Lecture in microbiology: Soil microbiology

Environmental Microbiology

Soil microbiology: الاحياء المجهريه في التربه

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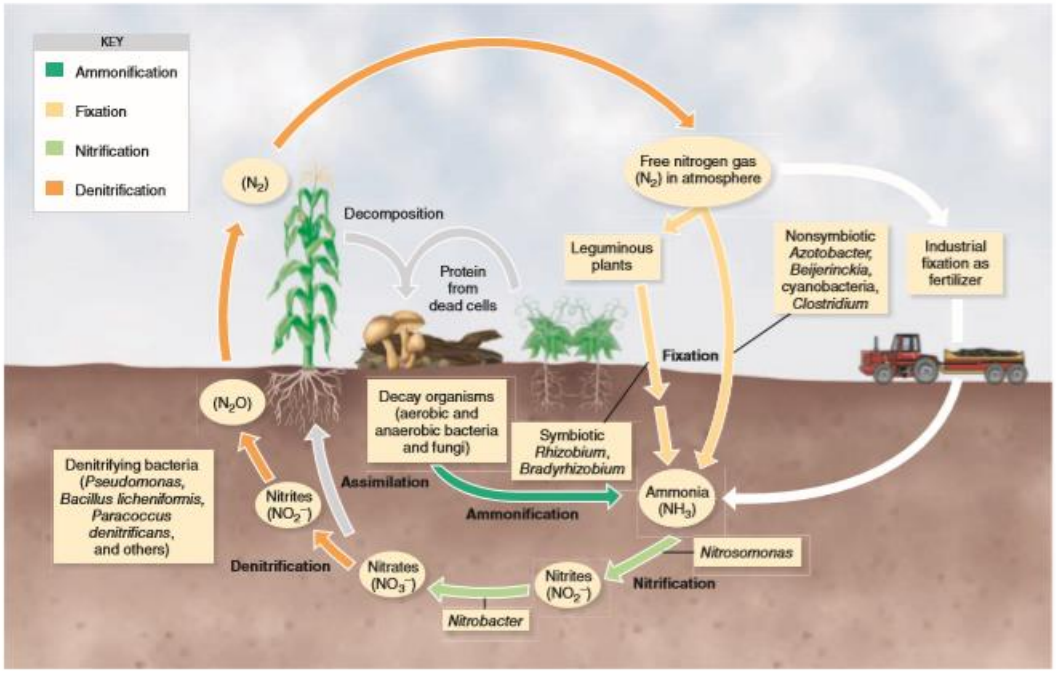


Figure 27.4 The nitrogen cycle. In general, nitrogen in the atmosphere goes through fixation, nitrification, and denitrification. Nitrates assimilated into plants and animals after nitrification go through decomposition, ammonification, and then nitrification again.

Q Which processes are performed exclusively by bacteria?

coal and petroleum. Burning these fossil fuels releases CO_2, increasing the amount of CO_2 in the atmosphere. Many scientists believe the increased atmospheric carbon dioxide may be causing a **global warming** of the Earth.

An interesting aspect of the carbon cycle is methane (CH_4) gas. Sediments on the ocean floor contain an estimated 10 trillion tons

The Nitrogen Cycle

The **nitrogen cycle** is shown in Figure 27.4. All organisms need nitrogen to synthesize protein, nucleic acids, and other nitrogen-containing compounds. Molecular nitrogen (N_2) makes up almost 80% of the Earth's atmosphere. For plants to

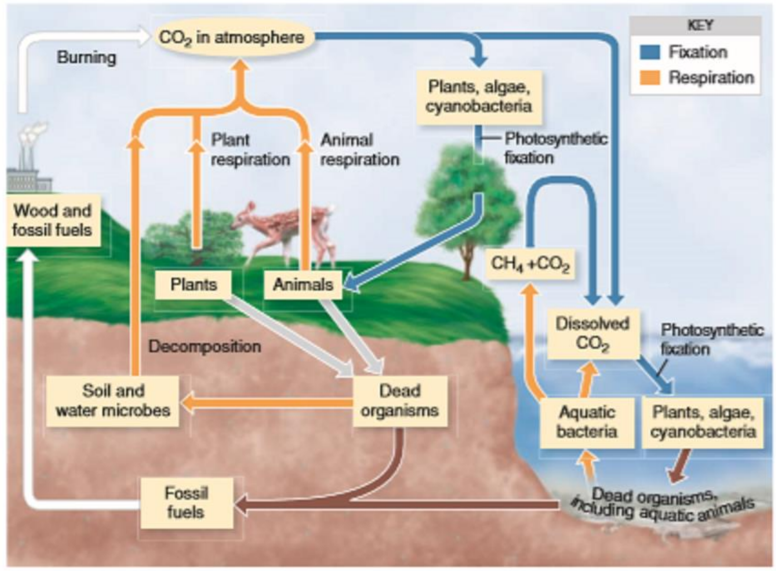


Figure 27.3 The carbon cycle. On a global scale, the return of CO_2 to the atmosphere by respiration closely balances its removal by fixation. However, the burning of wood and fossil fuels adds more CO_2 to the atmosphere. The destruction of forests and wetlands removes CO_2-fixing organisms; as a result, the amount of atmospheric CO_2 is steadily increasing.

Q How does the accumulation of carbon dioxide in the atmosphere affect Earth's climate?

(see Figure 27.4). Ammonification, brought about by numerous bacteria and fungi, can be represented as follows:

$$\text{Proteins from dead cells and waste products} \xrightarrow[\text{decomposition}]{\text{Microbial}} \text{Amino acids}$$

$$\text{Amino acids} \xrightarrow[\text{ammonification}]{\text{Microbial}} \text{Ammonia } (NH_3)$$

Microbial growth releases extracellular proteolytic enzymes that decompose proteins. The resulting amino acids are transported into the microbial cells, where ammonification occurs. The fate of the ammonia produced by ammonification depends on soil conditions (see the discussion of denitrification, which follows). Because ammonia is a gas, it rapidly disappears from dry soil, but in moist soil it becomes solubilized in water, and ammonium ions (NH_4^+) are formed:

$$NH_3 + H_2O \longrightarrow NH_4^+ OH \longrightarrow NH_4^+ + OH^-$$

Ammonium ions from this sequence of reactions are used by bacteria and plants for amino acid synthesis.

Nitrification

The next sequence of reactions in the nitrogen cycle involves the oxidation of the nitrogen in the ammonium ion to produce nitrate, a process called **nitrification.** Living in the soil are autotrophic nitrifying bacteria, such as those of the genera *Nitrosomonas* and *Nitrobacter.* These microbes obtain energy by oxidizing ammonia or nitrite. In the first stage, *Nitrosomonas* oxidizes ammonium to nitrites:

$$\underset{\text{Ammonium ion}}{NH_4^+} \xrightarrow{\textit{Nitrosomonas}} \underset{\text{Nitrite ion}}{NO_2^-}$$

In the second stage, such organisms as *Nitrobacter* oxidize nitrites to nitrates:

$$\underset{\text{Nitrite ion}}{NO_2^-} \xrightarrow{\textit{Nitrobacter}} \underset{\text{Nitrate ion}}{NO_3^-}$$

oxygen (see the discussion of anaerobic respiration in Chapter 5). This process, called **denitrification,** can lead to a loss of nitrogen to the atmosphere, especially as nitrogen gas. Denitrification can be represented as follows:

$$\underset{\text{Nitrate ion}}{NO_3^-} \longrightarrow \underset{\text{Nitrite ion}}{NO_2^-} \longrightarrow \underset{\text{Nitrous oxide}}{N_2O} \longrightarrow \underset{\text{Nitrogen gas}}{N_2}$$

Denitrification occurs in waterlogged soils, where little oxygen is available. In the absence of oxygen as an electron acceptor, denitrifying bacteria substitute the nitrates of agricultural fertilizer. This converts much of the valuable nitrate into gaseous nitrogen that enters the atmosphere and represents a considerable economic loss.

Nitrogen Fixation

We live at the bottom of an ocean of nitrogen gas. The air we breathe is about 79% nitrogen, and above every acre of soil (the area of an American football field from the goal line to the opposite 10-yard line, or 50.6×80 meters) stands a column of nitrogen weighing about 32,000 tons. But only a few species of bacteria, including cyanobacteria, can use it directly as a nitrogen source. The process by which they convert nitrogen gas to ammonia is known as **nitrogen fixation.**

Bacteria that are responsible for nitrogen fixation all rely on the same enzyme, *nitrogenase.* It is estimated that Earth's entire supply of this essential enzyme could fit into a single large bucket. Nitrogenase is inactivated by oxygen. Therefore, it probably evolved early in the history of the planet, before the atmosphere contained much molecular oxygen and before nitrogen-containing compounds were available from decaying organic matter. Nitrogen fixation is brought about by two types of microorganisms: free-living and symbiotic. (Agricultural fertilizers are made up of nitrogen that has been fixed by industrial physical–chemical processes.)

Free-Living Nitrogen-Fixing Bacteria Free-living nitrogen-fixing bacteria are found in particularly high concentrations in the *rhizosphere,* a region roughly 2 millimeters from the plant root. The rhizosphere represents something of a nutritional

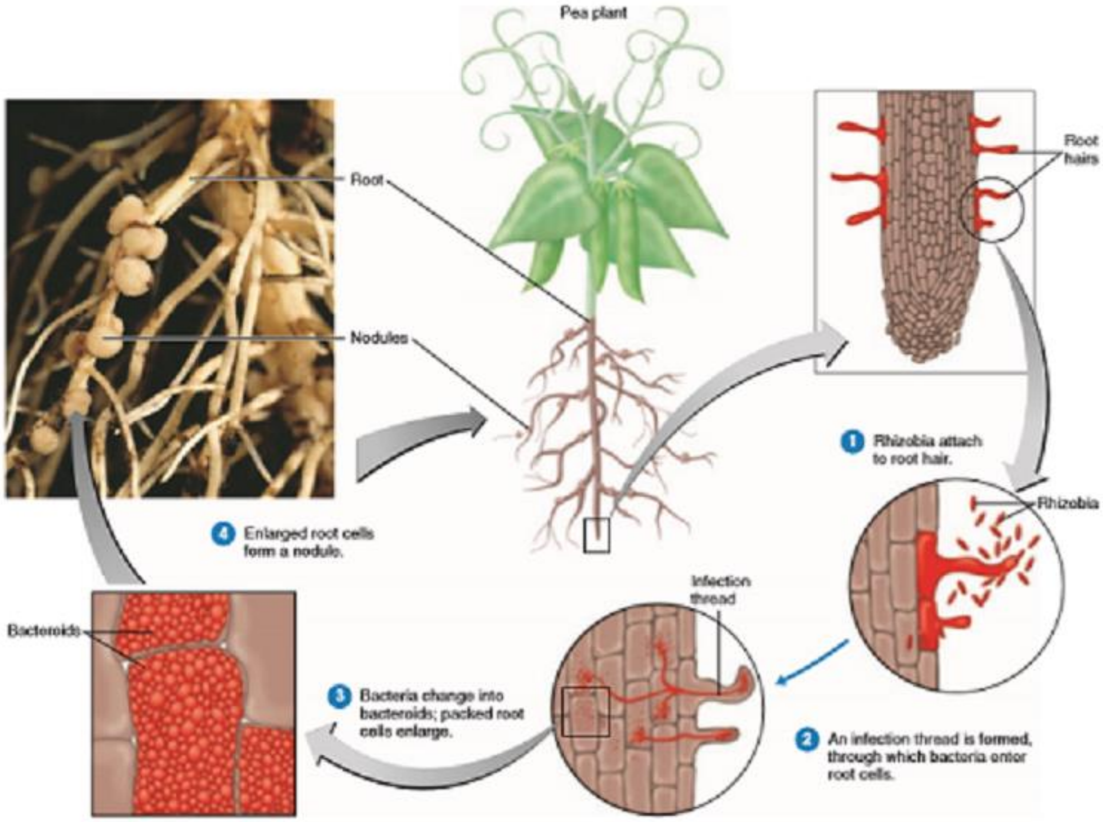
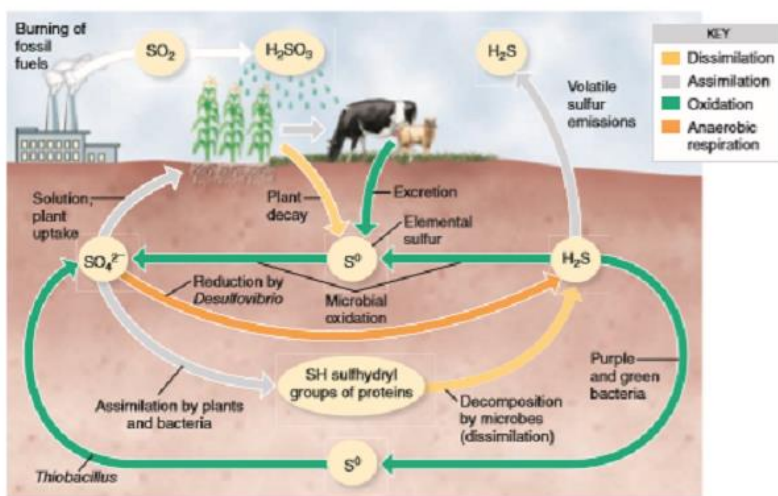


Figure 27.5 The formation of a root nodule. Members of the nitrogen-fixing genera *Rhizobium* and *Bradyrhizobium* form these nodules on legumes. This mutualistic association is beneficial to both the plant and the bacteria.

Q In nature, are leguminous plants most likely to be valuable in rich agricultural soils or poor desert soils?

Figure 27.7 The sulfur cycle. Reduced forms of sulfur such as H_2S and elemental sulfur (S^0) are energy sources for some microbes under aerobic or anaerobic conditions. Under anaerobic conditions, H_2S can be used as a substitute for H_2O in photosynthesis by purple and green bacteria (see page 324) to produce S^0. Oxidized forms of sulfur, such as sulfates (SO_4^{2-}), are used as electron acceptors, as a substitute for oxygen, under anaerobic conditions by certain bacteria. Many organisms assimilate sulfates to make the SH groups of proteins.

Q Why is a source of sulfur necessary for all organisms?



The Phosphorus Cycle

Another important nutritional element that is part of a biogeochemical cycle is phosphorus. The availability of phosphorus may determine whether plants and other organisms can grow in an area. The problems associated with excess phosphorus (eutrophication) are described later in the chapter.

Phosphorus exists primarily as phosphate ions (PO_4^{3-}) and undergoes very little change in its oxidation state. The **phosphorus cycle** instead involves changes from soluble to insoluble forms and from organic to inorganic phosphate, often in relation to pH. For example, phosphate in rocks can be solubilized by the acid produced by bacteria such as *Thiobacillus*. Unlike the other cycles, there is no volatile phosphorus-containing product to return phosphorus to the atmosphere in the way carbon dioxide, nitrogen gas, and sulfur dioxide are returned. Therefore, phosphorus tends to accumulate in the seas. It can be retrieved by mining the above-ground sediments of ancient seas, mostly as deposits of calcium phosphate. Seabirds also mine phosphorus from the sea by eating phosphorus-containing fish and depositing it as guano (bird droppings). Certain small is-

The Degradation of Synthetic Chemicals in Soil and Water

We seem to take for granted that soil microorganisms will degrade materials entering the soil. Natural organic matter, such as falling leaves or animal residues, are in fact readily degraded. However, in this industrial age many chemicals that do not occur in nature (**xenobiotics**), such as plastics, enter the soil in large amounts. In fact, plastics comprise about a fourth of all municipal wastes. A proposed solution to the problem is to develop biodegradable plastics made from polylactide (PLA) produced by lactic acid fermentation. When composted (see Figure 27.10 on page 782), PLA plastic degrades in a few weeks. PLA-based plastics are appearing in a number of commercial products, such as disposable water bottles and drinking cups. Another version of biodegradable plastic, also made from fermented corn sugars, is called polyhydroxyalkanoate, or PHA. Products made of PHA (Mirel) degrade more easily and can stand higher temperatures in use, but they are more expensive than PLA. The barriers are economic, not technological. Many synthetic chemicals, such as pesticides, are highly resistant to degradation by microbial