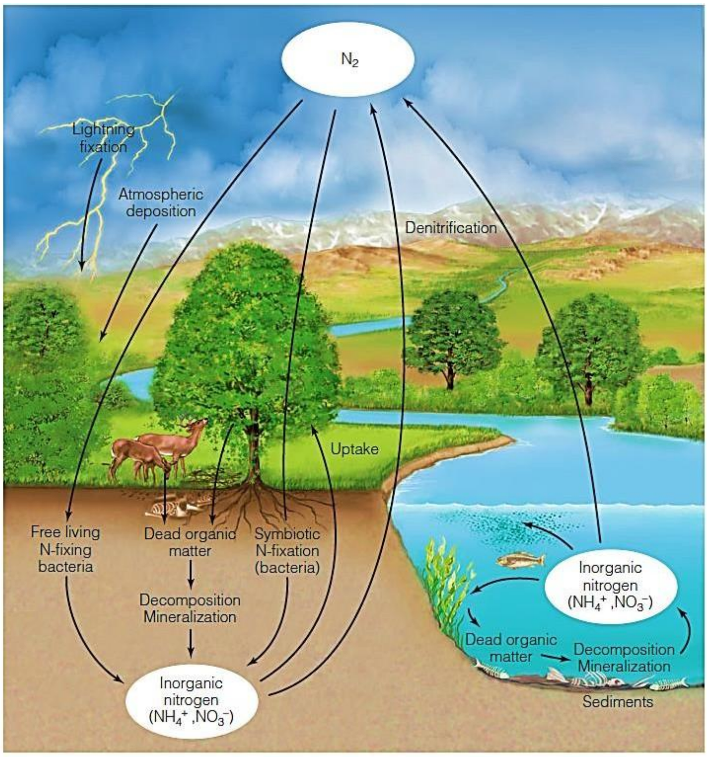
UG CBCS Semester-IV (MJC-7: Ecology)
Nitrogen Cycle

The Nitrogen Cycle Begins with Fixing Atmospheric Nitrogen

Nitrogen is an essential constituent of protein, which is a building block of all living tissue. Nitrogen is generally available to plants in only two chemical forms: ammonium (NH_4^+) and nitrate (NO_3^-). Thus, although Earth's atmosphere is almost 80 percent nitrogen gas, it is in a form (N_2) that is not available for uptake (assimilation) by plants. Nitrogen enters the ecosystem via two pathways, and the relative importance of each varies greatly among ecosystems. The first pathway is atmospheric deposition. This can be in wet fall—such as rain, snow, or even cloud and fog droplets—and in dry fall, such as aerosols and particulates. Regardless of the form of atmospheric deposition, nitrogen in this pathway is supplied in a form that is already available for uptake by plants.

The second pathway for nitrogen to enter ecosystems is via **nitrogen fixation.** This fixation comes about in two ways. One is high-energy fixation. Cosmic radiation, meteorite trails and lightning provide the high energy needed to combine nitrogen with the oxygen and hydrogen of water. The resulting ammonia and nitrates are carried to Earth's surface in rainwater. Estimates suggest that less than 0.4 kg N/ha comes to Earth annually in this manner. About two-thirds of this amount is deposited as ammonia and one-third as nitric acid (HNO_3).

The second method of fixation is biological. This method produces approximately 10 kg N/yr for each hectare of Earth's land surface, or roughly 90 percent of the fixed nitrogen contributed each year. This fixation is accomplished by symbiotic bacteria living in mutualistic association with plants, by free-living aerobic bacteria, and by cyanobacteria (blue-green algae). Fixation splits molecular nitrogen (N_2) into two atoms of free N. The free N atoms then combine with hydrogen to form two molecules of ammonia (NH_3) The process of fixation requires considerable energy. To fix 1 g of nitrogen, nitrogen-fixing bacteria associated with the root system of a plant must expend about 10 g of glucose, a simple sugar produced by the plant in photosynthesis. In agricultural ecosystems, *Rhizobium* bacteria associated with approximately 200 species of leguminous plants are the preeminent nitrogen fixers. In nonagricultural systems, some 12,000 species, from cyanobacteria to nodule-bearing plants, are responsible for nitrogen fixation.



The nitrogen cycle in terrestrial and aquatic ecosystems.

Also contributing to the fixation of nitrogen are free-living soil bacteria, the most prominent of the 15 known genera being the aerobic *Azotobacter* and the anaerobic *Clostridium.* Cyanobacteria (blue-green algae) are another important group of largely nonsymbiotic nitrogen fixers. Of some 40 known species, the most common are in the genera *Nostoc* and *Calothrix,*

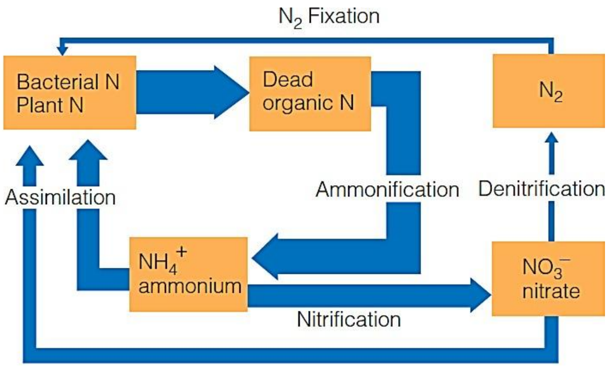


Figure 23.7 Bacterial processes involved in nitrogen cycling.

which are found in soil as well as in aquatic habitats. Certain lichens (*Collema tunaeforme* and *Peltigera rufescens*) are also involved in nitrogen fixation. Lichens with nitrogen-fixing ability possess nitrogen-fixing cyanobacteria as their algal component.

Ammonium in the soil can be used directly by plants. In addition to atmospheric deposition, NH_4^+ occurs in the soil as a product of microbial decomposition of organic matter wherein NH3 is released as a waste product of microbial activity. This process is called **ammonification**. Most soils have an excess of H^+ (slightly acidic) and the NH_3 is rapidly converted to ammonium (NH_4^+). Interestingly, because NH^3 is a gas, the transfer of nitrogen back to the atmosphere (volatilization) can occur in soils with a pH close to 7 (neutral)—a low concentration of H^+ ions to convert ammonia to ammonium. Volatilization can be especially pronounced in agricultural areas where both nitrogen fertilizers and lime (to decrease soil acidity) are used extensively.

In some ecosystems, plant roots must compete for NH_4^+ with two groups of aerobic bacteria, which use it as part of their metabolism. The first group (*Nitrosomonas*) oxidizes NH_4^+ to NO_2, and a second group (Nitrobacter*)* oxidizes NO_2^- to NO_3^-. This process is called **nitrification**. Once nitrate is produced, several things can happen to it. First, plant roots can take it up. Second, **denitrification** can occur under anaerobic ("lacking oxygen") conditions, when another group of bacteria (*Pseudomonas*) chemically reduces NO_3^- to N_2O and N_2. These gases are then returned to the atmosphere. The anaerobic conditions necessary for denitrification are generally rare in most terrestrial ecosystems (but can occur seasonally). These conditions, however, are common in wetland ecosystems and in the bottom sediments of open-water aquatic ecosystems.

Finally, nitrate is the most common form of nitrogen exported from terrestrial ecosystems in stream water although in undisturbed ecosystems the amount is usually quite small because of the great demand for nitrogen. Indeed, the amount of nitrogen recycled within the ecosystem is usually much greater than the amount either entering or leaving the ecosystem through inputs and outputs. Because both nitrogen fixation and nitrification are processes mediated by bacteria, they are influenced by various environmental conditions, such as temperature and moisture. However, one of the more important factors is soil pH. Both processes are usually greatly limited in extremely acidic soils due to the inhibition of bacteria under those conditions.

Inputs of nitrogen can vary, but the internal cycling of nitrogen is fairly similar from ecosystem to ecosystem. The process involves the assimilation of ammonium and nitrate by plants and the return of nitrogen to the soil, sediments, and water via the decomposition of dead organic matter.

The global nitrogen cycle follows the pathway of the local nitrogen cycle presented earlier, only on a grander scale. The atmosphere is the largest pool, containing 3.9×10^{21} g. Comparatively small amounts of nitrogen are found in the biomass (3.5×10^{15} g) and soils (95×10^{15} to 140×10^{15} g) of terrestrial ecosystems. Global estimates of denitrification in terrestrial ecosystems vary widely but are of the order 200×10^{12} g/yr, and more than half of that total occurs in wetland ecosystems. Major sources of nitrogen for to the world's oceans are dissolved forms in the freshwater drainage from rivers (36×10^{12} g/yr) and inputs in precipitation (30×10^{12} g/yr). Biological fixation accounts for another 15×10^{12} g/yr. Denitrification accounts for an estimated flux of 110×10^{12} g N/yr from the world's oceans to the atmosphere. There also are small but steady losses from the biosphere to the deep sediments of the ocean and to sedimentary rocks. In return, there is a small addition of new nitrogen from the weathering of igneous rocks and from volcanic activity. Human activity has significantly influenced the global nitrogen cycle. Major human sources of nitrogen input are agriculture, industry, and automobiles; in recent decades, anthropogenic inputs of nitrogen into aquatic and terrestrial ecosystems have been a growing cause of concern. The first major intrusion probably came from agriculture, when people began burning forests and clearing land for crops and pasture. Heavy application of chemical fertilizers to croplands disturbs the natural balance between nitrogen fixation and denitrification, and a considerable portion of nitrogen fertilizers is lost as nitrates to groundwater and runoff that find their way into aquatic ecosystems. Automobile exhaust and industrial high-temperature combustion add nitrous oxide (N_2O) nitric oxide (NO), and nitrogen dioxide (NO_2) to the atmosphere. These oxides can reside in the atmosphere for up to 20 years, drifting slowly up to the stratosphere. There, ultraviolet light reduces nitrous oxide to nitric oxide and atomic oxygen (O). Atomic oxygen reacts with oxygen (O_2) to form ozone (O_3).

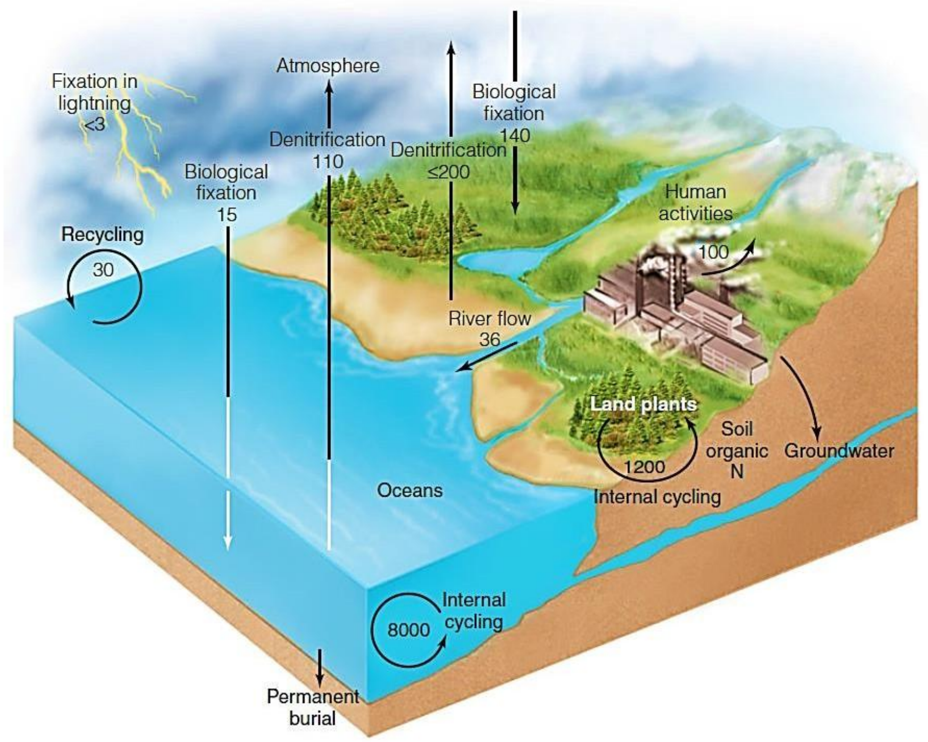


Figure 23.8 The global nitrogen cycle. Each flux is shown in units of 10^{12} g N/yr. (Adapted from Schlesinger 1997.)