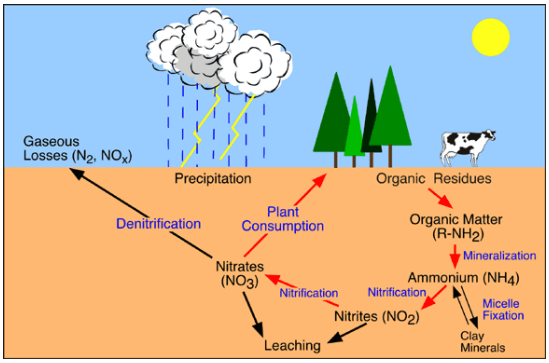
Nitrogen Cycle



Definition: Nitrogen cycle

- The nitrogen cycle is the biogeochemical cycle that describes the transformations of nitrogen and nitrogen-containing compounds in nature.
- It is a cycle which includes gaseous components

Importance of Nitrogen

- All life requires nitrogen-compounds, e.g., Proteins and nucleic acids.
- Air, which is 79% nitrogen gas (N_2), is the major reservoir of nitrogen.
- But most organisms cannot use nitrogen in this form.

The Processes of the nitrogen cycle

- Conversion of N_2 - fixation
- Assimilation
- Ammonification
- Nitrification
- Denitrification
- Anaerobic ammonium oxidation

Conversion of N_2

- The conversion of nitrogen (N_2) from the atmosphere into a form readily available to plants and hence to animals and humans is an important step in the nitrogen cycle, that determines the supply of this essential nutrient.
- There are four ways to convert N_2 (atmospheric nitrogen gas) into more chemically reactive forms
  - Biological fixation
  - Industrial nitrogen fixation
  - Combustion of fossil fuels
  - Other processes e.g. lightning

Assimilation

- Plants can absorb nitrate or ammonium ions from the soil via their root hairs.
- If nitrate is absorbed, it is first reduced to nitrite ions and then ammonium ions for incorporation into amino acids,proteins, nucleic acids (DNA), and chlorophyll

Ammonification

- When a plant or animal dies, or an animal excretes, the initial form of nitrogen is organic.
- Bacteria, or in some cases, fungi, convert the organic nitrogen within the remains back into ammonia, a process called ammonification or mineralization.

Amino acids + $1^1/_2O_2 \rightarrow CO_2 + H_2O + NH_3$

$CO(NH_2)_2$ (urea) $\xrightarrow[\text{soil enzymes \& } H_2O]{} NH_3 + CO_2 + H_2O$

Nitrification

- The conversion of ammonia to nitrates is performed primarily by soil-living bacteria and other nitrifying bacteria.
- The primary stage of nitrification, the oxidation of ammonia (NH_3) is performed by bacteria such as the *Nitrosomonas* species, which converts ammonia to nitrites (NO_2^-).
- Other bacterial species, such as the *Nitrobacter*, are responsible for the oxidation of the nitrites into nitrates (NO_3^-).
- Nitrites need to be converted to nitrates because accumulated nitrites are toxic to plant life

Nitrification…

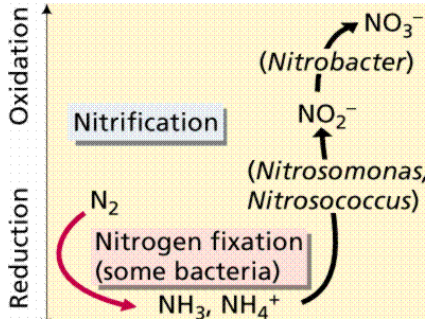
- This involves two oxidation processes
- The ammonia produced by ammonification is an energy rich substrate for ***Nitrosomas*** bacteria
- They oxidise it to nitrite:

$$NH_3 + 1^1/_2O_2 \rightarrow NO_2^- + H_2O$$

- This in turn provides a substrate for ***Nitrobacter*** bacteria oxidise the nitrite to nitrate:

$$NO_2^- + {}^1/_2O_2 \rightarrow NO_3^-$$

Nitrification…



Denitrification

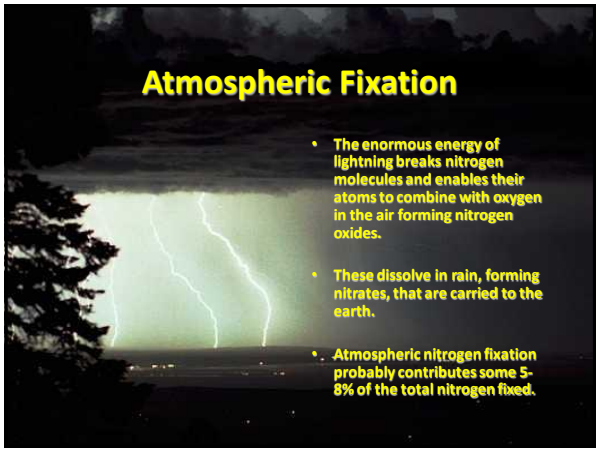
- Denitrification is the reduction of nitrates back into the largely inert nitrogen gas (N_2), completing the nitrogen cycle.
- This process is performed by bacterial species such as *Pseudomonas* and *Clostridium*.
- They live deep in soil and in aquatic sediments where conditions are anaerobic. These anaerobic bacteria can also live in aerobic conditions

Anaerobic ammonium oxidation

- In this biological process, nitrite and ammonium are converted directly into dinitrogen gas.
- This process makes up a major proportion of dinitrogen conversion in the oceans.

Conversion of N_2 (Nitrogen fixation)

- Nitrogen fixation is the process by which nitrogen is taken from its relatively inert molecular form (N_2) in the atmosphere and converted into nitrogen compounds such as:
- Ammonia (NH_3),
- nitrate (NO_3^-) and
- nitrogen dioxide (NO_2)



Atmospheric Fixation…

Lightning causes reaction with O_2 to form NO_3^- as follows:

- When a voltage of 30,000 volts passes through the air, nitric oxide is formed.

$$N_2 + O_2 \text{ ----> } 2\ NO$$

- This nitric oxide is next oxidised to nitrogen peroxide by atmospheric oxygen

$$2NO + O_2 \text{ ----> } 2\ NOO$$

Atmospheric Fixation…

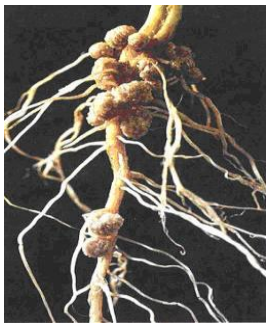
- This peroxide when washed with rain water comes down as nitric acid, HNO_3 and is introduced into the soil.

$$NOO + H_2O \rightarrow 2HNO_3$$

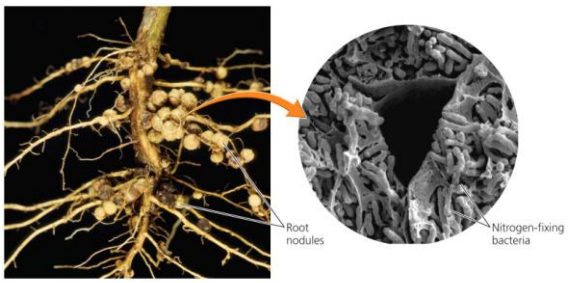
- This nitric acid reacting with $CaCO_3$, K_2CO_3, $(NH_4)_2CO_3$ are converted respectively to $Ca(NO_3)_2$, KNO_3 and NH_4NO_3.
- E.g. $2HNO_3 + K_2CO_3 \rightarrow 2KNO_3 + CO_2 + H_2O$
- Annually, 100 million tons of nitric acid are produced by lightning.

Biological Fixation

- The ability to fix nitrogen is found only in certain bacteria.
- Some symbiotic bacteria (most often associated with leguminous plants) and some free-living bacteria are able to fix nitrogen as organic nitrogen.
- An example of mutualistic nitrogen fixing bacteria are the *Rhizobium* bacteria, which live in legume root nodules.
- An example of the free-living bacteria is *Azotobacter*



Biological Fixation ….



Industrial Fixation

- Under great pressure, at a temperature of 600°C, and with the use of a catalyst, atmospheric nitrogen and hydrogen (usually derived from natural gas or petroleum) can be combined to form ammonia (NH_3).
- The Haber-Bosch Process

$$\mathbf{N_2 + 3H_2 \rightarrow 2NH_3}$$

- Ammonia can be used directly as fertilizer, but most of its is further processed to urea and ammonium nitrate (NH_4NO_3).