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Mycorrhiza Matter!

How land management impacts these microbes and how they can impact the world when soil is living and breathing.

By Alison Grantham

Dr. David Douds samples the bahia grass he uses to grow mycorrhiza inoculum for our potting mix. Interns Aaron Bini, Caitlin Splawski, and Miriam Gieske observe.

Maximizing carbon with fungi

To maximize mycorrhiza and carbon sequestration in your soil:

1. Feed the fungus! Keep plants growing on your soil as much as possible – use cover crops to fill in the gaps between crops.

2. Diversify your rotation to maintain an abundance of mycorrhizal species that can do well under

Never before has there been such a demand for answers to raising more food more sustainably with more understanding of the largely invisible microbial world underground.

The Rodale Institute is all about finding practical, accessible, biological solutions to some of the world's biggest problems, like climate change and famine. We've identified many ways that organic agriculture improves soil and builds resilience across varying conditions. One of the most amazing parts is our discovery that a beneficial type of soil fungus plays a major role in explaining the long-term positive changes that happen over a period of years in well-run organic systems.

Through working with a community of persistently curious scientists, we've found that arbuscular mycorrhiza (AM – Greek for "tree-like fungus roots") may play a big part in building soil health and good soil structure that lead to greater agricultural productivity. By sharing how this discovery has unfolded in our work over several decades, I'll suggest how you can apply new insights to your soil that can help to improve our world.

various conditions.

3. Include plants that span the spectrum of mycorrhizal dependence from highly dependent alliums to occasionally ambivalent tomatoes.

4. Grow your own mycorrhizal spores and inoculate the compost mix you start seedlings in. We've found that an inoculum with mixed species does better than a single species.

5. Watch your phosphorus levels – there's better colonization under lower-fertility conditions.

6. Minimize soil disturbance.

AM biology: required cooperation

These AM fungi are known as "obligate fungal symbionts," meaning they have to form an association with plant roots to survive. The hyphae, or root-like structures, of AM merge with the roots of plants, to deliver phosphorus, water and micronutrients to the plant. The plant utilizes these resources to grow and photsythesize, capturing carbon dioxide from the air and transforming it into carbohydrates, which the plant feeds to the mycorrhiza.

The mycorrhiza, in turn, transform these carbohydrates into various products including:

- longer hyphae, which scour a greater area of soil for plant resources;
- spores, which can inoculate new root tips;
- glomalin, a sugar-protein which they excrete into the soil.

We've found these mycorrhizal functions provide many direct and indirect services including increased agricultural productivity, improved water-infiltration and water-holding capacity, and soil carbon sequestration.

Functional fungi

Scientists elsewhere are also investigating mycorrhiza for their role in soil carbon storage. At the recent **International Symposium on Soil Organic Matter Dynamics**, PhD candidate Marie Spohn from Universität Oldenburg detailed the role of mycorrhiza as the primary soil organic matter (carbon) stabilization mechanism in sandy soils. She presented data from 70 sites across northern Germany that demonstrated how mycorrhiza, the glomalin they excrete, and the soil aggregate formation facilitated by the glomalin also play a "major role" in the stabilization and thus the carbon sequestration potential of sandy soils.

So what, you ask? Because the soil carbon scientific community has considered soil carbon sequestration potential to be constrained by the soil's clay content, this biological option was earth-shattering news. If increasing mycorrhiza can increase a soil's carbon storage capacity, we could manage land to put away much more carbon than had been previously thought when determined by soil chemistry-constrained estimates.

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Since 2006, Rodale Institute has been working to figure out just how to increase soil carbon sequestration with mycorrhiza in our Farming System Trial (FST). In this long-term trial we've documented significant carbon sequestration in our organic system plots. The Institute has partnered with USDA-ARS microbiologists Kristine Nichols and David Douds to address these objectives through the USDA's GRACEnet (Greenhouse gas Reduction through Agricultural Enhancement network). The program aims to "identify and develop agricultural strategies that will enhance soil carbon sequestration and reduce greenhouse gas emissions to provide a scientific basis for possible C credit and trading programs [to mitigate climate change and] improve environmental quality."

So far, we have taken cores of the soil profile to 80 cm (31.5 inches, where we hit rock) in late fall of 2006, 2007 and 2008 in FST's three systems:

organic legume, organic with composted manure and conventional. Nichols and Douds characterized the soils' carbon, glomalin and glomalin-carbon content as well as mycorrhizal spore abundance and diversity. They also recorded the important soil and environmental quality characteristics – soil aggregation, infiltration, stability and bulk density. Nichols presented their findings so far at the aforementioned symposium last month and was kind enough to discuss them for this article.

Measuring soil stability

One of the most exciting results of the project is the whole soil stability index that Nichols is developing. This will integrate information on soil particle aggregation to estimate effects of the mycorrhiza on water infiltration, water holding capacity and erosion. She explained that the key to an ideal soil is a balance between larger aggregates (>2mm) that mycorrhiza help to form and are important to good infiltration, and the smaller ones that are essential to good water-holding capacity.

A puzzling set of data shows seemingly opposing trends in two indicators of mycorrhizal abundance: spores and glomalin content. In the 1990s, it seemed that there were more spores and more mycorrhiza in the organic systems than in the conventional system. But now, in these last three sampling years, it appears that the spore counts in the conventional system are "catching up," according to Douds. (In the early 1990s, Douds found about 15 species of mycorrhiza in all systems, but many more spores in the organic systems.)

Conversely, Nichols reports that glomalin-carbon is displaying the opposite trend, with more glomalin in the organic systems in most years. This apparent inverse relationship may indicate that spore abundance is not a good measure of mycorrhizal activity or glomalin production, according to Nichols. Douds says the increase in mycorrhizal spores in the conventional system is occurring for unknown reasons, although Nichols hypothesizes what drives spores likely has to do with soil microenvironment.

In regards to climate change, soil carbon sequestration and mycorrhiza, I asked Nichols how key she felt the organic part of the equation was.

While it might be possible to achieve higher soil carbon sequestration levels in highly diverse conventional systems, organic system would still have a huge edge in terms of lowering net emissions due to the absence of synthetic inputs.

Nichols believes that farming approaches matter, too, in the quest to optimize mycorrhiza's role in building soil carbon. While it might be possible, she said, to achieve soil carbon sequestration levels (like those our FST organic plots) in highly diverse conventional systems that have extensive living plant cover, organic systems would still have a huge edge in terms of lowering net emissions due to the absence of synthetic inputs.

Managing for mycorrhiza – Two decades of research

For 20 years, Rodale has worked with USDA-ARS microbiologist David Douds to study the presence, diversity, and impacts of AM in agroecosystems – in our conventional and organic plots in the FST, elsewhere in research trials on our organic research farm, and in the fields of nearby collaborating farmers. Now in our 21st field-work season, we have identified numerous important intricacies of mycorrhizal effects on plant growth and yield as well as soil quality and soil carbon storage. We have also investigated and uncovered the impacts of farming system as well as specific land-management practices on mycorrhiza.

Intern, Ellen Mickle samples bahia grass roots for mycorrhiza.

Our first studies of mycorrhizae mainly examined the impact of various management practices on mycorrhizal colonization of plant roots and the abundance of mycorrhizal spores. We examined specific components of agricultural systems such as crop rotations, compost, synthetic fertilizers, fungicides, herbicides, moldboard plowing, chisel plowing, disking, and no till for their impacts.

We know some things that discourage good soil fungi. Crop fungicides obliterate mycorrhiza, and soils treated with them can benefit from re-inoculation with AM spores. Certain factors, including monoculture and herbicides, negatively impact the mycorrhizal community (decrease abundance and diversity) by limiting the abundance and diversity of potential plant partners. Other factors such as soil fertility and tillage have less definitive impacts – although low fertility (especially low phosphorus) and minimized soil disturbance generally benefit mycorrhizal abundance and diversity. Nichols feels that the most important factor for mycorrhiza is supporting a system that maximizes diversity and abundance of living plant cover throughout the year.

Other trials have investigated mycorrhizal parameters in the context of various organic and conventional systems. About 15 species of mycorrhiza have been isolated and identified from Rodale Institute soil. While spores of all 15 species persist in the conventionally farmed system, the organic farming systems – both the legume-based and the system with composted manure – support a greater abundance of mycorrhiza. Coincident with greater mycorrhizal abundance we've seen higher nutrient uptake and nutrient-use efficiency in the early plant growth stages.

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Over the last several years, we've performed numerous vegetable mycorrhiza inoculation trials on crops ranging from sweet potatoes and sweet corn to garlic leeks and potatoes. Dr. Douds has developed an on-farm mycorrhiza innoculum production system to conduct these trials. The system consists of black plastic bags of Rodale's compost-based potting mix inoculated with four species of AM isolated from Rodale soils as well as a fifth variety isolated from soil at Villanova. Douds plants bahia grass, a tropical grass that readily accepts mycorrhizal associations and supports high rates of spore formation. After one year, spore-rich soil from the bags is collected and mixed into potting mix to inoculate our veggie starts.

While the impact of the inoculums varies with the vegetable species, and is often masked by the high levels of native AM in our organically-managed soils, Douds has found significantly higher bell pepper yields, even in our high-phosphorus soil, with multi-species mycorrhizal inoculants. Unfortunately, other single species inoculums did not increase yields relative to the un-inoculated controls, leading Douds to conclude that some species are better matched to certain crop plants than others. For best results, a mix of species might be your best bet.

Managing for mycorrhiza: what's in the field today

Researcher and Science Editor, Christine Ziegler-Ulsh stands between rows of brandywine tomatoes planted into an old hayfield with healthy populations of native mycorrhiza. These plants are much larger and more dense than those pictured in below.

This year we kicked off a mycorrhizal exclusion experiment that has been in the works for years. To examine the impact of mycorrhiza on crops spanning the spectrum of mycorrhizal dependency (tomatoes-corn-leeks; low to high), Douds covered a field with a tarp for 3 years, which (theoretically) starved out the AM, which need living plant partners to grow. Each year he fed the rest of the soil microbial community with straw to really tease out the role of mycorrhiza in the soil ecosystem. (Other means of creating a "without mycorrhiza" control use chemical means, which also impair other soil biota.) This year, Douds rolled back the tarp on a portion of the field and started the trial. Much to his chagrin, mycorrhizal spores turned out to be very persistant, so the portion under the tarp that was not re-inoculated still has viable mycorrhiza. So, it remains to be seen how illustrative, in terms of the study's objectives, this year's data will be

Ziegler-Ulsh between much shorter scrawnier brandywine tomatoes planted into a field that had been covered by a tarp to kill off all mycorrhiza for since 2006.

We're also following three varieties of **inoculated and uninoculated tomatoes in a no-till trial**. This trial may help clarify the relative importance of various factors known to influence rates of mycorrhizal inoculation such as soil phosphorus levels and continuous living plant cover.

As part of the cover-crop based no-till system the plots in this trial had continuous living plant cover through the winter and spring until these tomatoes were planted in June, with no fallow period between cover crop termination and planting. This factor may allow us to see high rates of mycorrhizal association. Conversely, the soil in the plots has extremely high phosphorus levels, which may discourage mycorrhizal association. Further the native AM may mask any effects of greenhouse inoculation of the starts. All this remains to be seen.

Conclusion

For results of these trials, and other developments and discoveries in sustainable agricultural soil management stay tuned to updates on our website. Until then, use the six helpful hints in the sidebar to propagate fungi, promote carbon sequestration, and grow tasty food in whatever soil you may manage!

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