The Transition to Organic Partnership Program (TOPP)

Prepared for USDA Organic by Acres U.S.A.

United States Department of Agriculture
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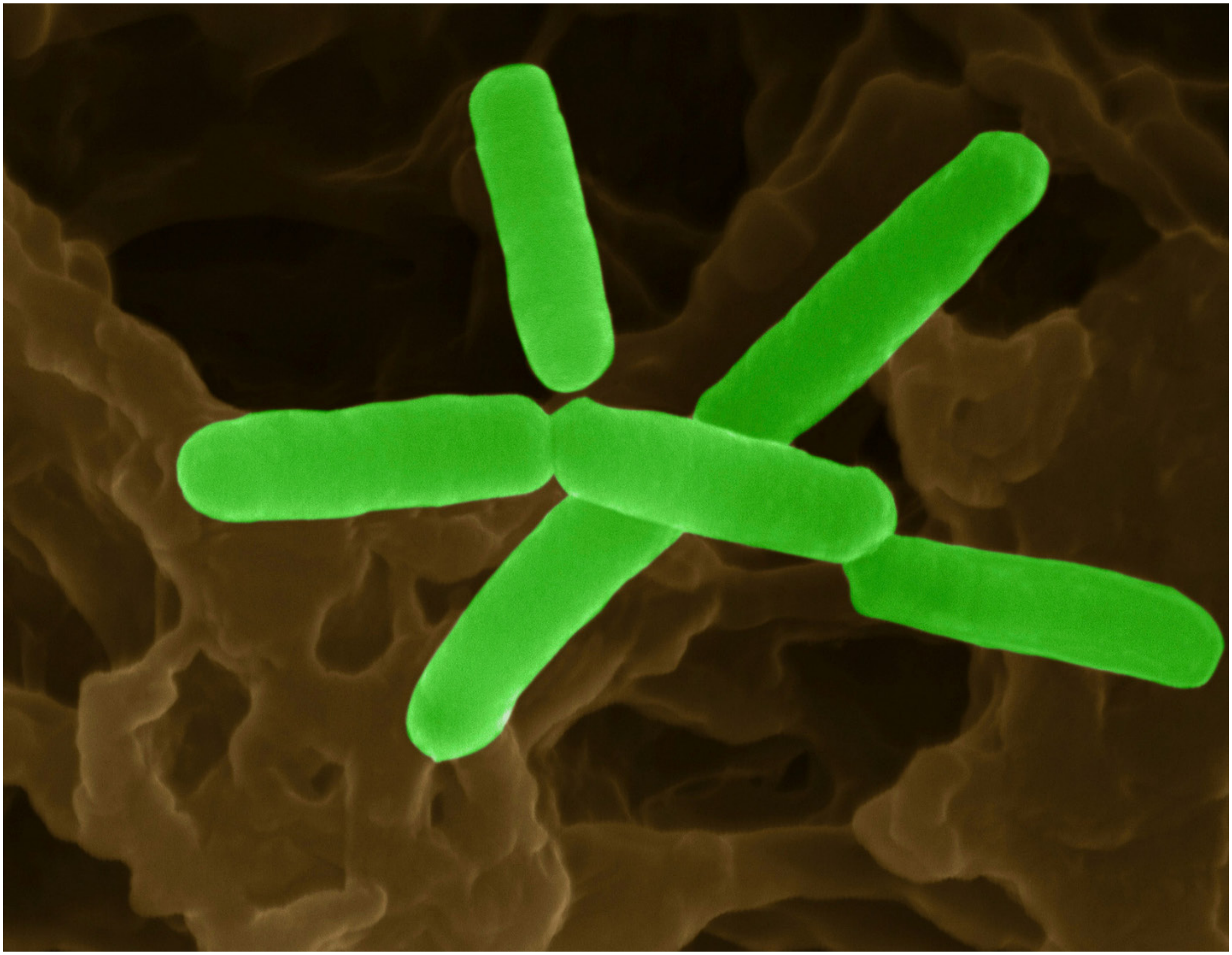
Transition to Organic Partnership Program

Managing Soil Biology for Organic Farming

SOIL MICROBES ARE INDISPENSABLE FOR PLANT NUTRITION, AND MANAGING THEM REQUIRES A FOCUS ON KEEPING THE SOIL COVERED AND ELIMINATING COMPACTION



Bradyrhizobium is a type of nitrogen-fixing bacteria.

Soil is alive. This is an idea that seems to have been known to our ancestors, forgotten for a few generations, and recently relearned. It's an important concept that's beginning to be reclaimed.

From bacteria and fungi to archaea, nematodes and higher-level organisms like worms and beetles, the soil is teeming with life. And while this microbial community is extremely resilient, the actions of farmers have a profound effect on it. Irrigation, tillage, fertilization and other interventions each either strengthens or weakens the microbial community. As soil-biology pioneer Bruce Tainio said, "Everything in this universe is connected to everything else. You cannot isolate one mineral, soil, microbe, plant, animal, or human component and treat that component as though the others don't exist."

PHOTO FROM CANVA

Wheat plants grown from seed without bacteria (left) and with (right).

HOW SOIL MICROBES INTERACT WITH PLANTS

There are many different types of soil microbes, from bacteria and protozoa to fungi, nematodes, and even worms and beetles. More important than understanding the physical characteristics of these organisms, which are mostly invisible to the naked eye, is understanding their functions and how they interact with plants.

The simplest way of explaining how microbiology helps plants is that plants, when in need of a certain nutrient, exude sugars, combined with molecules that communicate their exact need. They send these compounds out of their roots as signals to nearby microorganisms (bacteria, fungi, etc.), telling them what they need. Those microbes then use the sugar to feed themselves; in fact, the plant gives the them not just sugar but a complete range of primary metabolites — the organic compounds that are necessary for all life. These include carbohydrates (sugars), lipids, proteins and nucleic acids. The exact metabolites the plant sends out is probably its way of attracting the specific microorganisms that are able to give it the nutrients it needs.

If the microbe doesn't already have the nutrient the plant needs, it finds it within the soil and transforms the nutrient from whatever chemical structure it's in into a chemical structure that is available to the plant (the plant can't use, for example, nitrogen when it's in certain molecular combinations). The microbe then gives that newly available nutrient to the plant.

The whole process is much more complicated than this, and it's only within recent years that we've even had this elementary understanding of what's happening in the soil between microbes and plants.

RHIZOPHAGY

Within the past decade, groundbreaking work has been done to help us further understand how bacteria provide nutrients to plants. This work, led by Dr. James White at Rutgers University, discovered what's called the rhizophagy cycle. "Rhizo" means root, and "phagy" means to eat — this is the process whereby bacteria actually enter roots (are "eaten" by them).

Insert *Bacteria in root* (Courtesy of Dr. James White and Rutgers University): Figure 1: Bacteria inside a plant.

Within the root, the plant bombards the bacterial cell with reactive oxygen molecules that attack the cell wall of the bacteria. Some bacteria are completely broken apart and become food for the plant in their entirety. Serendipitously, it turns out that the bodies of bacteria are on average 10-2-2 plus traces — a perfect NPK fertilizer, along

Bacteria inside a plant.

PHOTOS COURTESY OF DR. JAMES WHITE AND RUTGERS UNIVERSITY with all the necessary trace minerals.

The bacteria that don't die inside the plant are simply damaged, giving off some of the nutrients they had collected for the plant, but remaining alive. The plant then pushes these bacteria out of the plant at the tips of root hairs in a process that simultaneously elongates the root hairs. The bacteria go back to work mining nutrients for the plant, completing the cycle.

The results of the rhizophagy process are that the plant is fed the nutrients it needs and also becomes more tolerant against oxidative stressors. Additionally, because bacteria involved in the cycle are taking some nutrients not just from the soil but also from fungi in the soil, those fungi that are pathogenic become less virulent and are thus less dangerous to the plant.

This is another major function of soil microbes: protecting the plant from disease. We should keep in mind that all organisms play important functions; it's only when they get out of balance that problems arise. Robust soil microbiology helps keep the beneficial and the virulent organisms in check so that the "pests" can stick to performing the role they're intended for — decomposing dead organisms so that new ones can thrive.

MANAGING SOIL BIOLOGY

The best farm managers oversee soil biology in the same way that a lab technician manages a petri dish: by attempting to provide the perfect environment that will enable the biology to thrive. On the farm, this means three things:

Providing optimal temperature. Microbial enzymes — molecules used by all organisms as catalysts in the production of other necessary compounds — are denatured at 105 degrees Fahrenheit. This highlights how critical it is to keep soil covered. Bare, uncovered (tilled) soil can reach temperatures of 150 F on the surface and 110 F three inches deep. In this situation — not uncommon in the summer on bare soil in between crops — there would be zero microbial activity in the first few inches of soil (the most important ones) — no nitrogen fixation, no transferring of nutrients to plants, etc.

Providing good gas exchange. The common understanding is that plant roots need to have loose soil in order to be able to breath. Actually, it's the microbes in the soil that require gases from the environment in order to thrive. Nitrogen and oxygen gases need to be constantly available to microbes from the air, and the carbon dioxide the microbes create needs to be able to escape the soil so it can be used by the plant above for photosynthesis.

The problem on many agricultural fields is that compaction layers often prevent this gas exchange from happening. This is unfortunately even the case on no-till operations. Reducing tillage is important — con-

The Rhizophagy Cycle

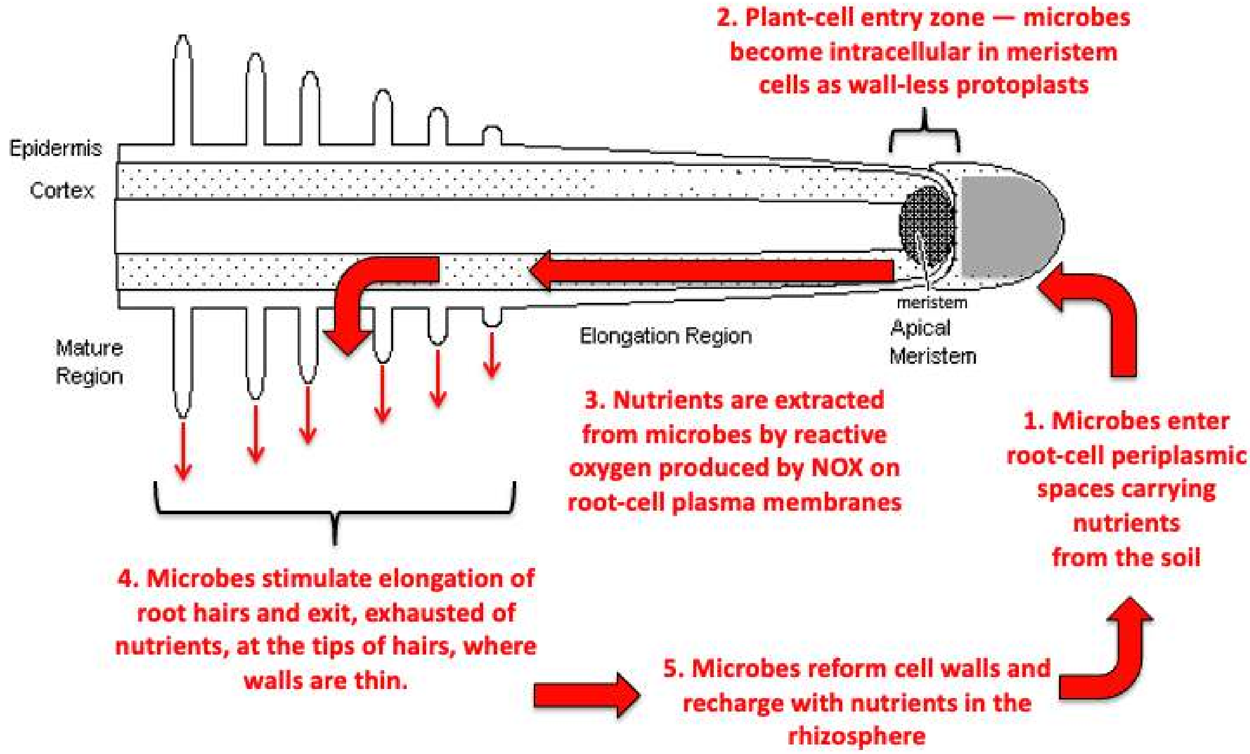


DIAGRAM COURTESY OF DR. JAMES WHITE AND RUTGERS UNIVERSITY

Cover crops are essential for covering the soil and protecting microbial life.

stantly churning up the soil destroys biological life, particularly fungi, with their delicate networks that transports nutrients to plants. However, reduced/no-till practices must be balanced against the unavoidable impact of compaction from never tilling. Although it is true, given a very long period of time, that biology and cover crops should be able to overcome compaction (if the field is never driven over), a better solution is occasional deep ripping — running a shank spaced every few feet through the field once every couple years. This breaks up the layer that prevents the penetration of both roots and vital gases — i.e., that prevents life beneath a certain depth.

Providing adequate water. The microbes in the soil essentially live in a sub-aquatic environment. Abundant water must be present in the soil aggregates in order for biology to thrive. The task for the farmer, then, is to provide both enough irrigation when there isn't rain and — particularly in dryland farming, but really in every situation — to provide good soil aggregate structure, which allows moisture to move within the soil. Like the points above, this primarily means keeping the soil covered and eliminating compaction as much as possible.

SOIL BIOLOGY TESTING

Growers have successfully nurtured thriving biological communities for thousands of years without having any way of measuring the organisms in their soil. Within the past decade or two, microbe measurement has become available to farmers. While the technology is still in its infancy, it can be profitably used to better understand what's happening in the soil and how management decisions help or hurt soil microbes.

One of the simplest forms of biological testing is ***microscopy.*** Take a soil sample, put it on a slide, and look at it under a microscope. This method provides undeniable results — you can see the bacteria and fungi with your own eyes — but it is not quantitative, and it suffers from needing to have a decent amount of training to know what you're looking at, particularly since the vast majority of microbial species are unidentified.

A different method is a ***PLFA (phospholipid fatty acid) test.*** This test measures chemical signals that arise from different groups of microbes — fungi (arbuscular vs. saprophytic), bacteria (gram-positive vs. gram-negative) and protozoa. It also provides the fungal:bacterial ratio, which can help a grower discern the state of their soil (perennial crops and grasslands perform better with fungal-dominated soils; annual crops prefer bacterial soils).

Another new test on the market is the ***Haney test***, which, along with providing other metrics like amount of available nitrogen, measures microbial respiration. In other words, it doesn't measure microbes directly, but it does give the farmer a general benchmark on how much microbial activity is going on underground.

Finally, the newest type of microbial measurement is the ***DNA test.*** It provides a comprehensive analysis of all the DNA of the biology that's in the soil, identifying the millions of different species — both pathogens and beneficials (although all living organisms can be either good or bad, depending on the context) — and categorizing them into functional groups. It has the power to tell growers things like "your nitrogen-fixing bacteria are low" or "you have plenty of phosphorus-solubilizing bacteria." This

Labs that offer soil microbial testing:

Microscopy testing —
Soil Food Web
(*https://www.soilfoodweb.com*)

PLFA and Haney testing —
Regen Ag Lab
(*https://regenaglab.com*)

DNA testing — Biome Makers
(*https://biomemakers.com*)

PHOTO FROM CANVA

method of testing holds enormous promise, although since it's new, the benchmarks are only now being established. It's also expensive — about $200 per test.

The same equipment that analyzes the DNA of humans and any other living thing can be used to determine the microbial makeup of the soil, providing organic farmers a glimpse into the bacteria, fungi and other organisms in their soil and giving them an opportunity to try to grow and/or alter those communities.

THE FUTURE OF FARM MICROBIAL MANAGEMENT

Is it possible to provide 100 percent of a crop's nutritional requirements through soil biology? Agronomists disagree, and certainly in very sandy soils, or soils that for some reason don't have even unavailable supplies of one or more nutrients, this won't be achievable. But many growers certainly could supply more of their nutritional requirements via biology.

Ecological farming is a process. It takes time, but positive changes build upon each other — although often more slowly than we'd like!

Improving soil biology is like the old adage about trees: the best time to start working to improve soil biology was twenty years ago, but the second-best time is right now.

Learn more about soil biology:

Advancing Biological Farming
by Gary Zimmer

The Farm as Ecosystem
by Jerry Brunetti

The Regenerative Agriculture Podcast,
hosted by John Kempf

Teaming with Bacteria, Teaming with Fungi, Teaming with Microbes
and *Teaming with Nutrients*
by Jeff Lowenfels

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PHOTO COURTESY OF BIOME MAKERS