SOIL MICROBIAL COMMUNITIES AND EARLY SEASON CORN GROWTH

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Abstract

The soil microbial community plays many roles in the soil. Although some microbes are pathogens, most are beneficial. Soil organisms are important for nutrient cycling, nutrient retention, soil structure improvement, water infiltration and water-holding capacity, disease suppression, and pollutant degradation. Soil microbial communities contain various types of organisms: fungi, bacteria, protozoa, microarthropods and nematodes. These organisms form a food web. There are multiple methods of characterizing these organisms; they can be counted, or quantified by their activity or cellular constituents. An overview of soil microbes and their roles will be provided as well as an introduction to methods for studying microbes.

Management can affect the soil community directly and indirectly. Plant roots influence the microbial community and are affected by microbes. During the early growing season, soils tend to be cool and wet, which affects growing conditions of the microbes and plants. Cool temperatures can change the material exuded from corn roots into the soil. Planting too early can result in poor germination. Corn will germinate and grow at 50°F but does better when average air temperatures are 55°F. Examples of how environmental conditions, soil microbes, and plant roots interact will be presented.

Soil Biology

The soil is home to a vast array of organisms: bacteria, cyanobacteria, algae, protozoa, slime molds, fungi, nematodes, mites, insects of all sizes, worms, small mammals and plant roots (Table 1). The diversity and function (ecology) of soil is very complex; it's a virtual rainforest below our feet in terms of the number of species and their diversity. Frequently, we are not aware of their presence due to their microscopic size.

Bacteria are the smallest and most numerous organisms in the soil. Collectively, there may be over a billion individuals in a gram of soil (there are over 28 g in an ounce). It is thought that less than half the species of soil bacteria have been identified. The purple bacteria (also called gram negative) include several examples of agriculturally important groups (Table 1). *Rhizobium* and *Bradyrhizobium* are nitrogen-fixating organisms when they are in symbiotic relationships with legumes. *Nitrosomonas* are necessary for nitrogen transformation in the soil, which change nitrogen containing-compounds into forms available to plants. *Pseudomonands* and others can be found living very closely around plant roots. *Pseudomonands* have many beneficial roles in the soil including decomposition, nutrient acquisition and bio-control against soil pathogens; however, there are a few which can be pathogenic.

Actinomycetes are bacteria that give tilled soil its characteristic earthy scent (Table 1). The most common form of actinomycete extracted from soil is *Streptomyces*, which is important in decomposing a wide array of compounds. Also, many antibiotics are produced by *Streptomyces* including erythromycin, tetracycline, streptomycin and others.

Table 1. Components of the Soil Biota

Component	**Subgroup**	**Agriculturally important examples**	**Comments**
Bacteria	Purple bacteria	*Rhizobium* *Bradyrhizobium* *Nitrosomonas* *Pseudomonands*	Nitrogen fixing. Nitrogen transforming. Associate with plant roots, roles in nutrient uptake, especially iron. Decomposition.
	Actinomycetes	*Streptomyces*	Decomposition. Antibiotics.
	Sporogenic Bacilli	*Bacillus* *Clostridium*	Bt toxin producers. Well-known pathogens.
	Cyanobacteria		Found everywhere.
Protists	Protozoa (animal-like)		Eat bacteria, other protozoa. Found on water films in soil.
	Slime Molds (fungi-like)		Decomposition. More common in forest soils.
	Water Molds (fungi-like)	*Phythium debaryanum* *Phytophthora infestans*	Decomposition. Plant pathogens – damping off, potato blight.
Fungi	Mold (Zygomycetes)	Mycorrhizae	Common bread mold, nematode trappers, decomposition in soil mycorrhizal association with many (80%) of plants important for nutrient uptake, especially phosphorus.
	Sac Fungi	*Aspergillus*, *Penicillium* Yeast Ergot	Common in soil. *Penicillium* more common in temperate areas. Penicillin. Yeast, brewing, baking Ergot toxic to humans Powder mildew
	Club Fungi	Mushrooms	Extensive underground growth. Many of the edible mushrooms in this group; some very toxic
Animals	Nematodes	Roundworms	Billion in top inch per acre. Microscopic.

Component	**Subgroup**	**Agriculturally important examples**	**Comments**
			Feed on bacteria, fungi, protists, other nematodes. Some pathogens.
	Arthropods	Mites	Eat plant debris. Spider mites – plant pests.
		Millipedes Centipedes	Feed on decaying organic debris. Centipedes eat insects and slugs.
		Spiders	Soil predator.
	Worms	Earthworms Night crawlers	Major decomposer. Move plant debris into soil. Cycle soil. Presence indicator of healthy soil.
	Insects	Unwinged	Soil-dwelling wingless insects. Eat plant debris, humus and fungi.
		Winged	Likely spend only juvenile part of life-cycle in soil.
Plants			Plants via photosynthesis are the primary food source for soil systems.

Source: (Paul and F. E. Clark,1996; Tugel and Lewandowski, 2001)

Another group of soil bacteria are the sporogenic bacilli. These bacteria form resting structures (endospores); endospores allow these bacteria to survive very harsh conditions (e.g., drought, heat). This group is very diverse. It is worth noting a few members of this group: *Bacillus thuringiensis* (Bt), which produces the Bt toxin; *Bacillus anthracis*, which is responsible for anthrax; *Clostridium tetani*, the cause of tetanus; and *Clostridium botulinum*, which produces the toxin responsible for botulism poisonings.

Protists are a very diverse group (Table 1). There are animal-like protozoa that are found in films of soil water. Protozoa graze on bacteria, and other protists. Another group is slime molds, which are more common in forest soils and on decaying wood. Water molds are fungi-like and have a role in decomposition, but there are a few notorious species responsible for diseases such as damping off and potato blight. Algae are plant-like protists, but they are more common in aquatic organisms.

Fungi are classified by how they reproduce (Table 1). Fungi include common molds such as bread mold. This common group, which scientifically is called *Zygomycetes*, also includes many species fungi that form mycorrhizal associations with plants. In these mycorrhizal associations the fungi receives food from the plant and in exchange provides the plant with additional mineral nutrients especially phosphorus. In the other groups of fungi, what is commonly called a mushroom, is a reproductive structure. The vast majority of fungi are microscopic and can cover very large areas of soil. Fungi are critical contributors to decomposition and nutrient cycling. Although most are beneficial, there are several fungal species that are notorious as pathogens (e.g., *Fusarium*, *Sclerotium*, *Verticillium*).

A diverse group of animals live in soil: microscopic nematodes, arthropods and many large worms and insects (Table 1). Nematodes are the most abundant animal in the soil. Many are beneficial because they graze on bacteria and other microorganisms, or eat organic matter and debris, and contribute to nutrient cycling. A few nematode species cause plant diseases, such as soybean cyst nematodes. Mites, millipedes and insects shred large pieces of plant biomass into smaller pieces making it more available to other soil organisms. The soil is home to predators of various sizes: centipedes, spiders, beetles and ants. Frequently, predators help keep the population of detrimental animals in check. In some cases, predators (e.g., beetles and parasitic wasps) have been exploited as bio-control mechanisms.

<u>Food Web</u>

Soil biota forms a food web. There may be 10,000 species of microbes in one gram if soil. A food web is a map of the connection among transfers of food energy from organism to organism. Plants that produce food energy through photosynthesis are at the bottom. The next level up is decomposers. The third level includes the shredders, predators, and grazers. The latter level eat plant biomass and reduce it into small pieces. Moving up the tropic levels, there are more predators, increasing in size but decreasing in number. Overlap exists; for example, nematodes may graze on fungi, but some species of fungi trap and consume nematodes. Decomposition, an integral part of a food web, is the breaking down of dead organisms to obtain nutrients.

Plants provide the carbon and energy that supports a food web. In the green portions of plants, the energy from light is used to convert water and carbon dioxide into sugar. The sugar is used to provide the carbon for making other compounds plants need. The food (energy) from plants can reach the soil through the roots. This is a very important pathway for moving food into the soil. Roots, in turn, become food to other organisms when they die. Unharvested crop biomass (residue and roots) provides some food for soil organisms.

As food energy passes through a food web, some of the food's carbon is released as carbon dioxide. Nitrogen and other nutrients are recycled into forms that can be used by plants. Mineralization converts organic material into inorganic material. There are a wide range of chemicals released into the soil from roots, bacteria, fungi, and earthworms. Some of these chemicals (e.g., sugars and proteins) and fungal filaments cause soil particles to stick together, forming soil aggregates. Soil containing well-structured aggregates is less likely to erode, and has better water infiltration. Soil organic matter, a combination of decomposing material and soil microbes, improves the soil's ability to absorb water (soil water-holding capacity). The burrowing of earthworms and other organisms, and root channels aid in water movement in the soil. Improving soil structure enhances root growth, which can further enhance soil structure.

A diverse soil biota is desirable. Diversity helps ensure a well-connected food web. By analogy, human society needs people with many talents and roles. If there were only bankers and lawyers, human society would not function. Continuing this analogy, if a town has several grocery stores and one closes, there would still be food to buy. In a soil community, diversity helps assure all steps of a food web or nutrient cycle are completed.

A variety of tools are available for studying microbes: microscopy, chemical or genetic signatures, physiological analysis and process studies. Frequently, multiple tools are used to describe and understand soil microbes. Microscopy is useful for determining morphology, numbers, or arrangement microbes. Microscopy may be used with plating and colony counting. Specific labels can identify some specific organisms. Chemical analysis, characteristic patterns of cellular material, or genetic patterns (e.g., DNA analysis) can be used to identify groups of organisms. Some organisms have unique chemical compounds. For example, the compound ergosterol is common in fungi, but does not occur in plants. Therefore, measuring this compound has been used to measure invasion of pathogenic fungi into plants.

Management and Soil Biology

Soil biota is diverse and dynamic. The soil community is essential to a productive soil. Therefore, it is advantageous to increase our understanding of this community. Agriculture greatly disturbs the original native soil community. While detailed recommendations to manage soil biology do not yet exist, there are general recommendations to improve biological functions, which result in improved soil structure, nutrient cycling, pest and disease control and detoxification or degradation of toxins. The NRCS Soil Quality Institute recommends adding organic matter regularly, diversifying the type of plants across the landscape, using diverse crop rotation (three or more crops), using cover crops, maintaining residue cover, and avoiding excess disturbance (e.g., excessive tillage, compaction, heavy use of pesticides) to promote soil biota. Organic matter from roots, plant biomass, and manure provide the food/energy to support the biological community. Cover crops or green manure increase the time a growing plant is on the soil, providing a steady influx of food and reducing soil erosion. Research has shown that growing more than two crops in rotation increases the diversity of the soil community. Crop rotation also can help disrupt some pathogen cycles. These recommendations aim to keep a healthy, diverse soil biological community.

The soil community is complex and dynamic. Progress has been made in understanding how management may affect the soil community; however, our knowledge and understanding of the interactions between the soil community and early season corn growth is limited. Early season corn growth has been described in the literature and is briefly reviewed below. Some of the crop management strategies that have been developed to cope with challenging conditions that corn experiences early in the season will also be reviewed.

Early season corn growth

It is generally recommended that corn be planted when the soil temperature at 2 inches is at 55^{o}F, or 50^{o}F at 6 inches. Germination and development of corn is greatly retarded at soil temperatures below 50^{o}F. Very early planting will not may not consistently advance maturity due to delayed germination and/or poor emergence. Seed rots caused by a variety of pathogens (fungal and bacterial) are favored in springs that are cool and wet; therefore, seeds in cold soil are more prone to seed rots. Cold soil temperatures delay seedling growth and development, in part because of limited root growth and subsequent restricted root nutrient uptake.

Current management recommendations to improve germination include: choosing hybrids best suited for your region, using fungicide on seeds, and delaying planting until soil is warmer and drier at planting depth. In a cool, wet spring, planting corn shallower in warmer, drier soils results in faster germination and emergence.

Nutrient uptake begins soon after germination, before the plant emerges from the soil. Plant roots are not attracted to fertilizer, so fertilizer must be placed where the roots are expected to be growing. Fertilizer can reach the plant root through three mechanisms: (1) mass flow moving with water, (2) diffusion, and (3) root intercept. Although the amounts of nutrients taken up early in the growing season are small, the nutrient concentrations in the soil surrounding the roots of the small plant at that stage often must be high to assure adequate uptake. Band application of starter fertilizer below and slightly to the side (1-3 inches) of the seed, places the fertilizer near the developing root overcoming early season nutrient uptake problems. The fertilizer should not be placed closer than within 1 inch of the seed or salt injury can occur. As the plant grows and the root system develops, precise fertilizer application becomes less critical.

Corn normally has mycorrhizal associates that promote phosphorus uptake. In some years, corn has a purple color early in the season and sometimes is referred to as “fallow syndrome.” Fallow syndrome occurs if there has been no host crop growing in the field — e.g., sugar beet. Usually the purple color disappears as the soil warms and dries. The problem can be avoided by banding phosphorus near the seed. Fertilizer rate when banding varies by the nutrient, crop, and soil texture. Research in Minnesota by George Rehm and others has shown that as little as 40 lb./acre phosphorus (P) and potassium (K) when banded can give the same yield results as broadcasting 200 lbs./acre of these nutrients. Phosphorus and potassium bind to the soil; therefore, banding phosphorus and potassium improves the efficiency that crops utilize these nutrients. Less than 30 lbs./acre nitrogen and less than 60 lbs./acre potassium should be placed within an inch of a seed.

New technology

Temperature activated polymer coating for seeds is a new technology designed to allow planting in cold soil, which is otherwise ready for planting. Polymer coatings are temperature activated, they allow the seed to imbibe water and germinate only if the soil temperature has warmed above a minimum temperature (50^{o}F). Thus, they delay germination and result in a more uniform stand. Early field tests in Iowa, Ohio, and Minnesota found this technology performed satisfactorily for corn planted early, resulting in increased seedling emergence. Polymers have also been used with canola and soybeans. A disadvantage of the polymer coated seeds is they cost $10 to $12 more per bag than non-coated seed. Polymer coated seed allows earlier planting with less risk of early season seed or seeding damage. However, it does not protect the seedling once germinated if it is too cold for seedling growth. Another potential advantage of early planting with polymer-coated seed is that corn may have more time to dry in the field at the end of the season, thus reducing drying costs.

Summary

The soil has a very diverse community of organisms. There are many species in the soil that have not yet been identified. Research is needed to understand the role of many of these species. Work is needed to determine how management can be modified to enhance a healthy, diverse soil community; and a soil community that promotes agricultural production and sustainable agriculture. Specific recommendations to manipulate the soil community to promote early season crop growth are lacking. Current production recommendations for promoting early season crop growth include banding of fertilizer near the seed, planting shallower if soils are cold, applying seed fungicides, and possibly using polymer coated seed technology.

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