Microbiology of Soils

By Eric B. Nelson

Soils vary considerably in physical and chemical composition. However, regardless of their properties, most contain a vast array of living organisms, ranging from larger creatures such as earthworms and insects, to microscopic invertebrates, bacteria, fungi, actinomycetes, yeasts, algae and protozoa. All of these organisms affect plant health in important ways. However, perhaps the most important and least understood are the bacteria, fungi and actinomycetes.

Microorganisms occur in soils in extremely high populations, making soils among the most dynamic sites of biological activity in nature. Many people assume that some soils, such as those with high sand content or those that have received high doses of pesticides, lack microorganisms. This is untrue. Regardless of the soil type, texture or history, abundant microbial populations are present. (However, microbial activities may be lower and certainly are different in sandy soils or those that have been treated with pesticides.)

Considerable diversity exists among soil microorganisms. It probably is safe to say that more biological diversity exists among the microorganisms in an ounce of soil than in the entire Amazon rain forest. This diversity is important in the maintenance of optimum soil and plant health.

Microorganisms perform a variety of functions, many of which are extremely important to the health of a plant. Chemical, physical and biological factors strongly affect their level of activity as well as the kinds of microorganisms present. Factors such as soil pH, fertility, organic matter, moisture, temperature, soil porosity, and plant species and cultivar all are important. As a result, anything that alters these factors also affects microbial activities. When management practices affect microbial processes in a negative way, we generally see the indirect effects as reduced plant health and vigor. When practices have a positive effect on microbial populations, we often see improved plant vigor, stress tolerance and pest tolerance.

Much of the microbiological activity in soils takes place in close association with plant roots called the rhizosphere. In the course of their normal growth and development, plant roots release a variety of organic compounds into the surrounding soil. This exudation creates a soil environment, the rhizosphere that stimulates microbial activity.

Because of root exudations, the rhizosphere is a carbon-rich environment. This carbon supplies much of the energy for the microorganisms there. The types and amounts of carbon compounds that plant roots release vary according to plant species and environmental factors and help determine the types and numbers of microorganisms that inhabit the rhizosphere.

In the absence of plants, soils have limited available carbon to support microbial growth. Much of the carbon in soils is in the form of humus, which already is in a highly decomposed state resistant to further decomposition. Therefore, microorganisms rely heavily on plants to supply most of their carbon needs. As microbes decompose root exudates and other forms of introduced carbon (such as from organic amendments), these materials become part of the humus fraction of soil.

Of the microorganisms present in soil, bacteria occur in the greatest numbers and are perhaps the most diverse in their morphology and physiology. Bacteria are small single-celled organisms that reproduce rapidly by simple cell division, producing huge numbers of cells in a short time. Under favorable conditions, bacteria may divide every 20 minutes. Conceivably, then, one bacterium could give rise to 1,000,000 bacteria in 10 hours! However, the size of each cell is quite small, usually not more than 1 or 2 microns (0.00004 inch) in length.

For the explosive growth of bacteria to occur, an array of carbon sources must be available. The metabolic transformation of these carbon sources produces a number of by-products. The resulting soil chemical changes may be vast and are why bacteria can be such significant microorganisms in the plant environment.

Bacteria require water to grow and reproduce, so soils with chronically low moisture limit their survival. Although many bacteria are saprophytic (they primarily live on decaying organic matter), some are endophytic (they live inside healthy plants, usually in roots). A few can cause diseases in plants, animals and humans, but those that occur in soils are either saprophytic or endophytic. In either case, they usually are good competitors with plant pathogens and, therefore, can minimize damage from plant-pathogenic fungi.

Bacteria that play a role in nutrient transformations in soil and in direct plant-growth promotion are particularly important. Bacteria within the genera Azotobacter, Azospirillum, Enterobacter and Klebsiella are efficient, free-living, nitrogen-fixing organisms. That is, they take nitrogen from the atmosphere and convert it to a form that plants can use.

Many of these same bacteria naturally produce hormones that stimulate plant growth. Bacteria in the genera Bacillus, Pseudomonas and Azospirillum are particularly well known for their growth-promotive effects. Azospirillum spp. are efficient at stimulating root growth and promoting seedling establishment, whereas Pseudomonas spp. possess pathogen-suppressive properties.

Bacteria also are important in organic-matter degradation. These organisms play a key role in maintaining the delicate balance between thatch accumulation and degradation, and, to some degree, you can manage them.

In fact, several preparations of thatch-degrading microorganisms or the enzymes they produce are commercially available. Some of these are useful in thatch-maintenance programs, whereas others-for reasons that are not always clear-fail miserably. Check with plant turf managers to see what has succeeded in conditions similar to yours, and keep in mind that the dynamics of thatch-degrading microorganisms are not fully understood.

Some bacteria impact plant health by controlling plant pathogens-these occur in all types of soils. Their effects sometimes go unnoticed, but they can have a huge impact on disease development. In some cases, high populations of these bacteria are responsible for what we call suppressive soils. These are soils where conditions are ideal for disease development and the pathogens are present, but no disease develops because of the activity of bacteria. These bacteria inhibit pathogens by competing for resources, producing antibiotic compounds or, occasionally, acting as fungal parasites. Because these bacteria are saprophytic, large amounts of organic matter-topdressings or direct soil amendments-usually are beneficial to their populations.

Many of these biological-control bacteria occur in particular types of organic matter such as composted material. In fact, the application of compost has been an effective alternative to fungicides in some instances. Similarly, several companies now market bacterial preparations as fungicides.

Fungi account for the greatest amount of living biomass in soils. Fungi are best known for their pathogenic activities in soils, because they cause nearly all economically important diseases. However, pathogenic fungi represent only a small proportion of the total fungal community in soil. The vast majority are beneficial to plant health. The genera of fungi present in soils include Penicillium, Aspergillus, Trichoderma, Gliocladium, Fusarium, Mucor and Mortierella.

Unlike bacteria, fungi grow in filamentous form and reproduce with spores. Fungi obtain their energy for growth primarily through the decomposition of organic matter. Generally, fungi are more prevalent than bacteria in soils of pH lower than about 5.5, whereas bacteria tend to predominate in soils with higher pH. Because fungicide use is common on golf-course turf, the composition of fungal communities in these soils can vary dramatically, depending on the type, rate and frequency of fungicide applications to that site.

Aside from their roles in disease and organic-matter decomposition, some groups of soil fungi perform more specialized functions in the rhizosphere.

Mycorrhizal fungi are specialized parasitic fungi that form unique symbiotic associations-mycorrhizae-with plant roots. In mycorrhizal relationships, the fungus benefits from the carbon the plant provides, while the plant benefits from the increased phosphorus nutrition and water availability that the fungus supplies. As with other fungi, mycorrhizal fungi are sensitive to several commonly used fungicides.

Some of the better known fungi in plant ecosystems are endophytic fungi. These typically are found in the seeds and leaf sheaths of nearly all plant species.

One of the least known and most poorly understood groups of soil microorganisms are the actinomycetes. These microbes apparently are more closely related to bacteria but grow more like a fungus. Although their populations in some soils can be quite high, their growth rates are much slower than other soil microorganisms. Much of the smell unique to high-organic-matter soils comes from the volatile compounds actinomycetes produce.

Actinomycetes typically are more abundant in dryer soils high in organic matter or in high-temperature soils. As a group, they are not tolerant of low soil pH (less than 5.0). They grow best at temperatures ranging from 80°F to 100°F. The major genera of soil actinomycetes include Streptomyces, Nocardia, Micromonospora and Actinoplanes.

These organisms are best known for their ability to produce several industrially and medically important compounds. Many antibiotics important to human and animal medicine come from soil actinomycetes. Like the fungi, actinomycetes rely on organic matter for their nutrition. In particular, they are well-adapted to the decomposition of the more resistant plant polymers such as cellulose, hemicellulose and lignin, as well as the fungal and insect polymer chitin. Because of this, actinomycetes play a major role in the formation of humus in soils.

Like some bacteria, actinomycetes help suppress soil-borne diseases. Many of the antibiotic compounds of actinomycetes affect the growth and development of pathogenic fungi. Composts are particularly rich in pathogen-suppressing actinomycetes. The beneficial effect of amending soils with composts is partly due to the disease-suppression properties of actinomycetes.

The challenge to the plant manager is to become an expert not only in the management of what everyone can see above ground, but in the management of beneficial soil microorganisms to maximize plant health. In general, all practices that promote a vigorous, healthy plant will also maintain high levels of microbial activity. The following strategies are particularly useful: * Use organic amendments composed of readily available carbon. Avoid sphagnum peat because it does not support adequate microbial activity. Reed-sedge peat, composted animal manures, and composted industrial or municipal sledges are preferable.

* Maintain soil moisture at constant levels, never allowing the soil to dry. Shallow, frequent watering is best. If other agronomic parameters are correct and microbial activity is high, disease should not be a serious problem.

* Maintain balanced pH and consistent fertility. Avoid “feast-or-famine” nutrient cycling. Also, research has shown that organic nitrogen sources or ammonium-based (NH4) fertilizers result in greater microbial populations than synthetic nitrate (NO3) sources.

* Maintain good soil porosity. Use physical amendments if necessary. Adequate soil-oxygen levels are extremely important for soil micro-organisms. * Any practice that enhances the volume of the plant root system-for example, aeration or cultivation will enhance microbial activity in the rhizosphere.

* If practical, limit the use of pesticides and growth regulators. Many of these have anti-microbial properties and may negatively impact soil and rhizosphere microbial communities.

It is apparent that soil contains a varied and abundant community of microorganisms. These microbes influence all the important processes related to plant nutrition and the general plant health. Further, soil microbial communities provide a potential genetic resource for useful products and processes that the plant industry may be able to exploit.

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