Making the Most of Microbes

Tiny Soil Organisms Provide Big Soil Health Benefits

by Mike Amaranthus Ph.D., Larry Simpson & Jeff Lowenfels

Here's a shocker: The next big thing in agriculture might not be big at all. According to biologists a single tablespoon of healthy farm soil may contain up to a billion assorted microbes, a mile or more of fungal filaments plus scores of various macrofauna creatures such as nematodes and arthropods. What do crop plants think of all these "little bugs" near their roots? They love 'em! Most plants convert 40 percent or more of their energy produced by photosynthesis into root exudates that actually feed and stimulate soil microbes (See Figure 1). In return, the numerous activities of these tiny soil organisms help keep the plant world running. Natural ecosystems have teemed with soil microbes for millions of years yet they remain productive and healthy despite the fact that no one irrigates, fertilizes or applies pesticides to these areas.

Natural ecosystems utilize a simple and elegant system to maintain soil fertility. Plants fuel the process by providing carbohydrates (sugars), the major food source for these various microbes. The sun energizes the plants, which feed the microbes that then fertilize the soil and promote plant growth. This never-ending cycle employs billions of tiny organisms to do the "heavy lifting" such as decomposing organic matter, promoting soil health, improving soil structure and storing, gathering and processing nutrients and water from the surrounding soil for plant use. This ensures that soil fertility and optimum plant-growing conditions are continued year after year.

Of the incredible plethora of microorganisms contained in healthy soil, most are very short-lived so that they function as tiny time-release fertilizer units.

Just 1,000 square feet of root zone in healthy soil can contain about 70 pounds of dead microorganisms, which represents nearly 7 pounds of nitrogen, 3½ pounds of phosphate, 1.4 pounds of calcium oxide, 1.4 pounds of magnesium oxide, and .28 pounds of sulfate. Obviously, the continuous release from the remains of these tiny creatures can go a long way toward improving crop production.

Figure 1: Mycorrhizal threads and associated bacteria

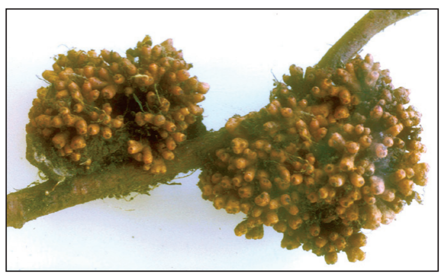

Figure 2: Root nodules of Frankia

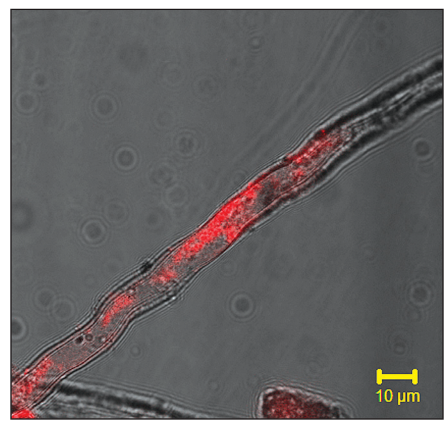

Photo courtesy of Matt Whitehead

Figure 3: An arbuscular mycorrhizal hyphae jammed full of organic nitrogen (red dots).

As world populations continue to grow and global food demands surge, a realization and shift toward sustainable and biological farming methods is underway. In recent years, worldwide fertilizer and other agricultural chemical costs have increased dramatically and savvy growers are starting to look for alternative ways to extend inputs and support crops. One of the most important things they are finding is that these tiny soil creatures deliver very big results — enhanced nutrient release, elevated nutrient uptake, improved moisture efficiencies, augmented soil tilth — these are just some of the many benefits of a living soil. By increasing yields and/or reducing costs, these "small things" offer natural and powerful solutions to some of farmers' most persistent and vexing challenges. In this article we will explore this interesting and under-appreciated aspect of plant growth and food production.

FERTILIZER FROM THIN AIR

For decades farmers have added specialized Rhizobia bacteria to the seeds of legume crops such as soybeans, field beans, peas and alfalfa that capture atmospheric nitrogen for their crops in root nodules. Scientists have researched the activities of these fertility-enhancing microbes in detail. These bacteria have the unique ability to convert nitrogen gas from the air into proteins in a process called nitrogen fixation. Eventually, these proteins biodegrade, adding essential available nitrogen fertilizers to the soil.

Rhizobia and Frankia bacteria are important types of symbiotic nitrogen fixers (See Figure 2). They can produce a lot of plant-useable nitrogen and can also be used in conjunction with cover crops. The nitrogen-producing root nodules are filled with these organisms that capture nitrogen from the air and trade it to the legume plant for some of the sugars it produces. The pinkish color of the nodules comes from a compound similar to hemoglobin found in animal red blood cells. The use of *Rhizobia* in growing legume crops and producing soil nitrogen is a well-established practice and can be a great way to grow your own nitrogen if you have the right kind of climate and crop.

Azotobacters and Azospirillum are other types of nitrogen-fixing bacteria that are "free-living" and produce soil nitrogen without entering into a symbiotic plant relationship such as a root nodule. Much research is underway to enhance the practical role of *Azotobacter* and *Azospirrillum* in crop production.

Other types of bacteria specialize in decomposing dead plant and animal proteins, releasing even more nitrogen compounds. There are still other organisms such as mycorrhizal fungi that have the unique ability to uptake nitrogen in an organic form before it is converted to an inorganic form or leached away (See Figure 3). Without these processes, nitrogen, the most important plant nutrient, would be rapidly depleted from soils, thereby diminishing both plant growth and crop yields.

PHOSPHATE MINERS

Another critical nutrient needed in abundance is phosphate. While most soils contain significant amounts of phosphate, most of this is present in forms of insoluble rock phosphate (See Figure 4). Plants cannot absorb minerals unless they are dissolved in water. Therefore, rock phosphate, which is insoluble, is unavailable and useless to plants. Fortunately, numerous bacteria and fungi can convert insoluble phosphate into water-soluble forms that plants can use. In the presence of these phosphorus-solubilizing bacteria and fungi, the phosphate reserves present in otherwise insoluble phosphate rocks become much more accessible to plant roots.

Researchers are working to develop mixtures of phosphate-solubilizing bacteria and fungi for farm use. Certain types of non- symbiotic bacteria (*Bacillus megaterium* var. *phosphaticum, Bacillus subtilis Bacillus circulans, Pseudomonas striata*) can free up insoluble phosphorus and either make it directly available to plants or put it into the "diffusion" stream in which nutrient ions (including P) flow through the soil toward roots. Similarly, certain fungi (*Penicillium sp, Aspergillus sp*) also free up phosphorus. They act indirectly on insoluble phosphorus by producing organic acids as they go about their business. These acids break the chemical bonds that tie up phosphorus, releasing some for plants.

SCAVENGING TRACE MINERALS

Some bacteria and fungi can efficiently remove or "sequester" from soils other important minerals that plants require such as iron, zinc, magnesium, copper and manganese. While bacteria and fungi are busy "gathering" these minerals for themselves, the process also makes them available to nearby plants. These organisms excrete special enzymes that unlock the chemical bonds that tightly bind these valuable micronutients in soil particles. Needless to say, the presence of such talented bacteria and fungi in the root zone is a significant benefit to plants.

KEYSTONE SPECIES

While the fertility-enhancing activities of soil bacteria are very impressive, the wealth of benefits provided to plants by mycorrhizal fungi is keystone to a healthy soil. Pronounced "Mike-O-Ri-Zal," these fungi form a close partnership with plant roots. The plant makes sugar and shares it with the fungi. In exchange, the fungi provide water and minerals to the plant.

The mycorrhizal fungi grow through the soil as fine hair-like strands called hyphae, which are similar in appearance to spider webs. These strands form a network of canals that absorb water and minerals from the soil and then transport them back to the plant root. Mycorrhizal fungi are unique because they cannot feed themselves. In order to survive and grow, the strands of mycorrhizal fungi must first enter the living root tissue of a plant. Once inside the root, the fungus is allowed to absorb sugar and other compounds from the plant. The mycorrhizal fungus uses this food to build an elaborate network of absorbing strands

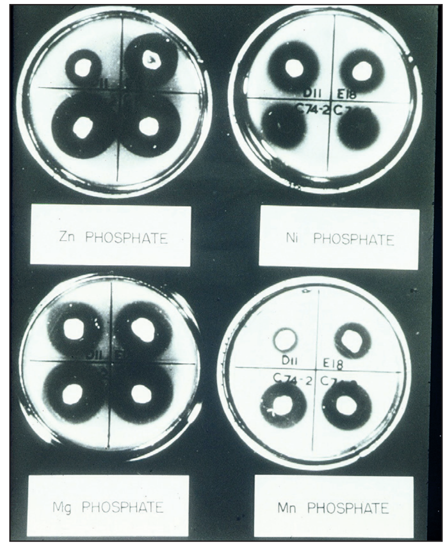

Figure 4: Petri dishes of mycorrhizal fungal colonies dissolving phosphorus with enzymes.

that reach out into the soil. This network of fungal strands act effectively as ultra-thin, absorbent roots. Water and minerals absorbed by this fungal network are delivered to the plant roots which is the "home base" for the fungus. Amply supplied with much-needed water and minerals, the plant grows vigorously, producing more sugar, which it continues to share with its fungal partner. Both the fungus and the plant benefit from this partnership, called a "symbiosis." (See Figure 5a, Figure 5b).

This plant-fungal symbiosis is so successful that the vast majority of the world's terrestrial plants, over 90 percent, form a mycorrhizal relationship in their natural habitats. In fact, the fossil record shows that mycorrhizal fungi were present some 460 million years ago, around the time when plants first began to colonize dry land. Today, it is common for many farmers to use mycorrhizal fungi to increase a crops' utilization of soil nutrients and water. These "little" things work to make a big difference in crop production in the dark, microscopic confines of a healthy soil.

The individual mycorrhizal filaments, or hyphae, are approximately 1/25th the diameter of a human hair and can grow up to 18-24 inches in length (See Figure 6). These strands originate from within the root cells of the host plant, spreading and branching into the surrounding soil, greatly increasing the surface area of the root system. The most widespread type of mycorrhizal relationships are known as arbuscular mycorrhizae (also commonly referred to as "AM," "VAM" or

Figure 5a: Comparison of mycorrhizal inoculated soybeans left and non inoculated soybeans right.

Figure 5b: Root system of inoculated corn plant (left) and non-inoculated corn plant.

"endo mycorrhizae."). Most agricultural crops are naturally disposed to achieve optimum growth and vigor by forming this fungal relationship.

Agricultural soils often contain abundant nutrients, but the availability of these nutrients to the crop is sometimes limited. Research confirms that mycorrhizae are especially important in mobilizing phosphorus, nitrogen, zinc, iron, calcium, magnesium, manganese and other tightly bound soil nutrients. The hyphae produce enzymes that can release these nutrients from their recalcitrant chemical bonds and then transport them in soluble forms back to the crop roots. The crop plant's uptake and utilization of fertilizers thus becomes far more efficient, often leading to significant savings in fertilizer and irrigation costs.

PRECIOUS RESOURCE

Water has become a highly precious resource. There are some places on earth where a barrel of water costs more than a barrel of oil. No one understands better than farmers that agriculture's need for fresh water is not always in sync with nature's propensity to provide it. We often see abundant, verdant vegetation in natural ecosystems without the benefit of irrigation. How do natural areas provide for such luxuriant plant growth without irrigation? One key factor is the extensive network of mycorrhizal threads attached to plant roots that thoroughly scour the soil for water. Like a sponge, they absorb water during moist periods then retain and slowly release it to the plant during periods of drought. Plant systems in natural areas generally achieve levels of drought tolerance far exceeding those found in agriculture partly due to the enormous web of mycorrhizal hyphae and specialized storage cells which protect the plant communities from extreme soil moisture deficits.

Mycorrhizal filaments are so thin that they can penetrate into the tiniest of soil openings to access microscopic sources of water that are unavailable to the much thicker roots. Research confirms the importance of the mycorrhizal relationship for efficient water use and drought protection among a wide array of important crop species (See Figure 6). The declining availability of water and its ever-increasing cost are formidable issues facing today's farmer and mycorrhizal fungi can be a powerful tool to enhance water-use efficiencies.

NOT HOME ALONE

Roots and mycorrhizal fungi produce a variety of organic compounds which fuel the activities of the other little things in the soil. Healthy soil hosts a whole complex of microscopic life-forms engaged in living, dining, reproducing, working, building, moving, policing, fighting, and dying; all these activities help the crop plants that feed them. The microbes excrete an array of important and beneficial exudates which include amino acids, organic acids, carbohydrates, enzymes, growth regulator compounds and others. Soil life such as bacteria, fungi, algae, protozoa, earthworms, and beneficial nematodes feed on and utilize these exudates. To show their appreciation for all these goodies, these tiny, beneficial soil organisms help the plants in BIG ways as noted earlier in this article.

Plant growth-promoting rhizobacteria (PGPR) such as *Pseudomonas fluorescens* are good examples of a whole host of bacteria that aid in the synthesis of nutrients, promote root growth and thus contribute to plant nutrition. PGPR are known to directly and indirectly enhance plant growth by a variety of mechanisms: fixation of atmospheric nitrogen that is transferred to the plant; production of chemicals that chelate iron making it available to the plant root; solubilization of nutrient minerals such as phosphorus and synthesis of root-enhancing compounds. Further studies of PGPR are underway and will help increase our understanding of the role these organisms play in crop production.

DOES MY FARM ALREADY HAVE BENEFICIAL SOIL ORGANISMS?

Since World War II, agronomy technology has focused primarily on the development of chemical and mechanical approaches to improving crop plant performance. Nutrient needs have been addressed using synthetic fertilizers; weed suppression accomplished by herbicides and sophisticated mechanized tillage and plant diseases controlled using an array of chemical pesticides. However, scientists now recognize that bacteria and mycorrhizal fungi are key components to optimum plant root efficiency and that plant roots in natural habitats are actually just one component in a complex "rhizosphere" of made up of many soil organisms.

Certain modern agricultural practices, including some common management methods, are known to suppress the biological activity in soils. Populations of soil microbes are lost when the land is cleared and turned over during tillage. Soil fumigation, fungicide use, cultivation, compaction, soil erosion and periods of fallow are all factors that can adversely affect populations of beneficial soil organisms.

Most research on soil disturbance effects has focused on mycorrhizal fungi. Soil testing worldwide indicates that many intensively managed croplands lack adequate populations of mycorrhizal fungi. Fallow soil is first and foremost among the causes for the demise of the mycorrhizal relationship. Remember, these fungi are dependent on their host plants for sustenance and cannot survive for any extended duration without the partnership of living roots. Field preparation prior to planting usually involves thorough tilling and sometimes fumigation and generally leads to a fallow condition that, in turn, eliminates the fungi.

Large-scale agricultural areas also become isolated from the beneficial mycorrhizal fungi that would, in natural ecosystems, be abundantly available to spread colonization to crop roots. Arbuscular mycorrhizal fungi, the type usually most important to agricultural plants, do not readily disperse spores via wind or water, but primarily reproduce by growing from root to root. The re-colonization of farm soil across long distances from undisturbed natural sites becomes slow and difficult. Plants cultivated in containers are also isolated from natural sources of mycorrhizal colonization. Inoculation with mycorrhizal inoculants has proven to be highly beneficial when growing container crops. A lab experienced in identifying mycorrhizal fungi can analyze feeder root samples to determine mycorrhizal population levels in farm soil or container media.

CONSIDER THE NEXT BIG THING

Products are now available that contain many species of beneficial soil bacteria and fungi. Some will pull nitrogen out of the air making it available to plants. Others contain microorganisms that solubilize phosphorus, decompose organic matter and break down toxic soil residues. And still other products contain beneficial mycorrhizal fungi that grow on the roots of plants, increasing the roots' ability to pull nutrients and water from the soil (See Figure 7). These biological products can be applied at planting or to established plants, but they must get into the soil and, in some cases, need direct contact with the roots to work.

It is also possible to inoculate ornamental, vegetable, fruit and nut crops that begin their life cycles in nurseries with beneficial soil organisms. For a variety of reasons, most crop plants

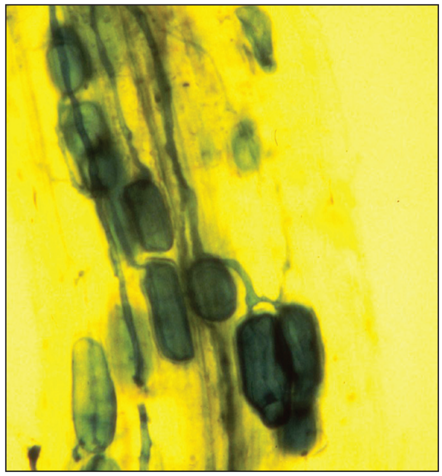

Figure 6: Specialized cells within mycorrhizae store and release water to the crop plant

propagated in greenhouses and nurseries are propagated in sterile "synthetic soil" media where they receive intensive fertilization, optimum irrigation and any necessary pesticides. While such artificial conditions often result in high plant production, these plants grown without beneficial soil organisms can be poorly adapted to the eventual harsher out-planted conditions of the open-field environment. However, nursery-grown plants already inoculated and colonized with beneficial organisms tend to establish faster and more successfully in the field. Why? Because their tiny biological allies enable them to better handle environmental stresses and take full advantage of limited soil resources.

Here is one more tiny fact that is BIG: The application of a quality mycorrhizal inoculum is required only once for the life of the crop. The relatively recent development of liquid and concentrated powder inoculants makes it easier than ever to inoculate seed or in furrow. Note that the inoculum must contact the roots to activate colonization, so foliar applications will not work.

Understanding the role of these tiny beneficial soil organisms and supporting the soil conditions that promote their populations are BIG steps toward achieving healthier crops, increasing yields and reducing costs. Another BIG step is the addition of these special fungi and bacteria to the root zone when planting, transplanting or restoring distressed soils. Mother Nature and her microorganism allies invested millions of years to develop that precious resource we know as good soil. Today's successful farmer wisely recognizes these helpers as the small things that are the next big thing when it comes to successful crop management.

Figure 7: Spraying a liquid Mycorrhizal inoculant to the roots of grape seedlings

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