Roles of Microorganisms in soil fertility and crop production:

- Soil microorganisms are very important as almost every chemical transformation taking place in soil involves active contributions from soil microorganisms.
- In particular, they play an active role in soil fertility as a result of their involvement in the cycle of nutrients like carbon and nitrogen, which are required for plant growth.
- For example, soil microorganisms are responsible for the decomposition of the organic matter entering the soil (e.g. plant litter) and therefore in the recycling of nutrients in soil.
- Certain soil microorganisms such as mycorrhizal fungi can also increase the availability of mineral nutrients (e.g. phosphorus) to plants.
- Other soil microorganisms can increase the amount of nutrients present in the soil. For instance, nitrogen-fixing bacteria can transform nitrogen gas present in the soil atmosphere into soluble nitrogenous compounds that plant roots can utilize for growth.
- These microorganisms, which improve the fertility status of the soil and contribute to plant growth, have been termed **'biofertilizers'** and are receiving increased attention for use as microbial inoculants in agriculture.
- Similarly, other soil microorganisms have been found to produce compounds (such as vitamins and plant hormones) that can improve plant health and contribute to higher crop yield. These microorganisms (called 'phytostimulators') are currently studied for possible use as microbial inoculants to improve crop yield. **Colonization of wheat roots by strains of Azospirillium... a bacterial inoculant acts as a phytostimulator.**
- In contrast to these beneficial soil microorganisms, other soil microorganisms are pathogenic to plants and may cause considerable damage to crops. Large numbers of pathogenic microorganisms are routinely found in the soil and many can infect the plant through the roots. However, certain native microorganisms present in the soil are antagonistic to these pathogens and can prevent the infection of crop plants.
- Antagonism against plant pathogens usually involves competition for nutrients and/or production of inhibitory compounds such as secondary metabolites (antimicrobial metabolites and antibiotics) and extracellular enzymes.

- Other soil microorganisms produce compounds that stimulate the natural defense mechanisms of the plant and improve its resistance to pathogens. Collectively, these soil microorganisms have been termed **'biopesticides'** and represent an emerging and important alternative (i.e. biological control) to the use of chemical pesticides for the protection of crops against certain pathogens and pests.
- *Azospirillum* induces the proliferation of plant root hairs which can result in improved nutrient uptake.
- Mycorrhizal fungi colonize the root systems of many plants and aid in the uptake of nutrients by the plant, thereby improving plant growth and overall health.

Beneficial Functions of Soil Organisms:

Scientists have discovered that soil organisms perform a number of important functions essential for good crop production including:

- Decompose and turn crop residues into fertilizer, humus, carbon dioxide and water and release their nutrients slowly for efficient plant use.
- Improve water absorption, retention, drainage and aeration of the soil creating a better environment for root growth.
- Release insoluble or "tied up" soil and fertilizer minerals and nitrogen, biologically transforming them into forms readily available for plant use.
- Fix atmospheric nitrogen into the soil which plants can use.
- Produce vitamins, amino acids, enzymes, plant growth regulators (auxins, gibberellins, cytokinins) and other biological factors important in crop production.
- Breakdown and eliminate herbicide, pesticide and other chemical residues in the soil.
- Produce antibiotic substances that inhibit potential disease producing organisms in the soil.

Carbon Cycle:

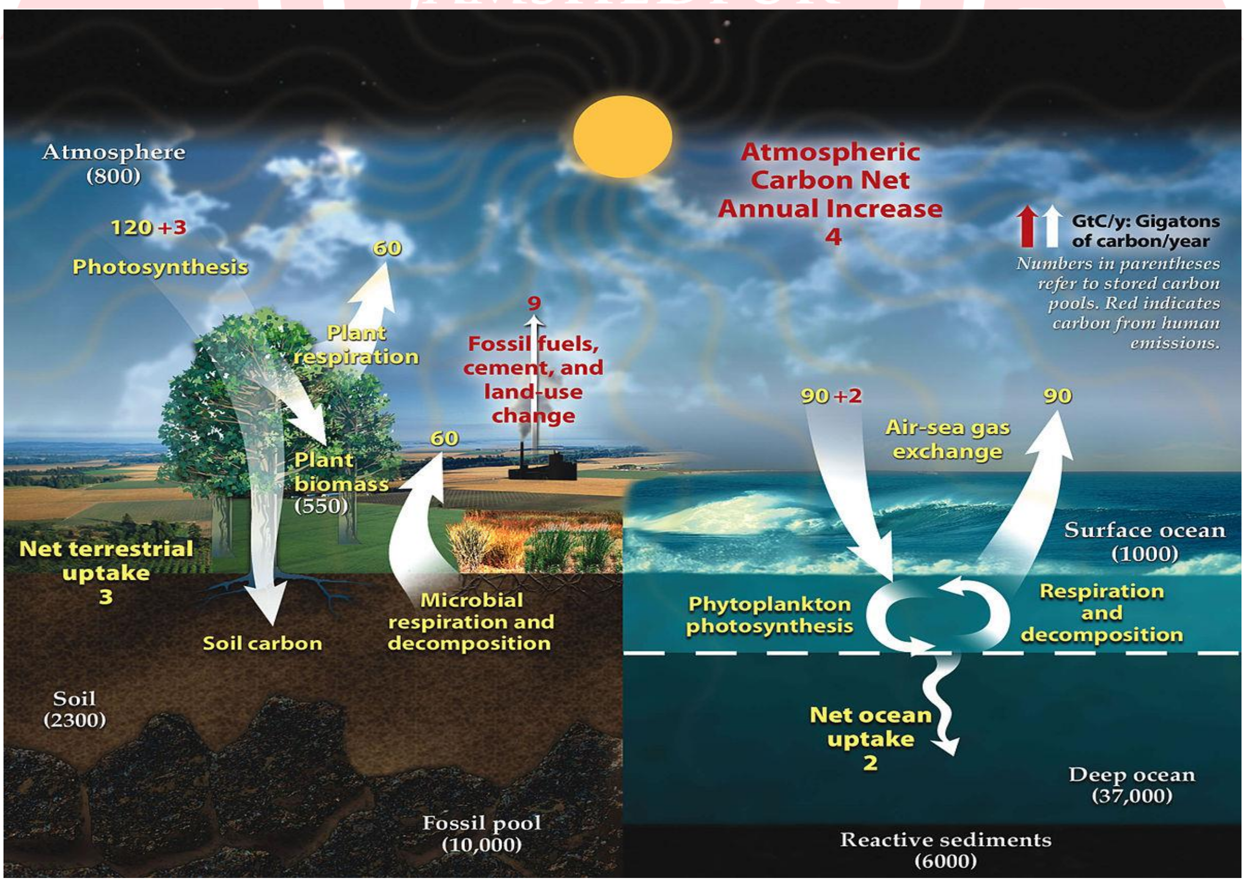
- The carbon cycle is the biogeochemical cycle by which carbon is exchanged between the biosphere, geosphere, hydrosphere and atmosphere of the Earth.

- Carbon is the fourth most abundant chemical element in the universe and forms the building blocks of the living world along with hydrogen and oxygen.

- In fact, its concentration in the biotic world (living world) is almost 100 times more than that in the abiotic (non-living) world.

- Other than this, carbon is an important element that forms a blanket around the Earth. It traps the heat of the sun within the atmosphere and hence prevents the Earth from freezing.

- There is a constant exchange of carbon between the biotic and the abiotic world, thus forming a cycle which is called the carbon cycle. This cycle plays an important role in maintaining proper levels of carbon in the Earth .



Steps of the Carbon Cycle:

Carbon is regularly being exchanged among the atmosphere, land, water, and the living beings. In fact, it is constantly on the move! Let us understand how the carbon cycle works.

1. CO_2 used by Plants for Photosynthesis –

• The primary producers (green plants), also known as photoautotroph's, are constantly removing carbon dioxide from the atmosphere through the process of photosynthesis (the process in which green plants make food for themselves in presence of sunlight). Certain bacteria, also referred to as chemoautotroph's, use carbon dioxide to synthesize the organic compounds they need.

2. Consumption by Animals –

• The carbon present in the food made by green plants reaches animals through the food chain. Carnivorous animals receive this carbon when they eat other animals.

3. Ocean Intake –

• Carbon dioxide is continuously being dissolved in the seas and oceans through the process of diffusion. Once dissolved, this carbon dioxide may remain as it is in the marine waters or may get converted into carbonates and bicarbonates.

• The carbon dioxide dissolved in water is used by marine plants for photosynthesis. The carbonates are converted into calcium carbonate by certain marine organisms. This calcium carbonate is used by corals and oysters to make their shells. When these organisms die, their shells deposit on the sea floor and finally turn into sedimentary rocks.

4. Decay and Decompose –

• When living organisms die, their bodies decay and decompose. This happens due to various natural reasons. The energy as well as the carbon dioxide present in their bodies is released by the chemical reactions taking place on the body.

5. Formation of Fossil Fuels –

• As plants and animals die and get buried under the ground after millions of years, they change into fossil fuels due to high pressure and other physical and chemical changes.

6. Use of Fuels for Industrial Purposes –

• Fossil fuels stored in the heart of the Earth are dug out and used by industries for purposes of energy production. It is also used as a raw material for other purposes.

7. Carbon Emissions –

•The fuel used by the companies leads to the production of waste gases. These gases also contain a large amount of carbon dioxide.

8**. Respiration by Plants and Animals –**

• Carbon dioxide is regularly being returned to the atmosphere by the process of respiration in plants and animals. Burning of wood and fossil fuels in industries and automobiles also releases carbondioxide.

Role of Microorganisms in Carbon Cycle:

- Many fungi and bacteria attack cellulose and release carbon in the soil.
- *Trichoderma*, *Aspergillus*, and *Penicillum* attack cellulose.
- *Marasmius, Ganoderma, Psalliotta* attack lignin.
- In less acid and neutral condition. Bacteria degrade cellulose and hemicellulose.
- Actinomycetes and some bacteria also attack lignin.
- Some specific groups of bacteria are particularly efficient in reducing carbon compounds to form lactic, butyric, and acetic acid. Likewise methane, hydrogen gas, and ammonia are also produced.
- Some bacteria utilize hydrogen and reduce carbondioxide to produce methane.

- An increase in the evolution of carbondioxide as a result of the decomposition of plant and animal residues added to the soil, or the soil humus, leads to an increase in carbondioxide content of the soil.
- This result in the rise of hydrogen ion concentration of the soil which further interact with phosphates and silicates making them available to the plants.
- Carbondioxide in soil also supplements carbondioxide in the atmosphere and in plants.
- If they (microorganisms) do not act on organic matter, the limited supply of carbondioxide in the atmosphere will be exhausted and green plants would cease to manufacture carbohydrates.
- If the microbes are more active, then all the organic matter will be reduced to carbondioxide, resulting in unfit for plant growth.
- Thus, the carbon cycle is largely maintained by balanced action of microorganisms in soil.

Phosphorous Cycle:

The phosphorus cycle is the biogeochemical cycle that describes the movement of phosphorus through the lithosphere, hydrosphere, and biosphere.

Unlike many other biogeochemical cycles, the atmosphere does not play a significant role in the movement of phosphorus, because phosphorus and phosphorus-based compounds are usually solids at the typical ranges of temperature and pressure found on Earth.

- The production of phosphine gas occurs only in specialized, local conditions.

Phosphorous is a chemical element found on Earth in numerous compound forms, such as the phosphate ion (PO43-), located in water, soil and sediments.

The quantities of phosphorus in soil are generally small, and this often limits plant growth.

That is why people often apply phosphate fertilizers on farmland. Animals absorb phosphates by eating plants or plant-eating animals.

The role of phosphorus in animals and plants:

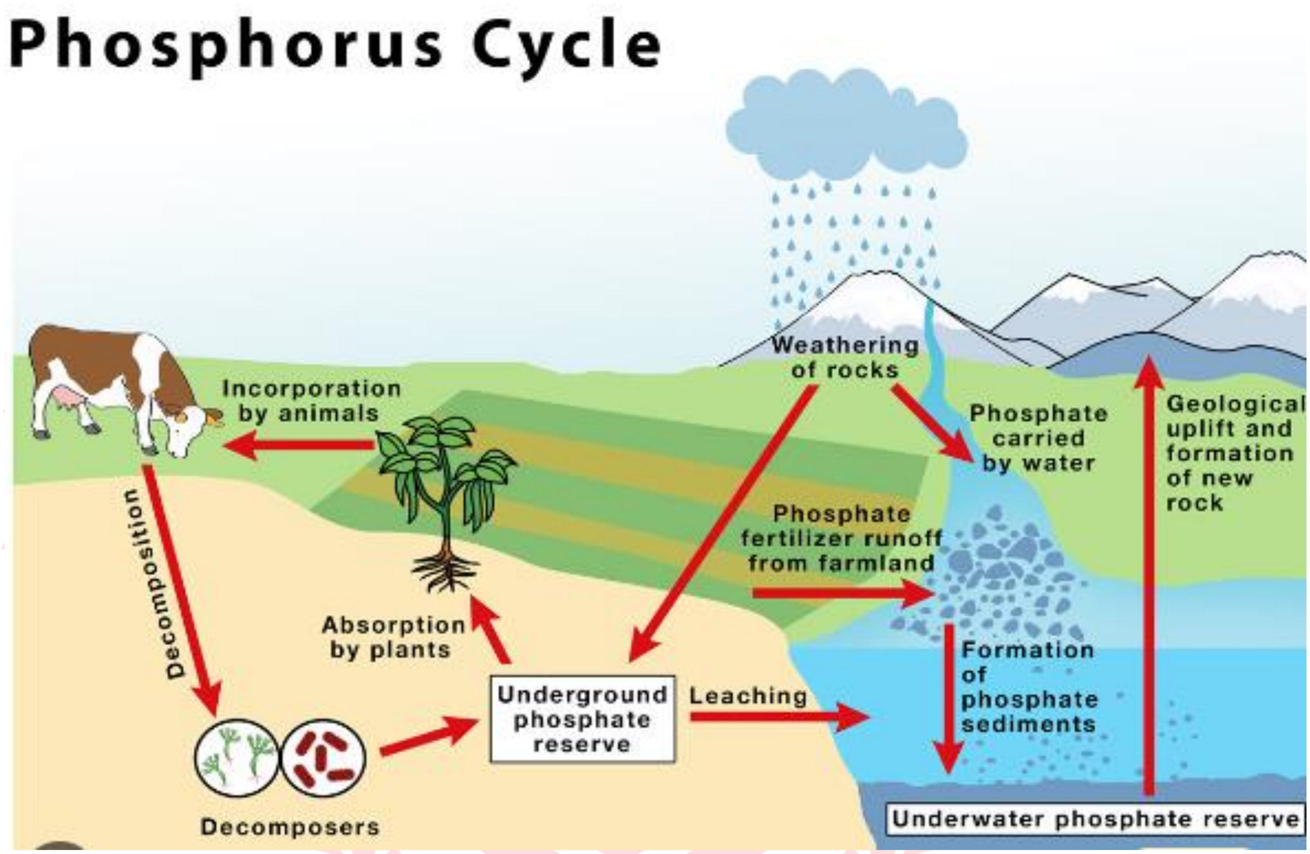
- Phosphorus is an essential nutrient for animals and plants.
- It plays a critical role in cell development and is a key component of molecules that store energy, such as ATP (adenosine triphosphate), DNA and lipids (fats and oils).
- Insufficient phosphorus in the soil can result in a decreased crop yield.

Key steps of the phosphorus cycle:

- Over time, rain and weathering cause rocks to release phosphate ions and other minerals. This inorganic phosphate is then distributed in soils and water.
- Plants take up inorganic phosphate from the soil. The plants may then be consumed by animals. Once in the plant or animal, the phosphate is incorporated into organic molecules such as DNA. When the plant or animal dies, it decays, and the organic phosphate is returned to the soil.

• Within the soil, organic forms of phosphate can be made available to plants by bacteria that break down organic matter to inorganic forms of phosphorus. This process is known as mineralisation.

• Phosphorus in soil can end up in waterways and eventually oceans. Once there, it can be incorporated into sediments over time.



Role of Microorganisms in Phosphorous Cycle:

• The residues of animal, man, plants, birds, etc. contain several phosphates.

• When they reach the soil, they are acted upon by several microorganisms.

• The organisms break down the P-containing compounds, with the liberation of minerals elements, such as Ca, Fe, Na and this process is known as mineralization.

• Sometimes, the bacteria remove soluble phosphates in soil and use them for cell synthesis. On the death of the bacteria, the phosphate is made available for plants.

• The activity of microorganisms in phosphate solubilization is influenced by various soil factors such as pH, moisture, and aeration.

• Many fungi and bacteria (*Aspergillus*, *Penicillum*, *Bacillus*) are potential solubilizers of bound phosphates.

• These organisms produce organic acids like citric, glutamic, succinic, oxalic, maleic, fumaric etc which are responsible for solubilization of insoluble forms of phosphorous.

• These organisms have a role in completing the phosphorous cycle in nature.

Sulphur Cycle:

• The sulfur cycle is the collection of processes by which sulfur moves to and from minerals (including the waterways) and living systems.

• Such biogeochemical cycles are important in geology because they affect many minerals.

• Biogeochemical cycles are also important for life because sulfur is an essential element, being a constituent of many proteins and cofactors.

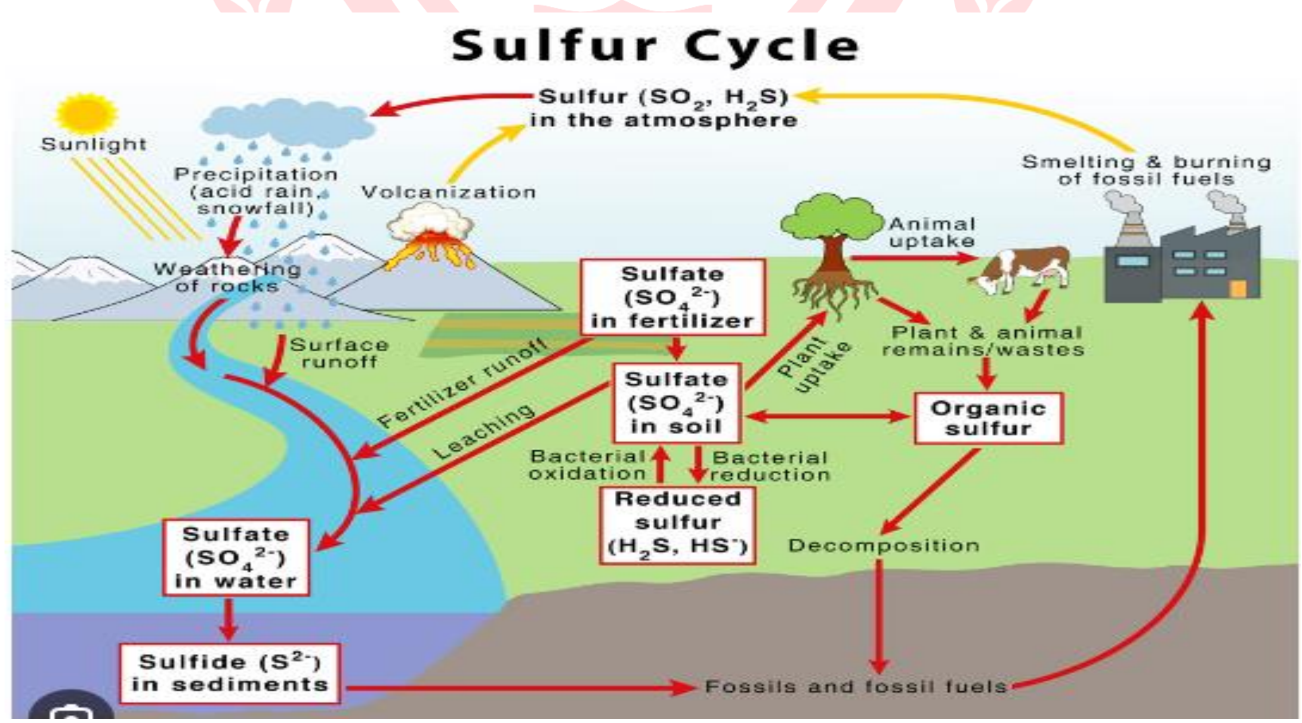
Importance of Sulphur:

• Plants utilize sulphur in the dissolved form as sulphate.

• Sulphur is important constitute of certain amino acids like cystine, methionine, thiamine, biotin.

• Indirectly influence nodulation in legumes, chlorophyll and other pigment formation.

• Animal life also requires sulphur.



Steps of Sulphur Cycle:

• Various transformations of the sulphur in soil results mainly due to microbial activity, although some chemical transformations are also possible (eg. oxidation of iron sulphide) the major types of transformations involved in the cycling of sulphur are:

I. Mineralization

II. Oxidation

III. Reduction

IV. Assimilation

1. Mineralization:

• Organic sulfur changes into inorganic forms, such as hydrogen sulfide (H_2S), elemental sulfur, as well as sulfide minerals.

2. Oxidation:

• Oxidation of elemental sulphur and inorganic sulphur compounds (such as H_2S, sulphite and thiosulphate) to sulphate (SO4) is brought about by chemoautotrophic and photosynthetic bacteria.

• Oxidation of hydrogen sulfide produces elemental sulfur.

• Further oxidation of elemental sulfur produces sulfate.

• Sulfide may be oxidized to elemental sulfur aerobically by species of Thiothrix and Beggiatoa and anaerobically by the purple sulfur bacteria. Both of these groups are primarily aquatic microbes.

• In soil, the predominant microbes involved in the oxidation of sulfide to elemental sulfur belong to the genus Thiobacillus.

• The major Sulphur Oxidiser microorganisms are:

Thiobacillus*, *Aspergillus, Penicillium, Microsporum

3. Reduction:

• Sulphate can be reduced to hydrogen sulphide (H_2S) by sulphate reducing bacteria (eg.*Desulfo vibrio* and *Desulfato maculum*) and may diminish the availability of sulphur for plant nutrition.

• The reduction process is particularly favored by the alkaline and anaerobic conditions of the soil, as the organisms use sulphate as a source of oxygen supply.

• Besides the strict autotrophs of the genus Thiobacillus, there are several other members which are facultative autotrophs capable of reducing H2S and drive energy from it.

For e.g. calcium sulphate is attacked under anaerobic condition by the members of the genus Desulfovibrio and Desulfatomaculum to release H_2S .

$CaSO4 + 4H_2 \Rightarrow Ca(OH)2 + H_2S + H_2O$

• Hydrogen sulphide produced by the reduction of sulphate and sulphur containing amino acids decomposition is further oxidized by some species of green and purple phototrophic bacteria (eg. Chlorobium, Chromatium) to release elemental sulphur.

$CO_2 + 2H_2 + H_2S \Rightarrow (CH_2O) + H_2O + 2S$

4. Assimilation:

• The sulphates and sulphuric acid, when dissolved in water, are made available for plant growth.

• The plants utilize the sulphates to form various amino acids, hormones, growth factors, etc.

• They are either eaten away by the animals are also in some form or other returned to the soil.

When the various complex orgnic sulphur compounds reach the soil, they are attacked by the soil organisms and the cycle of events continues.

Nitrogen Cycle:

The nitrogen cycle represents one of the most important nutrient cycles found in terrestrial ecosystems.

•The nitrogen cycle is the process by which nitrogen is converted between its various chemical forms.

• This transformation can be carried out through both biological and physical processes. Important processes in the nitrogen cycle include fixation, ammonification, nitrification, and denitrification.

• Nitrogen is one of the primary nutrients critical for the survival of all living organisms. It is a necessary component of many biomolecules, including proteins, DNA, and chlorophyll.

• Although nitrogen is very abundant in the atmosphere as dinitrogen gas (N_2), it is largely inaccessible in this form to most organisms, making nitrogen a scarce resource and often limiting primary productivity in many ecosystems.

• Only when nitrogen is converted from dinitrogen gas into ammonia (NH_3) does it become available to primary producers, such as plants.

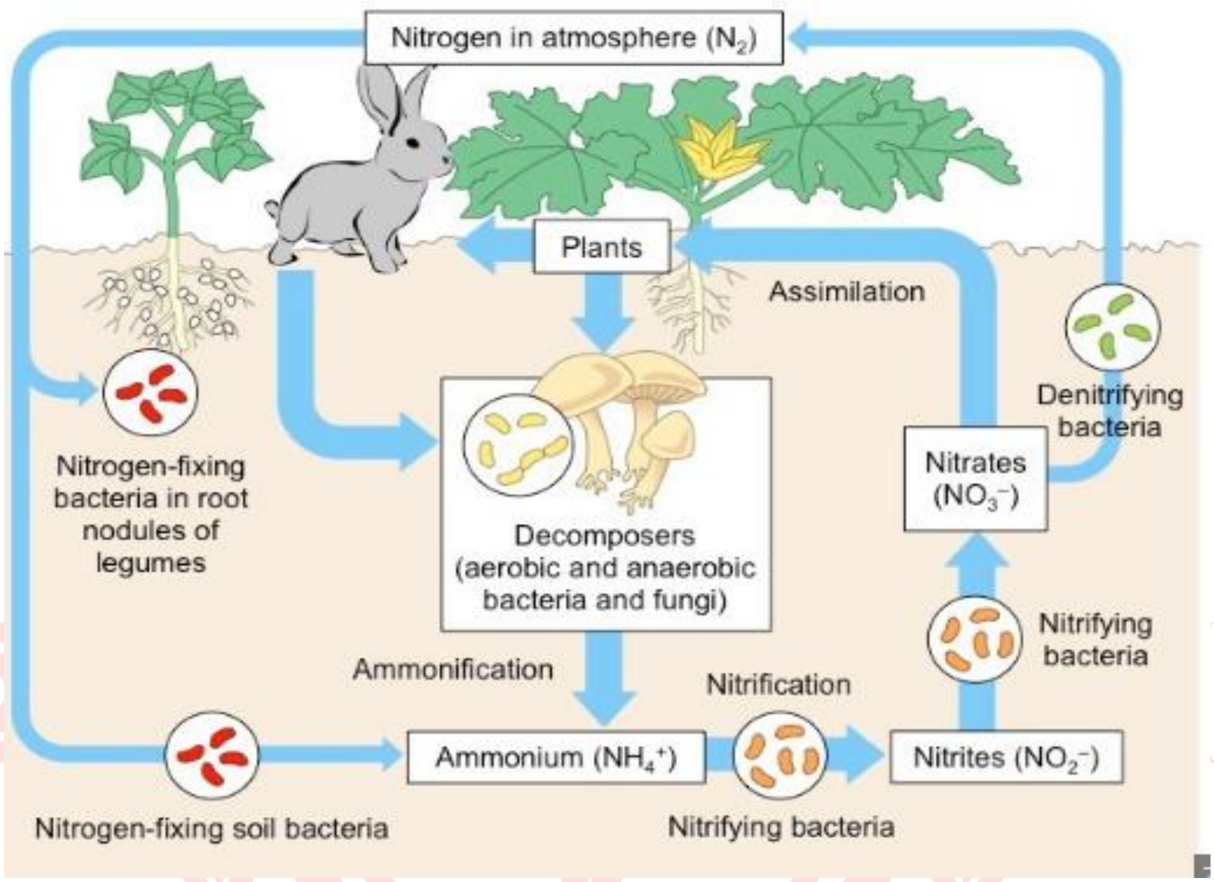
• In addition to N2 and NH3, nitrogen exists in many different forms, including both inorganic (e.g., ammonia, nitrate) and organic (e.g., amino and nucleic acids) forms.

• Thus, nitrogen undergoes many different transformations in the ecosystem, changing from one form to another as organisms use it for growth and, in some cases, energy.

• The major transformations of nitrogen are nitrogen fixation, nitrification, denitrification, anammox, and ammonification.

• The transformation of nitrogen into its many oxidation states is key to productivity in the biosphere and is highly dependent on the activities of a diverse assemblage of microorganisms, such as bacteria, archaea, and fungi.

Process of Nitrogen Cycle:



The basic step of Nitrogen Cycle includes:

1. Nitogen Fixation
2. Nitrification
3. Denitrification
4. Ammonification
5. Immobilization/ Assimilation

1. Nitrogen Fixation:

• For nitrogen to be available to make proteins, DNA, and other biologically important compounds, it must first be converted into a different chemical form.

• The process of converting N_2 into biologically available nitrogen is called nitrogen fixation.

N_2 + 8H+ 8 e- => $2NH_3$ +H2

- Nitrogenase Enzyme
- Bacterial activity
- Microorganisms involved

There are mainly four ways to fix atmospheric nitrogen:

1. Biological fixation,
2. Industrial Nitrogen Fixation
3. Combustion
4. Ligtening

2. Nitrification:

• Nitrification is the process that converts ammonia to nitrite and then to nitrate and is another important step in the global nitrogen cycle.

• Most nitrification occurs aerobically and is carried out exclusively by prokaryotes.

• There are two distinct steps of nitrification that are carried out by distinct types of microorganisms.

• The first step is the oxidation of ammonia to nitrite, which is carried out by microbes known as ammonia-oxidizers.

• **Nitrosomonas, and Nitrosococcus** carried out this proccess.

• The second step in nitrification is the oxidation of nitrite (NO2-) to nitrate (NO3-) .

• This step is carried out by a completely separate group of prokaryotes, known as nitrite-oxidizing Bacteria. Some of the genera involved in nitrite oxidation include **Nitrospira, Nitrobacter, Nitrococcus, and Nitrospina**.

NO_2 + ½ O2 = > NO_3

3. Denitrification:

• Denitrification is the process that converts nitrate to nitrogen gas, thus removing bioavailable nitrogen and returning it to the atmosphere.

• Dinitrogen gas (N_2) is the ultimate end product of denitrification, but other intermediate gaseous forms of nitrogen exist.

• Unlike nitrification, denitrification is an anaerobic process, occurring mostly in soils and sediments and anoxic zones in lakes and oceans. Similar to nitrogen fixation, denitrification is carried out by a diverse group of prokaryotes, Some denitrifying bacteria include species in the genera **Bacillus, Paracoccus, and Pseudomonas.**

• Denitrification is important in that it removes fixed nitrogen (i.e., nitrate) from the ecosystem and returns it to the atmosphere in a biologically inert form (N_2)

4. Ammonification:

• When an organism excretes waste or dies, the nitrogen in its tissues is in the form of organic nitrogen (e.g. amino acids, DNA).

• Various fungi and prokaryotes then decompose the tissue and release inorganic nitrogen back into the ecosystem as ammonia in the process known as ammonification.

• The ammonia then becomes available for uptake by plants and other microorganisms for growth.

5. Immobilization/ Assimilation:

• It is the reverse of mineralization. All living things require N; therefore microorganisms in the soil compete with crops for N. Immobilization refers to the process in which nitrate and ammonium are taken up by soil organisms and therefore become unavailable to crops.