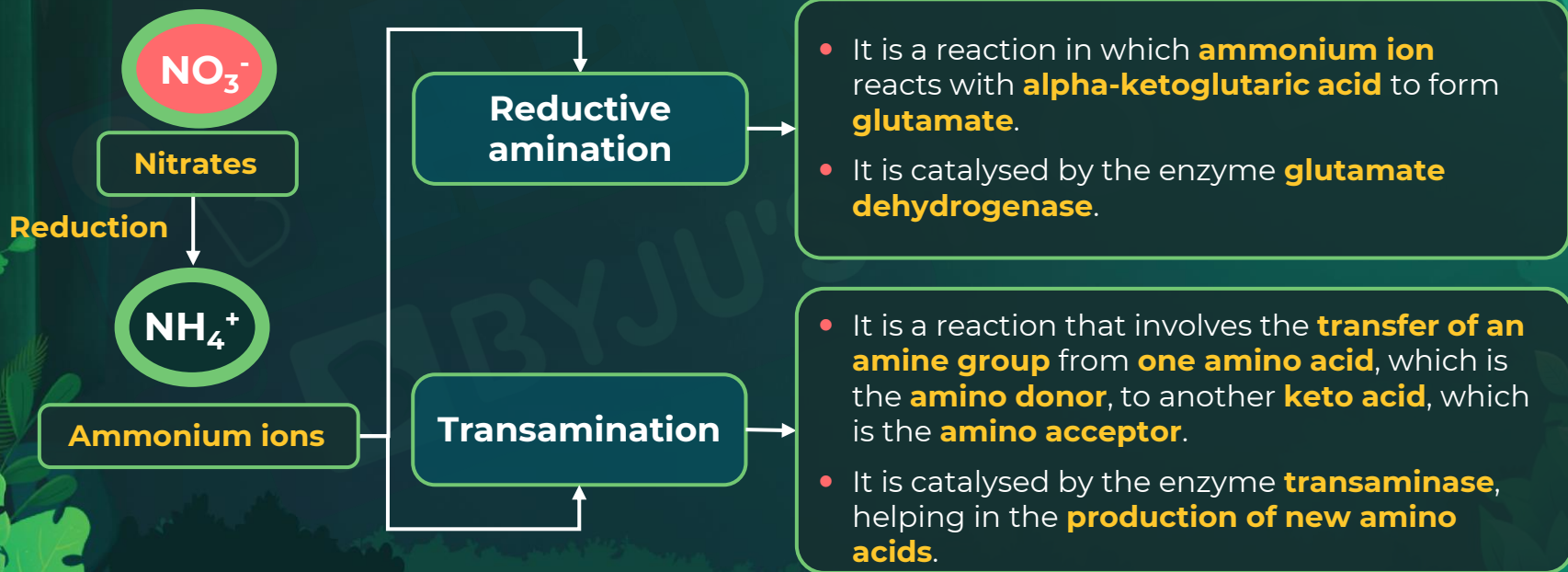


# Assimilation



## Fate of ammonia

- The nitrates assimilated in the parts of a plant get **metabolised** into different biomolecules via different metabolic pathways.

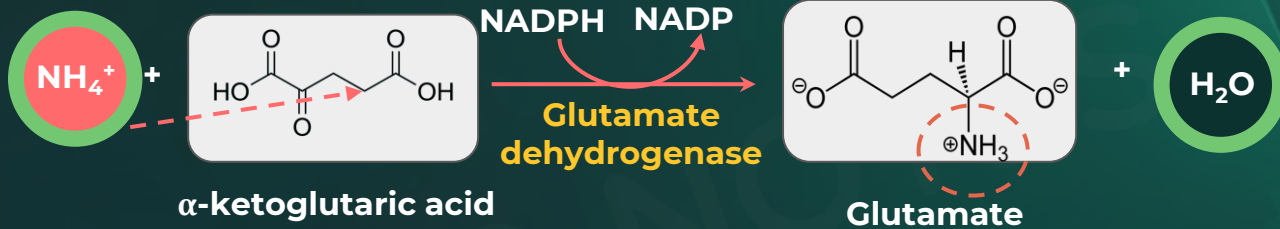




# Assimilation



## Reductive amination

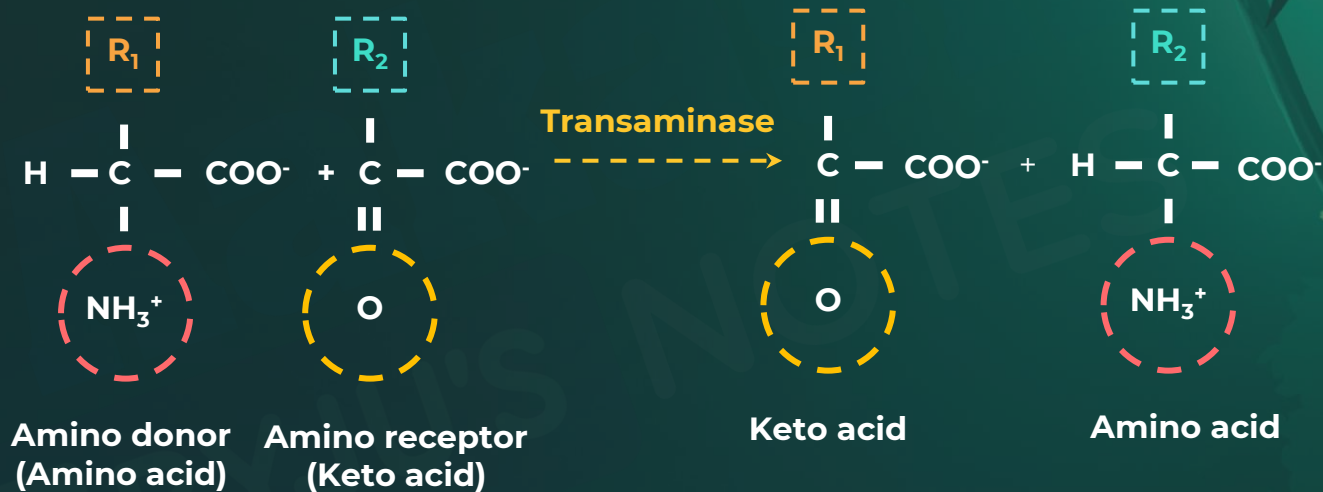




# Assimilation



## Transamination



Glutamic acid + Oxaloacetic acid  $\longrightarrow$  Alpha-ketoglutaric acid + Aspartic acid





# Utility of fixed nitrogen in plants



## Formation of structural proteins

- The amino acids produced in metabolic pathways like glutamate and aspartate are utilised to form **amides** like **glutamine** and **asparagine**.
- These amides are:
  - important components of the **structural proteins** in plants.
  - **richer in nitrogen** as compared to amino acids.
  - transported to other plant parts via **xylem vessels**.

## Formation of ureides

- The fixed nitrogen is exported in the form of compounds known as ureides from the nodules in some plants like soyabean.
- These ureides are also rich in nitrogen (**high N : C ratio**).



# Denitrification



Nitrification



Assimilation by plants

Nitrates



Nitrites



Nitrogen

*Pseudomonas,*  
*Thiobacillus*

Denitrification

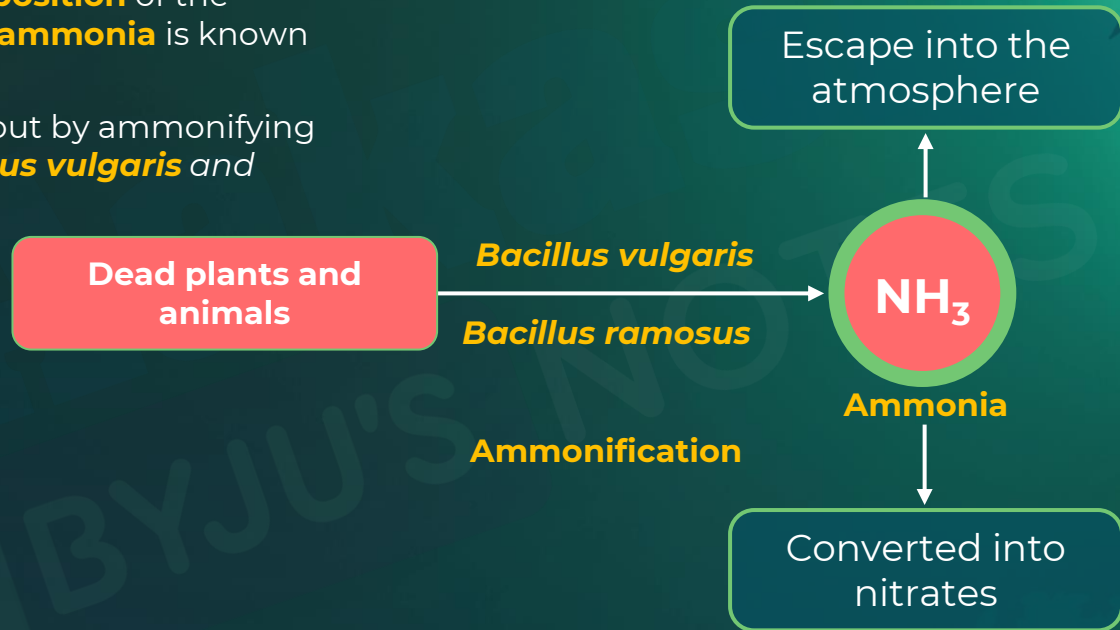
- The process of conversion of **nitrites/nitrates** into **atmospheric nitrogen** is known as denitrification.
- It is carried out by **denitrifying bacteria** like *Pseudomonas* and *Thiobacillus*.



# Ammonification



- The process of **decomposition** of the **organic nitrogen** into **ammonia** is known as ammonification.
- The process is carried out by ammonifying bacteria such as *Bacillus vulgaris* and *Bacillus ramosus*.





# Summary



## Types of hydroponics

### Tank system

- In this system, the roots are immersed in a nutrient medium.
- Air is bubbled through the nutrient solution to provide aeration.

Funnel for  
adding water  
and nutrients

Cotton

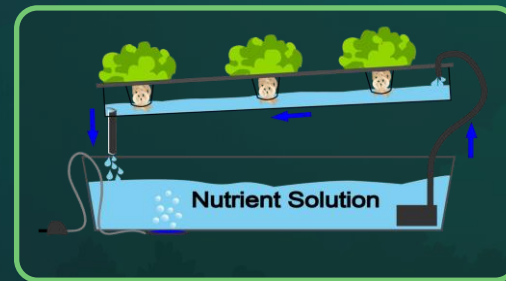


Aerating tube

Nutrient  
solution

### Nutrient film system

- In this system, plants are grown in a tube.
- The tube has a thin film of recirculated nutrient solution that provides nutrients to the roots of the plant.







# Summary

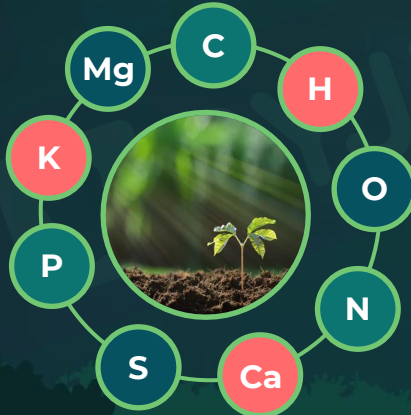


- Elements required for the growth and development of plants are known as essential elements.

## Essential elements

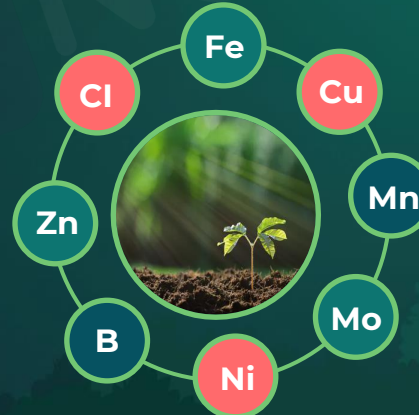
### Macronutrients

Present in large amounts (excess of **10 mmol Kg<sup>-1</sup>** of dry matter)



### Micronutrients

Present in small amounts (less than **10 mmol Kg<sup>-1</sup>** of dry matter)





## Summary

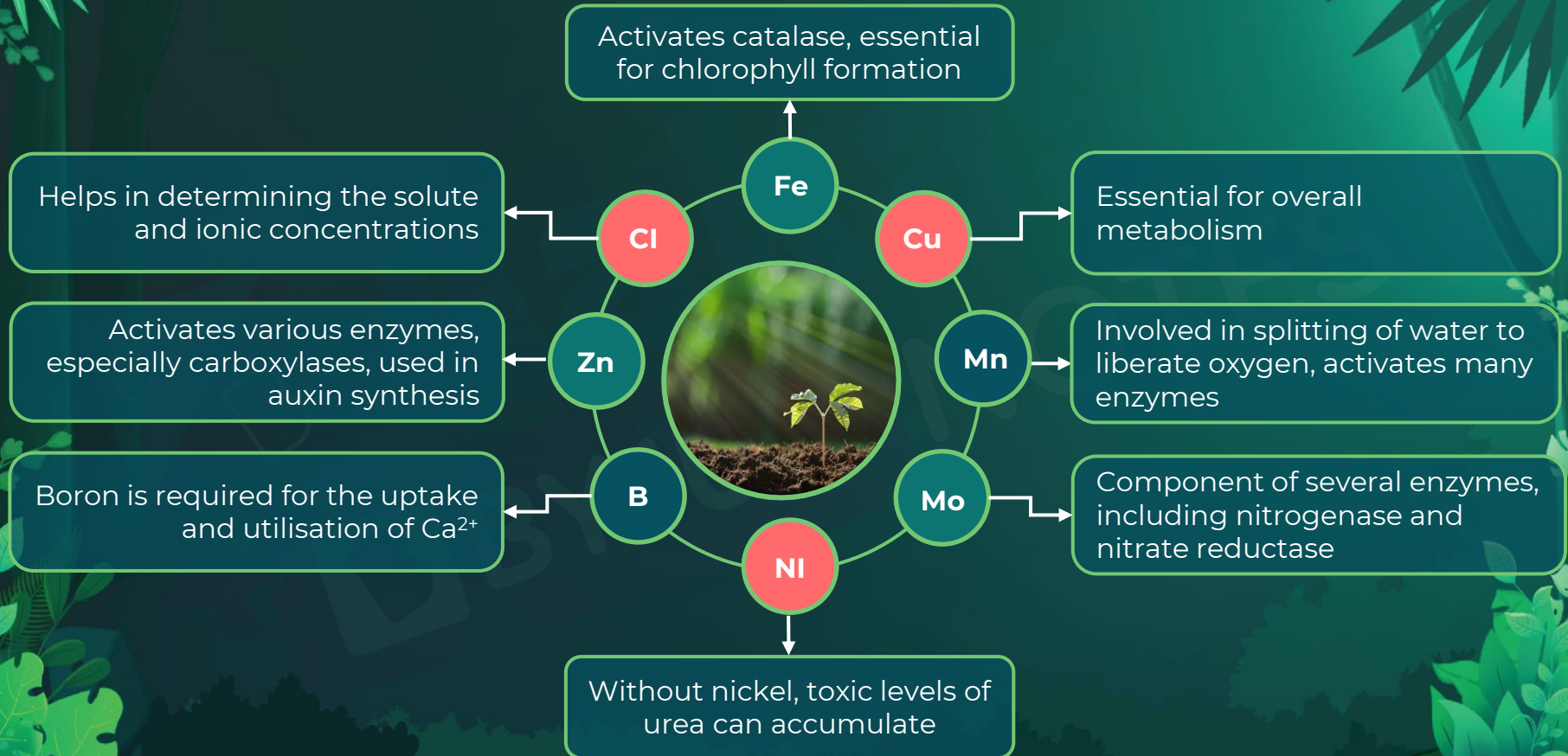


### Why do plants need minerals?

1. They help in the formation of the structural elements of cells.
2. They help in the formation of energy related chemical compounds.
3. They act as an activator or inhibitor of enzymes.
4. They help in changing the osmotic pressure and permeability of the cell membrane.



# Summary





# Summary



## Critical concentration

- The concentration of the essential element below which the growth of a plant is retarded is termed as critical concentration.
- **Below critical concentration**, plants show deficiency symptoms.
- **Above critical concentration**, elements become toxic to plants.





# Types of Essential Elements



## Mobile elements

- Elements/ nutrients that are **transported to the growing regions of plants** are known as mobile elements.
- Examples: Nitrogen, phosphorus, magnesium, and potassium.



Old leaf



New leaf

## Immobile elements

- Elements that are **not transported to the growing regions of plants** are known as immobile elements.
- Examples: Calcium and sulphur



Old leaf



New leaf



# Summary



## Common deficiency symptoms

### Chlorosis

- **Loss of chlorophyll** or normal green colouration
- Elements responsible for chlorosis
  - S, K, Mn, Mg, Zn, N, Fe, Mo



### Necrosis

- Death of tissue
- Due to the deficiency of Ca, Mg, Cu, K





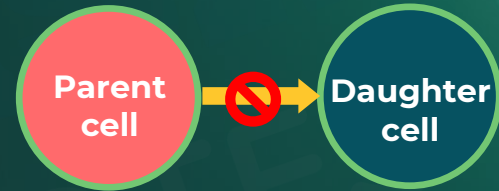
# Summary



## Common deficiency symptoms

### Cell division inhibition

- Due to the deficiency of Mo, K, S, N



### Delayed flowering

- Flowers take longer time to bloom
- Due to the deficiency of Mo, S, N





# Summary



## Absorption of minerals

### Phase 1: Apoplastic movement

- Molecules travel through free spaces of cells
- Movement is passive as transfer does not require energy
- Intake of minerals is rapid

### Phase 2: Symplastic movement

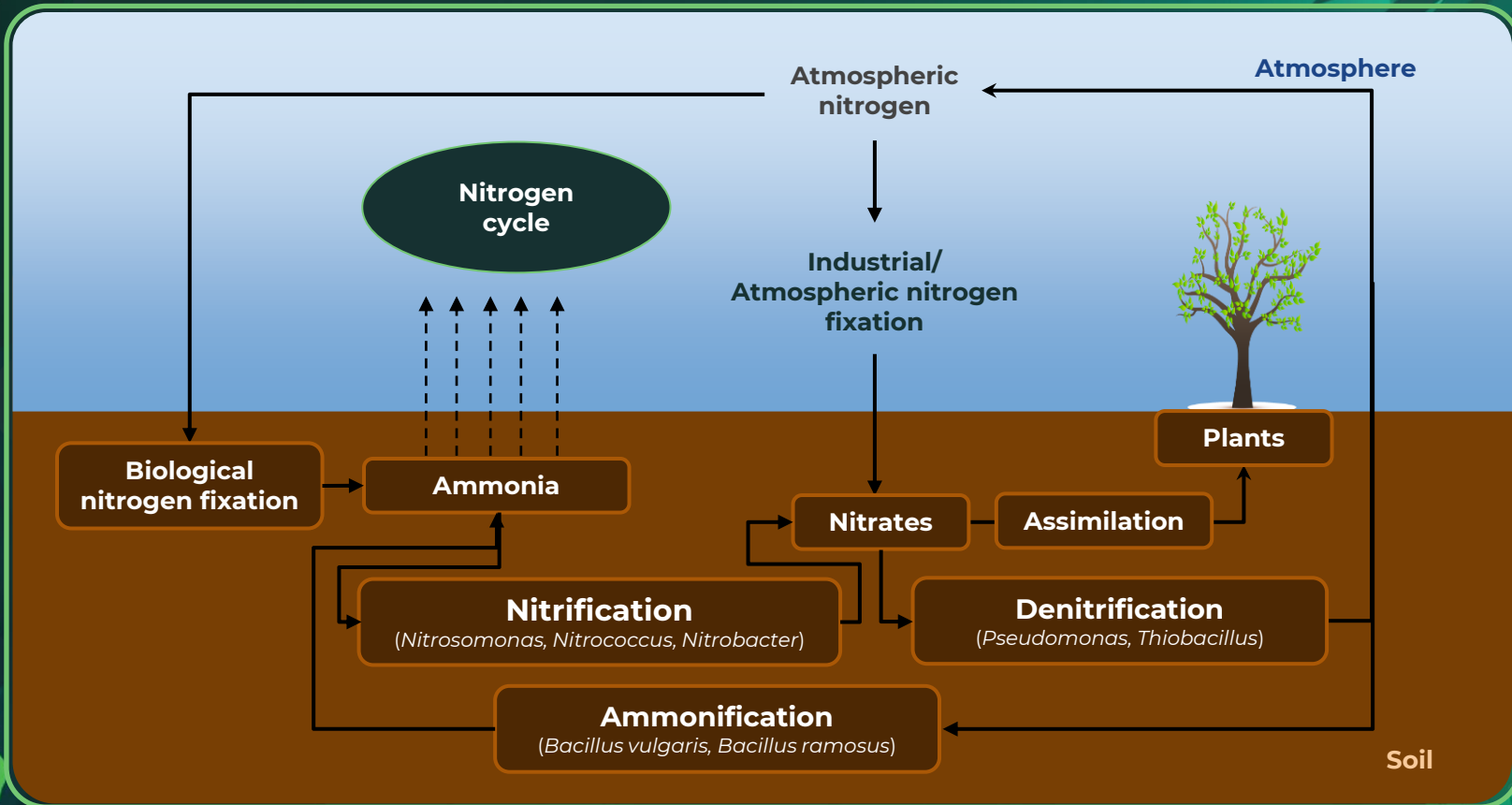
- Molecules move through cells
- Movement is active as transfer requires energy
- Intake of minerals is slow







# Summary





# Summary



## Nitrogen fixation

Atmospheric  
nitrogen fixation

Biological nitrogen  
fixation

Industrial nitrogen  
fixation

Free living

Symbiotic

Bacteria

Cyanobacteria

Bacterial component

Plant component

*Aerobic:*  
*Azotobacter,*  
*Beijerinckia*

*Anaerobic:*  
*Rhodospirillum*

*Anabaena,*  
*Nostoc*

Enzyme: Nitrogenase  
(Mo-Fe protein)

*Rhizobium,*  
*Frankia*

*Roots of*  
*leguminous plants*

**Leghemoglobin**  
(oxygen scavenger)

Nitrogen → Ammonia



# Summary



## Root nodule formation

Multiplication of *Rhizobium*



Curling of root hair



Formation of the infection thread



Formation of nitrogen-fixing cells



Formation of vascular connections