

A CASE FOR REPLACING INORGANIC AGRICULTURAL INPUTS WITH MYCORRHIZAL FUNGI

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RECLAIMING ABUSED LAND

“Nothing flourishes here, not even weeds”, Pius Floris exclaimed. The field where he was working used to be the bread basket of Spain.(1) However, over the years, drought, monoculture, fertilizers and other inputs to the soil have resulted in an area bereft of plants. Floris added his proprietary mixture of microbes and wine grape leavings to the rocky land, then planted oats and small olive trees. He was betting that this field would become productive again. Three years later Floris’ field was flourishing, the plants reached his waist, shading the field even though he never watered it. The adjacent field remained lifeless, baking under the Spanish sun despite the addition of fertilizers and water over the years.

THE SOIL FOOD WEB

In the early eons of the Earth’s existence, life showed up - tiny, structurally simple microbes comprised of ancient archaea, and bacteria. These kingdoms were (and are) wildly diverse, living in pockets of the Earth, manipulating minerals, gases and even radiation to sustain life. Together they ruled the earth for a couple billion years. Then things changed. The chemistry of the planet flipped from a reducing environment (think sulfur) to an oxygen-rich atmosphere similar to today’s, causing a massive extinction of species on earth.(2)

At the same time many microbes were going extinct, the oxygen-rich atmosphere created opportunities for larger, more structurally complex creatures.(3) Fungi, plants and animals evolved, eventually developing into the biological web of life - the ‘soil food web’. The web seethes with five kingdoms of life - bacteria, archaea, fungi, plants, animals, and viruses, too, though the latter don’t generally qualify as ‘living’. Many of these organisms partner with other creatures, often from other kingdoms of life, for more effective ecological results, as Pius Floris’ results suggest.

SYMBIOTIC FUNGAL-PLANT PARTNERSHIPS

When cyanobacteria - single-celled precursors of plants that make sugar using the energy of sunlight - left their watery environment for solid land about 470 million years ago, they were accompanied by fungal companions.(4) The fungi had ‘tails’ that allowed them to ‘swim’ as they searched for nutrients in the soggy soil which they exchanged for sugar from the cyanobacteria. Together, mycorrhizal fungi and photosynthetic ‘proto-plants’ are referred to as *mycorrhizae* - *mycor* for the fungi, and *rhizae* for roots, a sophisticated symbiotic relationship that has flourished over millions of years.

Mycorrhizal fungi form two basic types of symbionts, endo- and ectomycorrhizae. Endomycorrhizal fungi form enclosures of tiny hollow tubes called hyphae inside the plant root cells. The enclosures, called arbuscules, are sites where fungal and plant products are exchanged. In contrast, ectomycorrhizal fungi coat external surfaces of plant roots with a thick layer of fungal hyphae where nutrients are exchanged with the plant root. The original fungal symbiont, called arbuscular mycorrhizal fungi (AM fungi) - an endomycorrhizal symbiont - has evolved into > 300 species that interact with about ninety percent of the plant species on earth. Ectomycorrhizal fungi have an estimated 20,000 species, and are mostly tree specialists, supporting the health of the world's temperate forests, though not many tropical trees.(5)

WHAT'S THE BIG FUSS ABOUT MYCORRHIZAL FUNGI?

Mycorrhizal fungi are masters at finding, delivering and trading nutrients with their partners, including essential phosphorus and nitrogen, followed by calcium in depleted soils. Fungi may trade sugar made by their plant partners for nitrogen from nitrogen-fixing Rhizobium bacteria, or for phosphorus that the fungus finds far from the plant root zone. Fungal partners may specialize, absorbing sulfate that is released from organic matter in the soil, as well as potassium and lesser amounts of iron, copper, zinc, iodine, selenium, magnesium, manganese, fluoride, chromium, molybdenum and possibly silicon.

As noted above, phosphorus is essential for plants, but growers often spread it across their fields, even though an estimated 75 to 95 percent of the phosphorus fertilizer is not taken up by the crops.(6) In contrast, mycorrhizal fungi take up phosphorus, release it from bound soil particles, and make it accessible to plant partners.(7) And, as people consume the plants, we also receive phosphorus, an essential element for catalyzing a large majority of the enzymatic reactions in our bodies. Perhaps it is high time to reconnect plants with their symbiotic plant partners.

SOME MYCORRHIZAL FUNGI BENEFIT PLANTS

- Increases surface area of nutrient uptake
- Unlocks phosphorus for plants
- Acquires nitrogen from organic matter
- Improves uptake of trace minerals
- Enhances nutrient density of crops
- Relieves drought and heat stress
- Warning signals pass between plants
- Encourage healthy plants to make protective compounds
- Deliver water to drought-stricken plants

AM fungi's delivery service for plants ultimately benefits people, too. Magnesium levels in apples grown today have declined by at least 30 percent compared to apples grown a century ago. A Harvard meta-analysis found that people who ingest insufficient magnesium have a 22 percent higher risk of ischemic heart disease.(8) It is currently not known how much micronutrient levels have declined in our foods, an issue that may be partially due to declining fungal symbionts. However, a survey comparing apple cider

from apples grown with or without mycorrhizal fungi suggested that cider from mycorrhizal fungi-infected trees tasted better!

In addition to supplying nutrients, mycorrhizal fungal help protect plants by passing chemical messages between diverse plants, warning that disease might be nearby, encouraging healthy plants to make protective molecules that help sustain our crops. For New Mexico growers, however, the most valuable aspect of symbiotic fungi maybe their ability search for and deliver water to their plant partners! Fungal mycelia act as root extenders that can search the area some two to three times farther away from the plant's own roots to bring back water to trade for plant sugar or oil. Could declining nutrient levels in our foods be due to declining mycorrhizal fungi?

In an interesting twist, there have been a number of plant species that have abandoned the fungal-plant symbiosis. About 10% of the plants that have been tested do not associate with symbiotic fungi. Interestingly, we call most of these plants 'weeds', including the notorious bindweed and tumbleweed. The brassica family also includes several non-mycorrhizal plants including as cauliflower and broccoli, as well as most green leafy plants such as kale, spinach, chard.(9)

PRACTICES THAT SUPPORT SYMBIOTIC FUNGI

Peter Wohlleben, a German forester, related the following story in his book, *The Hidden Life of Trees*.(10) While Wohlleben was hiking in an old growth forest, he sat on what he thought was a rock. As he looked at it, he noted that it was green. Then he noted that several other green rocks formed a circle about 5 feet in diameter. "Ah, these aren't rocks!", he thought. They were the remains of a huge tree that had been felled about 400 or 500 years ago. But, the big surprise came as he realized that the remains of the huge tree stump were the green of chlorophyll. For at least 400 hundred years the stump had no trunk or leaves to photosynthesize. That meant one of two things. Either the stump had been living on stored nutrients for 400 years, which he deemed impossible. Or the trunk was still alive, supported by some other source of chlorophyll. His epiphany led him to discover an extensive underground nutrient network linking beech trees. He titled the book chapter *Friendships*.

Wohlleben's story underscores a key practice - non-disturbance of soil. In a healthy, undisturbed forest, the mycelia connect mother trees with their offspring, enabling them to deliver nutrients to the little trees that are shaded. However, if the soil is disturbed, such as when forests are logged or after a fire, mycelia maybe severely damaged or severed, causing the little trees to be cut off from the mother tree's assistance. Plowing a field can severely damage symbiotic fungal hyphae, cutting off water and nutrient supplies to the young trees. When annual crops are harvested, fungal symbionts maybe left without a plant root - their only source of sugar. Within a couple of weeks, the fungal spores are likely to be inviable.

If soil has been damaged, it may be possible to re-connect symbiotic fungi and plants by spreading appropriate types of fungal spores. As a rule of thumb, while trees in a nitrogen-limited temperate forest are mostly connected by ectomycorrhizal fungi, endomyc-

orrhizal fungi, particularly arbuscular fungi, dominate phosphorus-limited areas such as savannas, prairies, shrublands and grasslands. Tropical ecosystems also host mostly AM fungal networks.(11)

To grow your own mycorrhizal fungi, try this simple method from Sunseed Desert Technology (www.sunseed.org) to make your own mycorrhizal inoculum.(12)

To protect or restore fragile mycorrhizae, one might also want to adopt the following no-till practices:

Spread fungal spores along with your annual plant seeds.

Limit heavy equipment in crucial areas.

Cultivate your garden with a broadfork rather than a rototiller or tractor.

Maintain nurse plants to feed your fungal symbionts over time.

Insure growing space is not contaminated by glyphosate, or Round Up herbicide.

To increase fungi in compost, see Dr. David Johnson's video, *Johnson Su Bioreactor, Institute of Sustainable Agriculture Research, published Mar 15, 2016 at New Mexico State University*.(13) His U-Tube video demonstrates the no-turn composting system that 'produces a superior microbially-diverse and fungal-dominant compost'. His online presentation suggests that his fungal-enriched compost is effective at increasing growth rates of crops and increasing soil carbon sequestration rates. The website states, 'This compost can be used to restore biological functionality to soils from small to large farming operations and from third-world to advanced agroecosystems'.

SOIL CARBON SEQUESTRATION

Glomalin, a large, long-lived protein made by arbuscular mycorrhizal fungi, lines the inner surface of the hyphae. Glomalin's carbon-rich chains are responsible for its unusually high carbon content, as well as its sticky nature. Though it is one of thousands of proteins that the fungus makes, glomalin single-handedly accounts for 27 to 30% of the all the carbon sequestered in arbuscular mycorrhizal fungi-rich soil. When AM fungi die, the hyper-stable glomalin protein stays in the soil from seven to forty-two years, making it a good target for carbon sequestration, unlike many organic molecules that break down within days, releasing sequestered carbon from the soil in the form of carbon dioxide gas.(14)

References:

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