Bio-geochemical cycles
with special reference to Carbon Dioxide and Nitrogen

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Bio-geochemical Cycles

Introduction: The life on the earth depends upon the availability of energy and circulation of some 33 to 40 elements which plants and animals require for their normal growth and development. These elements or nutrients are termed as, biogenic salts and are of two types - the macronutrients and the micronutrients. The macronutrients include elements and their compounds that play a key role in the protoplasm and are required in relatively larger quantities such as carbon, nitrogen, oxygen, potassium, calcium, magnesium, phosphorus, etc. The micronutrients and their compounds are also very essential for the various activities of animals and plants but these are required in trace amounts, as is the case of iron, zinc, copper, sodium, molybdenum, cobalt, strontium, boron, etc. So it is important to consider the movement of these nutrients in the ecosystem. Their movement is cyclic one. These materials flow from non-living to the living, and back to the non-living, in a more or less circular path, called as the biogeochemical cycle (bio for living; geo for water, rocks and soil; chemical for the process involved). For the working of any type of ecosystem the cycling of these materials is necessary. Some of these elements are returned as fast as they are removed, some are stored in short term nutrient pools, others may be tied chemically or buried deep in the earth for long periods of time in long term nutrient pools.

Definition: A biogeochemical cycle may be defined as *'the more or less circular path which brings about the circulation of chemical elements, including all essential elements of protoplasm, from environment to organisms and back to the environment'*.

Kinds of biogeochemical cycles: From the standpoint of view of the biosphere as a whole, the biogeochemical cycles fall into two groups. (1) The gaseous types include carbon cycle, nitrogen cycle, and oxygen cycle. In gaseous types the air is a great reservoir and regulates the cycles.
(ii) The sedimentary types include the sulphur cycle and phosphorus cycle; in these cycles the reservoir is in the earth's crust.
Both these types involve the biological and non-biological agents and in both the water are needed.

Carbon Cycle

Carbon is a basic component of all organic compounds, the building material of which all living things are constructed. Carbon is present in a variety of carbohydrates, fats, proteins and nucleic acids. The carbon cycle is essentially a perfect cycle in the sense that carbon is returned to the environment about as fast as it is removed; it is an example of gaseous cycle as it involves a gaseous phase - the atmospheric carbon dioxide. The basic movement of carbon is from the atmospheric reservoir to producers, to consumers and from both these groups to decomposers, and then back to the reservoir i.e., the atmosphere. In atmosphere the concentration of carbon dioxide is about 0.03

- 0.04 percent. The main source of all carbon found in the living organisms is free atmospheric carbon dioxide and dissolved carbon dioxide in water.

The main stores of carbon are the sedimentary rocks, fossil fuels (coal, petroleum and natural gas), oceans and biosphere.

Carbon goes primarily through three cycles with different time constraints:

- a long-term cycle linking the sediments and the lithospheric depths;
- a cycle involving the atmosphere and the lithosphere; and
- a cycle relating the air and the oceans.

The cycles 2 and 3 are faster and subjected to anthropogenic interference.

Carbon cycle 1 - between air, oceans and sediments: This cycle occurs between air, oceans and sediments and entails a sluggish dissolution of carbon in the air and rock carbons by weathering into the oceans. Oceans contain huge deposits of carbon as calcium carbonate deposits. The carbon in the sediments dissolves slowly and some of the sediments are reverted into the air in the course of volcanic eruption. This cycle is extremely long and takes over hundreds of millions of years.

Carbon cycle 2 - between air and land: This cycle between the atmosphere and biosphere may range from few days to decades. Carbon dioxide serves is the basic food ingredient to the living beings and thus the biosphere plays an instrumental role in this cycling. Plants fix atmospheric carbon through photosynthesis. The chemical i.e. carbohydrate ($C_6H_{12}O_6$) may be represented as:

$$CO_2 + H_2O \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} C_6H_{12}O_6 + H_2O$$

Simple sugars are assimilated to form complex substances like starch and cellulose. Plants are consumed by animals; part of it is respired as CO2 and part turned into animal tissue. When plants and animals die they form detritus and most of it is decomposed into inorganic forms. Over millions of years, fossil fuels are formed as partially decomposed matter. Combustion of fossil fuels adds CO_2 to the air. Respiration of plants and animals also releases CO_2 in the air.

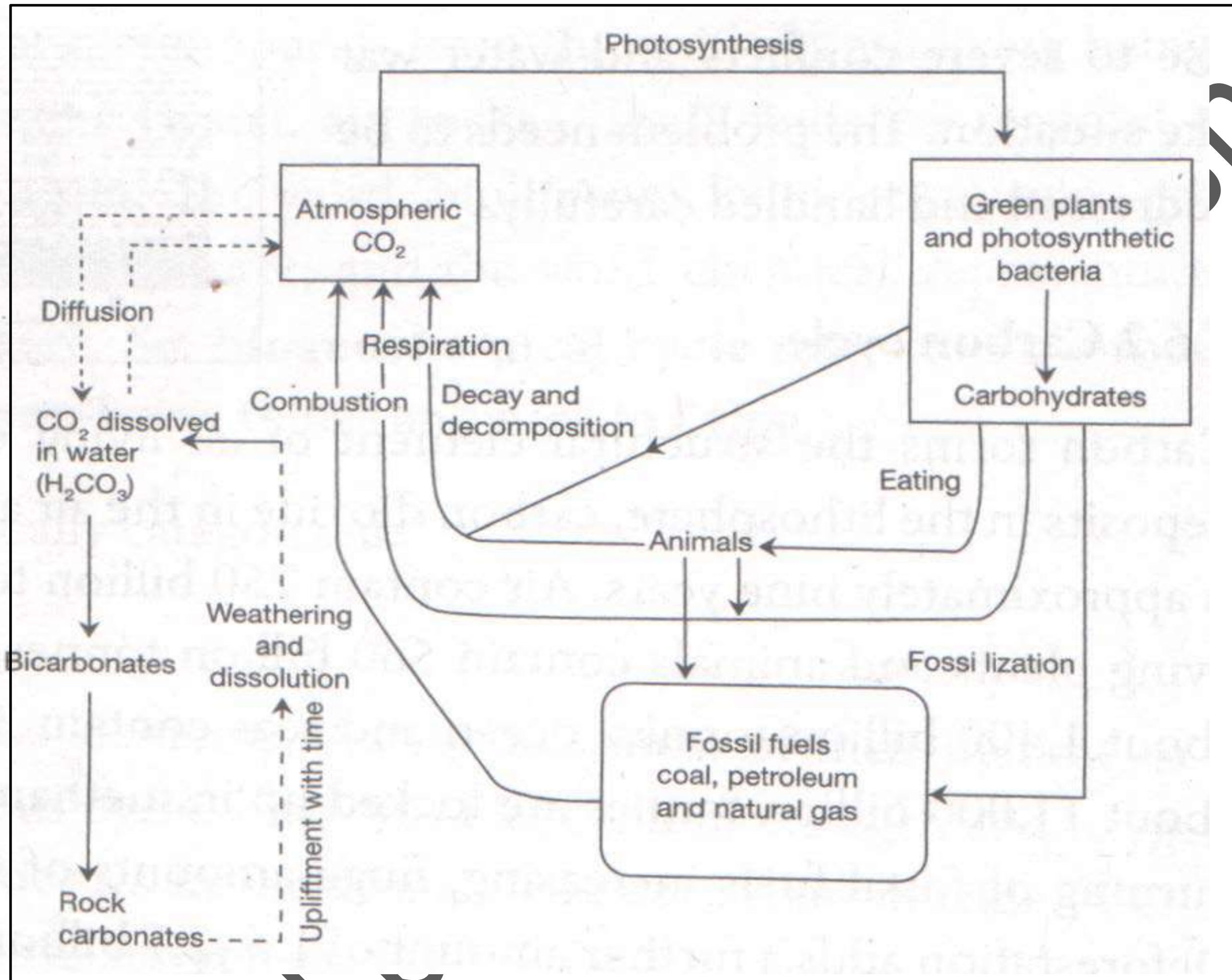
Carbon cycle 3 - air and sea cycle: Oceans are vast deposits of carbon. Over thousands of year the carbonates of the rocks dissolve and makes up the oceanic biomass. Small portion of carbon in the sea is found in the form of Calcium Carbonate ($CaCO_3$). CO_2 reacts with water to form carbonate in the following steps of reaction –

$$CO_2 + H_2O \longrightarrow \underset{\text{Carbonic Acid}}{H_2CO_3} \longrightarrow \underset{\text{Bicarbonate}}{H^+ + HCO_3^-} \longrightarrow \underset{\text{Carbonate}}{2\,H^+ + CO_3^{--}}$$

$CaCO_3$ is very commonly used by oysters, clams, protozoa and some algae for shell construction. They can combine carbonate or bicarbonate with calcium dissolved in water to form $CaCO_3$. After the death of the animals this $CaCO_3$ may either dissolve or remain in the sedimentary form.

The summary of the three cycles together is shown in Figure 1.

Figure 1: Three carbon cycles integrated



Human impacts: Human intrusion into the carbon cycle is significant. As we will see shortly, we are diverting or removing 40% of the photosynthetic effort of land plants in order to support human enterprises. By burning fossil fuels, we have increased atmospheric carbon dioxide by 35% over preindustrial levels. In addition, the Millennium Ecosystem Assessment reports that until the mid-20th century, deforestation and soil degradation released significant amounts of CO_2 to the atmosphere. However, more recent reforestation and changed agricultural practices have improved this somewhat.

Nitrogen Cycle

Nitrogen is an essential element in the living substances like proteins and nucleic acids. Though the atmosphere air contains 79 per cent nitrogen, yet most of the plants and animals cannot make use of the gaseous nitrogen. Animals must have their nitrogen in the form of amino acids and pants in the form of soluble nitrogen salts like nitrates. From the nitrogen of soluble salts, plants manufacture their proteins and amino acids.

Nitrogen is inert in the air. All living organisms want considerable amounts of nitrogen for sustenance. Neither plants nor animals are able to fix atmospheric nitrogen. Nitrogen from the air is fixed by three processes.

- by microbes;
- by lightning; and
- by Haber's process.

Microbial fixation can be symbiotic or asymbiotic. Symbiotic fixation is between the leguminous plants like peas, beans, alfalfa, clover and the symbiotic bacteria like *Rhizobium. Rhizobium* traps atmospheric nitrogen, converts it into nitrates and gives it to the plants. The plants give finished food to the bacteria. Symbiotic fixation is mediated by blue green algae like *Nostoc* and *Anabaena*.

Lightning momentarily raises the temperature causing the atomic nitrogen and oxygen to react together form nitrogen monoxide and further into nitrogen dioxides. The oxide dissolves in water to form nitric acid and nitrous acid and reach the soil. These acids join with the potassium and calcium salts of the soil and are converted into calcium and potassium nitrites and nitrates.

$$N_2 + O_2 \xrightarrow[\text{discharge}]{\text{Electric}} 2NO \text{ (Nitric oxide)}$$

$$2NO + O_2 \longrightarrow 2NO_2 \text{ (Nitrogen dioxide)}$$

$$2NO_2 + H_2O \longrightarrow HNO_2 + HNO_3$$

In industry, nitrogen and hydrogen is combined under controlled temperature and pressure and in presence of catalyst to form ammonia. The process is known as Haber's process.

$$NH_3 + H^+ \longrightarrow \underset{\text{Ammonium ions}}{NH_4^+}$$

Plants take up soluble nitrates from the soil, along with other minerals, and utilize them to build up plant tissues. Animals in turn get their nitrogen requirement by nourishing on plants. Plant and animal wastes and their dead remains are transformed into ammonia by the process of ammonification with the help of *Clostridium*. The use of fertilizers like ammonium nitrate is to compensate for the nitrogen deficit in the soil. Ammonia undergoes the process of nitrification in two steps aided by soil bacteria. In the first step, *Nitrosomonas* converts ammonia into nitrite and subsequently in the second step, *Nitrobacter* converts nitrite into nitrates.

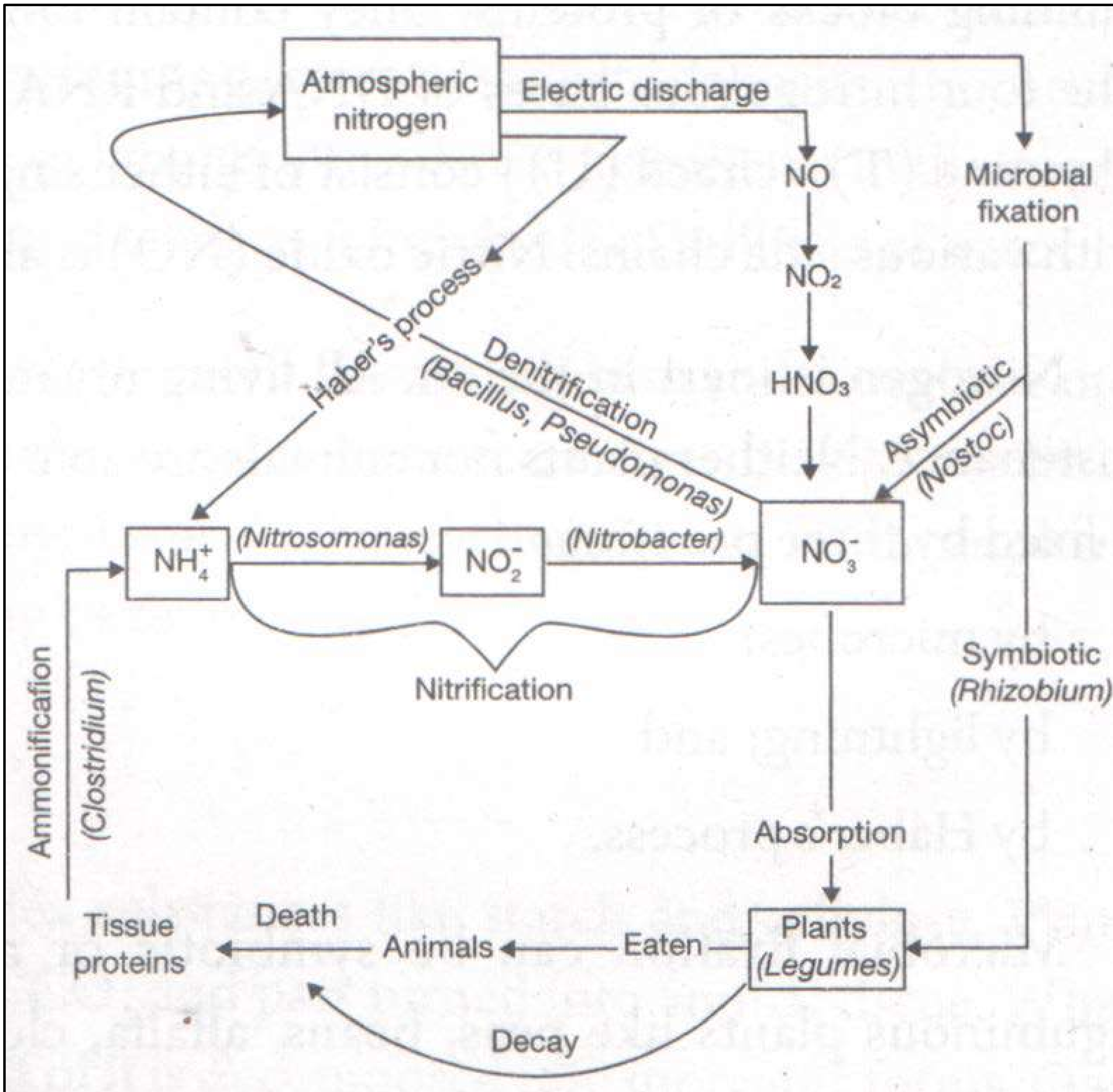
$$2NH_4^+ + 3O_2 \xrightarrow{\textit{Nitrosomonas}} 2NO_2^- + 2H_2O + 4H^+$$

$$2NO_2^- + O_2 \xrightarrow{\textit{Nitrobacter}} 2NO_3^- + \text{Energy}$$

Nitrates are then be easily taken up by the plants with the help of plant roots. Denitrifying bacteria like *Bacillus* convert the nitrates back into elemental nitrogen making it unavailable once again.

$$\underset{\text{Nitrate ions}}{2NO_3^-} \xrightarrow{-2[O]} \underset{\text{Nitrite ions}}{2NO_2^-} \xrightarrow{-2[O]} \underset{\text{Nitric oxide}}{2NO} \xrightarrow{-2[O]} \underset{\text{Nitrous oxide}}{N_2O} \xrightarrow{-2[O]} \underset{\text{Elemental Nitrogen}}{N_2}$$

Figure 2: The nitrogen cycle



Human impacts: Human involvement in the nitrogen cycle is substantial. Many agricultural crops are legumes (peas, beans, soybeans, alfalfa), so they draw nitrogen from the air, thus increasing the rate of nitrogen fixation on land. Crops that are non-leguminous (corn, wheat, potatoes, cotton and so on) are heavily fertilized with nitrogen derived from industrial fixation. Both processes benefit human welfare profoundly. Also, fossil fuel combustion fixes nitrogen from the air. In effect, we are more than doubling the rate at which nitrogen is moved from the atmosphere to the land.

The consequences of this global nitrogen fertilization are serious. Nitric acid (and sulfuric acid, produced when sulfur is also released by burning fossil fuels) has destroyed thousands of lakes and ponds and caused extensive damage to forests. Nitrogen oxides in the atmosphere contribute to ozone pollution, global climate change and stratospheric ozone depletion. The surplus nitrogen has led to “nitrogen saturation” of many natural areas, whereby the nitrogen can no longer be incorporated into living matter and is released into the soil. There it leaches cations (positively charged mineral ions) such as calcium and magnesium from the soil, which leads to mineral deficiencies in trees and other vegetation. Washed into surface waters, the nitrogen makes its way to estuaries and coastal areas of oceans, where, just like phosphorus, it triggers a series of events leading to eutrophication, resulting in dead seafood, harmful effects on human health and areas of the ocean that ate unfit for fish. This complex of ecological effects has been called the nitrogen cascade, in recognition of the sequential impacts of Nr as it moves through environmental systems, creating problems as it goes.

References:

1. *Concepts of Ecology by R.L. Kotpal and N.P. Bali*
2. *Environmental Science by R. T. Wright and D.F. Boorse*
3. *Fundamentals of Environmental Studies by M. Basu and S. Xavier*