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The Huge Impact of Mycorrhizal Colonization on Plant and Soil Health

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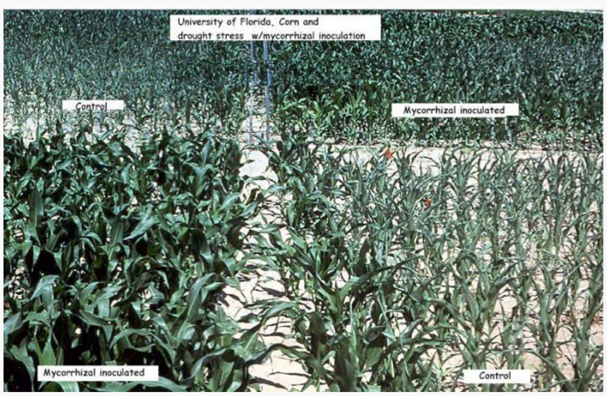

This University of Florida photo shows the effect of mycorrhizal inoculation on maize drought response. Mycorrhizal colonization (front left and back right) helps plants avoid severe drought losses compared to the control (front right and back left).

Leonardo da Vinci remarked, "in order to be a successful farmer one must know the nature of the soil." Even today in the age of hydroponics, most of our food, over 98 percent by some estimates, is grown from field on a soil medium. Beyond growing our food, the way we treat our soil determines the nature of our environment and the climate.

There is a great and still relatively undeveloped agronomic and environmental opportunity that could make an important global difference. This opportunity is hidden underneath our feet, in the living soil. The soil is home to the most populous community on the planet. Around the seven continents, the living soil is the Earth's most valuable bio-system, providing ecosystem services worth trillions of dollars. The most limiting resource for global food system is drought, with over 75 percent of the crop insurance outlay related to these events.

The vast majority of our cultivated soils are in an eroded and degraded state. As we increase demands on our soil to feed billions, we are losing it and depleting it at an unprecedented rate. Our ability to transform it will address both of these key issues. In addition to addressing drought and climate, the web of soil life is critical to maintaining and building soil resources we need now and into the foreseeable future.

Elaine Ingham emphasized the concept of the soil food web. In the living soil food web the keystone species of the living soil community are mycorrhizal fungi. These unsung heroes cannot be cultured apart of plant roots. Mycorrhizal fungi are obligate symbionts growing from the soil into the plant roots.

About 80-90 percent of all land plants depend on these fungi for the procurement of water and nutrients. The fungal network represents a massive “web” of opportunity. When optimized, the multiplication of soil/root interfaces increases by several magnitudes via mycorrhizal colonization.

Mycorrhizal Importance

When roots are colonized with mycorrhizal fungi they exude the sticky sugary protein glomalin that promotes the adherence of soil particles together.

Scientists suggest mycorrhizal evolution appeared over 460 million years ago, coinciding with land plant development. Mycorrhizae are viewed as an evolutionary advancement that allowed plants on land to survive on periodically dry and hostile land surfaces.

Researchers suggest that less than 1 of 20 soil microorganisms have ever been identified and cultured. Considering this startling statistic, soil microbiology still represents a largely unchartered and vast frontier filled with promise and potential that could make a significant difference to agriculture.

The traditional underestimation of mycorrhizal importance may partly be based on unfamiliarity since most scientists have little knowledge, experience or appreciation for these microscopic underground denizens. Even many mycologists are not well versed on this topic. Beyond the scientific community, farmers, extension specialists and public policymakers are even more in the dark.

Soil Erosion Control

While the development of topsoil is considered a slow process, losses of topsoil by erosion can be rapid and vast. Erosion can easily overrun the natural capacity of soil genesis. While erosion has been viewed as a physical process, everything in the soil is affected by the life within it. For example, sticky mycorrhizal filaments create an organic glue that binds soil into stable aggregates that resist detachment, erosion and rapidly move water into the soil profile, preventing overland flow of soil.

When roots are colonized with mycorrhizal fungi they exude the sticky sugary protein glomalin promotes the adherence of soil particles together. Since mycorrhizae can form with so many of our important crop species, could these microscopic organisms reverse the effects of soil deterioration? If they can, then how do they do it?

There are copious citations showing how the loss of topsoil and the decay of soil organic matter can lead to a degradation of our land resources. The disappearance of soil organic matter under modern cultivation practices gives a typical bathtub-shaped disappearance curve where initiation of continuous cultivation gives a rapid plummeting of the soil organic matter which then reaches a degraded equilibrium value less than one half of the original value.

In 1876 the Morrow plots of the University of Illinois were started. There rotations demonstrate this bathtub disappearance of soil organic matter related to modern farming techniques. The results were similar to results in Sanford plots of University of Missouri and Macgruder plots of Oklahoma State University as well as studies from other major land grant universities. In practice the potential of loss of productivity is particularly associated with maize monoculture that dominates the modern North American landscape.

During the 1930s in the United States the Great Depression coincided with massive soil erosion known as the Great Dust bowl era. In order to address this massive soil loss, soil conservation methods were marshaled through Soil Conservation Service of the U.S. Department of Agriculture under President Franklin Delano Roosevelt and Agriculture Secretary Henry Wallace.

Giant dust clouds common during Great Depression during droughts in the Plains region.

Differing Outcomes From Synthetic Input and Organic Agriculture Systems

Since the end of World War II, the high productivity of agriculture has focused on intensive use of cultivation, synthetic fertilizers, monocultural production methods and intensive use of pesticides. These methods were also degrading mycorrhizal populations important for stabilizing surface soils from wind and water erosion.

Methods that were traditionally employed for maintaining and building biological robust soils were not a prime consideration. These practices included organic manuring, rotations and employment of forage and haying in rotations that employed mixed crop and animal systems of production.

In 1978 The Rodale Institute started the Farming Systems Trial (FST) that directly compares a biological input approach exemplified by organic agricultural systems compared to a typical synthetic input approach. The conventional approach used a maize and soybean crop rotation with full input packages, i.e. synthetic fertilizers and pesticides. The biological input approach used a more extended crop rotation with cover crops and a focus on legume crops and cover cropping that has been shown to promote mycorrhizal populations.

While the short-term effects of synthetic fertilizers on crops can be rapid and spectacular the long-term effects of these may be quite different. When nitrogen is applied to legumes the result is atrophy of the natural fixation of nitrogen by bacteria. Likewise when synthetic phosphorus is applied in abundance to the seed zones of crops it can trigger the plant not to accept the mycorrhizal fungi that mobilize soil phosphorus.

Because biological inputs take time to accumulate in the form soil organic matter, maize yields were only fully competitive with synthetic approaches until the fourth year of the FST. After that time, the yield in drought years was consistently superior with biological approaches compared to conventional maize and soybean control systems. These results are the cumulative effect of soil improvement that Robert Rodale coined as soil regeneration.

System analysis has clearly demonstrated that not only does the biological input approach produce highly competitive crop yields over time, but also soil carbon and nitrogen values increase significantly. The FST puts the soil organic matter disappearance curve on its head, leading to a soil organic matter accrual curve. This is only appreciated under a long-term experimental vista.

Mycorrhizal Fungi and Glomalin

In 1996 Sara F. Wright of USDA-ARS began publishing scientific articles on the ability of mycorrhizal fungi to capture soil carbon, suggesting fully one-third of the carbon in soil is related to these organisms. Dr. Wright and her collaborators showed the profound effect of the sugary organic glue, glomalin, excreted from mycorrhizal fungi as a key for aggregating or clumping soil.

As the sticky glycoprotein glomalin increases in the soil so does the size and persistence of soil aggregates. Persistent large aggregates reduce the ability of small soil particles to be dislodged by wind and water.

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Studies at Rodale Institute show that biological inputs including rotation, cover cropping and organic amendments can be highly stimulative to mycorrhizal diversity and activity. Using *Paspalum notatum flugge*, a bay grass, mycorrhizal fungi were effectively propagated to provide the ability to artificially inoculate and enhance mycorrhizal activities with positive results for crops such as potato and strawberries in multiple-year trials.

We see the great potential of utilizing mycorrhizal fungi and organic amendments for their symbiotic and synergistic effects, and we see gradual appreciation and adoption by the agricultural community.

Some scientists express a valid concern about the exact nature of glomalin, citing need for better knowledge it mode of action. We concur with this need for additional information, and we also see its potential in critical issues pressing in our future. In a warming world, soil organic matter resources are needed more than ever.

In addition, agriculture issues related to water quality and global greenhouse gas emissions are addressed by putting soil organic matter in a positive trajectory. One of the biggest potentials to counteract these degradation issues may well be grounded in a sticky fungus that can be re-established and preserved in modern agricultural systems.

How Mycorrhizal Fungi Help Plants Deal with the Stress of

Climate Change

The massive capacity of mycorrhizal fungi (white threads) to extend beyond the much more limited plant root system (brown).

In March, the United Nations Intergovernmental Panel on Climate Change pointed to melting ice caps and rising sea levels, stressed water supplies, heat waves and erratic weather, with a stern warning about the danger to global food supply.

Food demand is rising 14 percent every decade, while there is tremendous need to reduce the environmental impact of agriculture. By 2030 our planet is expected to support 8.3 billion people. The United Nations Food and Agriculture Organization has stated that by then farmers will have to produce 30 percent more grain than they do now to keep pace with demand.

The UN Panel points to serious risk of major disruption to social stability due to coming climate change, drought and food shortages. Historically, we have seen how drought induces a cascade of changes, disrupting agriculture, trade and social cohesion.

In the American Southwest in the 12th century, the people known as the Anasazi reached their cultural peak and then collapsed because of drought. Most recently, increased food prices and water shortages were a major contributing cause to the unrest that led to the Arab Spring, particularly to unrest in Syria.

Closer to home, we saw a devastating drought in California with its massive impact on agriculture in a state that grows half the nation's fruits and vegetables. The year 2013 was the driest in California's recorded history.

Agriculture needs to use resources more efficiently. We need to produce more food per unit of water, energy and fertilizer. Few people comprehend how much water is needed to grow food. On average it takes 1 liter of irrigation water to grow 1 calorie of food. Consider the average American consumes in excess of 3,000 calories a day and you can grasp the enormity of water necessary to sustain the population here in the United States.

The UN Panel suggests many steps to adapt to a changing climate. They suggest that farmers could breed new species to better resist heat and drought. Drip irrigation, (where water is applied directly to the plant's base) reduces water use compared to overhead spray applications. Mulching the soil surface and no till agricultural systems retain water in the soil. Reducing water loss from irrigation systems and evaporation from canal and reservoirs could also help. Better water harvesting techniques could be used to collect and disperse water to crops.

In a world of increasingly volatile weather and depleted soils, water has become a precious resource. There are some places on Earth where a barrel of water costs more than a barrel of oil. No one understands this better than farmers, especially today with severe drought events seeming to become the norm. Yet 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 a partnership between mycorrhizal fungi and plants. Fungal filaments extend into the soil and help the plant by gathering water and nutrients and transporting these materials back to the roots. Plants that have mycorrhizal fungi growing on their roots survive better after transplantation and grow faster. The fungal symbiont receives shelter and food from the plant, which in turn acquires an array of benefits such as improved uptake of water, drought and salt tolerance, and an overall increase in plant growth and development.

Mycorrhizal plants show higher tolerance to drought. Like a sponge, they absorb water during moist periods and 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 fungi above produced on bay grass P. notatum flugge. The effects of these fungi were particularly notable under periodic drought common in rain-fed agriculture.

As research shows, mycorrhizae help plants become more drought-tolerant due to effects on soil structure and improved plant nutrition. In addition, the hyphae of the fungi allow access to soil pores of very small diameter that retain both water and nutrients as soil dries. Mycorrhizal fungi can act as a kind of drought insurance as farmers struggle with the effects of a less predictable, changing climate.

Degraded lands are more likely to experience significant drought impacts. Populations of soil microbes are lost when the land is cleared and intensively tilled. Soil fumigation, fungicide use, cultivation, compaction, soil erosion and periods of fallow are factors that can adversely affect populations of beneficial soil organisms and soil organic matter. These influences compromise the ability of the soil to store water and release it to plants.

Soil and carbon losses are the root of many soil degradation issues and the intensive use of some chemical fertilizers and pesticides have caused tremendous harm to the environment and life in the soil. Part of our strategy to combat this degradation is to re-establish beneficial life in the soil using biological inoculants.

Biological inoculants contain organisms that enrich the nutrient and water-holding capacity of soil. Bio-fertilizers and bio-inoculants are the fastest growing sector of agricultural research and technology because they increase yields for many important crop species. They represent a step we can take now to begin to transition to a long-term sustainable system based on healthy living soils.

For millions of years the powerful combination of organic amendments and soil biology has demonstrated its success, and today we are beginning to see these benefits on large-scale farming. In North America both large-scale conventional and organic farmers are applying mycorrhizal fungi to wheat, corn, soybean, alfalfa and vegetables. Many will also use other organic amendments to stimulate their soils with beneficial biology, improving water retention and uptake.

In India, Europe and South America, farmers are using mycorrhizal inoculation to decrease their inputs and increase yields. In America several large seed companies utilize a “smart seed” mix and inoculate millions of pounds of seeds annually with mycorrhizal fungi to increase the plants’ drought tolerance.

Our work suggests in the roots of our crops and their fungal extension are critical to keeping our soil resources from being washed and blown away. Biological and organic matter inputs will allow a more productive agriculture future while simultaneously reducing the need for inputs that have known side effects on our soil and its biological capacity.

Healthy soil hosts a 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. Perhaps the most important activity the living soil provides for plants is storing, accessing and absorbing water and nutrients.

The living soil is the ultimate source of our health. It is also a fundamental source of our security and social well-being. The living soil and mycorrhizal fungi are not a silver bullet that will solve all the world’s problems, however, starting underfoot can make a difference and a healthier and safer world.

By Paul Reed Hepperly, David Douds & Mike Amaranthus. This article appeared in the May 2018 issue of Acres U.S.A.

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Resources

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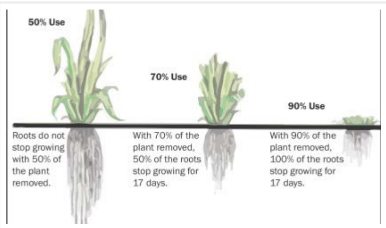

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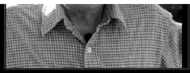

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