Soil Microorganisms And Their Functions

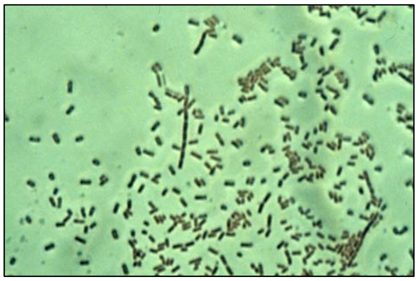


Figure 1: A ton of microscopic bacteria may be active in each acre of soil. ***Credit****: Michael T. Holmes, Oregon State University, Corvallis.*

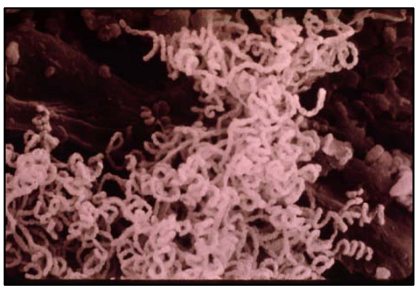


Figure 3: Actinomycetes, such as this Streptomyces, give soil its "earthy" smell. ***Credit:*** *No. 14 from* Soil Microbiology and Biochemistry Slide Set. *1976. J.P. Martin, et al., eds. SSSA, Madison, WI*

Actinomycetes are a large group of bacteria that grow as hyphae like fungi (Figure 3). They are responsible for the characteristically "earthy" smell of freshly turned, healthy soil. Actinomycetes decompose a wide array of substrates, but are especially important in degrading recalcitrant (hard-to-decompose) compounds, such as chitin and cellulose, and are active at high pH levels. Fungi are more important in degrading these compounds at low pH. A number of antibiotics are produced by actinomycetes such as Streptomyces

BACTERIA

Bacteria are organisms that have only one cell and are therefore microscopic. But don't let their size fool you! There are anywhere from 100 MILLION to 1 BILLION bacteria in just 1 TEASPOON of soil!!! They are decomposers, eating dead plant material and organisms' waste. By doing this, the bacteria release nutrients that other organisms could not access. The bacteria do this by changing the nutrients into a form that can be used. Do you know what soil smells like? Well actinomycetes, a unique type of bacteria, cause that smell, and it is a good sign of healthy soil. Actually, people have been smelling soil for many, many years as a way to judge if the land is good for planting.

A FEW IMPORTANT BACTERIA

Nitrogen-fixing bacteria form symbiotic associations with the roots of legumes like clover and lupine, and trees such as alder and locust. Visible nodules are created where bacteria infect a growing root hair (Figure 4). The plant supplies simple carbon compounds to the bacteria, and the bacteria convert nitrogen (N_2) from air into a form the plant host can use. When leaves or roots from the host plant decompose, soil nitrogen increases in the surrounding area.

Denitrifying bacteria convert nitrate to nitrogen (N_2) or nitrous oxide (N_2O) gas. Denitrifiers are anaerobic, meaning they are active where oxygen is absent, such as in saturated soils or inside soil aggregates.

Figure 2: Bacteria dot the surface of strands of fungal hyphae. ***Credit:*** *R. Campbell. In R. Campbell. 1985.* Plant Microbiology. *Edward Arnold; London. P. 149. Reprinted with the permission of Cambridge University Press.*

Figure 4: Nodules formed where Rhizobium bacteria infected soybean roots. ***Credit:*** *Stephen Temple, New Mexico State University*

Nitrifying bacteria change ammonium (NH_4^+) to nitrite (NO_2^-) then to nitrate (NO_3^-) – a preferred form of nitrogen for grasses and most row crops. Nitrate is leached more easily from the soil, so some farmers use nitrification inhibitors to reduce the activity of one type of nitrifying bacteria. Nitrifying bacteria are suppressed in forest soils, so that most of the nitrogen remains as ammonium.

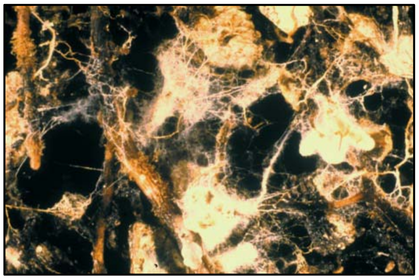


Figure 1: Many plants depend on fungi to help extract nutrients from the soil. Tree roots (brown) are connected to the symbiotic mycorrhizal structure (bright white) and fungal hyphae (thin white strands) radiating into the soil.
Credit: *Randy Molina, Oregon State University, Corvallis*

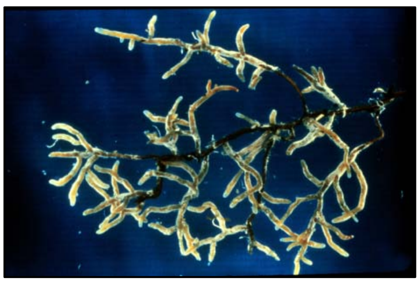


Figure 3: Ectomycorrhizae are important for nutrient absorption by tree and grape roots. The fungus does not actually invade root cells but forms a sheath that penetrates between plant cells. The sheath in this photo is white, but they may be black, orange, pink, or yellow.
Credit: *USDA, Forest Service, PNW Research Station, Corvallis, Oregon*

Figure 5: In arid rangeland systems, such as southwestern deserts, fungi pipe scarce water and nutrients to plants.
Credit: *Jerry Barrow, USDA-ARS Jornada Experimental Range, Las Cruces, NM.*

FUNGI

Fungi are organisms. They are not plants, nor are they animals. They group themselves into strings called hyphae. The hyphae then form groups called mycelium. They are less than an 1/32 of an inch wide but can get as long as several meters. They are helpful but could also be harmful to soil organisms. Fungi are helpful because they have the ability to break down nutrients that other organisms cannot. Fungi release them into the soil, and other organisms get to use them. Fungi can attach themselves to plant roots. Most plants grow much better when this happens. This is a good relationship called mycorriza. The fungi help the plant by giving it those needed nutrients, and the fungi get food from the plant, the same food that plants give to humans. On the other hand, fungi can get food by being parasites, attaching themselves to plants or other organisms, but for selfish reasons.

A FEW IMPORTANT FUNGI

Decomposers – saprophytic fungi – convert dead organic material into fungal biomass, carbon dioxide (CO2), and small molecules, such as organic acids. These fungi generally use complex substrates, such as the cellulose and lignin, in wood, and are essential in decomposing the carbon ring structures in some pollutants.

A few fungi are called “sugar fungi” because they use the same simple substrates as do many bacteria. Like bacteria, fungi are important for immobilizing, or retaining, nutrients in the soil.

In addition, many of the secondary metabolites of fungi are organic acids, so they help increase the accumulation of humic-acid rich organic matter that is resistant to degradation and may stay in the soil for hundreds of years.

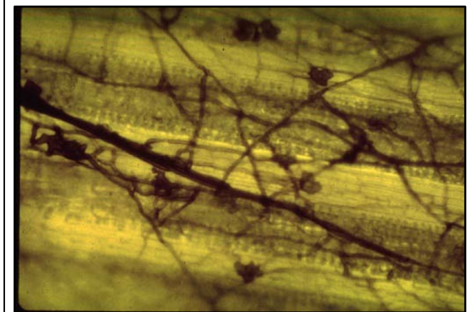


Figure 2: Fungus beginning to decompose leaf veins in grass clippings.
Credit: *No. 48 from Soil Microbiology and Biochemistry Slide Set. 1976. J.P. Martin, et al., eds. SSSA, Madison WI.*

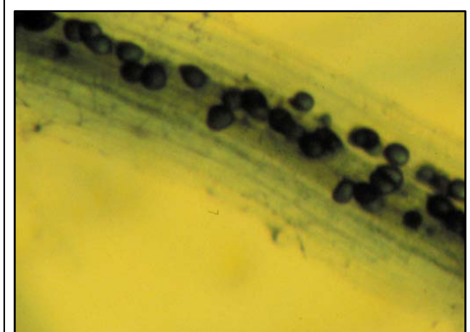


Figure 4: The dark, round masses inside the cells of this clover root are vesicules for the arbuscular mycorrhizal fungus (AM).
Credit: *Elaine R. Ingham, Oregon State University, Corvallis*

Figure 6: Mushrooms, common in forest systems, are the fruiting bodies made by a group of fungi called basidiomycetes. Mushrooms are "the tip of the iceberg" of an extensive network of underground hyphae.
Credit: *Ann Lewandowski, NRCS Soil Quality Institute*

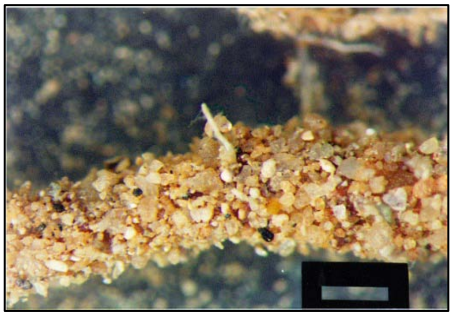


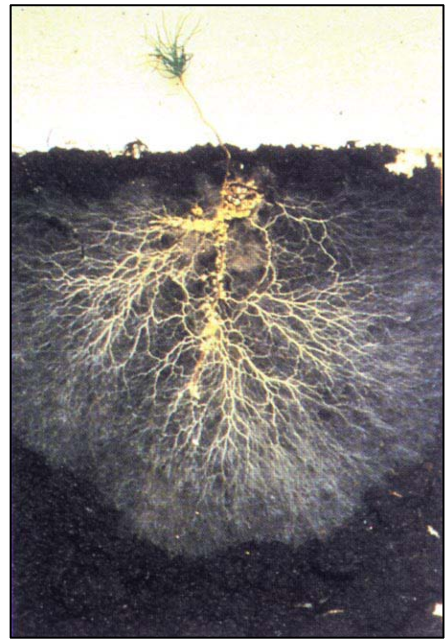
Figure 7: Mycorrhizal fungi link root cells to soil particles. In this photo, sand grains are bound to a root by hyphae from endophytes (fungi similar to mycorrhizae), and by polysaccharides secreted by the plant and the fungi.
Credit: *Jerry Barrow, USDA-ARS Jornada Experimental Range, Las Cruces, NM.*

FUNGI- *(Continued)*

Mutualists – the mycorrhizal fungi – colonize plant roots. In exchange for carbon from the plant, mycorrhizal fungi help solubolize phosphorus and bring soil nutrients (phosphorus, nitrogen, micronutrients, and perhaps water) to the plant. One major group of mycorrhizae, the *ectomycorrhizae* (Figure 3), grow on the surface layers of the roots and are commonly associated with trees.

The second major group of mycorrhizae are the *endomycorrhizae* that grow within the root cells and are commonly associated with grasses, row crops, vegetables, and shrubs. Arbuscular mycorrhizal (AM) fungi (Figure 4) are a type of endomycorrhizal fungi. Ericoid mycorrhizal fungi can by either ecto- or endomycorrhizal.

Parasites - The third group of fungi, *pathogens* or *parasites*, cause reduced production or death when they colonize roots and other organisms. Root-pathogenic fungi, such as *Verticillium*, *Pythium*, and *Rhizoctonia*, cause major economic losses in agriculture each year. Many fungi help control diseases. For example, nematode-trapping fungi that parasitize disease-causing nematodes, and fungi that feed on insects may be useful as biocontrol agents.



MYCORRHIZAL FUNGI IN AGRICULTURE

Mycorrhiza is a symbiotic association between fungi and plant roots and is unlike either fungi or roots alone. The level of dependency on mycorrhizae varies greatly among varieties of some crops, including wheat and corn.

Land management practices affect the formation of mycorrhizae. The number of mycorrhizal fungi in soil will decline in fallowed fields or in those planted to crops that do not form mycorrhizae. Frequent tillage reduce mycorrhizal associations, and broad spectrum fungicides are toxic to mycorrhizal fungi. Very high levels of nitrogen or phosphorus fertilizer may reduce inoculation of roots. Some inoculums of mycorrhizal fungi are commercially available and can be added to the soil at planting time.

WHERE ARE FUNGI?

Saprophytic fungi are commonly active around woody plant residue. Fungal hyphae have advantages over bacteria in some soil environments. Under dry conditions, fungi can bridge gaps between pockets of moisture and continue to survive and grow, even when soil moisture is too low for most bacteria to be active. Fungi are able to bring nitrogen up from the soil, allowing them to decompose surface residue which is often low in nitrogen.

Fungi are aerobic organisms. Soil which becomes anaerobic for significant periods generally loses its fungal component. Anaerobic conditions often occur in waterlogged soil and in compacted soils.

Fungi are especially extensive in forested lands. Forests have been observed to increase in productivity as fungal biomass increases.

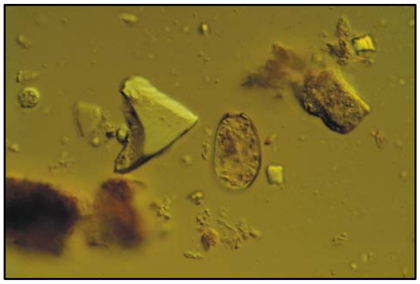


Figure 1: Protozoa play an important role in nutrient cycling by feeding intensively on bacteria. Notice the size of the speck-like bacteria next to the oval protozoa and large, angular sand particle.
Credit: *Elaine R. Ingham, Oregon State University, Corvallis*

Figure 3: Flagellates have one or two flagella which they use to propel or pull their way through soil. A flagellum can be seen extending from the protozoan on the left. The tiny specks are bacteria.
Credit: *Elaine R. Ingham, Oregon State University, Corvallis*

WHERE ARE PROTOZOA?

Protozoa need bacteria to eat and water in which to move, so moisture plays a big role in determining which types of protozoa will be present and active. Like bacteria, protozoa are particularly active in the rhizosphere next to roots.

Fungal-dominated soils (e.g. forests) tend to have more testate amoebae and ciliates than other types. In bacterial-dominated soils, flagellates and naked amoebae predominate. In general, high clay-content soils contain a higher number of smaller protozoa (flagellates and naked amoebae), while coarser textured soils contain more large flagellates, amoebae of both varieties, and ciliates

PROTOZOA

Protozoa are organisms that have only one cell, and are microscopic, but larger than bacteria. They are grouped by the ways they move: amoebae use a psuedo (fake) foot, ciliates have cilia (short hair) and move them very fast, and flagellates have one or more flagella (whips) and move them very fast. Protozoa eat bacteria which actually helps keep the bacteria population growing. Protozoa help other soil organisms and plants by releasing a usable form of nitrogen into the soil. These other organisms and plants cannot do this by themselves.

As they eat bacteria, protozoa release excess nitrogen that can then be used by plants and other members of the food web.

WHAT DO PROTOZOA DO?

Protozoa play an important role in mineralizing nutrients, making them available for use by plants and other soil organisms. Protozoa (and nematodes) have a lower concentration of nitrogen in their cells than the bacteria they eat. (The ratio of carbon to nitrogen for protozoa is 10:1 or much more and 3:1 to 10:1 for bacteria.) Bacteria eaten by protozoa contain too much nitrogen for the amount of carbon protozoa need. They release the excess nitrogen in the form of ammonium (NH4+). This usually occurs near the root system of a plant. Bacteria and other organisms rapidly take up most of the ammonium, but some is used by the plant. (See figure for explanation of mineralization and immobilzation.) Another role that protozoa play is in regulating bacteria populations. When they graze on bacteria, protozoa stimulate growth of the bacterial population (and, in turn, decomposition rates and soil aggregation.) Protozoa are also an important food source for other soil organisms and help to suppress disease by competing with or feeding on pathogens.

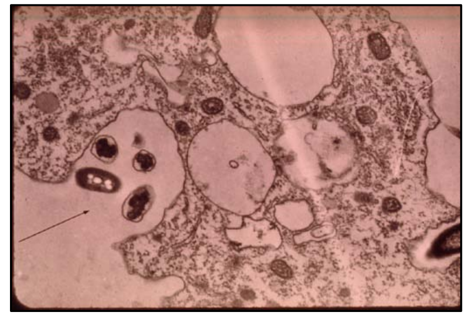


Figure 2: Bacteria ingested by an amoeba.
Credit: *No. 35 from* Soil Microbiology and Biochemistry Slide Set*. 1976. J.P. Martin, et al., eds. SSSA, Madison, WI*

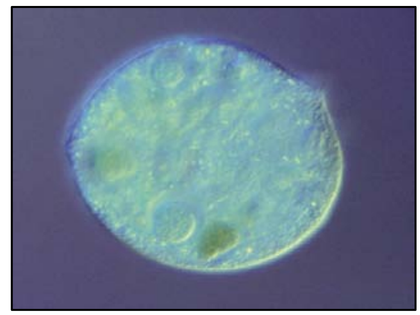


Figure 6: Ciliates are the largest of the protozoa and the least numerous. They consume up to ten thousand bacteria per day, and release plant available nitrogen. Ciliates use the fine cilia along their bodies like oars to move rapidly through soil.
Credit: *Elaine R. Ingham, Oregon State University, Corvallis*

NEMATODES AND PROTOZOA

Protozoa and bacterial-feeding nematodes compete for their common food resource: bacteria. Some soils have high numbers of either nematodes or protozoa, but not both. The significance of this difference to plants is not known. Both groups consume bacteria and release NH4+.

Figure 1: Most nematodes in the soil are not plant parasites. Beneficial nematodes help control disease and cycle nutrients. ***Credit:*** *Elaine R. Ingham, Oregon State University, Corvallis*

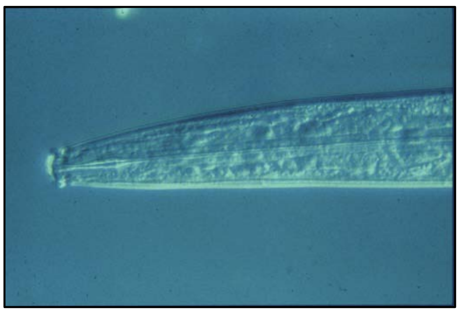


Figure 3: Fungal-feeding nematodes have small, narrow stylets, or spears, in their stoma (mouth) which they use to puncture thecell walls of fungal hyphae and withdraw the cell fluid. This interaction releases plant-available nitrogen from fungal biomass. ***Credit:*** *Elaine R. Ingham, Oregon State University, Corvallis*

NEMATODES

Worms typically 1/500 of an inch (50 µm) in diameter and 1/20 of an inch (1 mm) in length. Those few species responsible for plant diseases have received a lot of attention, but far less is known about the majority of the nematode community that plays beneficial roles in soil.

An incredible variety of nematodes function at several trophic levels of the soil food web. Some feed on the plants and algae (first trophic level); others are grazers that feed on bacteria and fungi (second trophic level); and some feed on other nematodes (higher trophic levels).

Free-living nematodes can be divided into four broad groups based on their diet. Bacterial-feeders consume bacteria. Fungal-feeders feed by puncturing the cell wall of fungi and sucking out the internal contents. Predatory nematodes eat all types of nematodes and protozoa. They eat smaller organisms whole, or attach themselves to the cuticle of larger nematodes, scraping away until the prey's internal body parts can be extracted.

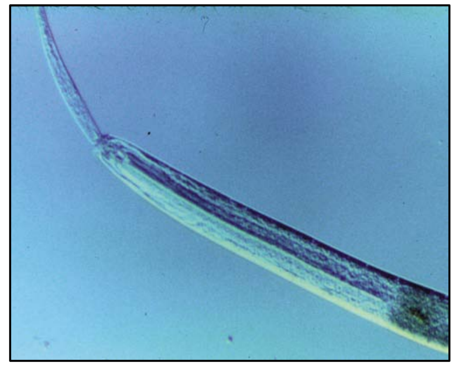


Figure 2: A predatory nematode consumes a smaller nematode. ***Credit:*** *Kathy Merrifield, Oregon State University, Corvallis.*

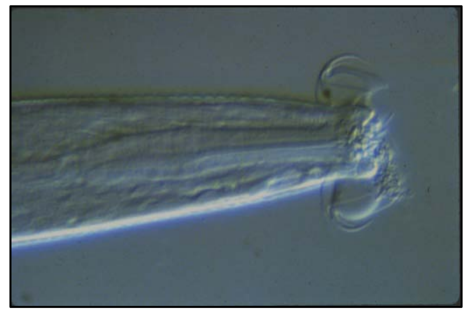


Figure 4: This bacterial-feeding nematode, *Elaphonema,* has ornate lip structures that distinguish it from other nematodes. Bacterial-feeders release plant-available nitrogen when they consume bacteria. ***Credit:*** *Elaine R. Ingham, Oregon State University, Corvallis*

WHAT DO NEMATODES DO?

Grazing. Predatory nematodes (Figure 2) may regulate populations of bacterial-and fungal-feeding nematodes, thus preventing over-grazing by those groups. Nematode grazing may control the balance between bacteria and fungi, and the species composition of the microbial community.

Disease suppression and development. Some nematodes cause disease. Others consume disease-causing organisms, such as root-feeding nematodes, or prevent their access to roots. These may be potential biocontrol agents.

Nutrient cycling. Like protozoa, nematodes are important in mineralizing, or releasing, nutrients in plant-available forms. When nematodes eat bacteria or fungi, ammonium (NH_4^+) is released because bacteria and fungi contain much more nitrogen than the nematodes require.

Dispersal of microbes. Nematodes help distribute bacteria and fungi through the soil and along roots by carrying live and dormant microbes on their surfaces and in their digestive systems.

Food source. Nematodes are food for higher level predators, including predatory nematodes, soil microarthropods, and soil insects. They are also parasitized by bacteria and fungi.

NEMATODES AND SOIL QUALITY

Nematodes may be useful indicators of soil quality because of their tremendous diversity and their participation in many functions at different levels of the soil food web.

Shredders
Many large arthropods frequently seen on the soil surface are shredders. Shredders chew up dead plant matter as they eat bacteria and fungi on the surface of the plant matter. The most abundant shredders are millipedes and sowbugs, as well as termites, certain mites, and roaches. In agricultural soils, shredders can become pests by feeding on live roots if sufficient dead plant material is not present.

Figure 3: Millipedes are also called Diplopods because they possess two pairs of legs on each body segment. They are generally harmless to people, but most millipedes protect themselves from predators by spraying an offensive odor from their skunk glands. This desert-dwelling millipede is about 8 inches long.
Orthoporus ornatus.

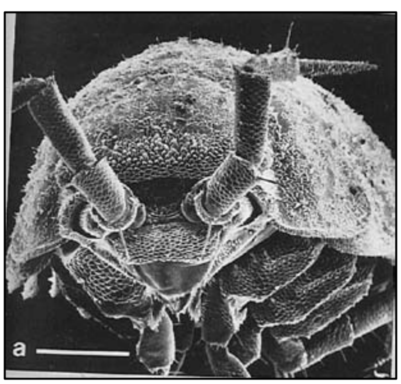


Figure 4: Sowbugs are relatives of crabs and lobsters. Their powerful mouth-parts are used to fragment plant residue and leaf litter. ***Credit:*** *Gerhard Eisenbeis and Wilfried Wichard. 1987.* Atlas on the Biology of Soil Arthropods. *Springer-Verlag, New York. P. 111.*

ARTHROPODS

Many bugs, known as arthropods, make their home in the soil. They get their name from their jointed (arthros) legs (podos). Arthropods are invertebrates, that is, they have no backbone, and rely instead on an external covering called an exoskeleton.

WHAT DO ARTHROPODS DO?
Although the plant feeders can become pests, most arthropods perform beneficial functions in the soil-plant system.

Shred organic material. Arthropods increase the surface area accessible to microbial attack by shredding dead plant residue and burrowing into coarse woody debris. Without shredders, a bacterium in leaf litter would be like a person in a pantry without a can-opener – eating would be a very slow process. The shredders act like can-openers and greatly increase the rate of decomposition.

Stimulate microbial activity. As arthropods graze on bacteria and fungi, they stimulate the growth of mycorrhizae and other fungi, and the decomposition of organic matter. If grazer populations get too dense the opposite effect can occur – populations of bacteria and fungi will decline. Predatory arthropods are important to keep grazer populations under control and to prevent them from over-grazing microbes.

Mineralize plant nutrients. As they graze, arthropods mineralize some of the nutrients in bacteria and fungi, and excrete nutrients in plant-available forms.

Predators
Predators and micropredators can be either generalists, feeding on many different prey types, or specialists, hunting only a single prey type. Predators include centipedes, spiders, ground-beetles, scorpions, skunk-spiders, pseudoscorpions, ants, and some mites. Many predators eat crop pests, and some, such as beetles and parasitic wasps, have been developed for use as commercial biocontrols.

Control pests. Some arthropods can be damaging to crop yields, but many others that are present in all soils eat or compete with various root- and foliage-feeders.

A fundamental dilemma in pest control is that tillage and insecticide application have enormous effects on non- target species in the food web. Intense land use (especially monoculture, tillage, and pesticides) depletes soil diversity. As total soil diversity declines, predator populations drop sharply and the possibility for subsequent pest outbreaks increases.

WHERE DO ARTHROPODS LIVE?
The abundance and diversity of soil fauna diminishes significantly with soil depth. The great majority of all soil species are confined to the top three inches.

Figure 1: Earthworms generate tons of casts per acre each year, dramatically altering soil structure.
Credit: *Clive A. Edwards, The Ohio State University, Columbus.*

Figure 3: A mixture of soil and organic matter within an earthworm burrow. Earthworms incorporate large amounts of organic matter into the soil.
Credit: *Clive A. Edwards, The Ohio State University, Columbus.*

Increase infiltration. Earthworms enhance porosity as they move through the soil. Some species make permanent burrows deep into the soil. These burrows can persist long after the inhabitant has died, and can be a major conduit for soil drainage, particularly under heavy rainfall. At the same time, the burrows minimize surface water erosion.

Stimulate microbial activity. Although earthworms derive their nutrition from microorganisms, many more microorganisms are present in their feces or casts than in the organic matter that they consume. As organic matter passes through their intestines, it is fragmented and inoculated with microorganisms.

EARTHWORMS

Of all the members of the soil food web, earthworms need the least introduction. Most people become familiar with these soft, slimy, invertebrates at a young age. Earthworms are hermaphrodites, meaning that they exhibit both male and female characteristics.

They are major decomposers of dead and decomposing organic matter, and derive their nutrition from the bacteria and fungi that grow upon these materials. They fragment organic matter and make major contributions to recycling the nutrients it contains.

Earthworms occur in most temperate soils and many tropical soils. They are divided into 23 families, more than 700 genera, and more than 7,000 species. They range from an inch to two yards in length and are found seasonally at all depths in the soil.

WHAT DO EARTHWORMS DO?

Earthworms dramatically alter soil structure, water movement, nutrient dynamics, and plant growth. They are not essential to all healthy soil systems, but their presence is usually an indicator of a healthy system. Earthworms perform several beneficial functions.

Mix and aggregate soil. As they consume organic matter and mineral particles, earthworms excrete wastes in the form of casts, a type of soil aggregate. Charles Darwin calculated that earthworms can move large amounts of soil from the lower strata to the surface and also carry organic matter down into deeper soil layers. A large proportion of soil passes through the guts of earthworms, and they can turn over the top six inches (15 cm) of soil in ten to twenty years.

Figure 2: A corn leaf pulled into a night crawler burrow.
Credit: *Soil and Water Management Research Unit, USDA-Agricultural Research Service, St. Paul, Minnesota.*

Figure 8: Earthworm cocoons. One or two worms will hatch from a cocoon after several weeks. *L. terrestris* cocoons are about a quarter inch long.
Credit: *Clive A. Edwards, The Ohio State University, Columbus.*

Improve water-holding capacity. By fragmenting organic matter, and increasing soil porosity and aggregation, earthworms can significantly increase the water-holding capacity of soils.

Provide channels for root growth. The channels made by deep-burrowing earthworms are lined with readily available nutrients and make it easier for roots to penetrate deep into the soil.

Bury and shred plant residue. Plant and crop residue are gradually buried by cast material deposited on the surface and as earthworms pull surface residue into their burrows.

Citation:
Tugel, A.J., A.M. Lewandowski, eds. (February 2001 -- last update). *Soil Biology Primer* [online]. Available: www.statlab.iastate.edu/survey/SQI/soil_biology_primer.htm November 4, 2010.