Soil organisms include a wide diversity of life forms- from bacteria, fungi (such as molds, mushrooms and some parasites), arthropods (like spiders, insects and mites) and many kinds of worms, to vertebrates (including mice, moles, groundhogs and salamanders) (Figure 1). Collectively, these organisms play extremely important roles in cycling nutrients, soil aeration, decomposition of dead plant material and animal waste and increasing soil fertility.

Bacteria and Archaea, collectively known as prokaryotes, are by far the most numerous members of the soil community, with more than $2.25 \times 10^9$ individuals per gram of soil. However, they are very small (1-50 µm) single-celled organisms and, therefore, cannot be seen...
without a compound microscope. Due to their metabolic versatility, prokaryotes are responsible for nearly all chemical transformations that convert organic and inorganic nutrients from one form to another. Some groups of bacteria transform, or “fix”, atmospheric nitrogen (N₂) to ammonium (NH₄⁺), which is a form of nitrogen that is useable by plants and other primary producers.

Legume plants, such as peas and beans, are especially well-known for forming symbioses with nitrogen-fixing bacteria of the genus Rhizobium (Figure 2). These bacteria live within nodules in the legumes' root system, producing nitrogen compounds that help the plant grow in places where soil nitrogen is limited. Another subset of bacteria convert ammonium (NH₄⁺) to nitrite (NO₂⁻) and then to nitrate (NO₃⁻) and finally back into atmospheric nitrogen (N₂), to complete the nitrogen cycle.

Figure 2: Nitrogen fixing Rhizobium bacteria live in root nodules of legume plants, proving the plants with a source of nitrogen.
A group of Archaea (single-celled prokaryote microorganisms) known as **methanogens** (Figure 3) are responsible for most of the biologic methane (CH$_4$) production on Earth. Bacteria and Archaea also produce most **enzymes** that break down larger organic molecules in decaying plant and animal matter, and along with fungi, are the major decomposers in soil. Many larger soil organisms such as **protozoa, nematodes, collembola** and earthworms eat soil that contains concentrated organic matter and colonies of bacteria or archaea. These predators can digest both the organic matter and prokaryotes to gain energy and nutrients, while indigestible material is excreted as mineralized inorganic waste.

**Protozoa**: Soil-dwelling protozoa are small single-celled **eukaryotes**, ranging in size from 5-500 µm and with population densities of up to 10,000-1,000,000 individuals per gram of dry soil. These “animal like” organisms feed primarily on bacteria. In the process of digesting bacteria, they excrete nitrogen in the form of ammonium (NH$_4^+$), which can be readily utilized by plants. Soil protozoans are classified into 3 major groups, defined in part by their mode of motility, and include **flagellates**, **amoeba** and **ciliates** (Figure 4).
Nematodes: Nematodes are a very important and diverse group of small (1000 µm in length) wormlike organisms (Figure 5) and are very abundant in healthy soils. Some nematodes feed on fungi, while others feed on plant roots and are considered parasitic, potentially damaging or killing the plants upon which they feed. Other groups of nematodes are predatory and feed on protozoa and other nematodes. While significantly larger than protozoa, many groups of nematodes also feed on bacteria and compete with bacteria-feeding protozoans. As a result, soils typically contain either an abundance of bacteria-feeding protozoans or bacteria-feeding nematodes, but not both.
**Fungi**: This group of organisms plays an important role in breaking down recalcitrant components of organic matter that are hard for other decomposers to digest, such as **lignin**. Lignin is a class of complex organic **macromolecules** (large molecules) that form important structural materials in support tissues of plants.

The majority of fungi live in the soil, forming interconnected webs of **mycelium** (Figure 6) that are made of individual hair-like **hypha**. Hyphae are individual slender threadlike fibers that collectively make branched fungi mycelium. These below ground networks of mycelium help maintain soil structure and improve the soil’s water-retention capacity. Most fungi are either **saprotrophs** (which get their energy by decomposing organic matter), parasites (which infect living plants and can be significant agricultural pests), or **mycorrhizal** (which have give plants the nutrients and water they need in exchange for carbohydrates that the plant produces through **photosynthesis**). Ninety-five percent of plant species are believed to have

![Figure 6: White webs of fungal mycelium growing throughout soils.](image-url)
associated mycorrhizal fungi. These fungi are essential to their growth in nature.

Figure 7: a) mushroom spore print; b) red toadstool

The most visible form of fungi are mushrooms or toadstools, which are above-ground fruiting bodies of fungi (Figure 7). These contain spores which are easily spread by wind and water, and can germinate into new hyphae.

Figure 8: Soil arthropods in the shredder feeding group: a) sow bug; b) Madagascar hissing cockroach; c) millipede; d) mites
**Arthropods**: Arthropods are named for their jointed legs, and they all have protective **exoskeletons**. They are very diverse, including insects, **amphipods, isopods**, spiders, centipedes, millipedes and many other groups, and are among the larger organisms of the soil community (500µm-3cm).

Arthropods contain members of all functional feeding groups, including shredders, herbivores, predators, parasites and fungal feeders. Shredders chew up leaves and other course organic matter, making it more available to smaller decomposers. Millipedes, isopod, sowbugs, roaches, termites and some mites are all shredders (Figures 8 and 9). Soil arthropod predators include spiders, pseudoscorpions, some mites, centipedes and beetles (Figure 9). Soil arthropod herbivores include cicada larvae, some fly and beetle larvae and some mites (Figure 9).
Figure 9: Examples of soil arthropods in the herbivore and predator feeding groups: a) Phidippus clarus spider; b) termites; c) centipede; d) fruit fly larvae; e) Alder leaf beetle; f) cicada larva; g) pseudoscorpion; h) Eastern Bess beetle larvae
The most abundant fungal feeders are collembola, also known as springtails (Figure 10). Like many soil organisms, arthropods mineralize nutrients, making them available to plants. Because they are relatively large and mobile, they help mix and aerate soil, create soil structure and redistribute nutrients from one area to another.

**Earthworms**: These are among the most recognizable of soil-dwelling animals, and are often found on the soil surface following rainfall (Figure 11). Earthworms ingest leaves and other coarse organic matter, digesting the bacteria and fungi that are already present and excreting what they cannot digest along with mineralized nutrients. Their feeding activity helps to break down leaf litter, converting it into rich organic soil. Like arthropods, they help mix soil and create structure.

**Vertebrates**: The largest and least abundant soil-dwelling animals are vertebrates. These can be herbivores, such as voles and groundhogs, or predators such as moles and salamanders (Figure 12). They can create significant changes in soil structure through their movement, burrowing and nest-building activities, but are probably less important than smaller organisms in terms of basic soil biochemical processes.
Figure 12: Soil vertebrates are among the largest of soil-dwelling organisms: a) vole; b) mole; c) salamander

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