Soil Geography

Amiya Gayen

Bio-functions of Soil; Soil organic matter, Soil organisms and Micro-organisms and their relation with soil fertility.

Bio-functions of Soil

Soil has a threefold function to perform viz. physical, chemical and biological. The soil is the habitat of a very large number of organisms of both plant and animal origin. Some of these organisms like worms, insects etc. are big, while others like fungi, bacteria etc. are of a microscopic size. Perhaps the most significant biological function of soils is the decomposition of dead plant tissues.

Some functions of a healthy soil ecosystem

- Decompose organic matter towards humus.
- Retain N and other nutrients.
- Glue soil particles together for best structure.
- Protect roots from diseases and parasites.
- Make retained nutrients available to the plant.
- Produce hormones that help plants grow.
- Retain water.

Soil Fertility

Soil fertility may be defined as the inherent capacity of soil to supply plant nutrients in adequate amount and suitable proportion and free from toxic substances. This is a comprehensive definition that covers physical, biological and chemical aspects of soils. The fertility of a soil is determined by the amount of nutrients it contains. Nitrogen (N), phosphorus (P), and potassium *(K)* are three of the most important nutrients needed by plants for optimum plant growth. Soil is a place of habitation for myriads of minute living organisms upon whose activity much of its fertility depends. They are responsible for many important chemical processes which make the soil constituents more available and better adapted to the nutrition of crops.

One cubic centimetre of soil taken within a foot or so from the surface contains from 1 to 2 millions of bacteria of many different kinds, as well as large numbers of fungi. In the lower depths of soil the numbers decrease, few being present at a depth of 5 or 6 ft. Billions of organisms inhabit the upper layers of soil, where they break down dead organic matter, releasing the nutrients necessary for plant growth. The microorganisms include bacteria, actinomycetes, algae and fungi. Macro-organisms include earthworms and arthropods such as insects, mites and millipedes. Each group plays a role in the soil ecosystem.

Soil Organic Matter (SOM) and Fertility

The organic matter of the soil arises from the debris of green plants, animal residues and excreta deposited on the surface and mixed to a variable extent with the mineral component. The dead organic matter is colonized by a variety of soil organisms, most importantly micro-organisms, which derive energy for growth from the oxidative decomposition of complex organic molecules (the substrate). The combination of living and dead organic matter, irrespective of its source or stage of decomposition, is called soil organic matter (SOM). It excludes the living parts of plants above ground. SOM has an important role in plant growth and development. Functions of soil organic matter are manifold and usually beneficial for crop production and soil conservation. SOM in soils has great diversity and a highly variable composition. SOM content can range from one per cent, in the case of a sandy soil in which no special management practices have been used to build SOM, to more than 30 per cent in a muck soil.

Decomposition and Accumulation of Soil Organic Matter

The primary or original source of soil organic matter (SOM) is the production of the primary producers - the higher plants. Decomposition involves the breakdown of large organic molecules into smaller, simpler components. When organic tissue is added to an aerobic soil, four general processes take place: oxidation, release, synthesis, and protection. Although in most cases mechanical shredding by soil fauna or physical processes must occur before these processes can efficiently take place. The reactions themselves result mainly from microbial activity. Plant carbon compounds are oxidized to produce carbon dioxide, water, energy, and decomposer biomass. Essential nutrient elements such as nitrogen, phosphorus, and sulfur are released and/ or immobilized by a series of specific reactions. New compounds are synthesized by microbes. Some of the original plant compounds, their breakdown products and microbial compounds become physically or chemical protected from further microbial decay via interactions with the soil environment.

Thus organic matter also includes microbial products of living and dead microbial cells and their waste or excretion products. Some of the organic compounds that are synthesized in the soil during decomposition react with each other and with mineral soil components. Consequently, the decomposition of plant residues results in the production of:

a) a considerable mass of microbial products,
b) a wide variety of materials of varying resistance to decomposition.

As a result of the addition and decomposition of plant and animal residues in soils, labile (organic residues) and stable fractions (humus) of organic matter are produced. Labile organic matter is liable to change or is unstable.

Labile Soil Organic Matter

The labile fraction of SOM consists of any readily degradable materials from the plant and animal residues, and readily degradable microbial products. It constitutes about 10 to 20 percent of the total SOM. It is an important reservoir of nutrients because the nutrients, especially nitrogen, are rapidly recycled in the soil ecosystem. Any labile organic matter incorporated within soils tends to disappear quickly if conditions are favorable for decomposition. Therefore, the decomposers are frequently quite inactive, owing to the rapid disappearance of readily decomposable substrates or labile organic matter.

Stable Soil Organic Matter

The stable SOM fraction consists of resistant compounds: (1) in the decomposing residues, (2) in microbial products, and (3) that formed as a result of interaction of organic compounds with each other and with the mineral components of the soil, especially clay. The stable organic matter is equivalent to humus. The nutrients within it are recycled very slowly.

Effective Humus

When fresh OM is added to soil, the microorganisms immediately start to decompose it. The partially-decomposed residue is called effective humus. It holds nutrients by absorption, releasing them to plants as needed and prevents their loss by leaching. During decomposition, essential elements are converted from organic combination to simple inorganic forms, a process called mineralization. For example, organically combined N, P and S appear as NH_4^{+}, $H_2PO_4^{-}$ and SO_4^{2-}, ions, and about half the C is released as CO_2. Mineralization, especially the release of CO_2, is vital for the growth of succeeding generations of green plants. The remainder of the substrate C used by the micro-organisms is incorporated into their cell substance or microbial biomass, together with a variable proportion of other essential elements such as N, P and S. This incorporation makes these elements unavailable for plant growth until the organisms die and decay, so the process is called immobilization.

Stable soil organic matter or humus originates from several processes. Much of the stable organic matter is intimately associated with the mineral particles, particularly, clay. The stable organic matter has a long residence time in the soil and plays important roles in structure formation and stability, water adsorption, and adsorption of nutrient cations.

Properties of Stable Soil Organic Matter

Stable soil organic matter (humus) is a heterogeneous mixture of amorphous compounds that are resistant to microbial decomposition and possesses a large surface area per gram. The large surface area enables humus to absorb water equal to many times its weight. All organic substances, by definition, contain the element carbon, and, on average, carbon comprises about half of the mass of soil organic matter. Organic matter in the world's soil profiles contains four to six times as much carbon as is found in the entire world's vegetation. Humus contains about 50 to 60 percent carbon and about 5 percent nitrogen, producing a C: N ratio of 10 or 12 to 1. The more decomposed the humus is the lower or narrower will be the C: N ratio. Compared with plant materials, humus is relatively rich in nitrogen and, when mineralized, humus is a good source of biologically available nitrogen. Humus is also a significant source of sulfur and phosphorus. The ratio of C:N:P:S is about 100:10:1:1.

Effect of SOM on Soil Physical Conditions

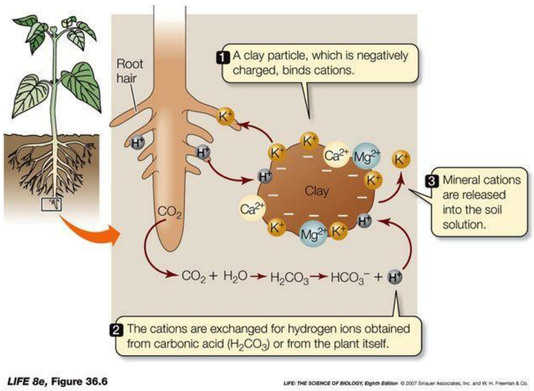
Organic matter is an important binding agent through which elementary soil particles are joined to form larger aggregates. Thus porosity improves soil water relations, aeration and root penetration. The risk of erosion is reduced. Due to the generally darker color, soils may be warmer which is often beneficial.

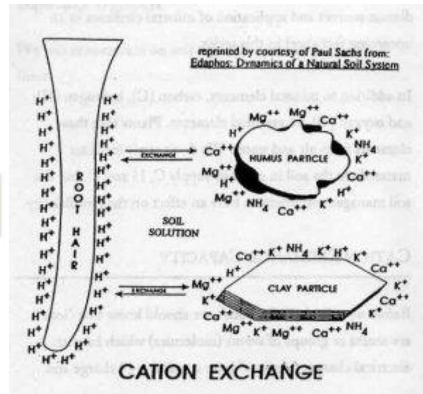
Soil Fertility and SOM

Plant nutrition benefits in many respects from soil organic matter:

i. ***Ion exchange***

Cation exchange capacity (CEC) is a measure of the soil's ability to hold positively charged ions. It is a very important soil property influencing soil structure stability, nutrient availability, soil pH and the soil's reaction to fertilisers and other ameliorants. The clay mineral and organic matter components of soil have negatively charged sites on their surfaces which adsorb and hold positively charged ions (cations) by electrostatic force. This electrical charge is critical to the supply of nutrients to plants because many nutrients exist as cations (e.g. magnesium, potassium and calcium). In general terms, soils with large quantities of negative charge are more fertile because they retain more cations. The main ions associated with CEC in soils are the exchangeable cations calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}) and are generally referred to as the base cations.





Soil organic matter is a potent ion exchanger of equal importance to that of clays. Large quantities of nutrients can be held in a readily exchangeable and available, form. The exchange capacity is pH dependent. Cation exchange is more important, but exchange sites for anions also exist. Soils with a low CEC are more likely to develop deficiencies in potassium (K^{+}), magnesium (Mg^{2+}) and other cations. High CEC soils are less susceptible to leaching of these cations.

ii. ***Mobilization-immobilization of nutrients***

Nutrients can be released from (mobilized) and immobilized by soil organic matter. Decomposition of soil organic matter by microorganisms frees nutrients, which are then available for plants. The CO_2 released during decomposition diffuses out of the soil and may be taken up by plant leaves and used for photosynthesis before escaping into the free atmosphere. The remainder of the substrate C used by the micro-organisms is incorporated into their cell substance or microbial biomass, together with a variable proportion of other essential elements such as N, P and S. This incorporation makes these elements unavailable for plant growth until the organisms die and decay, so the process is called immobilization. Whether mobilization or immobilization occurs depends on the C:N ratio of the organic matter. Immobilization of nutrients, i.e., incorporation of nutrients into insoluble soil organic matter by microorganisms, reduces leaching losses, (especially of nitrate), and volatilization losses (especially of ammonia). On the negative side of the mobilization-immobilization cycle, there is an increased risk of losses after mobilization and a deficiency of nutrients after immobilization. A substantial fraction of the crop's requirement could be supplied by the organic matter. The major interest is usually in soil nitrogen, but soil organic matter also stores other nutrients such as phosphorus and sulfur.

iii. ***Complex formation***

Some nutrients, in particular zinc, iron, and copper, form water soluble complexes with organic substances.

iv. ***Fixation of nutrients***

Some nutrients, especially copper, can be held very tightly by soil organic matter. These processes are probably more often deleterious since they may result in nutrient deficiencies.

Benefits of humus:

- ✓ Supplies nutrients, especially nitrogen (N), phosphorus (P) and sulphur (S), when the plant needs them;
- ✓ Holds nutrients, thereby reducing nutrient leaching;
- ✓ Binds soil particles together, stabilising loose soils against erosion;
- ✓ Increases the friability of heavy soils;
- ✓ Improves porosity, thereby facilitating air and water movement, and increases soil's water-holding capacity.

Soil Organisms and Fertility

The soil is the home of innumerable forms of plant, animal, and microbial life. Life in the soil is amazingly diverse, ranging from microscopic single-celled organisms to large burrowing animals. Soil organisms have many effects on soil fertility. The plants being grown must compete with but also benefit from weeds and microorganisms.

Weeds interfere with the growth of desirable plants by competing for light, water, nutrients, and space. Under certain circumstances, weeds may consume half of the water applied in irrigation. Weeds, like all plants, will improve soil physical conditions and protect soils from erosion. Weeds may also damage crop plants by exuding toxic substances, i.e., by allelopathic interactions. Weeds may harbour pests that attack crops, but they may also harbour insects that prey on the pests.

Soil animals can be considered both consumers and decomposers because they feed on or consume organic matter and some decomposition occurs in the digestive tract. Some animals are parasitic vegetarians that feed on roots, whereas others are carnivores that prey on each other. Microorganisms play an important role in the physical and chemical decomposition of plant detritus and cycling of nutrients. Their reactions in the soil may beneficial, neutral or harmful to the crop plants being grown. Soil fauna contain a number of species that are important pests in crop production and must be controlled. Many of the larger animals move soil to such an extent that they affect soil formation.

The soil organisms may be grouped according to size into:

Macro-organisms (>2 mm) – which live wholly or partly underground such as:

Major Taxonomic Groups	Examples
Vertebrates	Gophers, moles, snakes, salamanders
Arthropods	Ants, beetles and their larvae, centipedes, grubs, maggots, millipedes, spiders, termites, large collembola
Annelids	Earthworms
Mollusks	Snails, slugs
Vascular plants	Feeder roots
Bryophytes	Mosses

Meso-organisms (0.1–2 mm) – small invertebrate animals such as:

Major Taxonomic Groups	Examples
Arthropods	Mites, collembola (springtails),

	pseudoscorpions
Annelids	Enchytraeid (pot) worms

Micro-organisms (< 0.2 mm in length) – comprising the microfauna (soil animals) and the microflora (algae, fungi, bacteria, actinomycetes and viruses)

Major Taxonomic Groups	Examples
Nematoda	Nematodes
Rotifera	Rotifers
Tardigrades	Water bears, *Macrobiotus sp*.
Protozoa	Amoebae, ciliates, flagellates
Vascular plants	Root hairs
Algae	Greens, yellow-greens, diatoms
Fungi	Yeasts, mildews, molds, rusts, mushrooms
Bacteria	Acidobacteria, proteobacteria
Cyanobacteria	Blue-green algae
Actinobacteria	Streptomyces
Archaea	Methanotrophs, *Thermoplasma sp*., halophiles

Macro-fauna

Many rodents, including mice, ground squirrels, marmots, gophers, and prairie dogs inhabit the soil. Soil animals play an important role in earth-moving activities. In terms of their abundance and their soil forming roles, earthworms, termites and ants are the most important components of soils. They burrow and are important in mixing the soil – known as bioturbation. (The mixing of sediments by living organisms such as worms, clams, or arthropods that make burrows in soft sediment. OR A movement of soil material within the soil profile by animals or plants.)

Arthropods

This group includes the isopods (wood lice), arachnids (mainly mites), insects (winged and wingless) and myriapods (centipedes and millipedes). Activities of mites include the breakup and decomposition of organic material, movement of organic matter to deeper soil layers, and maintenance of pore spaces.

The more numerous are the mites and many of the insects, present as adults and larvae. Many beetles and insect larvae live in the soil, some feeding saprophytically, whereas others feed on living tissues and can be serious pests of agricultural crops. Of particular value, however, are the dung beetles of Africa, Asia and other tropical regions that feed on the dung of large herbivores. The termites (member of the Isoptera) are important comminuters of all forms of litter – tree trunks, branches and leaves – in the forest and termites inhabit especially the seasonal rainfall regions (savanna) of the tropics and subtropical soils. They exhibit great diversity in food and nesting habits. Some feed on wood, some feed on organic refuse, and others actively cultivate fungi.

Ants transport large quantities of material from within the soil, depositing it on the surface. Ants also harvest large amounts of plant material and in some ecosystems are important consumers. Leaf harvester ants march long distances to cut fragments of leaves and stems and bring them to their nests to feed fungi. The fungi are used as food. Thus organic matter is incorporated into the soil depths and nutrients concentrate in the nest sites.

Other important soil arthropods include millipedes and centipedes Millipedes and centipedes are elongate, fairly large soil animals, with many pairs of legs. Centipedes are carnivorous whereas millipedes feed on vegetation, much of which is in the form of living roots, bulbs and tubers.

Arthropods function on two of the three broad levels of organization of the soil food web: they are plant litter transformers or ecosystem engineers. Litter transformers fragment, or comminute, and humidify ingested plant debris, which is deposited in feces for further decomposition by micro-organisms, and foster the growth and dispersal of microbial populations. Large quantities of annual litter input may be processed (e.g., up to 60% by termites). The comminuted plant matter in feces presents an increased surface area to attack by micro-organisms, which, through the process of mineralization, convert its organic nutrients into simpler, inorganic compounds available to plants. They alter soil structure, mineral and organic matter composition, and hydrology. The burrowing by arthropods, particularly the subterranean network of tunnels and galleries that comprise termite and ant nests, improves soil porosity to provide adequate aeration and water-holding capacity below ground, facilitate root penetration, and prevent surface crusting and erosion of topsoil. The movement of particles from lower horizons to the surface by ants and termites aids in mixing the organic and mineral fractions of the soil. The feces of arthropods are the basis for the formation of soil aggregates and humus, which physically stabilize the soil and increase its capacity to store nutrients.

Annelids: Earthworms

Earthworms are perhaps the best known of the soil animals. One kind of earthworm worm makes a shallow burrow and forages on plant material at night. Some of the plant material is dragged into the burrow. In the soil, the plant materials are moistened and more readily eaten. Other kinds of earthworms exist by ingesting organic matter found in the soil. Earthworms eat their way through the soil by ingesting the soil en masse. Excreted materials (earthworm castings) are deposited both on and within the soil. The intensive mixing of organic and inorganic materials in the digestive tract of the earthworm, combined with chemical changes and vertical transports in the soil profile, leads to improved soil physical conditions. The intimate mixing of soil materials in the digestive track of earthworms, the creation of channels, and production of castings, alter soil structure and leave the soil more porous. Channels left open at the soil surface greatly increase water infiltration.

The cycling of nutrients is a critical function that is essential to life on earth. Activity of earthworms is beneficial because it can enhance soil nutrient cycling through the rapid incorporation of detritus into mineral soils. In addition to this mixing effect, mucus production associated with water excretion in earthworm guts also enhances the activity of other beneficial soil microorganisms. This is followed by the production of organic matter. So, in the short term, a more significant effect is the concentration of large quantities of nutrients (N, P, K, and Ca) that can be easily assimilated by plants in fresh cast depositions. In addition, earthworms seem to accelerate the mineralization as well as the turnover of soil organic matter. Earthworms are known also to increase nitrogen mineralization, through direct and indirect effects on the microbial community. The increased transfer of organic C and N into soil aggregates indicates the potential for earthworms to facilitate soil organic matter stabilization and accumulation in agricultural systems.

Mesofauna

The mesofauna is the next smaller group and the animals range in size from 200 μm to 10 mm. in length (0.1–2 mm in diameter). These include mainly microarthropods, such as pseudoscorpions, protura, diplura, springtails, mites, small myriapods and the worm-like enchytraeids. These organisms have limited burrowing ability and generally live within soil pores, feeding on organic materials, microflora, microfauna and other invertebrates.

The function of mesofauna is physically breaking down of organic matter into smaller particles is much more important than the chemical alteration caused by their digestive processes. For this reason, the mesofauna have collectively been called reducers to distinguish them from the microflora, or decomposers, which cause chemical alteration through the action of intracellular and extracellular enzymes.

Micro-Organisms

Microfauna

Some plant substances decompose in the soil completely; others are partially attacked; and still others remain almost intact. These variations in composition are associated with the differential activities and types of microbes which, in turn, are largely influenced by climate. Nematodes (roundworms), which are all heterotrophs, are microscopic worms and are the most abundant animals in soils. Among them the threadlike nematodes, next to the protozoa, are the smallest. They are plentiful in soil and litter and may be saprophages or carnivores feeding on fungi, bacteria or other nematodes. Nematodes affect growth and metabolic activities of microbes and alter the microbial community, thus regulating rates of decomposition and nutrient mineralization, particularly of nitrogen.

Microbes: protozoa, algae, fungi, bacteria, archaea, viruses

The major distinguishing feature of microorganisms is their relatively simple biological organization.They are consumers in the sense that they consume materials for growth and, at the same time, they are decomposers in the sense that carbon is released as CO_2. Microbial activity causes mineralization which is the conversion of an element from an organic form to an inorganic state for example, conversion of nitrogen in protein into nitrogen in ammonia (NH_3). The decomposers secrete enzymes that digest organic matter outside the cell, and they absorb the soluble end products of digestion. Microorganisms release different enzymes depending on the decomposing material as for example the enzyme cellulase is released to decompose cellulose, and the enzyme protease to decompose protein. The microorganisms are considered to be the major or ultimate decomposers and make the nutrients available for another cycle of plant growth. Only about 5 percent of the primary production of green plants is consumed by animals. By contrast, about 95 percent of the primary production is ultimately decomposed by microorganisms.

The microorganisms near plant roots share the same environment with roots, and they compete with each other for the available growth factors. Plants and microorganisms also play roles that benefit each other. Roots shed cells and leak organic compounds that serve as food for microorganisms, whereas the microbes decompose the organic materials, which results in the mineralization of nutrient ions for root absorption.

In the case of symbiotic nitrogen fixation, the nitrogen-fixing organisms obtain energy and food from the plant while the plant benefits from the nitrogen fixed. Nitrogen fixation is the conversion of molecular nitrogen (N_2) to ammonia and subsequently to organic combinations or to forms utilizable in biological processes. The net effect of the fixation is the transfer of nitrogen in the atmosphere, which is otherwise unavailable to plants.

Thus, microbes decompose the organic residues for their nutritional and other life functions. At the same time they render the dead organic matter available again for plant metabolism releasing carbon dioxide and minerals which are rebuilt by plants into food. And so the cycles continue.

Soil Microbes and Their Specific Functions

Soil microbes perform various functions like plant growth promotion, nutrient cycling, soil formation, water regulation, protection from invasive species, soil parasites and pathogens. Soil bacteria and fungi are especially important in helping maintain a nontoxic soil environment by breaking down toxic compounds. The most important reactions which the micro organisms carry out and have significant bearing on soil properties and plant growth, are decomposition of organic matter and synthesis of humic substances in soil, biological fixation of nitrogen, microbial transformation of nutrients and nutrient cycling N, C, P, S, etc.) in soil.

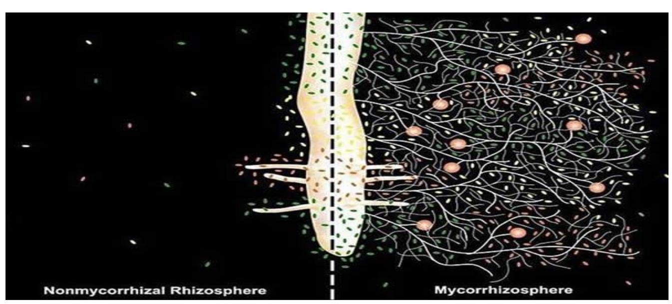
(To add Nitrogen, Carbon, Phosphorus and Sulphur Cycles)

Protozoa – they are the smallest of the animal kingdom. They help in decomposition of organic matter and release plant nutrients.

Algae – These microscopic plants are capable of fixing nitrogen from air. Actually as chlorophyll-bearing organisms, the algae produce sugars and that is used by Azotobacter and other microbes which fix N in the soil.

Fungi - Fungi commonly known as molds, are a diverse group of microorganisms. Their cells have a tendency to be arranged in a network of branched filaments known as hypha. The mass of hyphae is called mycelium. The most common fungi are molds and mushrooms. Rhizopus is a common mold that grows in soil. It has rootlike structures that penetrate and absorb nutrients, much like the roots of plants. Fungi are heterotrophs that vary greatly in size and structure. One of the specific functions of fungi is to produce a glue-like substance which stabilizes soil structural units.

Mycorrhizal fungi – Facilitate nutrient and water acquisition by plants by colonizing plant roots and extending far into the soil. They send their mycelium into the roots of many plants without destroying the tissues of the host. This union of fungi and roots of trees is known as mycorrhiza. The nature of mutual relations between mycorrhizal fungi and the roots is to fix N. They also transfer water and plant nutrients from the soil to plants.



Endophytic fungi reduce incidence of certain diseases by inhibiting the growth of other fungus. Some fungi degrade soil contaminants such as insecticides and herbicides through mineralization.

Actinomycetes – This group of microbes is intermediate between bacteria and fungi. Like fungi, they consist of delicate threads (hyphae). They are not as important as bacteria and fungi as decomposers. Only when very resistant materials remain actinomycetes are active. Some Actinomycetes fix major amounts of nitrogen in forest ecosystems.

Bacteria – Bacteria are single celled, among the smallest living organisms, and exceed all other soil organisms in kinds and numbers. A gram of fertile soil commonly contains 10^1 to 10^{10} bacteria. The most common soil bacteria are rod-shaped. Most are heterotrphic organisms and require pre-formed carbon (such as carbon in organic compounds). They utilize the energy stored in organic matter for their life processes. The release of energy is accomplished by the microbes as they decompose organic matter by means of enzymes. Most of these heterotrophic organisms are saprophytes, i.e. they thrive on the dead organic residue. The fixation of elemental nitrogen gas into compounds usable by plants is one of the most important microbial processes in soils. Nitrogen fixing bacteria such as *Rhizobium* spp. enable nitrogen fixation after establishing inside root nodules of legumes. Rhizobia bacteria are the most important group for the capture of gaseous nitrogen in grassland and agricultural soils. The zone immediately around plant roots (the rhizosphere soil and the root surface itself) supports a dense population of microorganisms. Bacteria especially adapted to living in this zone are termed rhizobacteria, many of which are beneficial to higher plants (the so-called plant growth–promoting rhizobacteria). By far the greatest amount of nitrogen fixation by these organisms occurs in root nodules or in other associations with plants. In nature, root surfaces are almost completely encrusted with bacterial cells, so little interaction between the soil and root can take place without some intervening microbial influence. In addition to those that ward off plant diseases, certain rhizobacteria promote plant growth in other ways, such as enhanced nutrient uptake or hormonal stimulation. Regarding hormonal effects, a single species of *Pseudomonas* bacteria has been shown to completely alter a plant's root growth, branching and root hair development in ways that benefit both the rhizosphere bacteria and its plant partner. *Azotobacter* spp (free- living) supplies small amounts of nitrogen to plants when in their proximity. Cyanobacteria are important in flooded rice paddies, wetlands, and deserts.

Nitrates, sulfates, and, to a lesser degree, phosphate ions are present in soils primarily due to inorganic transformations, such as the oxidation of sulfide to sulfate or ammonium to nitrate stimulated by microorganisms. Likewise, the availabilities of other essential elements, such as iron and manganese, are determined largely by microbial action. In well-drained soils, these elements are oxidized by autotrophic organisms, into quite insoluble forms. This keeps iron and manganese mostly in low solubility and nontoxic forms, even under fairly acid conditions. If such oxidation did not occur, plant growth would be jeopardized because of toxic quantities of these elements in solution. Microbial oxidation also controls the potential for toxicity in soil contaminated with selenium or chromium.
