FACT SHEET
Agriculture and Natural Resources

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The Role of Soil Fungus

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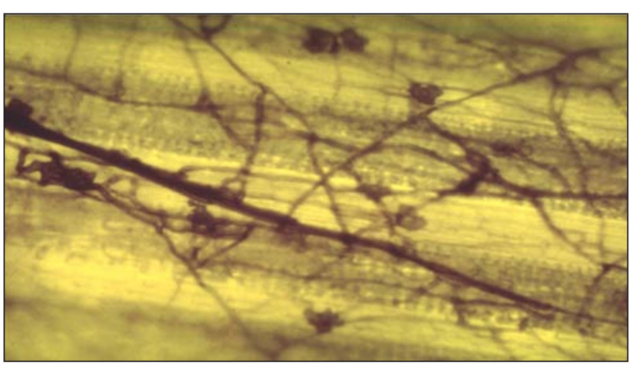
Introduction

Fungi are microscopic cells that usually grow as long threads or strands called hyphae. Hyphae interact with soil particles, roots, and rocks forming a filamentous body that promotes foraging for food. These networks release enzymes into the soil and break down complex molecules that the filaments then reabsorb. Fungus act like natural recycling bins, reabsorbing nutrients in the soil. Hyphae are usually only several thousandths of an inch (a few micrometers) in diameter. Single hyphae can span in length from a few cells to many yards. Hyphae sometimes group into masses called mycelium or thick, cord-like "rhizomorphs" that look like roots.



Soil fungus, like a spider web, increases the ability of plant roots to explore the soil surface area for soil nutrients. (Photo credit: No. 48 from *Soil Microbiology and Biochemistry Slide Set*. 1976. J.P. Martin, et al., eds. SSSA, Madison WI. File name: SSSA48).

Mushrooms are a special type of fungus with special features (spores, gills, fruiting bodies). A single individual fungus can include many fruiting bodies scattered across a large area (as big as a baseball diamond). They generally make up 10–20% of the total microorganisms in the soil rhizosphere. Fungus generally have a lower number of individuals in a healthy soil, however they dominate the soil biomass due to their larger size. Fungus biomass in the soil ranges from the equivalent of two to six cows in a healthy soil. There are at least 70,000 different species of fungus but it is estimated that there are at least 20 times that number worldwide. See "Understanding Soil Microbes and Nutrient Recycling" for more information on microbial numbers.

Role of Soil Fungus

Fungi perform important services related to water dynamics, nutrient cycling, and disease suppression. Along with bacteria, fungi are important as decomposers in the soil food web, converting hard to digest organic material into usable forms. In no-till, fungal population dominate the soil food web (although they are less in number than the bacteria). Fungi have 40–55% carbon use efficiency so they store and recycle more carbon (C) compared to bacteria. Bacteria are less efficient at retaining C and release more into the air as carbon dioxide.

Fungi have higher C content (10:1 C:N ratio) and less nitrogen (N=10%) in their cells than bacteria. Fungus help recycle both N and phosphorus (P) to plants. Due to their smaller size and much greater surface area, fungus can efficiently scavenge for N and P better than plant root hairs and greatly increase the plant root nutrient extraction efficiency. Many plants cultivate certain species of both bacteria and fungus to increase nutrient extraction from the soil.

Genetically, fungi are closely related to plants and animals. Membrane bound organelles present in each cell are similar to insects, plants, and animals. They evolved about a billion years ago and are equal in rank to plants and animals. In fact, fungi have 80% or more of the same genes as humans. They generally reproduce by spores (microscopic parts similar to plant seeds). The longevity of fungus has not been measured in many species but their open-ended growth suggests that they have a longevity measured in millions of years, because they are basically the same organism. For example, fairy fungal rings grow in ever widening circles, much like rings on a tree, and are measured in decades and centuries instead of days and weeks for most microbes.

Classification of Fungi

Fungi are classified by their method of reproduction (both sexual and asexual). Historically they have been divided into four taxonomic divisions: Zygomycota, Ascomycota, Basidiomycota, and Deuteromycota.

a) Zygomycetes

There are less than 1,000 species of zygomycetes. Common bread molds are in this group, as are a few species that parasitize plants and animals. Most zygomycetes feed on dead or decaying plant and animal material.

b) Ascomycetes

Ascomycota contains more than 30,000 species of unicellular (yeasts) to multicellular fungi. Yeasts reproduce asexually by budding and sexually by forming a sac (or ascus). One yeast, *Saccharomyces cerevisiae*, is important for genetic research as well as its commercial applications in baking and brewing. Sac fungi are also important in decomposing and recycling organic matter. Some ascomycetes are parasites responsible for Dutch Elm disease and Chestnut blight. Other sac fungi are used in wine making and in the production of antibiotics.

c) Basidiomycetes

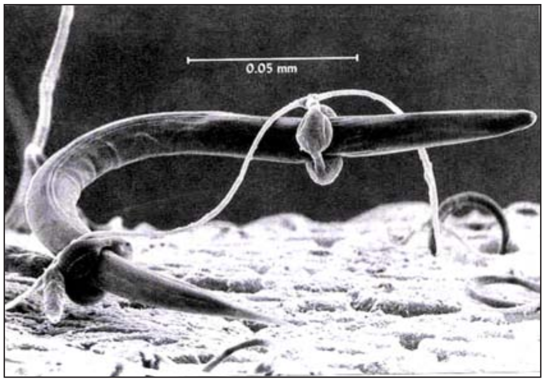
Mushrooms, toadstools, and puffballs are commonly encountered basidiomycetes. Club fungi are important as commercial crops. They also cause many diseases that result in loss or reduction of grain yields. *Agaricus campestris* is the common mushroom found in grocery stores; *Lentinus edodes* is the less commonly bought shitake mushroom: more than $14 billion per year of these products are sold. Rusts and smuts are significant crop parasites: corn smut almost destroyed the entire U.S. corn crop in the 1970s.

d) Deuteromycota: Lichens and Mycorrhizae

Lichens are a symbiosis between a photosynthetic organism (alga or cyanobacterium) and a fungus (sac or club). Mycorrhizae are fungi (usually a zygomycete or basidiomycete) symbiotic with the roots of plants. Both relationships are mutualistic: both parties benefit. Fungi provide nutrients from the substrate, the phototroph provides food. Plants with mycorrhizae grow better: the plant gets nutrients from the fungus in exchange for carbohydrates.

There are generally three groups of soil fungi:

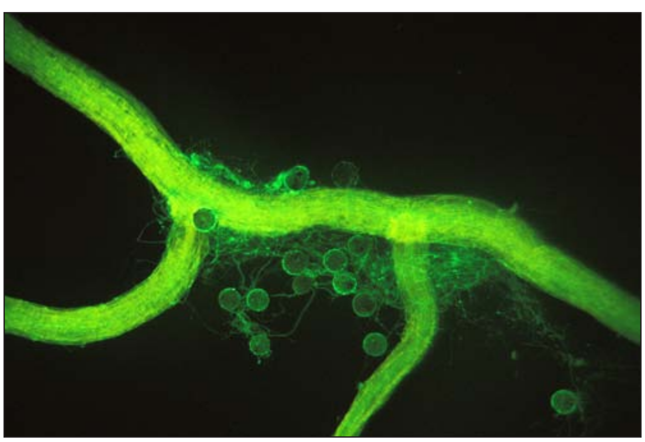
1. *Decomposers* or saprophytic fungi convert dead organic material into fungal biomass, carbon dioxide (CO_2), and small molecules, such as organic acids. Fungi generally decompose complex substrates, such as the cellulose and lignin, in wood, and are essential in decomposing the carbon ring structures in some pollutants. Some fungi consume the same simple sugars as bacteria. Fungi are important for immobilizing, or retaining, nutrients in the soil. Many of the secondary metabolites of fungi are organic acids, which increase humus organic matter that is resistant to degradation and may stay in the soil for thousands of years. Most bacteria are early decomposers along with the sugar fungus (Zygomycetes) but the majority of the fungi help to decompose more resistant organic matter (recalcitrant) high in cellulose and lignin.
2. Fungus that are *pathogens* or *parasites* cause reduced production or death when they colonize



A fungus parasitizing a nematode from Fotosearch Waukesha, WI.

roots and other organisms. Root-pathogenic fungi, such as *Verticillium*, *Pythium*, and *Rhizoctonia*, *Phytophthora*, and downy mildew; cause major economic losses in agriculture each year. Many pathogenic fungi are not true fungi (Oomycetes) and are classified as unicellular in the soil genera "Pythium."

Many true fungi help control diseases. For example, nematode-trapping fungi that parasitize disease-causing nematodes, and fungi that feed on insects may be useful as bio-control agents. Fungus common to agricultural or grassland soils include the Ascomycetes fungus (soil genera Saccharomycetes), which are microscopic in size while forest soils are dominated by Basidiomycetes (soil genera Boletus) with large fruiting bodies (mushrooms) dependent on high organic matter residues.

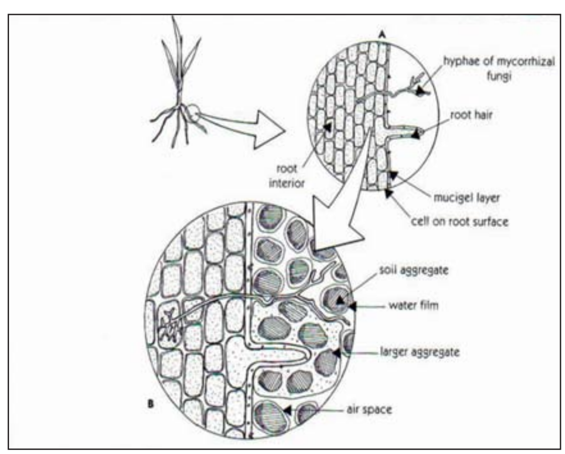


A microscopic view of an arbuscular mycorrhizal fungus growing on a corn root. The round bodies are spores, and the threadlike filaments are hyphae. The substance coating them is glomalin, revealed by a green dye tagged to an antibody against glomalin. Photo by Dr. Sara Wright, USDA-ARS.

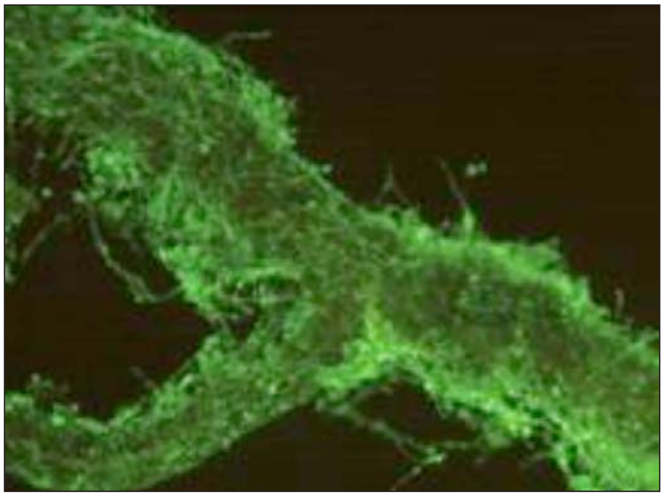
3. The third group of fungus is mycorrhizal fungus which are *mutualist,* creating a symbiotic relationship (mutually beneficial) with many plants. There are more than 5,000 mycorrhizal fungal species. *Endomycorrhizae* grow within the root cells and are commonly associated with grasses, row crops, vegetables, and shrubs. Arbuscular mycorrhizal (AM) fungi are a type of endomycorrhizal fungi. AM fungi have a symbiotic (beneficial) relationship with plants. AM fungi form a mycorrhizal network with plant roots, helping the plant roots be more efficient at gathering soil nutrients, especially N and P. Fungi produce enzymes such as proteases and phosphatases that mineralize and release N and P. AM fungi and rhizobacteria evolved from plants with a common plant-microbe interaction ancestor, likely fungal in nature. This position is supported by the fact that AM fungus and rhizobia share proteins that regulate both AM fungus and rhizobia associations with plants.

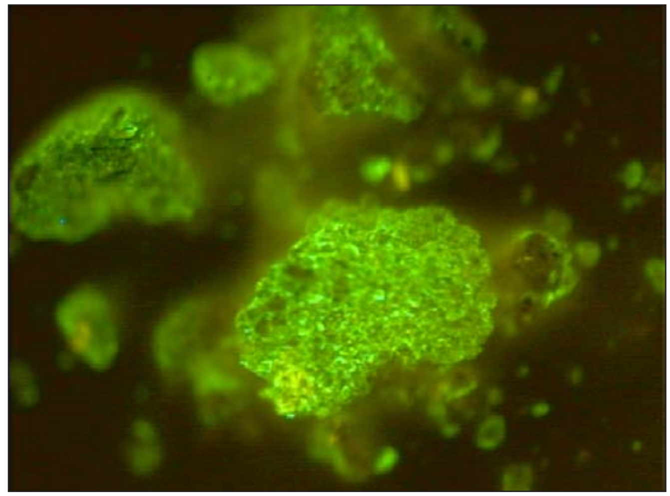
Benefits of Soil Mycorrhizal Fungus

Fungal hyphae have advantages over bacteria in some soil environments. Under dry conditions, fungi may 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.



Mycorrhizal fungus and plant roots. Photo from *Building Soils for Better Crops*, 2nd ed., Dr. Fred Magdoff and Dr. Harold van Es.





Glomalin surrounding a root heavily infected with mycorrhizal fungi and soil macroaggregates surrounded by glomalin.
Photos by Dr. Sara Wright, USDA-ARS.

Fungus hyphal filaments translocate and store deficient nutrients to distant parts of the soil where nutrients may be lacking, allowing reproduction and growth to continue. The plant supplies simple sugars to the fungus while fungus supply N, P, other nutrients and possibly water to the plant. As much as 20% of the total carbon assimilated by the plant may be transferred to the fungal partner. The mycorrhizal network of fungi hyphae greatly increases the surface area for plant roots and efficiently transport nutrients back to the plant. Mycorrihzal networks explore up to 20% of the soil volume due to their smaller size compared to only 1% of the soil volume for a typical plant root hair. However, when excess nutrients like N and P are supplied by commercial fertilizer to plant roots, the AM fungi stop working. Tillage also decreases the effectiveness of the AM fungus by destroying the mycorrhizal network associated with plant roots.

Fungal hyphae physically bind soil particles together, creating stable macroaggregates (>250 μm) that help increase water infiltration and soil water holding capacity. Typically there are from 1 to 20 meters of AM hyphae in each gram of soil (as much as 5 miles of AM hyphae in a pound of soil).

AM fungi produce a sticky substance call glomalin. Glomalin is an amino polysaccharide composed of sugars from the plant root and protein from the fungus forming a glycoprotein. Glomalin surrounds the microaggregate soil particles and glues them together to form macroaggregate soil particles. Polysaccharides like glomalin enhance good soil tilth and good soil structure. Some inoculums of mycorrhizal fungi are commercially available and may be added to the soil at planting time.

Conventional tilled soils are dominated by bacteria, which do not produce glomalin. Tillage disrupts and breaks down the macroaggregates into microaggregates and results in denser, more compacted soils, lacking soil structure. Tilled soils lack soil organic matter (SOM) and the ideal soil habitat to feed and keep large numbers of beneficial fungal populations healthy. Fungus need well-aerated soils and cannot tolerate saturated or anaerobic (lack of oxygen) soil conditions that occur under tilled compacted soils. Tillage also injects excess oxygen into the soil, stimulating bacteria populations to increase, and the expanding bacteria populations consume active carbon (polysaccharides and glomalin) for food.

In a good soil, glomalin may represent 1–5% of the total carbon in the soil. Glomalin is 30% carbon, 1–2% nitrogen, and up to 5% iron, which gives it a reddish soil color. Broad spectrum fungicides are toxic to mycorrhizal fungi populations. So tillage, excess commercial fertilizer, pesticides, short crop rotations, and long fallow periods tend to decrease fungal populations and decrease the production of glomalin in the soil. See "Biology of Soil Compaction" for more information about soil structure.

Some plant species like the Cruciferae family (e.g., broccoli, mustard), and the Chenopodiaceae family (e.g. lambsquarters, spinach, beets) do not form mycorrhizal associations. The level of dependency on AM fungus varies greatly among varieties of some crops, including wheat and corn; however, greater than 90% of plants have an association with AM fungus.

Ecological Plant-Microbe Interactions

Plant-microbe interactions in the rhizosphere are responsible for a number of soil processes that include carbon sequestration, ecosystem services, and nutrient recycling. The composition and quantity of microbes in the soil influence the ability of plants to obtain nitrogen and other nutrients. Plant can influence these ecosystem changes through the deposition of root exudates or carbon rich substances into the soil to attract or inhibit the growth of specific organisms. These carbon rich substances can range from less than 10% to as much as 44% of a plant's total carbon production. Soil microbes utilize this abundant carbon source, implying that the plant's selective secretion of specific compounds between plants and microbes may encourage beneficial symbiotic and protective relationships against pathogenic microbes. Plants basically feed, raise, and encourage certain microbes just like farmers raise and feed plants and livestock for food and fiber.

Fungi benefit most plants by suppressing plant root diseases and promoting healthier plants by attacking plant pathogens with fungal enzymes. Fungi enhance and cultivate good bacteria, especially Rhizobia bacteria for nitrogen fixation, which help legume plants grow. Fungi aid plants in N and P soil extraction and help in drought stress to supply more water to plants through the fungal hyphal network and by providing a protective shealth around plant roots under dry conditions. During drought stress, as soils dry down, P becomes limiting even in soils with high P availability. Fungi protect the plants by supplying a protective sheath to supply both water and P to the plant roots.

Mycorrhizal fungus may have over 5 miles of hyphae in a pound of soil. The hyphae are usually white or yellow or tan. The root at the top is tan or light brown color. Photo by Randall Reeder.

When environmental conditions decline, fungus form spores, which store large amounts of nutrients to allow the fungus to survive until environmental conditions recover. Fungus with specialized nutrient requirements are more likely to decline or die out when a non-host plant is included in a crop rotation while a fungus with a wide host range will survive and possibly flourish. Soil fungi often have enough resiliency to convert from one resting stage to another when nutrient levels are low. These patterns are important in agricultural management systems that involve fallow periods between cropping cycles.

Fungal hyphae must be in close contact with living or dead organic soil residues to absorb nutrients, so they usually grow in association with other soil microorganisms. They compete aggressively for scarce nutrients, and competition usually results in a succession or change in microbial composition as nutrients are absorbed or depleted. Initial colonizers absorb simple sugars, amino acids, and vitamins from plant parts such as fruits, seeds, and vegetables and are classified as "sugar fungus." The dominance of these fungi is short-lived because waste products accumulate quickly.

Cellulose degraders appear next and they are the most diverse and competitive. Degradation of straw has a high C:N ratio (80:1) and requires that fungus parasitize or decompose other fungi to obtain nitrogen for growth and enzyme production. Degradation of lignin is stimulated by low nitrogen. Lignin makes up 60% of the total mass of humus, but the low number of fungal species that can degrade lignin reduces competition. Fungi also use antagonism to reduce competition by producing antibodies, which suppress other microorganisms from growing.

Summary

Microorganisms abound in the soil and are critical to decomposing organic residues and recycling soil nutrients. Most soil fungi decompose recalcitrant organic residues high in cellulose and lignin. Fungi carbon use efficiency is about 40–55% so they store and recycle more C (10:1 C:N ratio) and less N (10%) in their cells than bacteria. Fungi are more specialized but need a constant food source and grow better under no-till conditions. Arbuscular Mycorrhizal (AM) fungi produce an amino polysaccharide called glomalin. Glomalin surrounds the soil particles and glues macroaggregate soil particles together and gives soil its structure. AM fungus store and recycle N and P in the soil and have a symbiotic relationship with most plants, greatly increasing the N and P extraction efficiency and improving soil structure and water retention.

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 Bacteria
- The Role of Soil Protozoa and Nematodes
- Homegrown Nitrogen