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Ecology Class Notes – Biogeochemical Cycle (Nutrient cycle)

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Biogeochemical cycle (Nutrient cycle):

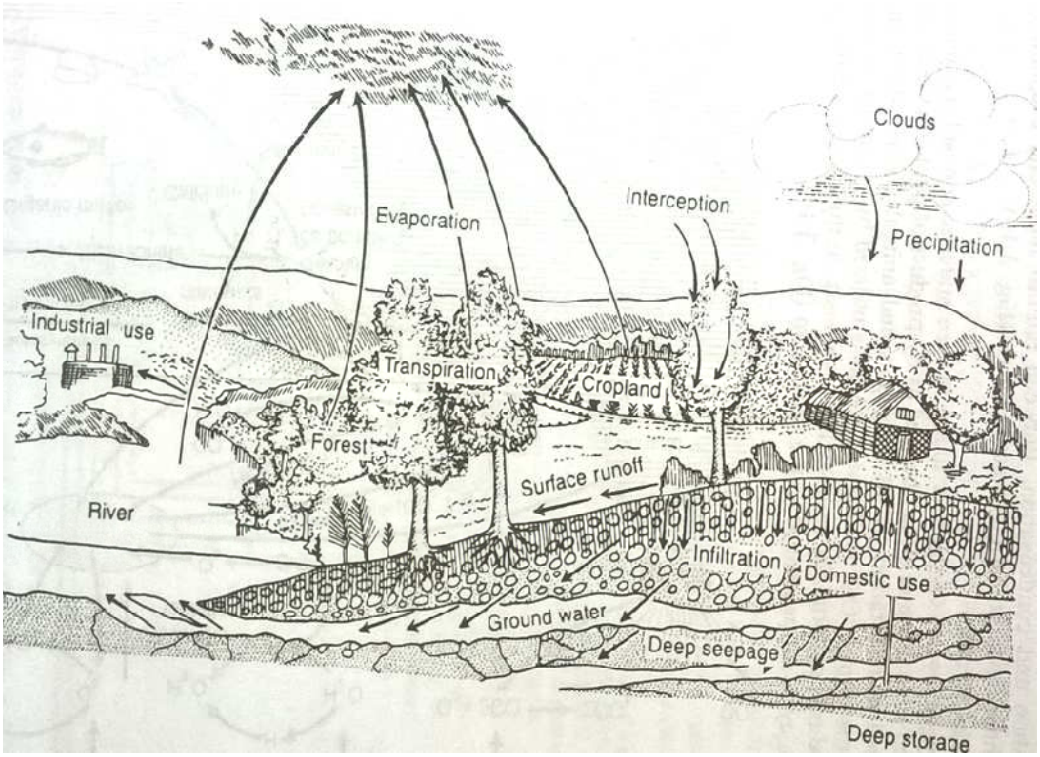
- You have already learnt that living organisms required several chemical elements for their life processes.
- There may be used as part of their structural component or as parts of enzymes which influence various life processes unlike energy which flows unidirectionally, nutrients are continuously exchanged between the organisms and their physical environment.

- ("Bio" - living, "Geo" – earth - rock, "Chemical" - element).
- The cycling of the nutrients in the biosphere is called biogeochemical or nutrient cycle.
- It involves movement of nutrient elements through the various components of an ecosystem.
- There are more than 40 elements required for the various life processes by plants and animals; that it's proper growth and development.
- Most important elements are C, H, O, P, K, N, S, Ca, Fe, Mg, B, Zn, Cl, Mo, Co, I & Fe.
- These elements are continuously cycling in the ecosystem through the biogeochemical cycles and the planet earth has no input of these nutrients.
- The nutrients (matter) from the dead remains of organisms are recovered and made available to the producers by decomposers.
- Thus the nutrients are never lost from the ecosystems.
- Exchange of nutrients between organisms and their environment is one of the essential aspects of an ecosystem.
- All organisms require nutrients for their growth, development, maintenance and reproduction.
- Circulation of nutrients within the ecosystem or biosphere is known as biogeochemical cycles and also called as **'cycling of materials'.**
- There are 3 basic types, **1. Hydrologic or Water cycle, 2. Gaseous cycle (**It includes atmospheric Oxygen, Carbon and Nitrogen cycles) and 3**. Sedimentary cycle** – It includes the cycles of Phosphorus, Sulphur and Calcium - Which are present as sediments of earth.

1. Hydrologic or Water cycle:

- Earth is a watery planet of the solar system but a very small fraction of this is available to animals and plants.
- Water is not evenly distributed throughout the surface of the earth.
- Major percentage of the total water on the earth is chemically bound to rocks and does not cycle.

- Out of the remaining, nearly 97.3% is in the oceans and 2.1% exists as polar ice cubes.
- Thus only 0.6% is present as fresh water in, the form of atmospheric water vapors, ground and soil water.
- The ice cubes and the water deep in the oceans form the reservoir.
- Solar radiation and earth's gravitational pull are the main driving forces of water cycle.
- *Evaporation, condensation* and precipitation are the main processes involved in water cycle these processes alternate with each other.
- Water from oceans, lakes, ponds, rivers, streams and soil surface evaporates by sun's heat energy.
- Plants also transpiration huge amounts of water through their leaves.
- Water remains in the vapour state in air and forms clouds, which float with the wind.
- Clouds meet with the cold air in the mountainous regions above the forests and condense to form rain, which falls due to gravity.



2. Gaseous cycle:

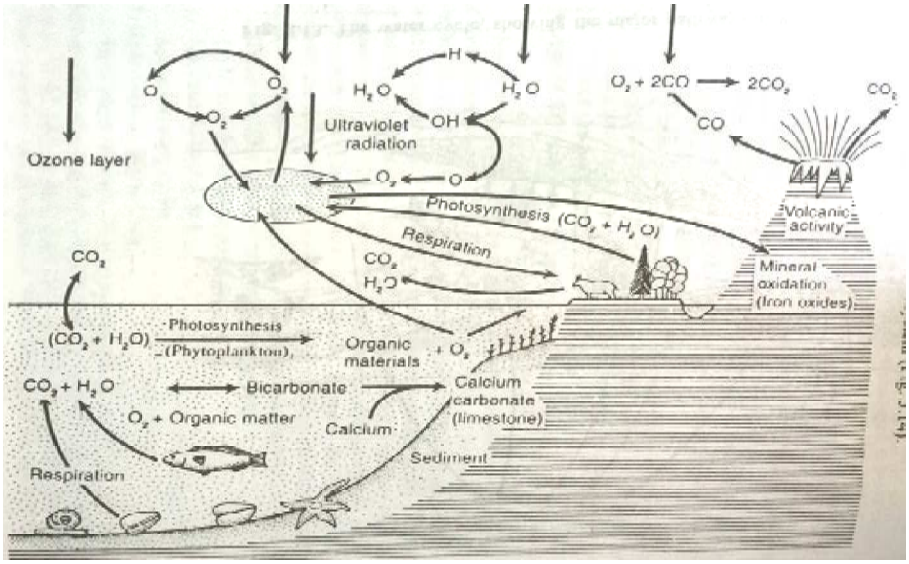
2.1. Oxygen cycle:

- The oxygen cycle is the biogeochemical transitions of oxygen atoms between different oxidation states in ions, oxides, and molecules through redox reactions (oxidation-reduction reaction) within and between the spheres/reservoirs of the planet Earth.
- The word oxygen in the literature typically refers to the most common oxygen allotrope(element changeable form), elemental/diatomic oxygen (O_2), as it is a common product or reactant of many biogeochemical redox reactions within the cycle.
- Processes within the oxygen cycle are considered to be biological or geological and are evaluated as either a source (O_2 production) or sink (O_2 consumption).

- **Reservoirs:** Oxygen is one of the most abundant elements on Earth and represents a large portion of each main reservoir.
- By far the largest reservoir of Earth's oxygen is within the silicate and oxide minerals of the crust and mantle (99.5% by weight).
- The Earth's atmosphere, hydrosphere and biosphere together weigh less than 0.05% of the Earth's total mass.
- Besides O_2, additional oxygen atoms are present in various forms spread throughout the surface reservoirs in the molecules of biomass, H_2O, CO_2, HNO_3, NO, NO_2, CO, H_2O_2, O_3, SO^2, H_2SO_4, MgO, CaO, AlO, SiO_2, and PO_4.

- **Atmosphere:**
- The Atmosphere is ~20.9% oxygen by volume which equates to a total of roughly $34x10^{18}$ mol of oxygen.
- Other oxygen containing molecules in the atmosphere include ozone (O_3), carbon dioxide (CO_2), water vapor (H_2O), and sulfur and nitrogen oxides (SO_2, NO, N_2O, etc.).
- **Biosphere:**
- The Biosphere is 22% oxygen by volume present mainly as a component of organic molecules ($C_xH_xN_xO_x$) and water molecules.
- The Hydrosphere is 33% oxygen by volume present mainly as a component of water molecules with dissolved molecules including free oxygen and carbonic acids (H_xCO_3).
- **Lithosphere -** is 46.6% oxygen by volume present mainly as silica minerals (SiO_2) and other oxide minerals.
- **Reservoir Dynamics:**

- Free Oxygen (O_2) from the atmosphere forms an equilibrium concentration by gas exchange with the hydrosphere as a dissolved gas in aqueous solution according to Henry's law.
- According to this law, O_2 saturates in water at 450µM at 0ºC and 270µM at 25ºC, but other dissolved solutes in seawater can reduce this saturation concentration.
- Oxygen concentrations in the hydrosphere can be influenced locally by the presence or absence of turbulent mixing or local production or consumption of O_2 by biological metabolism.
- Oxygen concentration in the soil and groundwater of the pedosphere(soil) is determined by gas diffusion through soil pore space in air and rainwater and can also be influenced locally by biological processes.
- Oxygen is cycled between the biosphere and lithosphere within the context of the calcium cycle, marine organisms in the biosphere create calcium carbonate shell material ($CaCO_3$) that is rich in oxygen.
- When the organism dies, its shell is deposited on the shallow seafloor and buried over time to create the limestone sedimentary rock of the lithosphere.
- Weathering processes initiated by organisms can also free oxygen from the lithosphere.
- Plants and animals extract nutrient minerals from rocks and release oxygen in the process.
- Seasonal high latitude O_2 level fluctuations of +/- 15 ppm in the northern hemisphere(half circle world) have been observed and attributed to seasonal cycles of primary production and respiration.
- Human combustion of fossil fuels has been linked to a measured decrease of around $1x10^{15}$ mol per year in O_2 concentrations in recent decades.



- **Sources and sinks:**
- While there are many abiotic sources and sinks for O_2, the presence of the abundant concentration of free oxygen in modern Earth's atmosphere and ocean is attributed to O_2 production from the biological process of oxygenic photosynthesis in combination with a biological sink known as the biological pump and a geologic process of carbon burial involving plate tectonics.
- Biology is the main driver of O_2 flux on modern Earth, and the evolution of oxygenic photosynthesis by bacteria, which is discussed as part of **The Great Oxygenation Event**, is thought to be directly responsible for the conditions permitting the development and existence of all complex eukaryotic metabolism.
- The main source of atmospheric free oxygen is photosynthesis, which produces sugars and free oxygen from carbon dioxide and water:

2.2. Carbon cycle:

- The circulation of carbon between organisms and environment is known as the carbon cycle.
- Carbon is an inevitable part of all biomolecules and is substantially impacted by the change in global climate.
- Cycling of carbon between organisms and atmosphere is a consequence of two mutual processes of photosynthesis and respiration.
- The releasing of carbon in the atmosphere increases due to burning of fossil fuels, deforestation, forest fire, volcanic eruption and decomposition of dead organic matters.
- Atmospheric carbon dioxide is the source of all carbon in both living organisms as well as in the fossils (used as fossil fuel).
- It is highly soluble in water. Oceans also contain large quantities of dissolved carbon dioxide and bicarbonates.
- The carbon cycle (Fig) comprises the following processes:

- **Photosynthesis**
- Terrestrial and aquatic plants utilize CO_2 for photosynthesis. Through this process the inorganic form of carbon is converted into organic matter in the presence of sunlight and chlorophyll.
- The carbon dioxide is thus fixed and assimilated by plants. It is partly used by them for their own life processes and the rest is stored as their biomass which is available to the heterotrophs as food.

- **Respiration**
- Respiration is a metabolic process reverse of photosynthesis in which food is oxidized to liberate energy (to perform the various life processes) and carbon dioxide and water.
- Thus the carbon dioxide of the atmosphere is recovered through this process.
- **Decomposition**
- After the death of the organisms the decomposers break down the remaining dead organic matter and release the left over carbon back into the atmosphere.
- **Combustion (burning)**
- Fossil fuel such as crude oil, coal, natural gas or heavy oils on burning releases carbon dioxide and carbon monoxide into the atmosphere.
- Forests make a large amount of fossil fuel. Fossil fuel is product of complete or partial decomposition of plants and animals as a result of exposure to heat and pressure in the earth's crust over millions of years.
- Forests also act like carbon reservoirs as carbon fixed by them cycles very slowly due to their long life.
- They release CO_2 by forest fires.

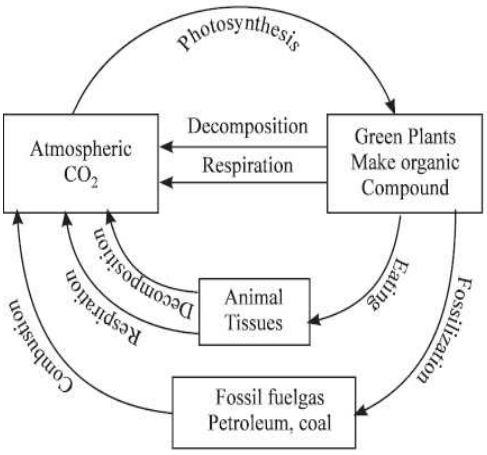
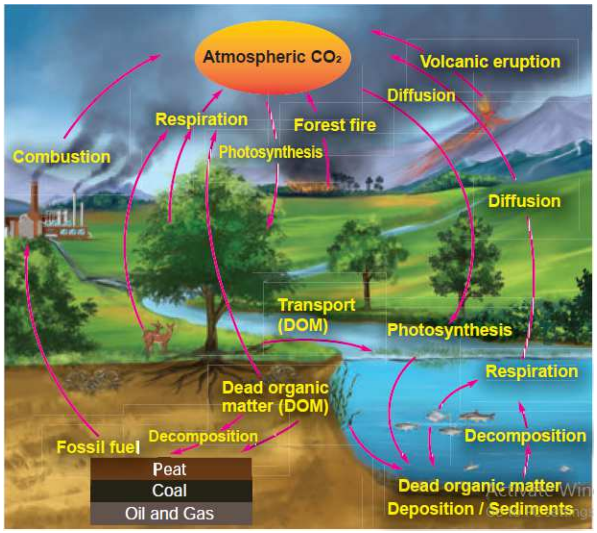


Fig. 25.18: Carbon cycle



2.3. Nitrogen cycle:

- ✓ The nitrogen cycle is the biogeochemical cycle by which nitrogen is converted into multiple chemical forms as it circulates among atmosphere, terrestrial, and marine ecosystems.
- ✓ The conversion of nitrogen can be carried out through both biological and physical processes.
- ✓ The majority of Earth's atmosphere (78%) is atmosphere nitrogen, making it the largest source of nitrogen.

- ✓ However, atmospheric nitrogen has limited availability for biological use, leading to a scarcity of usable nitrogen in many types of ecosystems.
- ✓ The nitrogen cycle is of particular interest to ecologists because nitrogen availability can affect the rate of key ecosystem processes, including primary production and decomposition.
- ✓ Human activities such as fossil fuel burning, use of artificial nitrogen fertilizers, and release of nitrogen in wastewater have dramatically altered the global nitrogen cycle.
- ✓ Human modification of global nitrogen cycle can negatively affect the natural environment system and also human health.

- ✓ Nitrogen is present in the environment in a wide variety of chemical forms including organic nitrogen, ammonium (NH^+_4), nitrite (NO^-_2), nitrate (NO^-_3), nitrous oxide (N_2O), nitric oxide (NO) or inorganic nitrogen gas (N_2).
- ✓ Organic nitrogen may be in the form of a living organism, humus or in the intermediate products of organic matter decomposition.
- ✓ The process in the nitrogen cycle is to transform nitrogen from one form to another.
- ✓ Many of those processes are carried out by microbes, either in their effort to harvest energy or to accumulate nitrogen in a form needed for their growth.
- ✓ For example, the nitrogenous wastes in animal urine are broken down by nitrifying bacteria in the soil to be used by plants.
- ✓ Nitrogen cycle consists of the following steps: **fixation, ammonification, nitrification, denitrification and sedimentation.**
- ✓
- ✓ **1. Nitrogen fixation**: Conversion of free nitrogen of atmosphere into the biologically acceptable form or nitrogenous compounds is referred to as nitrogen fixation. This process is of two types:
- ✓ (a) Physicochemical or non-biological nitrogen fixation
- ✓ (b) Biological nitrogen fixation.
- ✓ In physicochemical process of nitrogen fixation, atmospheric nitrogen combines with oxygen (as ozone) during lightning or electrical discharges in the clouds and produces different nitrogen oxides :

N_2, + 2(O) Electric = 2NO

2NO + 2 (O) Discharge = $2NO_2$,

2NO2 + (O) = $N_2 O_5$

- ✓ The nitrogen oxides get dissolved in rain water and on reaching earth surface they react with mineral compounds to form nitrates and other nitrogenous compounds :

$$N_2O_5 + H_2O = 2HNO_3$$

$$2HNO_3 + CaCO_2 = Ca(NO_3) + CO_2 + H_2O$$

- ✓ During combustion of various types, some nitrogenous compounds are formed which are washed down along with rain water.
- ✓ At high pressure and temperature, nitrogen and hydrogen react to form ammonia (industrial nitrogen fixation).

2. Biological nitrogen fixation: is carried out by certain Prokaryotes.

- ✓ Some blue-green algae fix significant amounts of nitrogen in the oceans, lakes and soils.
- ✓ Symbiotic bacteria (*Rhizobium*) inhabiting the root nodules of legumes and also the species of alder, buckbrush and a number of other non-leguminous genera and symbiotic blue-green algae (species of *Nostoc*, *Anabaena*, etc.) found in free state or in the thalli of *Anthoceros*, *Salvenia*, *Azolla*, coralloid roots of *Cycas* fix atmospheric nitrogen.
- ✓ The relation is mutualistic because the microbes use energy from the plants to fix nitrogen that is made available to the host plants and other plants of the community.
- ✓ Certain free living nitrogen fixing bacteria, such as *Azotobacter*, *Clostridium*, *Beijerinckia*, *Derxia*, *Rhdospirillium* also fix free nitrogen of atmosphere in the soil.
- ✓ *Frankia*, an actinomycetous fungus found in the roots of *Alnus*, *Percia*, *Casuarina*, etc. also fixes nitrogen.
- ✓ Nitrogen fixing organisms combine the gaseous nitrogen of atmosphere with hydrogen obtained from respiratory pathway to form ammonia which then reacts with organic acids to form aminoacids.
- ✓ Biological nitrogen fixation is the major source of fixed nitrogen upto 140-700 $mg/m^2/year$ as against $35mg/m^2/year$ by electrical discharge and photochemical fixation.

- ✓ **2. Nitrogen assimilation:** Inorganic nitrogen in the form of nitrates, nitrites and ammonia is absorbed by the green plants and converted into nitrogenous organic compounds.
- ✓ Nitrates are first converted into ammonia which combines with organic acids to form aminoacids.

- ✓ Aminoacids are used in the synthesis of proteins, enzymes, chlorophylls, nucleic acids, etc.
- ✓ Animals derive their nitrogen requirement from the plant proteins.
- ✓ Plant proteins are not directly utilized by the animals. They ale first broken down into amino acids during digestion and then the amino acids are absorbed
- ✓ and manipulated into animal proteins, nucleic acids, etc.

- ✓ **3. Ammonification**: The dead organic remains of plants and animals and excreta of animals are acted upon by a number of microorganisms especially actinomycetes and bacilli (*Bacillus ramosus*, *B. vulgaris*, *B. mesenterilus*).
- ✓ These organisms utilize organic compounds in their metabolism and release ammonia.

- ✓ **4. Nitrification**: Certain bacteria, such as *Nitrosomonas*, *Nitrococcus*, *Nitrosogloea* and *Nitrospira* in oceans and soils convert ammonia into nitrites and then nitrites into nitrates.
- ✓ These bacteria primarily use the energy of dead organic matter in their metabolism.

$$2NH_4^+ + 2O_2 = NO_2^- + 2H_2O + \text{energy}$$

- ✓ Conversion of nitrites to nitrates is brought about by several microbes like *Penicillium* species, *Nitrobacter*, *Nitrocystis* etc.
- ✓ *Nitrocystis oceanus* is the common marine autotroph which performs nitrification for obtaining energy.

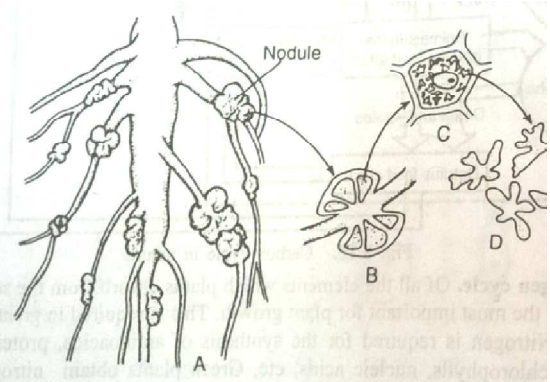
$$2NO_2^- + 2O_2 = NO_3^- + \text{energy}$$

- ✓ Some nitrates are also made available through weathering of nitrate containing rocks.
- ✓
- ✓ **5. Denitrification**. Ammonia and nitrates are converted into free nitrogen by certain microbes.
- ✓ This process is referred to as denitrification. *Thiobacillus denitrificans*, *Micrococcus denitrificans*, *Pseudomonas aeruginosa* are the common examples of denitrifying bacteria.

$$2NO^-_3 \text{ ----- } 2NO^-_2 \text{ ----- } 2NO \text{ ----- } N_2O \text{ ------} N_2$$

- ✓ 6. **Sedimentation**: Nitrates of the soil are washed down to the sea or leached deep into the earth along with percolating water.
- ✓ Nitrates thus lost from the soil surface are locked up in the rocks, this is sedimentation of nitrogen.
- ✓ Nitrogen of rock is released only when the rocks are exposed and weathered.

- ✓ Thus a large part of nitrogen is fixed up and stored in plants, animals, and microbes.
- ✓ Nitrogen leaves the living system in the same amount is taken in from the atmosphere and the input and outflow of nitrogen are balanced in the ecosystem.
- ✓ The overall nitrogen cycle in nature is presented in Figure.



. 3.16- Root nodules of a legume plant. A—Legume root with n
T.S. of root-nodule. C—Single cell of nodule. D—Nitr
bacterium, *Rhizobium*.

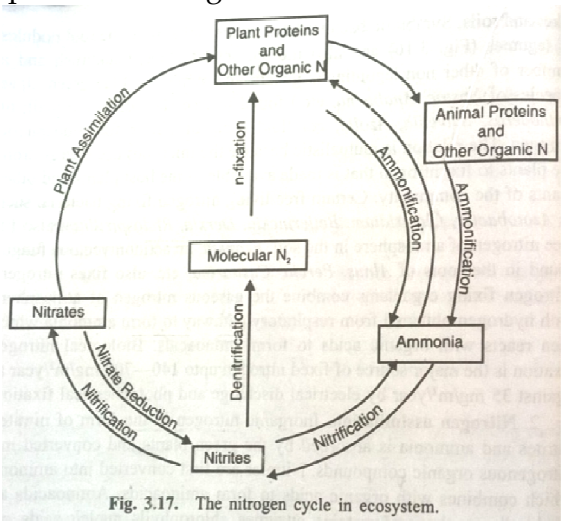


Fig. 3.17. The nitrogen cycle in ecosystem.

3. Sedimentary cycles:

- ➢ Mineral elements required by living organisms are obtained initially from inorganic sources.
- ➢ Available forms occur as salts dissolved in soil water.
- ➢ Mineral cycles essentially consist of two phases : (i) the salt solution phase, and (ii) rock phase.
- ➢ Mineral salts come directly from earth crust by weathering.
- ➢ Soluble salts then enter the water cycle.
- ➢ By movement of water minerals move from the soil to streams, lakes and ultimately to sea where they remain permanently.

- ➢ Other salts return to the earth's crust (outside) through sedimentation.
- ➢ They become incorporated into sediments or rock beds and after weathering of rocks they again enter the cycle.
- ➢ Plants and some animals take minerals in the form of mineral solution from their habitats.
- ➢ After the death of living organisms the nutrients return to the soil and water through the action of decomposers (bacteria and fungi) and transformers.
- ➢ Green plants at one end and decomposers at the other play very important role in circulation of nutrients.

3.1.Phosphorus cycle:

- Already we know that plants and animals obtain phosphorus from the environment.
- Phosphorus is a component of nucleic acid, found in the biomolecules like DNA, RNA, ATP, NADP and phospholipid molecules of living organisms.
- Phosphorus is not abundant in the biosphere, whereas a bulk quantity of phosphorus is present in rock deposits, marine sediments and guano (excrete materials from seabirds used as manure for plant).
- It is released from these deposits by weathering process.

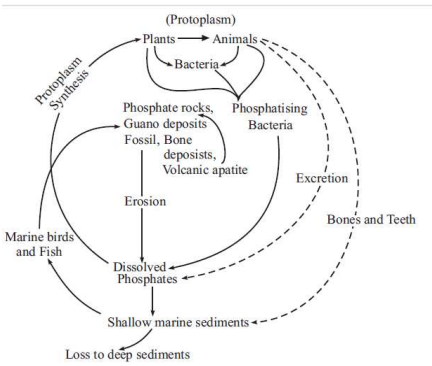
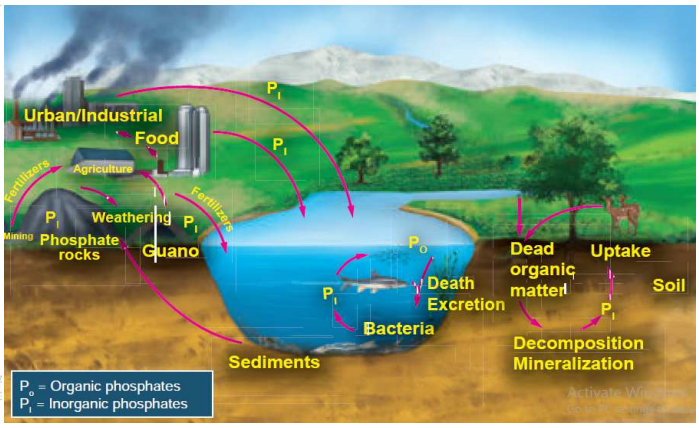


Fig. 25.9 Phosphorus Cycle



- After that, it circulates in lithosphere as well as hydrosphere.
- The producers absorb phosphorus in the form of phosphate ions, and then it is transferred to each trophic level of food chain through food.
- Again death of the organisms and degradation by the action of decomposers, the phosphorus is released back into the lithosphere and hydrosphere to maintain phosphorus cycle.

- Phosphorus along with many other mineral elements reaches the Oceans and settles down as sediment.
- A good proportion of phosphorus leaches down to deep layers of soil.
- In this way, major proportion of phosphate becomes lost to this cycle by physical processes, such as sedimentation and leaching.
- Biological processes such as formation of teeth and bones also keep phosphorus locked up for some time.

3.2 Sulphur Cycle.

- Sulphur cycle links soil, water and air.
- Sulphur occurs in the soil and rocks as sulphides (FeS, ZnS, etc.) and crystalline sulphates,

- In the atmosphere sulphur occurs in the form of SO_2 and H_2S. SO_2 gas is formed during combustion of fossil fuels or as a result of decomposition.
- H_2S or hydrogen sulphide gas is released to the atmosphere from water logged soils, continental layer, lakes and springs.
- The organic and inorganic sulphur and SO_2 are formed through oxidation of H_2S in the atmosphere.
- A small amount of sulphur occurs in dissolved state in rain water and through rains it reaches earth surface.
- Except a few organisms which need organic form of sulphur as amino acids and cystein, most of the organisms take sulphur as inorganic sulphates.
- Most of the biologically incorporated sulphur is produced in the soil from aerobic breakdown of proteins by bacteria and fungi.
- Under an aerobic condition, however, sulphur may be reduced directly to sulphides, including H_2S.

- $2H_2S + O2 \xrightarrow{\textit{Baggiatoa spp}} 2S + 2H_2CO$
- $2S + 2H_2O + 3O2 \xrightarrow[\text{Thio-oxidation}]{\textit{Thiobacillus}} 2H2SO_4$
- Green and purple photosynthetic bacteria use hydrogen of H_2S as the oxygen acceptor in reducing carbon dioxide.

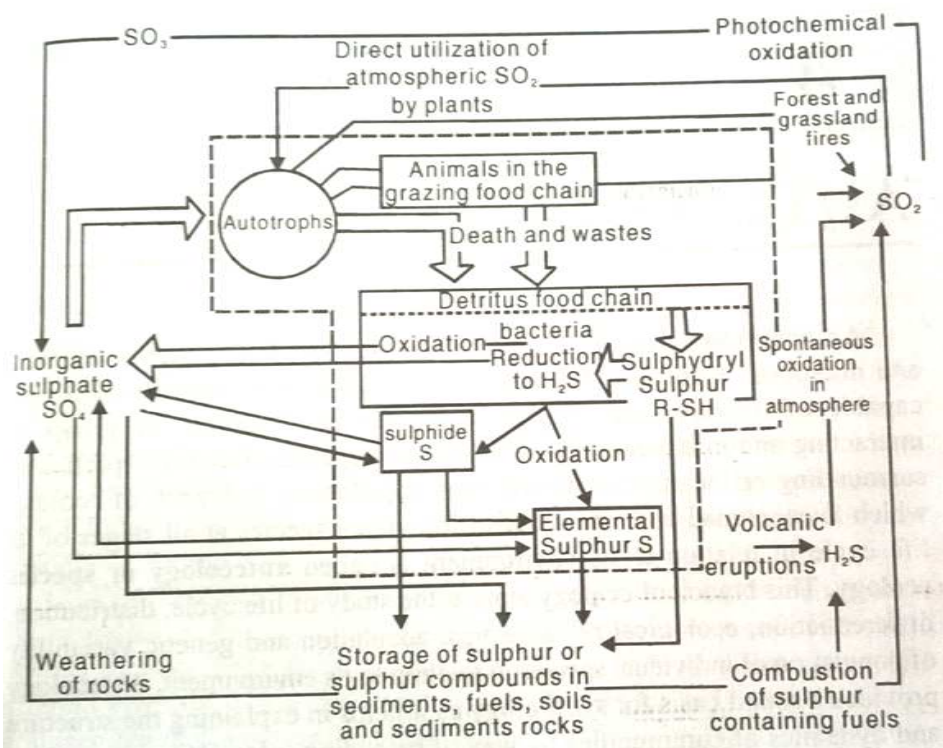


Fig. 3.19. Sulphur cycle. Organic phase is shown within broken lines.

- Green bacteria are able to oxidise sulphide to elemental sulphur whereas the purple bacteria can carry oxidation to sulphate stage.
- In the ecosystems, sulphur is transferred from autotrophs to animals, then to decomposers and finally it returns to environment through the decay of dead organic remains (Figure).
- Sedimentary aspect sulphur cycling involves precipitation of sulphur in presence of iron anaerobic conditions.
- Sulphides of iron copper, zinc, cadmium, cobalt are insoluble in neutral and alkaline water and consequently sulphur is bound to limit the amount of these elements.
- Thus, sulphur cycle affords an excellent example of interaction and complex biochemical regulation between the different mineral cycles.

- The study of biogeochemical cycles in the ecosystem makes it clear that the abiotic components of ecosystem are transformed into biotic structures through metabolic processes and locked up in the biomass for some time depending upon the return rate.
- In lower plants with soft tissues the return rate is quicker than in higher plants and animals.
- The materials held up in the biomass are released to the environment by decomposing activities.

- The nutrient cycle is not a close circuit within an ecosystem.
- The nutrients are continuously being imported as well as carried out of the ecosystem.
- Appreciable quantities of plant nutrients are brought to ecosystem by rain and snow.
- Small quantity of nutrients is carried to the forest by rains.
- The gain of nutrients to the ecosystem from precipitation (rainfall),extraneous material and mineral weather conditions is balance by losses.
- Water draining away from forest carries with it more mineral matter than supplied through precipitation.
- Considerable quantities of nutrients in the forest are locked up in the trees and the humus layer.
- When trees and vegetation are removed, sufficient amounts of nutrient are removed.
- Intensive forestry and agriculture on some soils may reduce the nutrient reserves to such an extent that soils become unfertile.
- Ecosystem can remain productive only if the nutrients withdrawn are balanced by an inflow or replacement.

- **QUESTIONS**
- What is ecosystem? What are the various components of ecosystem.
- What are the major ecosystems of the world? Describe forest and pond ecosystems in detail.
- What is meant by energy flow in an ecosystem? What are the laws of thermodynamics?
- Write short notes on the following: Producers, Food chain and Food web, Ecological pyramids, Hydrologic cycle, Nitrogen cycle, Productivity, Ecological niches.
- Describe various Biogeochemical cycles occurring in nature.

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