FACT SHEET
Agriculture and Natural Resources

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The Role of Soil Bacteria

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Introduction

Microbes in the soil are the key to carbon and nitrogen recycling. A teaspoon of productive soil generally contains between 100 million and 1 billion individual bacteria. That is as much mass as two cows per acre. A ton of microscopic bacteria may be active per acre and there may be over one million species of bacteria present. Bacteria are tiny, one-celled organisms about 4/100,000 of an inch wide (1 μm, range from 0.2 to 2 μm) and somewhat longer in length (1–10 μm). Bacteria are similar in size to clay soil particles (<2 μm) to silt soil particles (2–50 μm). They grow and live in thin water films around soil particles and near roots in an area called the rhizosphere. The small bacteria size enables these microbes to grow and adapt to changing environmental conditions more rapidly than larger, more complex microorganisms.

Living roots release many types of organic materials into the rhizosphere within 50 μm of the surface of the root. The rhizosphere typically contains 1,000 to 2,000 times more microorganisms than the typical soil without roots.

Most soils are simply a graveyard for dead bacteria cells. Since most bacteria live under starvation conditions or water stress in the soil, they have adapted to quickly reproduce when water, food, and the environmental conditions are abundant. Bacteria populations can easily double in 30 minutes. Bacteria are so simple in structure that they have been called a bag of enzymes.

Classification of Bacteria

Bacteria are mainly classified into phyla (phylum is a scientific classification of organisms). For simplification, bacteria can be grouped into the following groups:

a) Bacteria based on shapes

Before the advent of DNA sequencing, bacteria were classified based on their shapes and biochemical properties. Most of the bacteria belong to three main shapes: rod (rod shaped bacteria are called bacilli), sphere (sphere shaped bacteria are called cocci), and spiral (spiral shaped bacteria are called spirilla) and slender branching filaments called actinomycetes. Some bacteria belong to different shapes, which are more complex than the above mentioned shapes.

b) Aerobic and anaerobic bacteria

Bacteria that need oxygen for their survival are called aerobic bacteria and bacteria that do not require oxygen for survival are called anaerobic bacteria. Anaerobic bacteria cannot bear oxygen and may die if kept in an oxygenated environment (anaerobic bacteria are found in places like under the surface of earth, deep ocean, and bacteria that are living inside soil particles).

c) Gram Positive and Gram Negative bacteria

Bacteria are grouped as "Gram Positive" bacteria and "Gram Negative" bacteria, which is based on the results of Gram Staining Method (in which an agent is used to bind to the cell wall of the bacteria) on bacteria. Gram Negative bacteria are the smallest and tend to be more sensitive to water stress, while Gram Positive bacteria are larger in size, have a thicker cell wall, a negative charge on the outer surface, and tend to resist water stress.

d) Autotrophic and heterotrophic bacteria

This is one of the most important classification types as it takes into account the most important aspect of bacteria growth and reproduction. Autotrophic bacteria (also known as autotrophs) obtain the carbon it requires from carbon dioxide. Some autotrophs directly use sunlight in order to produce sugar from carbon dioxide, whereas others depend on various chemical reactions. Heterotrophic bacteria obtain carbohydrates and/or sugar from the environment they are in (for example, the living cells or organism they are in).

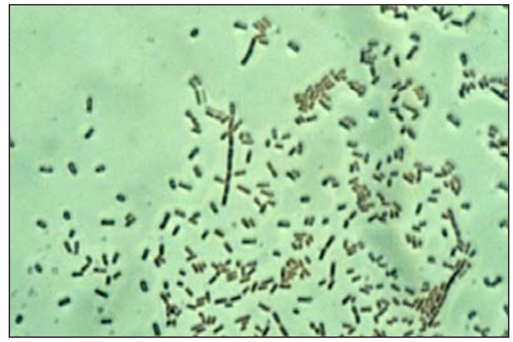
e) Classification based on phyla

Based on the morphology, DNA sequencing, conditions required, and biochemistry, scientists have classified bacteria into 12 phyla. Each phylum further corresponds to number of species and genera of bacteria. The bacteria classification includes bacteria that are found in various types of environments such as bacteria that can survive extreme temperatures (extreme hot as in sulfur water spring bacteria and extreme cold as in bacteria found in Antarctic ice), bacteria that can survive in a highly acidic versus highly alkaline environment, aerobic bacteria versus anaerobic bacteria, autotrophic bacteria versus heterotrophic bacteria, etc.

Bacteria Functions

Bacteria perform important functions in the soil, decomposing organic residues from enzymes secreted in the soil. There are basically four functional soil bacteria groups:

1. *Decomposers,* which are bacteria that consume simple sugars and simple carbon compounds, such as root exudates and fresh plant litter.
2. Bacteria *mutualists* form partnerships with plants including the nitrogen-fixing bacteria *(Rhizobia).*
3. Bacteria can also become *pathogens* to plants.
4. *Lithotrophs* or *chemoautotrophs bacteria* obtain energy from compounds of nitrogen, sulfur, iron, or hydrogen instead of from carbon compounds. Some of these species are important to nitrogen cycling and degradation of pollutants.



Soil bacteria (Michael T. Holmes, Oregon State University, Corvallis).

Bacteria convert energy in soil organic matter into forms useful to the rest of the organisms in the soil food web. A number of bacteria decomposers can break down pesticides and pollutants in soil. Decomposers are especially important in immobilizing, or retaining, nutrients in their cells, thus preventing the loss of nutrients, such as nitrogen, from the rooting zone. Bacteria dominate in tilled soils but they are only 20–30% efficient at recycling carbon (C). Bacteria are higher in nitrogen (N) content but lower in total carbon (10 to 30% nitrogen, 3 to 10 C:N ratio) than most microbes.

Bacteria from all four groups perform important services related to water dynamics, nutrient cycling, and disease suppression. Some bacteria produce substances that help bind soil particles into microaggregates (diameters of 1/10,000–1/100 of an inch or 2–200 μm). Stable aggregates improve water infiltration and the soil's water-holding ability. A diverse bacterial community will compete with disease-causing organisms in roots and on plant surfaces.

Nitrogen-fixing bacteria *(Rhizobia)* form symbiotic associations with the roots of legumes like alfalfa and clovers. *Rhizobia* are Gram negative rod-shaped bacteria. Visible nodules are created where bacteria infect a growing root hair. The plant supplies simple sugars to the bacteria and the bacteria convert nitrogen (N_2) from air into a nitrogen form (NO_3^- or NH_4^+) the plant can use. When leaves or roots from the plant decompose, nitrogen increases in the soil. Dinitrogen (N_2) fixing bacteria need anaerobic (no oxygen) conditions and fix nitrogen in microsites provided by legume nodules characterized by pink or red tissue (anerobic conditions) in nodules.

Nitrifying bacteria change ammonium (NH_4^+) to nitrite (NO_2^-) then to nitrate (NO_3^-), which is a preferred form of nitrogen for grasses and most row crops. Nitrifying bacteria need well-aerated soils. Nitrate is leached more easily from the soil, so some farmers use nitrification inhibitors to reduce the activity of nitrifying bacteria. Denitrifying bacteria convert nitrate to nitrogen (N_2)

Nitrogen-fixing bacteria. Nodules formed where *Rhizobium* bacteria infected soybean roots. Source: Ray Archuleta, USDA-NRCS. Photo credit: Stephen Temple, University of Minnesota, St. Paul.

or nitrous oxide (N_2O) gas. Denitrifiers are anaerobic, meaning they are active where oxygen is lacking, such as in saturated soils, compacted soils, or inside soil microaggregates. In heavy clay soils, 40–60% of the nitrogen may be lost to denitrification.

Although there are many bacteria in the soil that cycle nitrogen from organic material, it is only a small group of specialized nitrogen fixing bacteria that can fix atmospheric nitrogen in the soil. Nitrogen fixation cannot happen without the production of the nitrogenase enzyme by these specific bacteria. Nitrogen fixing bacteria are generally widely available in most soil types (both symbiotic and free living species), however they generally only comprise a very small percentage of the total microbial population and are often bacteria strains with low nitrogen fixing ability.

Sulfur and many other nutrients are transformed in the soil in the same manner as nitrogen. Sulfur-reducing bacteria under anaerobic conditions make sulfur less available to plants by converting sulfur to H_2S in water-saturated soils, precipitating out into the soil as an insoluble metal sulfide. Under well-aerated conditions, sulfur-oxidizing bacteria generates SO_4^- by oxidizing metal sulfides to elemental sulfur or thiosulfate ($S_2O_3^{2-}$).

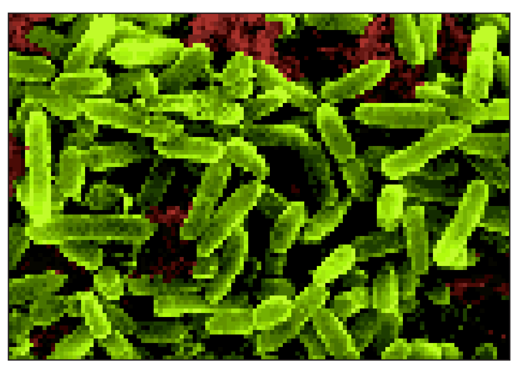
A large group of bacteria are actinomycetes that grow hyphae like fungi and are similar to fungus in their function. Actinomycetes (1–2 μm) are smaller in size than fungus (10–50 μm) and are sensitive to antibacterial agents. When farmers plow or till the soil, actinomycetes are responsible for that "earthy" smell, which is geosmins formed from streptomycetes. A number of antibiotics are produced by actinomycetes including Streptomycin. Actinomycetes decompose many substances but are more active at high pH levels. Actinomycetes are especially important in degrading hard to decompose (recalcitrant) compounds, such as chitin, lignin, keratin, cellulose fungal, and animal polymers. Fungi are more important in degrading recalcitrant compounds at low pH. Actinomycetes are important in forming stable humus, which enhances soil structure, improves soil nutrient storage, and increases soil water retention; slowly releasing nutrients and water as the complex substances are decomposed by specific groups of bacteria.

Soil Benefits from Bacteria

Various species of bacteria thrive on different food sources and in different microenvironments. In general, bacteria are more competitive when easy to metabolize (labile) substrates are present (simple sugars) which tend to turn over very rapidly in the rhizosphere. This includes fresh, young plant residue and compounds found near living roots. Bacteria (especially rod bacteria and Gram negative bacteria) and actinomycetes are especially concentrated in the rhizosphere, the narrow region next to and around the root. Actinomycetes may account for 10 to 30% of the total microorganisms in the soil rhizosphere, depending upon nutrient availability. Some plants produce certain types of root exudates to encourage the growth of protective bacteria.

Many bacteria produce a layer of polysaccharides or glycoproteins that coats the surface of the cell. Some form a slime layer while others form a thick gelatinous capsule which reduces water loss from the bacteria cell and is used by the bacteria to form biofilms so that they can attach to structures. These substances play an important role in cementing sand, silt, and clay soil particles into stable microaggregates that improve soil structure.

In order for bacteria to survive in the soil, they must adapt to many microenvironments. In the soil, oxygen concentrations vary widely from one microsite to another. Large pore spaces filled with air provide high levels of oxygen, which favors aerobic conditions, while a few millimeters away, smaller micropores may be anaerobic or lack oxygen. This diversity in soil microenvironments allows bacteria to thrive under various soil moisture and



Scanning electron micrograph of the common soil bacteria *Pseudomonas aeruginosa*. These bacteria are actively motile in aqueous environments but can attach to a submerged surface and grow into a sessile, slimy colony called a "biofilm."

oxygen levels, because even after a flood (saturated soil, lack of oxygen) or soil tillage (infusion of oxygen) there exist small microenvironments where different types of bacteria and microorganisms can exist to repopulate the soil when environmental conditions improve.

As natural succession occurs in a plant community, succession also occurs in the soil. Bacteria have the ability to alter the soil environment to favor certain plant communities. On fresh sediments, photosynthetic bacteria establish first, fixing atmospheric N and C, producing organic matter, and other nutrients to initiate nitrogen-cycling processes in the young soil. Bacteria dominate in tilled or disrupted soils, soils with higher pH, and soils with high nitrate-nitrogen availability, which is the perfect environment for low successional plants called weeds. Early successional plant species start to grow, and as the plant community is established, different types of organic matter enter the soil and change the type of food available to bacteria. Slowly, the altered bacterial community changes soil structure and the environment for other plants to succeed.

As the soil is disturbed less and plant diversity increases, the soil food web becomes more balanced and diverse, making soil nutrients more available in an environment better suited to higher plants. Diverse microbial populations with fungus, protozoa, and nematodes keep nutrients recycling and disease causing organisms in check.

Summary

Microorganisms abound in the soil and are critical to decomposing organic residues and recycling soil nutrients. Bacteria are the smallest and most hardy microbe in the soil and can survive under harsh or changing soil conditions. Bacteria are only 20–30% efficient at recycling carbon, have a high N content (10 to 30% N, 3–10 C:N ratio), a lower C content, and a short life span. There are basically four functional soil bacteria groups including decomposers, mutalists, pathogens, and lithotrophs. Decomposer bacteria consume simple sugars and simple carbon compounds, while mutualist bacteria form partnerships with plants including the nitrogen-fixing bacteria *(Rhizobia)*. Bacteria can also become pathogens to plants and lithotrophic bacteria convert nitrogen, sulfur, iron, or other nutrients for energy and are important in nitrogen cycling and pollution degradation. Actinomycetes are classified as bacteria but are very similar to fungus and decompose recalcitrant (hard to decompose) organic compounds. Bacteria are important in producing polysaccharides that cement sand, silt, and clay particles together to form microaggregates and improve soil structure. Bacteria have the ability to adapt to many different soil microenvironments (wet vs. dry, well oxygenated vs. low oxygen). They also have the ability to alter the soil environment to benefit certain plant communities as soil conditions change.

Acknowledgment

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Related Publications

- Using Cover Crops to Improve Soil and Water Quality
- Sustainable Crop Rotations with Cover Crops
- The Biology of Soil Compaction
- Using Cover Crops to Convert to No-till
- Understanding Soil Microbes and Nutrient Recycling
- The Role of Soil Fungus
- The Role of Soil Protozoa and Nematodes