Soil Microorganisms Contribute to Plant Nutrition and Root Health

By Mark S. Coyne and Robert Mikkelsen

Soil microorganisms provide an essential function in nourishing and protecting plants. They also play a crucial role in providing soil, air, and water services that are absolutely critical to human survival. Understanding this linkage allows better nutrient management decisions.

Sustainable crop production is essential to a healthy and adequate food supply. At first glance, a healthy crop reveals only the above ground plant; the roots that support the visible plant are seldom seen.

But these plant roots grow in an incredibly complex environment, teeming with billions of soil organisms, particularly bacteria and fungi, which play a crucial role in promoting root health and maintaining an adequate supply of plant nutrients for crop growth.

There is still much to learn about the complex interaction between soil microorganisms and plant nutrition, but the importance of these relationships are now clearly recognized. Only a few of the key interactions between soil microbes and plant nutrition can be discussed in this brief summary.

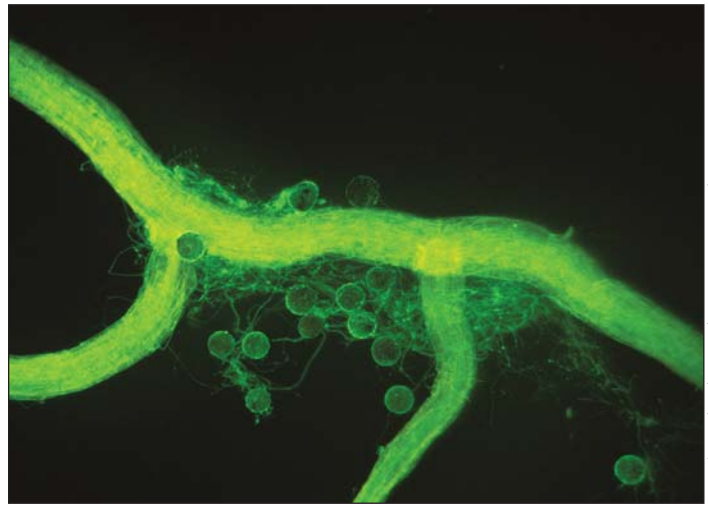
It has long been observed that plants conspicuously modify their soil environment by exuding large amounts of carbon from their roots. This rhizosphere zone becomes a biological hotspot in the soil. Adding carbon to the soil surrounding the roots leads to a huge increase in the number of microorganisms living within and outside the roots. These root exudates are composed of a complex mixture of low-molecular weight compounds such as amino acids, organic acids, sugars, and phenolics. Root mucilage, a carbon-rich gel layer surrounding the root tip, also provides a complex mixture of sugars, proteins, and enzymes to rhizosphere organisms. In some plants, as much as one-third to one-half of all the total carbon assimilated by photosynthesis can be transferred to the soil through the roots (Kuzyakov and Domanski, 2000).

As soluble carbon is released by roots, microorganisms are stimulated and colonize the soil surrounding the roots. This can result in competition for nutrients because plants and microbes rely on the same essential nutrients for growth.

Nutrients are Converted to Plant-Available Forms

Living organisms have a crucial role in controlling the transformations of plant nutrients in soil. In most soils, N, P and S are mainly present as various organic compounds that are unavailable for plant uptake. Understanding the role of microorganisms in regulating the conversion of these organic pools into plant-available forms has received considerable attention from soil scientists and agronomists.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Fe = iron; Mn = manganese; Mo = molybdenum; Zn = zinc.



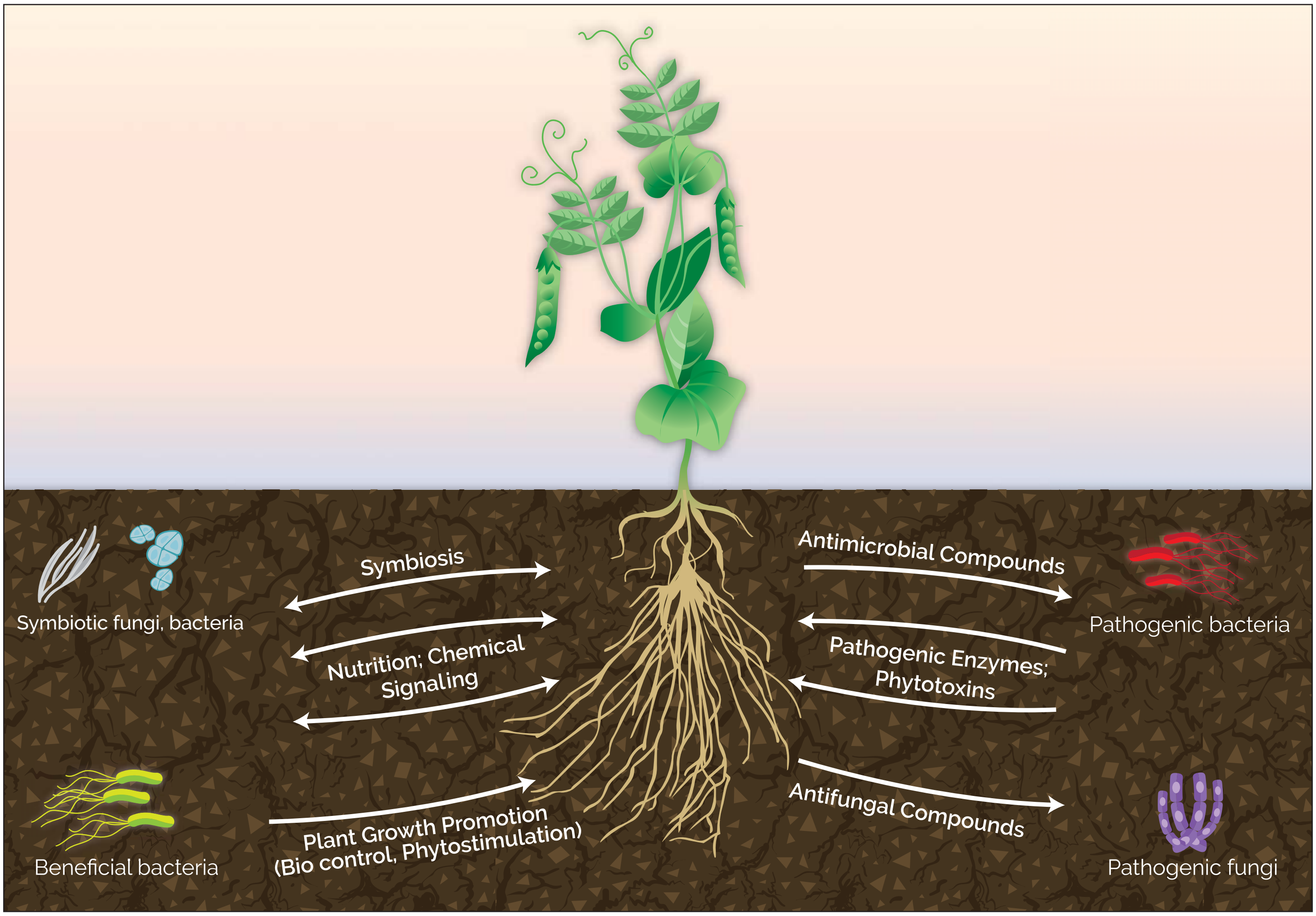
Glomalin, the substance coating this microscopic fungus growing on a corn root, can keep carbon in the soil from decomposing for up to 100 years.

The microbial conversion of nutrients into a soluble form takes place through numerous mechanisms (**Table 1**). Extracellular enzymes and organic compounds can be specifically excreted to solubilize plant-available nutrients from soil organic matter, crop residues, or manures. Organic acids released by microbes can dissolve precipitated nutrients on soil minerals and speed mineral weathering. Nutrients can be made more soluble (e.g., Fe) as microbes derive energy from oxidation and reduction reactions.

Management practices, including tillage, irrigation, residue placement, manure utilization, addition of specific biological inhibitors and stimulators, and inoculation are all commonly

Table 1. Selected examples of microbially mediated soil transformations that influence plant nutrient availability.

Nutrient	Microbial transformation
Nitrogen	Mineralization, immobilization, nitrification, denitrification, urea hydrolysis, N_2 fixation, extracellular protease and chitinase activity
Phosphorus	Mineralization, immobilization, extracellular phosphatase activity, acidic dissolution of mineral P, facilitated uptake by mycorrhizal fungi
Potassium	K solubilization
Sulfur	Mineralization, immobilization, oxidation, reduction, extracellular sulfatase activity
Iron	Change in oxidation state, production of siderophores, chelation
Zinc	Facilitated uptake by mycorrhizal fungi
Copper	Facilitated uptake by exudates and mycorrhizal fungi
Manganese	Change in oxidation state



Representation of the complex interactions that take place in the rhizosphere between plant roots and microorganisms (from Haichar et al., 2014).

used to influence these important microbial processes. Failure to account for soil processes such as mineralization and immobilization can result in excessive nutrient loss or in plant nutrient deficiency, with a significant reduction in crop yield or quality.

Nutrient Recovery is Enhanced

Mycorrhizal fungi are found in symbiotic association with the roots of 80% of land plants. Among the mycorrhizal fungi adapted for specific association with plant species are ecto-mycorrhizal fungi (especially woody plants), arbuscular mycorrhizal fungi (AMF, numerous crop plants), and ericoid mycorrhizal fungi. The AMF fungi penetrate the root cells and form an extension of the plant root system through hair-thin strands (hyphae) that extend into the soil. The small diameter of the fungal hyphae allows greater access to soil pores than roots alone, providing better utilization of water and nutrients, and maintaining root sorption activity in older parts of the root.

Mycorrhizal fungi can increase the supply of various nutrients to plants (including Cu, Fe, N, P, and Zn) in exchange for plant carbon. The boost in P uptake provided by mycorrhizal fungi is especially important for crops with high P requirements or for plants growing in soil with low concentrations of soluble P. Mycorrhizal fungi also release various enzymes to solubilize organic P and they can extract soluble P from the soil at lower concentrations than plant roots are able to do alone.

Nitrogen Fixation is Facilitated

Certain specialized symbiotic bacteria can fix atmospheric N_2 into ammonium-based compounds for plant nutrition. The most important of these organisms for agricultural plants are from the species *Rhizobium* and *Bradyrhizobium*. There are also symbiotic N_2 fixing bacteria (*Frankia*) that infect woody shrubs. An additional group of root-associated asymbiotic bacteria, such as *Azospirillum*, can provide some additional N to the roots of grasses such as sugarcane. It is estimated that N_2 fixation provides between 10 and 20% of the N requirement for cultivated crops and between 25 and 40% of the entire annual reactive N in the world.

Much work has been done to understand N_2 fixation and how to optimize its contribution to plant nutrition. This includes matching the proper bacteria inoculum with the correct host crop, and also optimizing soil conditions (such as providing adequate soluble P and Mo and adjusting soil pH) to increase the effectiveness of the symbiosis. A better understanding of the contribution of rhizosphere microbes to associative N_2 fixation is also needed.

Improved Soil Structure Promotes Root Growth

An often-overlooked contribution of soil microorganisms to plant nutrition is their enhancement of soil physical properties. Good soil structure enhances plant root growth and results in greater extraction of water and nutrients. For example, long-term trials at Rothamsted, UK show that less soluble P is required for plant growth when good soil structure is maintained.

Individual soil particles are bound into aggregates by various organic compounds (especially polysaccharides) released from soil microbes. Glomalin, a protein released by mycorrhizal fungi, binds soil particles and improves overall soil structure. The small hyphal strands of mycorrhizal fungi also contribute to improved soil aggregation by binding small particles together. More aggregation results in greater porosity, which often results in greater soil aeration and water storage capacity.

Pathogens are Controlled

There is growing appreciation of the link between soil microbes and plant pathogen control. Many reports show the benefits of soil microorganisms to improved plant growth and enhanced resistance to disease and stress. Soil bacteria that produce siderophores can deprive pathogenic fungi of Fe because fungal siderophores have less affinity for Fe. Various antibiotics have been identified in soil that can suppress pathogenic organisms. Certain bacteria can detoxify pathogenic viruses, while others can trigger "induced systemic resistance" in plants. Rhizosphere organisms can compete with pathogens for attachment to the plant root and essential nutrients for growth.

There is still much more to learn about how soil microorganisms improve the health of plant root systems and overall nutrient efficiency. Unfortunately, much research apart from the well-known microbial symbioses has failed to translate into measurable crop yield and quality benefits in the field. This is commonly because of insufficient soil colonization by the added microbes, the harsh soil environment to which these microbial additives are introduced, or the lack of an ecological niche that allows them to survive and fully function. Advances in rhizosphere engineering or improved manipulation of the soil environment may allow some of these potential benefits to be realized in the future.

Effects of Fertilizer on Soil Microbial Communities

Any management practice has the potential to influence soil microbial communities in positive or negative ways. For example, most mineral fertilizers added to soil consist of concentrated soluble nutrients that will impact short-term microbial activity. The concentrated salt around a dissolving fertilizer granule or band can cause temporary osmotic stress to nearby microorganisms until the nutrients diffuse into the soil. Similarly, the elevated pH surrounding the injection point of anhydrous ammonia will temporarily inhibit microbial activity.

The long-term effect of mineral fertilizer inputs on microbial processes was studied in a 160-year field experiment with contrasting fertilizer inputs at Rothamsted, UK. (Ogilvie et al., 2008). Balanced fertilization did not significantly influence the diversity of the bacterial population or two genes specific to important N transformations (N fixation and ammonium uptake).

A meta-analysis of world literature by Geissler and Scow (2014) reported that mineral N fertilizer application was associated with an average 15% increase in microbial biomass and 13% increase in soil organic carbon, compared with unfertilized control soils. They found that increases in microbial biomass were largest in studies with at least 20 years of fertilization. However, when the acidifying effects of nitrification were not addressed by liming (soil pH <5), microbial biomass was negatively affected.

Complex reactions with symbiotic and free-living microorganisms are necessary and normal for healthy crop growth. Soil microorganisms interact intimately with plants to stimulate productivity by supplying essential nutrients in a soluble form. Healthy plants in turn stimulate the microbial community of the soil through the root exudates they secrete and the organic residue they leave behind.

Better understanding the essential link between soil microbes and plant growth will allow more informed management decisions to be made for proper stewardship of soil resources and for sustaining acceptable levels of crop productivity. BC

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