NUTRIENT CYCLES AND THEIR GENERAL FEATURES

Not all chemical elements found on earth are nutrients of living organisms involved in constructing biological material. The majority of biological material, (at least about 90% of the total biomass) is composed of three elements: carbon, hydrogen and oxygen. These major nutrients are derived from the intake of water and carbon dioxide either directly from the atmosphere or from air dissolved in water. The remainder, the macronutrients and micronutrients are taken in from nature by plants either in solution or in their gaseous form.

Basic features of a nutrient cycle

- All nutrient cycles operate as closed systems. The movement of nutrients within the biosphere occurs in a cyclic manner, from environment to organisms and back to the environment. Therefore the system as a whole does not lose nutrients.
- Cycles are driven by solar energy and since most nutrients are soluble in water, their cycling in nature is closely linked with the water cycle.
- Each nutrient cycle basically consists of reservoirs and pathways. The reservoirs are of two types: non-biological and biological reservoirs. The non-biological reservoirs include air (atmosphere), water (hydrosphere) and soil (lithosphere). The biological reservoirs are the living organisms. Fig. 10.2 shows a generalized biogeochemical cycle indicating the interchanges amongst various reservoirs.
- The pathways of the nutrient cycles are processes which include
  − biological processes like absorption of nutrients by roots of plants or by aquatic organismsand
  − physical processes like removal of nutrients from land to aquatic bodies by erosion and expulsion of gases during volcanic eruptions. These pathways connect reservoirs to each other and facilitate the exchange of nutrients from one reservoir to another.

  The rate of movement of nutrients between two reservoirs along these pathways is called the flow rate or flux rate. The speed of movement depends on the physical and chemical properties of each nutrient.
- The nutrients show different residence times in different reservoirs. While cycling through the ecosystem, nutrients may remain in one or more reservoirs for shorter or longer periods of time. The period of time for which a nutrient stays within a reservoir is called the residence time.

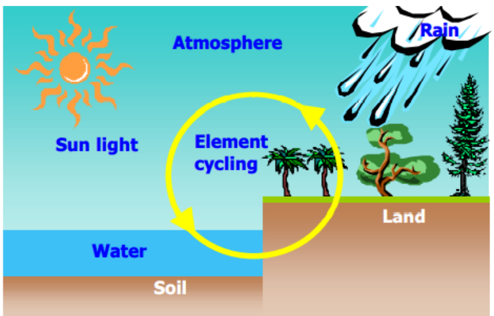


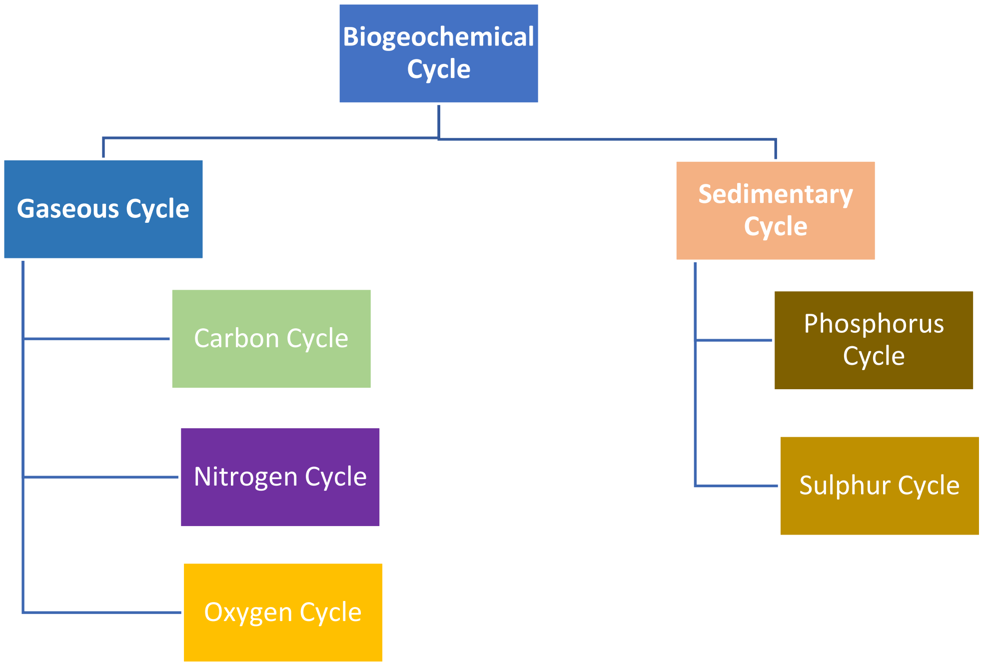
Fig.10.2: A generalised representation of biogeochemical cycles

Biogeochemical Cycle:

The cyclic movement of nutrients between biotic and abiotic components of the environmentis called Biogeochemical Cycle. These cycles depict the material movement and their conservation. Based on the nature of reservoir, there are two types of cycles namely Gaseous and Sedimentary Cycles.

Gaseous Cycle: It is that cycle where the reservoir is the atmosphere or the hydrosphere. Eg: Carbon, Nitrogen Oxygen cycles

Sedimentary Cycle: It is that cycle where the earth's crust acts as a reservoir.Eg: Phosphorus cycle and sulphur cycle.



CARBON CYCLE:

Carbon is important for all life on Earth. All living things are made up of carbon. Carbon is produced by both natural and human-made (anthropogenic) sources.Carbon cycle is the circulation of carbon among the biosphere, geosphere, hydrosphere and atmosphere of the earth.

Nature's Carbon Sources:

- Carbon is important for all life on Earth. All living things are made up of carbon. Carbon is produced by both natural and human-made (anthropogenic) sources.
- Carbon is found in the lithosphere in the form of carbonate rocks. Carbonate rocks came from ancient marine plankton that sunk to the bottom of the ocean hundreds of millions of years ago that were then exposed to heat and pressure. Carbon is also found in fossil fuels, such as petroleum (crude oil), coal, and natural gas. Carbon is also found in soil from dead and decaying animals and animal waste.
- Carbon is found in the hydrosphere dissolved in ocean water and lakes. Carbon is used by many organisms to produce shells. Marine plants use Carbon for photosynthesis. The organic matter that is produced becomes food in the aquatic ecosystem
- Carbon is found in the biosphere stored in plants and trees. Plants use carbon dioxide from the atmosphere to make the building blocks of food during photosynthesis

Natural Carbon Releases into the Atmosphere

- Gases containing Carbon move between the oceans surface and the atmosphere through a process called diffusion.

- Volcanic activity is a source of Carbon into the atmosphere

How Do Humans Place Carbon in the Atmosphere?

Humans place carbon into the atmosphere in a variety of ways.

- Deforestation. When we cut down trees and forests, they can no longer remove carbon dioxide from the air. This results in additional carbon dioxide placed in the atmosphere.
- Wood burning. When we burn wood, the carbon stored in the trees becomes carbon dioxide and enters the atmosphere.

NITROGEN CYCLE

Nitrogen is essential for protein synthesis in all living organisms. Nitrogen is an essential component **of DNA, RNA and Protein**, the building block of life. All organisms require nitrogen to live and grow. It constitutes nearly 16% by weight of all the proteins.

Atmosphere contain 78% of nitrogen in the form of gas. Although it is present in abundant in atmosphere but most of the nitrogen in atmosphere is unavailable for use by organisms. This is because the strong bond between the nitrogen atom in N_2 molecule make it relatively inert and unreactive,whereas organism **need reactive nitrogen** to be able to incorporate into cells.

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

Reservoirs holding nitrogen: Nitrogen is tied up in four different types of reservoirs at any time of its cycling. These are the **atmosphere, soil, water and living organisms**.

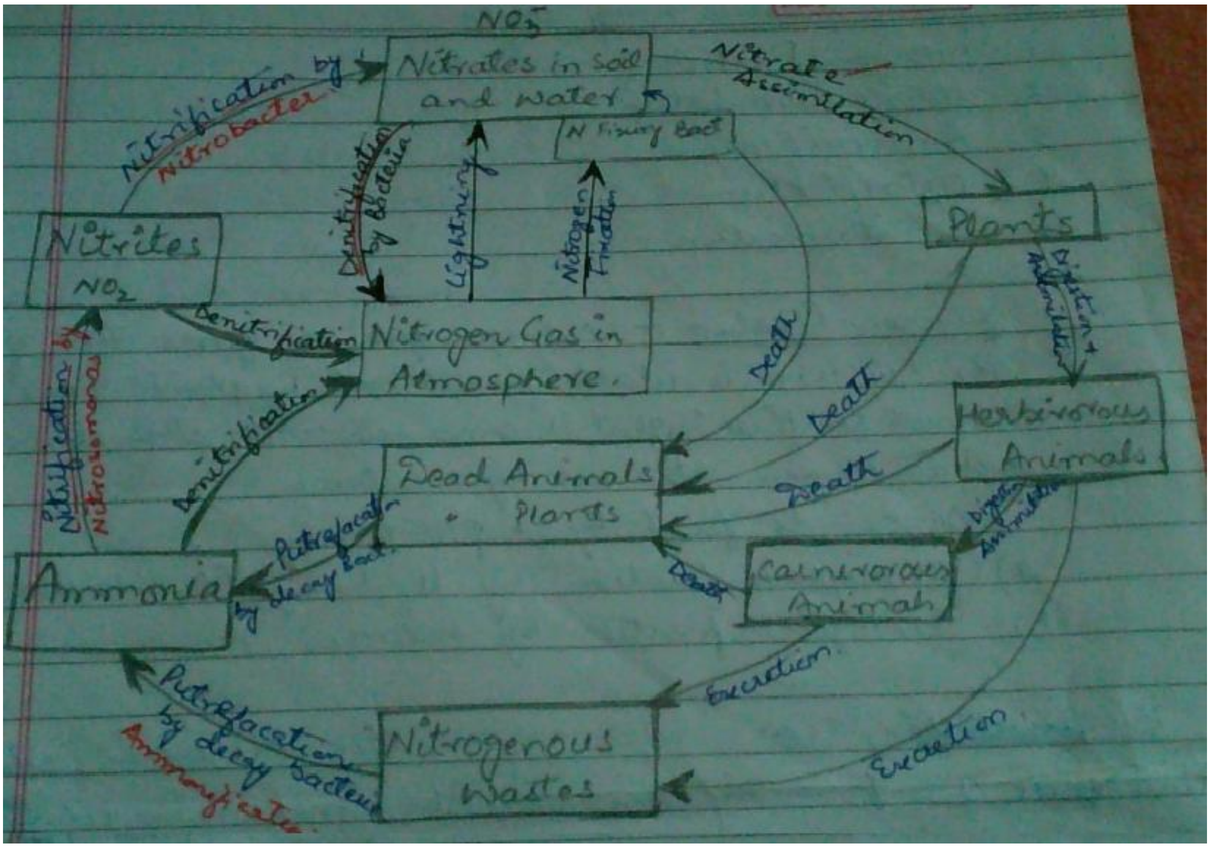
- Gaseous nitrogen makes up nearly 80% of the earth's atmosphere by volume, which is the largest reservoir of nitrogen.

- The total amount of fixed nitrogen in the soil, oceans and the bodies of organisms is only about 0.03% of that figure.

- The atmospheric nitrogen reservoir of molecular nitrogen is chemically inactive. The aqueous reservoir of nitrogen is biologically more important to living organisms and it comprises soil-water and the other aquatic ecosystems such as oceans. Nitrogen is present in these aquatic reservoirs in the form **of nitrates (NO_3-) or ammonia (NH_3 or NH_4+)** which can be absorbed by plants and then be incorporated into plant tissues in a variety of forms such as proteins, pigments, nucleic acids and vitamins.

- These nitrogen containing compounds are then transferred to animals via food chains. Therefore, organisms are also one of the main reservoirs of nitrogen.

NH3 (Ammonia) is a gas and sometimes called toxic or free ammonia.
NH4 (Ammonium) is a nontoxic salt



Basic steps of nitrogen cycle-

The cycling process of nitrogen, from the atmospheric reservoir, through organisms and then back to the atmosphere, involves five processes.

1. Nitrogen Fixation**(Conversionof N_2 to Nitrate NO_3 or Ammonia NH_3)**
2. Nitrate Assimilation (Nitrates taken up by plants)
3. Ammonification**(Formation of Ammonia)**
4. Nitrification (**ammonia→Nitrite →Nitrate)**
5. Denitrification**(Nitrate→ Nitrogen gas)**

1. **Nitrogen Fixation:**Nitrogen gas (N_2) makes up nearly 80% of the Earth's atmosphere, yet nitrogen is often the nutrient that limits primary production inmany ecosystems. Why is this so? Because plants and animals are not able to use nitrogen gas in that form. 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 gas is a very stable compound due to the strength of the triple bond between the nitrogen atoms,** and it requires a large amount of energy to break this bond. The whole process requires eight electrons and at least sixteen ATP molecules (Figure 2).

As a result, only a select group of prokaryotes are able to carry out this energetically demanding process. Although most nitrogen fixation is carried out by prokaryotes, some nitrogen can be fixed abiotically by lightning or certain industrial processes, including the combustion of fossil fuels.

$$N_2 + 8\ H^+ + 8\ e^- \longrightarrow 2\ NH_3 + H_2$$

Nitrogen fixation is the phenomenon of conversion of atmospheric nitrogen(N_2) into usable form (ammonium ions, nitrres or nitrates)to make it available for absorption by plants. On the basis of agency through which nitrogen is fixed, the fixation of nitrogen is divided into three types:

Types of Nitrogen Fixation

A. Atmospheric Fixation
B. Chemical Nitrogen Fixation
C. Biological Nitrogen Fixation

a) Atmospheric Fixation: Out of total nitrogen fixed by natural agencies, approximately 10% of this occurs due to physical processes such as lightening (i.e. electric discharge) and thunder storms. The lightening and ultra violet radiations in the atmosphere favours combination of gaseous nitrogen and oxygen to form nitric oxide (NO). These nitric oxides are again oxidized with oxygen to form nitrogen peroxide (NO_2).

$N_2 + O_2 \rightarrow 2NO$

$2NO + O_2 \rightarrow 2NO_2$

The nitrogen peroxide can combine with H2O during rains to form nitrous acid and nitric acid. The acids fall on the ground along with rain water and react with alkaline radicals to produce water soluble **nitrate (NO3) and nitrate (NO2).**

$2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$

HNO3 + Ca or K→ Ca or K nitrates

Nitrates are soluble in water and are directly absorbed by plants.

b) **Chemical Nitrogen Fixation:**Ammonia is produced in industries by the direct combination of nitrogen gas and hydrogen, and the process is called Haber Bosch process.

c) Biological Nitrogen Fixation: The conversion of atmospheric nitrogen into inorganic or organic usable forms through the agency of living organisms is called biological nitrogen fixation. The process is carried by two main type of microorganisms: **those who are free living or asymbiotic and those which live in close symbiotic association with plants.**

i. **Asymbiotic Biological Nitrogen fixation:** A large number of free-living bacteria fix atmospheric nitrogen into usable form.

- Free living aerobic nitrogen fixing bacteria (e.gAzobacter)
- Free living anaerobic nitrogen fixing bacteria (e.g Clostridium)
- Free living photoautotrophic nitrogen fixing bacteria (e.gChlorobium)
- Free living chemosynthetic nitrogen fixing bacteria (e.gDesulfovibrio)

ii. **Symbiotic Biological Nitrogen fixation:** Some bacteria fix atmospheric Nitrogen in symbiotic association with other plants.
e.g Bacteria **Rhizobium** in association with roots of leguminous plants.

1. **Nitrogen Assimilation:**Once the nitrogen has been fixed in the soil, plant can absorb nitrogen through their roots. This process of absorption is called assimilation. Thus, in this step there is assimilation of inorganic nitrogen (**Incorporation of ammonia and nitrate**) into biological tissue.

2. **Decomposition and Ammonification:** When a plant or animal dies or an animal expels waste, the initial form of nitrogen is organic and **bacteria, fungi convert this organic nitrogen into ammonium**. This process of decomposing complex, dead organic matter into ammonia is called Ammonification.

   The process of conversion of organic nitrogen into ammonia and ammonium salts is called ammonification. The resulting ammonia may enter into the atmosphere and the ammonium salts released to the soil are mostly absorbed by the plants

3. **Nitrification:** Process of conversion of **ammonia into nitrite** and then into **nitrate** with the help of Nitrifying bacteria like*Nitrosomonas and Nitrobacter.Nitrosomonas* utilize the ammonia in the soil as their source of energy and the ammonia is converted to nitrite ions. The nitrite ions are then further transformed into nitrate ions, by the other group of bacteria, *Nitrobacter.*

   Ammonia $\xrightarrow{\text{Nitrosomonas}}$ **Nitrite** $\xrightarrow{\text{Nitrobacter}}$ **Nitrate**

   The roles of nitrifying bacteria in the cycling of nitrogen can be listed as follows:
   • They prevent the loss of ammonia from soil into the atmosphere as a gas.
   • They transform ammonia into a usable form, which can be directly absorbed by plants

A part of the nitrate ions formed during nitrification may be absorbed by plants. A certain part of soil nitrates are lost to the system and are transported away by the surface run-off or ground water due to its high solubility in water. The leached nitrate ions then run off to streams, lakes and eventually accumulate in the sea where it is available for aquatic organisms. Ultimately, they may be lost to deep ocean sediments or brought back to the surface waters by upwelling of cold water from the depths. The nitrogen compounds that reach the deep sediments return to the surface layers very slowly. Generally, they are brought back to the land by birds that feed on fish.

4. **Denitrification:** Process of reduction of **nitrate** back into atmospheric **nitrogen gas** (N_2) by bacteria *Pseudomonas*, *Bacillus denitrificant*, *Thiobacillusdenitrificant*.

Nitrate ions present in the soil are degraded to form gaseous nitrogen under the action of a particular group of bacteria. This transformation is called **denitrification**. The bacteria that carry out this process are termed denitrifying bacteria, particularly *Pseudomonas*. The denitrification process takes place under certain conditions.

- It needs a low oxygen concentration,
- a pH range of 6 to 7,
- an optimum temperature of $60^{o}C$ and a
- a sufficient supply of organic matter.

The role of denitrifiying bacteria is very important. Without them, the nitrogen taken from the atmosphere would not be released from plant and animal tissues and also ocean sediments.

PHOSPHORUS CYCLE:

The Phosphorus cycle is the movement of phosphorus from the environment to the organisms and then back to environment.It is based on the interactions between the biotic components and the soil and water of the ecosystem.

Phosphorus is the key element of all living organisms. Phosphate are necessary for the growth and maintenance of animals bone and teeth while Organophosphate are essential for cell division involving production of Nuclear DNA and RNA. The main reservoir of phosphorus are **crystalline rocks** and natural **phosphate deposits.**

Reservoirs holding phosphorous: The main reservoirs of phosphorous are rocks and natural phosphate deposits. During the geological era, phosphorous gradually accumulated in the ocean sediments. These sediments, over tens of millions of years of geological time periods were converted into sedimentary rocks. These rocks are attacked by weathering, leaching and erosion and phosphorus is released and made available to other organisms. The phosphorous found in the oceanic sink is transported to the land as guano deposits when marine organisms are consumed by birds. The guano deposits havebeen exploited by humans as a source of phosphate rich material which is used as a fertilizer

Cycling of phosphorus: The phosphorus cycle could be considered as occurring in two phases: **an organic phase and a sedimentary phase**.

The main steps in the cycling of phosphorus are:

- Absorption, assimilation and incorporation of phosphates in organisms.
- Decomposition of organic phosphates by microbes.
- Sedimentation of inorganic phosphate in terrestrial and aquatic ecosystems

1. sedimentation of inorganic phosphate: The main input comes from the weathering of phosphorus containing rocks and sediments. These rocks gradually eroding, releasing phosphate to the ecosystem but much phosphate escape to the sea (by surface run off to rivers and then to sea) where part of it is deposited in the shallow sediments and part of it is lost in deep sediments. In the sea, the phosphorus get incorporated into sea weed and this phosphorus from sea weed are taken by sea birds and animals, and in the form of guano (faecal matter of sea birds / animals), this phosphorus again comes into soluble phosphate form to lithosphere.

2. Phosphorus in the living organism: In the organic phase, phosphorous is made available to living organisms, generally as ionic phosphate. These ionic phosphates are then absorbed by plants through their root systems. From the plants, phosphorus is passed to the rest of the community along the grazing food chains.

3. Decomposition of organic phosphate: The phosphorous that is incorporated into plant and animal tissues is returned to the ecosystem by excretion and the death of organisms. The organic phosphates in dead plant and animal matter are transformed into inorganic phosphates by the action of bacteria. The inorganic phosphates may take different routes. They can be immediately taken up by plants; some of them are transformed into various other compounds by chemical processes and some are immobilized in the bodies of microbes. Some of the phosphorous of terrestrial ecosystems may escape into the lakes and seas. In the aquatic systems phosphorous is rapidly recycled through planktons..