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Soil Microbes & Symbiotic Relationship in Plants

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By **Robert Turner**

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An entire world exists underground, inhabited by tiny creatures with complex, mysterious lives. Just as the new James Webb telescope is opening vast expanses of the universe to human eyes, scientists employing high-powered microscopes are digging deep into the dark recesses of the earth to unlock its subterranean secrets. What they're revealing is a vast communications network that connects microorganisms in the soil with plants aboveground, allowing entire ecosystems to share nutrients, minerals, water, and even warnings of impending danger.

As a farmer in Appalachia, I’ve witnessed the productivity of microbes on my own farm for years. I often marvel at the world beneath my feet: There are more microbes in a tablespoon of healthy soil than there are people living on Earth. What’s more, healthy soil can contain over 1 million different species of bacteria and fungi, the vast majority not yet catalogued by scientists. While recent discoveries in soil science make a strong case for no-till agriculture, my own observations led me to determine long ago that I should avoid ripping up farmland with my plow.

Symbiotic Relationship in Plants

We’ve known for a long time that healthy soil is teeming with life and that the presence of bacteria and archaea (all folding into the blanket term “microbes”) in agricultural soils boosts crop yields – an average of 10 percent to 20 percent for many field crops that are amended with microbial fertilizers. Yet despite their importance for food production, we know surprisingly little about soil microbes’ daily lives.

Science has historically focused its attention aboveground, perhaps because of technological limitations. Centuries of research unlocked the miracle of photosynthesis, whereby plants bind together hydrogen atoms from water with carbon-dioxide molecules from the air to create simple carbohydrates, such as glucose. But more recent advances have shown that while plants turn atmospheric carbon into usable energy, they actually store a lot more carbon sugars underground. This soil carbon becomes a glue that binds and clumps soil together, boosting water-storage capacity and overall soil health. Because the process pulls carbon-dioxide molecules out of the atmosphere, it’s also a key to sequestering the planet-warming greenhouse gas.

Why would a plant expend any additional energy to store excess carbon in the soil? This is where things get even more interesting.

All life-forms on our planet – from people to plants to soil microbes – are carbon-based, and we all need to continually consume carbon atoms to maintain our physical bodies. Whereas plants can source carbon directly from the air, microbes have evolved over hundreds of millions of years to earn their carbon by partnering with plants for mutual benefit. In a symbiotic partnership, a plant exudes sugars from its root system to attract and feed bacteria in the soil. The bacteria reciprocate by making sure the plant gets enough water and nutrients.

You can compare the exchange to our own human gut biomes: Just as intestinal bacteria help us digest and process food, plants depend on soil microbes to help them break down and "digest" – or "fix" – the nutrients they need, including nitrogen and phosphorous. Research indicates that between 50 percent to 90 percent of minerals and nutrients a plant fixes might come from this exchange. As if the deal needs sweetening, some bacteria also colonize a plant's roots and aboveground surfaces to ward off pests and pathogens.

For these reasons, the scientific community generally accepts that improved microbial life in the soil can reduce our dependence on synthetic, petrochemical-based fertilizers and pesticides, reducing fossil fuel use while lowering input costs for farmers.

Douglas Fir Mycorrhizal Fungi

This story has an additional hero: At the same time bacteria are partnering with plants, mycorrhizal fungi are also nestling in among plant roots, creating a spiderweb structure of mycelium that effectively extends a plant's root system using microscopic filaments called "hyphae." The surface area of this mass of tentacle-like hyphae can be up to 100 times greater than that of a plant's roots, creating a secondary "root system." The mycelium draws in valuable nutrients and water that otherwise are unreachable for the plant, and in return, mycorrhizae receive carbohydrates (comprised of carbon) from the host plant.

As if the process isn’t otherworldly enough, evidence suggests mycorrhizae facilitate communication between plants.

Canadian ecologist Suzanne Simard was one of the earliest researchers to promote the idea that plants (particularly trees) “talk” to one another – with the help of mycorrhizal fungi – to support the exchange of carbon, water, nutrients, and defenses against predators. As one of the few women working in forest ecology 30 years ago, Simard’s work was ridiculed by male colleagues who didn’t believe in the hidden communication channels. Now, she’s regarded as one of the first scientists to understand the forest-fungi phenomena. For instance, Simard discovered that paper birch and Douglas fir trees loan each other carbon using the fungal web. As the seasons shift into summer each year, fast-growing birches will send nutrients to slower-growing fir trees; in winter, the process reverses after the birches lose their leaves.

Suzanne Simard Mother Trees

Simard’s research also identified what is now called a “mother tree.” Mother trees are often the largest trees in the forest and act as central hubs for vast belowground mycorrhizal networks. (The Tree of Souls in the Avatar movies is loosely based on Simard’s discoveries.) Through the underground network, a mother tree will inoculate seedlings with fungi and supply them with the nutrients they need to grow. Mother trees change their root structures to make room for baby trees and will elicit warnings and mount defenses to protect their young. Mother Douglas firs will even play favorites, sending more carbon to her own seedlings than to unrelated baby firs growing nearby.

Do Trees Communicate?

When the roots of two Douglas firs meet underground, they can fuse into a single vascular system. Whole forests feed and heal each other in this way, feeding the young and unhealthy trees with donated water and nutrients. Aspen forests, found throughout the foothills of the Rocky Mountains, may appear to be composed of hundreds of individual trees. They’re actually one living organism stretching across the landscape, enabled by a vast, interconnected root-and-fungi network that shares nutrients.

These findings are working to dispel the view of forests as conglomerations of individuals trying to out-compete one another. Rather, trees and other plants are more like nodes in a circuit board connected to a living internet that's continuously giving and getting information from the mycorrhizal web.

At this point, I should acknowledge that plants and microbes aren't "talking" the way humans (and many animals) speak. Rather, plants communicate through touch and smell – chemical and electrochemical signals communicated both aboveground and belowground – that warn each other of a grazing deer, an insect invasion, or a water shortage. These messages and more are "spoken" in a language that scientists are only just beginning to translate.

For example, when a bug chews on a leaf, the host plant can respond by releasing volatile organic compounds, including the hormone jasmonic acid, into the air. Other plants detect these compounds, ramping up their production of chemical defenses in response. In turn, predator bugs have evolved to know the chemical smell means dinner is nearby, and they soon come looking for the gnawing herbivore bug. Plants attract predators to come to their defense! We humans can also smell the distress signal – in the scent of freshly mowed grass. Scientists believe the sweet cut-grass smell to be a chemical signal intended to warn nearby plants of impending danger.

Modern industrial agriculture is harmful when it rips apart the mycorrhizal web. In addition, heavy cultivation (tilling) disrupts nature’s carbon-storage capacity by exposing the soil to air and sunlight, and the use of synthetic nitrogen fertilizers reduces fungal populations. Microbes stop fixing nitrogen when it’s over-applied, and the reciprocal system starts to break down. If you kill nearly every plant in a field using Roundup prior to planting a crop (as many industrial farmers have been encouraged to do through heavy marketing), you’ve broken the chain.

Microbial Inoculants

Companies have sold microbial inoculants for years, in part to counteract the harmful disruption industrial agriculture imposes on the soil web. I used a group of microbes called “nematodes” at a neighboring farm to control seedcorn maggots that infested the crop after years of monocropping. It was as simple as ordering them online; they came in a FedEx box. But working with microbes can be tricky: Over a million species exist, and microbial ecosystems are complex and delicate, making it challenging for scientists to identify and isolate those that supply consistent results.

Still, companies are trying, in some cases using DNA sequencing to unlock soil's secrets. For example, AgBiome is attempting to capture and screen more than 100,000 species of microbes to develop new biologically based products. The company asserts that the bacterium *Pseudomonas chlororaphis* can be used as an inoculant against certain types of crop fungi that cause stem and root rot. Other companies sell microbes and microbe food as all-in-one products, such as BioSafe Systems' TerraGrow blend of five *Bacillus* species. Microbes from the Streptomycetaceae and Lactobacillaceae families also show benefits for crops.

But with so much that we still don't understand about microbial communities, some scientists, including Tom Thompson, a professor of agronomy at Virginia Tech, are a bit skeptical.

"Poor microbial populations in the soil are what they are for a reason, and it's usually the result of monocropping, over-tilling, and the over-application of chemicals," Thompson says. "What we do know for certain is that we need to protect the soil from erosion, we need biodiversity, crop rotation, cover crops, and more organic matter in the soil that will protect and grow the microbes that are already present in the soil." Thompson works with a lot of farmers and doesn't want anyone spending limited resources on products if research doesn't back up their claims.

Farmers can feel empowered without inputs. Organic and regenerative agriculture techniques protect and build microbial life in the soil. Practices such as low or no tilling, planting cover crops, composting, planning crop rotations, and carefully managing cattle on pasture can enhance the soil's carbon-storage capacity. Biologically based fertilizers, including worm castings, compost, and kelp, give microorganisms the nutrients they can mineralize and exchange with plants.

When organic farmers and home gardeners feed the land with care, we're not only feeding crops – we're feeding microbes and the wider ecosystem. I believe that when we actively participate in this symbiotic relationship between microbes, mycorrhizae, plants, and trees, we can feel more connected to the land – as though those tiny filaments in the soil are reaching up through our feet to intertwine with the synapses within our minds.

Azotobacter Bacteria Strains Boost Crop Yields

Increase in Yield Compared to Chemical Fertilizers

- Crop Increase (%)
- Wheat 8-10
- Rice 5

- Sorghum 15-20
- Maize 15-20
- Potato 13
- Carrot 16
- Cauliflower 40
- Tomato 2-24
- Cotton 7.27
- Sugarcane 9-24

Wani, Sartaj A. et al. Soil Science, 2016.

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