Soil Microbial Interactions and Organic Farming

ORGANIC FARMING RESEARCH FOUNDATION

HEALTHY SOIL

Organic farming utilizes diverse communities of microorganisms to protect plants from disease and to keep soil healthy and productive. Microorganisms such as bacteria, single-celled fungi, microalgae, and protozoa are all part of the soil ecosystem, along with the plants and animals that rely on the soil to survive. These microflora and microfauna form the foundation of an ecological web of organisms that live in the soil and play an important role in cycling nutrients that sustain plant and animal life (Figure 1). As agents for biological, chemical and physical change, these microorganisms transform soil properties.

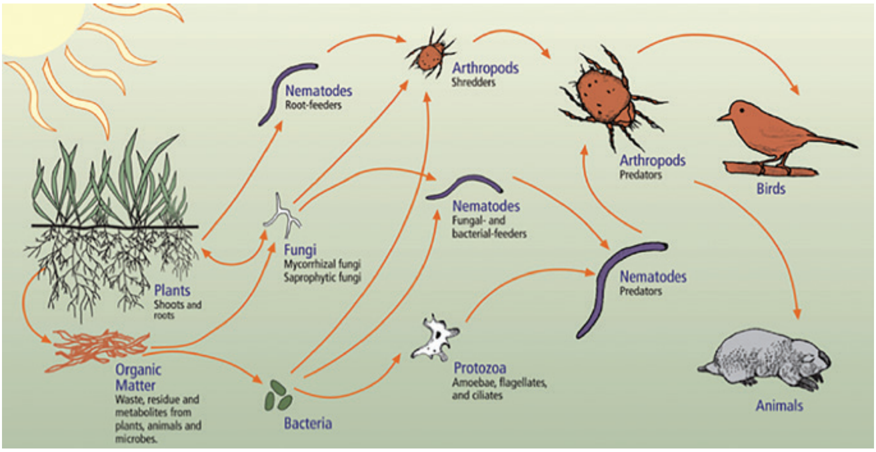

Figure 1. The soil food web (Source: Ingham, 2000).

Soil quality can be measured in different ways. Healthy soil has diverse populations of microorganisms and microfauna, sufficient organic matter, and is resilient to disturbances like tillage, drought, and flooding (Doran and Zeiss, 2000). Monoculture agriculture, in combination with intensification and heavy chemical use, reduces the quality and biodiversity of the soil ecosystem, and thus its resilience, sustainability and long-run productivity (Postma-Blaauw et al., 2012). These farming methods can make the soil more susceptible to adverse weather conditions and infestations by pests and diseases that reduce productivity.

Better soil quality provides higher yields and greater profits for farmers over the long run. To enhance soil quality, farmers can use soil building techniques that maintain or increase the amount of organic matter in the soil. These techniques include growing cover crops and adding compost. Crop rotation and intercropping also play an important role in diversifying the soil ecological system over time.

Twenty years ago, most soil quality indicators looked at the chemical and physical characteristics of the soil. Today, we have a better understanding of soil ecology and know that soil health can also be measured by the life within it. While chemical and physical characteristics of the soil change slowly from year to year, soil biology has dynamic properties with implications for soil chemistry and structure. Populations of selected species, microbial biomass, respiration rates, and enzymatic activity can be used to measure total soil microbiological activity and estimate the ecosystem services provided by soil microorganisms.

There are several methods for regenerating soil health, including soil building for plant health and nutrition, biological remediation, and the introduction of beneficial soil organisms. These methods all complement each other and use the same principles of soil ecology.

Table 1. Best Practices for Soil Health
• Maintain and build soil organic matter by growing cover crops and applying compost.
• Rotate annual crops to alternate hosts of pathogens.
• Where possible, intercrop or grow mixed crops to provide a diversified habitat.
• Plant disease-free, uncontaminated seed.
• Replace harvested nutrients by applying amendments from plants, animals and minerals.
• Avoid highly soluble sources of nutrients, particularly those that have a high salt index or are contaminated with elemental contaminants.
• When growing legumes, inoculate with rhizobial bacteria symbiotic with the host plant.
• Inoculate seeds with treatments comprised of beneficial microorganisms that protect seedlings from soil borne diseases.

PLANT HEALTH AND NUTRITION

Plants require air, water and nutrients to survive, but the biological basis for plant health goes beyond survival and productivity. Most terrestrial plants have adapted to grow in soil conditions with symbiotic, mutualistic, and parasitic microorganisms. Although plant pathology has focused on the parasitic or pathological interactions, the beneficial relationships of plants with microorganisms have long been recognized. One of the most studied interactions is that of nitrogen-fixing rhizobial bacteria that have a synergistic relationship with legumes. These bacteria form nodules on the roots of plants in the bean and pea family, which in turn capture nitrogen from the atmosphere and make it available to the plants.

A healthy, balanced soil ecosystem provides a habitat for crops to grow without the need for interventions such as soil fumigants and drench pesticides. Replacing and building soil organic matter enables sustainable cycling of nutrients, like nitrogen. Sources of soil organic matter include cover crops, compost, and other soil amendments that come from plants and animals. Cover crops are grown and turned back into the soil without being harvested. Compost is decomposed organic matter teeming with microorganisms that cycle nutrients to build healthy soil. Soils rich in organic matter offer the benefit of reduced leaching and volatilization of soil nitrogen (Kramer et al., 2006). Soil microorganisms also make other nutrients more bioavailable through the decomposition of organic matter and biochemical reaction with the mineral portion of the soil.

Researcher Dr. Gladis Zinati at the Rodale Institute.

The Rodale Institute provides research and guidelines for building optimal organic compost and compost extracts. Learn more

Vesicular-arbuscular mycorrhizae (VAM) are microorganisms that have specific symbiotic functions with plants. These microscopic fungi attach themselves to the roots of plants and exude various enzymes and other chemicals that make soil nutrients more plant available.

Nutrients become biologically available (bioavailable) when released from the mineral or organic fraction of the soil to be taken up by plant roots and other organisms in the soil. In the case of crop nutrition, bioavailability is a good thing, helping the soil to feed the plants. In the case of soil contamination with heavy metals, bioavailability may be harmful, in that the contaminants can be taken up by the plants and the animals and humans that consume those plants.

BIOREMEDIATION

Biological remediation is necessary in agricultural soils because conventional farming practices using chemical fertilizers and pesticides, industrial pollution, and atmospheric deposition pollute the soil. Some contaminants can persist and have adverse effects on plants and animals for years. As part of the process of transitioning to organic agriculture, farmers face the challenge of remediating polluted soil.

Bioremediation is an intentional process used to eliminate environmental pollutants from contaminated sites (Madsen, 2003). Other contaminants that can by removed via bioremediation include those from industrial processes and hazardous waste. The process includes using microorganisms, fungi and plants to decompose, sequester or remove soil contaminants, such as agricultural pesticides and fertilizers (Figure 2).

Figure 2. Seedling.

Through a series of complex metabolic interactions, often involving a number of different organisms, unwanted contaminants can be broken down, immobilized or removed. Organic farmers can choose the appropriate bioremediation technique for their farm based on the pollutants to be removed, soil types, weather conditions, and biome.

One technique involves introducing organisms that biodegrade, make bioavailable, or sequester different contaminants. There are also a number of microbial inoculants for introducing beneficial bacteria or fungi to seeds and soil. Plants grown as cover or catch crops can also help with the breakdown or removal of various soil-borne contaminants.

Soil amendments can change the mix of organisms as well. For example, amendments with hard, slow to break down surfaces—like crab shells—have a layer of what is known as 'chitin' that needs to decompose. The microorganisms that decompose chitin can also suppress plant-eating nematodes by dissolving their shells. Sesame chaff also suppresses pathogenic nematodes.

However, there are situations where bioremediation can make a contamination situation worse by making a sequestered contaminant more bioavailable. Therefore, laboratory experimentation is helpful before trying an approach in the field.

For example, elemental contaminants—such as arsenic, lead, and cadmium—are not biodegradable and can only be sequestered and / or removed. Treatments combine microorganisms to make the contaminants bioavailable for plants that are heavy accumulators of those contaminants. Once the plants absorb the contaminants, the plant biomass needs to be removed, otherwise the contaminants will be concentrated in the organic matter in a relatively bioavailable form.

While most carbon-based pollutants will break down more quickly with greater biological activity; some pollutants, such as chlorinated hydrocarbons, actually become more persistent with higher levels of organic matter. With so many different contaminants, environmental conditions, and possible approaches, it may take some trial and error to find a successful approach to remediating a given contamination situation (Megharaj et al., 2011). Bioremediation is becoming more cost effective compared with chemical and physical approaches, which are increasing in costs and also have their drawbacks.

MICROBIAL BENEFITS FOR DISEASE AND WEED CONTROL

Under ordinary conditions, soil-borne pathogens play an important role in agricultural ecosystems by helping with the decay of plant tissue. Severe outbreaks of disease are themselves symptoms of imbalance in a system, whether it is a nutrient excess or deficiency, lack of genetic diversity, or a monoculture system that provides too great a host population. Biological control using soil borne organisms works by several different modes of action. These include competitive exclusion, hyperparasitism, the production of natural antibiotics, systemic acquired resistance, and induced systemic resistance.

In competitive exclusion, one organism creates an environment that is unwelcoming for another organism, effectively excluding the second organism from becoming established without directly killing it. An example of this would be the creation of film on a root surface to prevent pathogens from infecting the plant.

The same mycorrhizae that help make nutrients biologically available can also be antagonistic for a number of opportunistic plant pathogens (Azcón-Aguilar and Barea, 1997). Some of these microorganisms produce natural antibiotics, like Streptomyces, which became a commercial source for antibiotics. These antibiotics work to suppress different pathogens in the soil the same way they do in people and animals; the microorganisms produce the antibiotic that kills the exposed pathogens.

Specific organisms are known to protect seeds and seedlings from various diseases. For instance, various *Bacillus, Trichoderma* and *Pseudomonas* species protect the roots of plants from infectious diseases (Trabelsi and Mhamdi, 2013). These organisms can be introduced by inoculation of the soil. The efficacy of soil inoculants varies widely. Biological control inoculants are not as well understood as nitrogen fixing rhizobial inoculants, and the circumstances where they work and do not work is a subject of ongoing investigation.

The Organic Farming Research Foundation (OFRF) has funded three projects researching the ability of beneficial microbes to aid organic farming. Carr (2016) investigated the benefits of using compost to introduce microbes that would protect seedlings against damping off disease caused by a *Pythium* species (Carr, 2016). Nebert looked at seed disinfection and inoculation as a way to avoid or prevent seed-borne diseases, particularly Fusarium (Nebert et al., 2016; Figure 3). Zinati examined the use of compost extract as a means to inhibit weed seed germination and reduce weed competition (Zinati, 2015). These projects highlight the potential for new research to explore the beneficial role microbes can play in organic plant production.

Figure 3. Fusarium infection on corn seeds. (Photo: Lucas Nebert)

CONCLUSION

Soil health and quality can be restored and improved by working with natural systems to cycle nutrients and enhance system biodiversity. Bioremediation is able to clean up contaminated soils by introducing organisms that specialize in the degradation or uptake of the targeted contaminants. Plants can be protected from pests and diseases by the introduction of beneficial microorganisms and the creation of a habitat that enhances their biological activity. The soil is built upon a complex network of organisms; the health of the soil relies on keeping that network vibrant, active and dynamic.

ADDITIONAL RESOURCE

USDA Natural Resources Conservation Service
http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/biology/?cid=nrcs142p2_053868

Ingham, E. 2000. Soil Biology Primer. Soil and Water Conservation Society, Ankeny, IA, USA
www.mdpi. com/2071-1050/7/1/988/pdf

Rodale Institute, Improved Compost Management for Certified Organic Operations
http://rodaleinstitute.org/improved-compost-management-for-certified-organic-operations/

ACKNOWLEDGEMENTS

Brian Baker, Research Consultant: writing, research, and editing
Diana Jerkins, Research Program Director, OFRF: editing and design
Joanna Ory, Research Program Associate, OFRF: editing and design
Vicki Lowell, Communications Coordinator, OFRF: editing and design

REFERENCES

Azcón-Aguilar, C. and Barea, J. 1997. "Arbuscular Mycorrhizas and Biological Control of Soil-Borne Plant Pathogens–an Overview of the Mechanisms Involved." *Mycorrhiza* 6 (6): 457–64.

Carr, R. 2016. "Deploying Microbes as a Seed Treatment for Protection against Soil-Borne Plant Pathogens." Rodale Institute. More information at OFRF:
http://ofrf.org/research/grants/outcome-deploying-microbes-seed-treatment-protection-against-soil-borne-plant

Doran, J.W. and Zeiss, M. 2000. "Soil Health and Sustainability: Managing the Biotic Component of Soil Quality." *Applied Soil Ecology* 15 (1): 3–11.

Ettema, Christien H. 1998. "Soil Nematode Diversity: Species Coexistence and Ecosystem Function." *Journal of Nematology* 30 (2): 159–69.

Kramer, S., Reganold, J., Glover, J., Bohannan, B., and Mooney, H. 2006. "Reduced Nitrate Leaching and Enhanced Denitrifier Activity and Efficiency in Organically Fertilized Soils." *Proceedings of the National Academy of Sciences of the United States of America* 103 (12): 4522–27.

Madsen, E. 2003. *Report on Bioavailability of Chemical Wastes with Respect to the Potential for Soil Bioremediation.* US Environmental Protection Agency, National Center for Environmental Research.

Megharaj, M., Ramakrishnan, B., Venkateswarlu, K., Sethunathan. N., and Naidu, R. 2011. "Bioremediation Approaches for Organic Pollutants: A Critical Perspective." *Environment International* 37 (8): 1362–75.

Nebert, L., Bohannan, B., Ocamb, C., Still, A., Kleeger, S., Bramlett, J., and Heisler, C. 2016. "Managing Indigenous Seed-Inhabiting Microbes for Biological Control against *Fusarium* Pathogens in Corn." University of Oregon. More information at OFRF:
http://ofrf.org/research/grants/managing-indigenous-seed-inhabiting-microbes-biological-control-against-fusarium

Postma-Blaauw, M., de Goede, R., Bloem, J., Faber, J., and Brussaard, L. 2012. "Agricultural Intensification and de-Intensification Differentially Affect Taxonomic Diversity of Predatory Mites, Earthworms, Enchytraeids, Nematodes and Bacteria." *Applied Soil Ecology* 57: 39–49.

Trabelsi, D. and Mhamdi. R. 2013. "Microbial Inoculants and Their Impact on Soil Microbial Communities: A Review." *BioMed Research International* 2013. doi:http://dx.doi.org/10.1155/2013/863240.

Zinati, Gladys. 2015. "Effect of Compost Extracts on Organic Seed Germination and Reduction of Weed Seed Expression." Rodale Institute. More information at OFRF: http://ofrf.org/sites/ofrf.org/files/staff/OFRF%20FINAL%20REPORT-Zinati%202015-Compost%20Extracts-WEEDS.pdf.

Organic Farming Research Foundation works to foster the improvement and widspread adoption of organic farming systems. OFRF cultivates organic research, education and federal policies that bring more farmers and acreage into organic production.

Thank you to UNFI for their support of this project.

ORGANIC FARMING
RESEARCH FOUNDATION
P.O. Box 440
Santa Cruz, CA 95061
831.426.6606
info@ofrf.org
www.ofrf.org