Groundwork BioAg

# Mycorrhizal Inoculants: The Path to Improving and Preserving Soil Carbon in Mainstream Agriculture

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With the help of mycorrhizal inoculants, conventional, tillage-based farmers can improve and preserve their soil organic matter (SOM) and soil organic carbon (SOC) levels, tapping into the powerful and potentially profitable impacts of carbon sequestration in agricultural soils.

Today's agricultural community understands and recognizes the benefits of improving SOM and SOC through conservation and regenerative practices. But many commercial farmers are reluctant to give up the conventional tools they have come to rely upon for weed management, bed prep and soil fertility.

Mycorrhizal inoculants change the equation entirely.

## The Potential Conservation of Agricultural Soils

Weather-related climate extremes are impacting farmers' ability to grow crops, jeopardizing agricultural profitability and threatening global food security. However, recent data shows agricultural soils represent one of the biggest opportunities to mitigate climate instability.

Today, many agricultural soils are deficient in organic carbon. Generations of intensive tillage have left one-third of the world's soils degraded and precariously low in SOC and SOM, jeopardizing the ability to support and sustain plant life. But farmers have the potential to reverse this trend by drawing down atmospheric carbon ($CO_2$) through their plants and sequestering it via mycorrhizae into the soil as part of the natural carbon cycle.

U.S. farmland has the potential to significantly offset annual emissions. While U.S. land-based carbon sinks currently sequester 758.9 MtCO2eq tons of carbon annually, U.S. farmland is still a relatively small contributor to that total (roughly about 3%). Globally, however, scientists believe agricultural soils could sequester an additional 1.85 gigatons of carbon annually, enough to offset all emissions from the global transmission sector.

**Soil Organic Matter Versus Soil Organic Carbon - What's the Difference?**

Soil organic carbon (SOC) and soil organic matter (SOM)are closely related concepts in soil science but it is important to understand their differences.

SOM is all the organic compounds existing in the soil, including carbon, whereas SOC is just the carbon within SOM. How much SOC exists is directly proportional to the amount of SOM.
Building SOM increases SOC levels.

Though SOM is widely recognized as the key component for maintaining soil fertility, water-holding capacity and healthy soil ecosystems, SOC is the unit of measurement used by most carbon registry programs for quantifying the carbon sequestration benefits of land management practices that increase SOM.

**Carbon is at a deficit in the soil and at a surplus in the atmosphere**. For farmers, the current low state of carbon in agricultural soils represents an opportunity for their farms, their profits and their legacy. Conservation and regenerative farming practices sequester carbon into the soil, qualifying farmers for lucrative carbon credit programs while boosting soil health, improving crops and reducing their reliance on expensive inputs.

But changing farm practices is challenging, especially on large scale operations - and may be insufficient to prove additionality and allow farmers to become eligible for carbon credits.

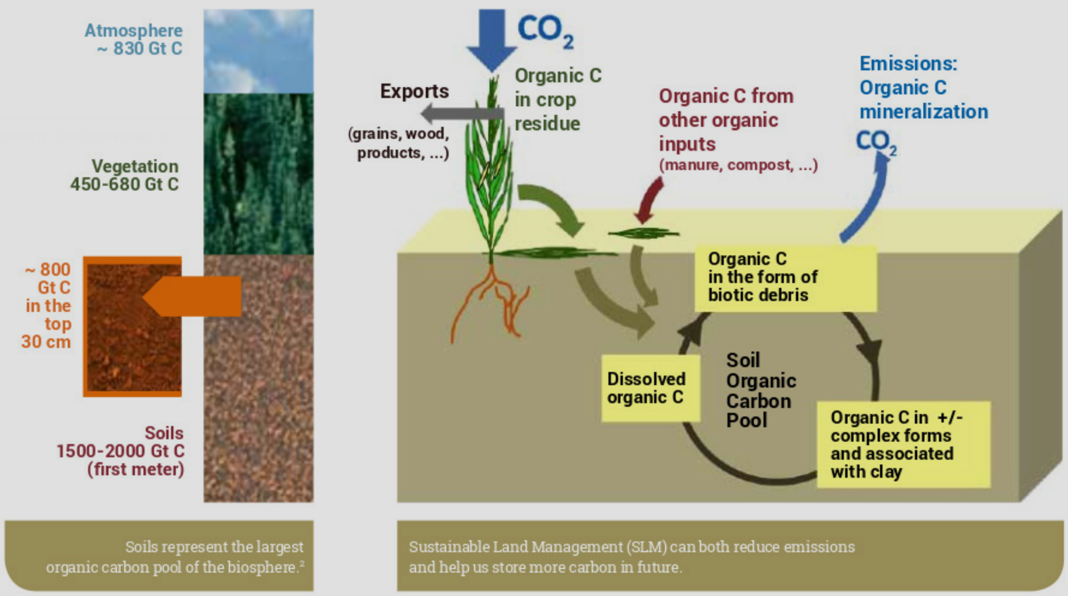
To date, most of the emphasis on agriculture as a climate change and soil health solution has relied heavily on converting farmers to conservation-based practices well-documented for improving SOC levels. These include no-till and low-tillage techniques, cover-cropping and limiting chemical applications. All of these practices are primarily meant to preserve and enhance the microbial ecosystem in agricultural soils, and specifically mycorrhizae.

But, in the real world of farm economics, the adoption of new practices has been slow due to implementation, crop cycles and scaling challenges. For example, a [2022 study] found that despite nearly doubling the amount of no-till acres over ten years, no-till acreage still only makes up 14.7% of total global cropland.

To accelerate the natural carbon sequestration process and achieve higher SOM (and therefore, SOC) levels, farmers need a more flexible solution that integrates science and farm practices with farm economics and day-to-day realities.

Latest studies have revealed mycorrhizae as critical to building SOM and SOC through short- and long-term sequestration of labile (easily decomposed) and recalcitrant (degradation resistant) compounds in the soil, even when the land is managed under conventional farming practices.

Soil Carbon Cycle. Source: United Nations Convention to Combat Desertification.




## Mycorrhizal Inoculants Deliver a New Solution for Mainstream Agriculture

Mycorrhizal inoculants are the key to carbon sequestration in mainstream agriculture - and a bridge to soil health for all growers hoping to improve and preserve their SOC stock.

But to understand how mycorrhizal inoculants relate to SOC, we must first understand the critical role of mycorrhizae in our agricultural soils.

### What is Mycorrhiza?

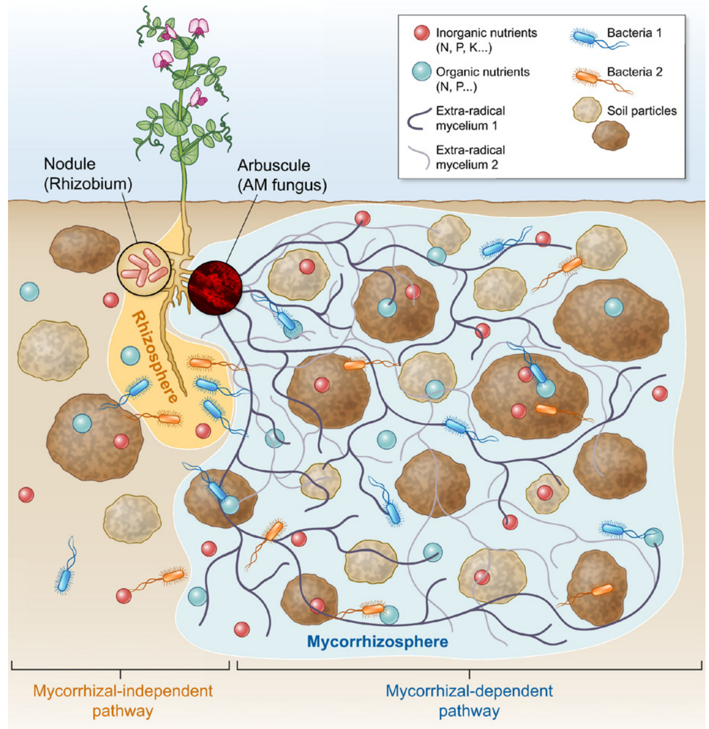
Mycorrhiza is a group of fungi that forms a symbiotic relationship with plant roots. The earliest mycorrhizal species originated with the terrestrialization of plants on Earth over 400 million years ago.

Arbuscular Mycorrhizal Fungi (AMF) establish beneficial symbiotic associations with plants by colonizing plant roots and consuming organic molecules (i.e. sugars) produced by the plant's photosynthetic process. The mycorrhiza returns the favor, delivering water and nutrients from the soil to the plant.

Phosphorus, which is generally abundant in the soil but not in plant-available forms, is particularly relevant, as mycorrhizal symbiosis releases chemically-bound soil phosphorus, availing it to the plant.

[Approximately 90% of plant species](#) are considered mycotrophs - plants that benefit from mycorrhizae - although a few notable crops are indifferent to and essentially repel mycorrhizal presence, including brassica species like cabbage and broccoli. Indeed, some of the most popular commercial crops, like corn, carrots, sorghum, onions, olives and cannabis, are obligate mycotrophs - meaning they require mycorrhizal colonization to achieve optimal growth.

Mycorrhizae effectively extend a plant's root system with fungal mycelia - webs of long, microscopic filaments called hyphae. This "secondary root system" can increase a plant's effective root structure by as much as 100 times, allowing the plant to absorb far more nutrients and water than would otherwise be accessible.



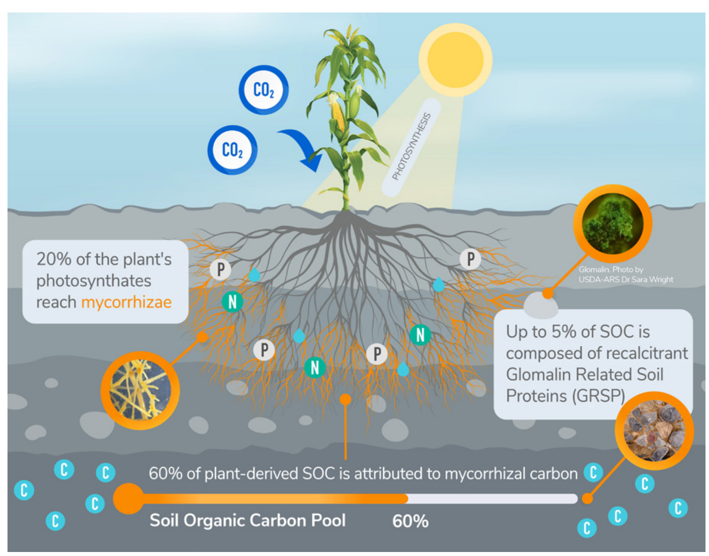

Trading on the arbuscular mycorrhiza market: from arbuscules to common mycorrhizal networks. Source: New Phytologist, Volume: 223, Issue: 3, Pages: 1127-1142, First published: 07 March 2019, DOI: (10.1111/nph.15775)

## How Mycorrhizal Fungi Build Permanent SOC

But that's not all that mycorrhizae do for the soil. AMF is a critical player in building carbon stocks by maintaining a net flux of carbon into the soil, yielding carbon permanence.

Carbon permanence means that once we draw carbon (CO2) out of the atmosphere and sequester it into the soil, that carbon remains in the soil for an extended period of time, in part due to the microbiome living there. For growers, carbon permanence means that the practices they adopt to strengthen mycorrhizal colonization have both an immediate and long-term ROI. Their soils remain healthy today and for future generations of production. Moreover, it means that growers are eligible for valuable carbon credits as a direct result of this permanency.

Multiple soil microbes are known to transport and sequester carbon into the soil, but AMF has been recognized as a significant contributor. It is estimated that [up to 20%](#) of the plant carbon photosynthate is allocated directly to mycorrhizal fungi. In fact, the mycorrhizal contribution to total SOC is estimated at [23-87%](#), making it a significant contributor to SOC levels and highlighting the potential of agricultural soils to sequester atmospheric carbon.




Mycorrhiza is the pathway for carbon into the soil. Source: Groundwork BioAg.

## The Magic of Glomalin-Related Soil Proteins (GRSP)

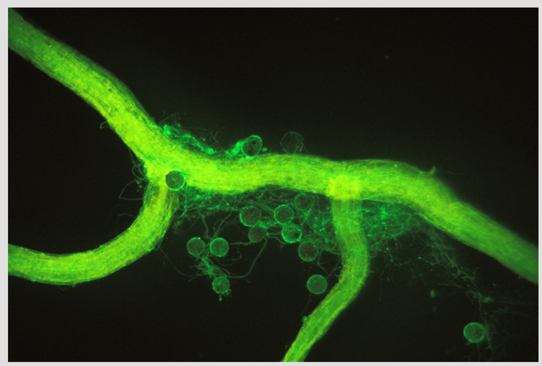
The discovery of Glomalin-Related Soil Proteins (GRSP) in 1996 by the USDA completely changed how we think about SOC and carbon permanence.

Not only does GRSP store carbon itself via its composition (it has been measured to contain up to 46.9% carbon), it also creates micro-aggregates by binding soil particles together, thus preserving other forms of organic compounds not produced by AMF. GRSP has been found to be one of the most recalcitrant repositories of SOC, even able to withstand conventional tillage.

"In the context of global climate change, increased C sequestration through GRSP-induced aggregate formation and organic matter stabilization prolong the mean residence time of soil C. Protecting soils against degradation under intensive land use, stable aggregate formation, and prolonging the residence time of C calls for strategies that maximize GRSP production and functions based on reduced tillage, AMF-relevant crop rotations and organic farming,"

Glycoproteins of arbuscular mycorrhiza for soil carbon sequestration: Review of mechanisms and controls

A microscopic view of an arbuscular mycorrhizal fungus growing on a corn root. The round bodies are spores, and the threadlike filaments are hyphae. The substance coating them is glomalin, revealed by a green dye tagged to an antibody against glomalin. Photo: Sara Wright.



## The Impact of Agricultural Practices on GRSP

GRSP's relevance to commercial agriculture begins with its decay resistance and persistence in the soil.

Highly correlated to the presence of AMF in all kinds of soils, GRSP acts like a 'superglue,' binding organic matter and clay particles into stable soil aggregates, thus maintaining a healthy soil structure, capable of carrying more water, minerals and nutrients, and avoiding erosion.

Sara Wright, the USDA soil scientist who first identified GRSP, characterizes it as unique among soil components for its strength and stability. "It requires an unusual effort to dislodge glomalin for study: a bath in citrate combined with heating at 250°F for at least an hour," Wright said. "No other soil glue found to date required anything as drastic as this."

Multiple studies have now shown that different farming practices have little effect on established soil GRSP, which can persist in soils for at least seven and as long as 40 years.

A South African study found that even after 90 years of cropping and despite farm practices such as tillage, chemical fertilization and back-to-back cropping rotations known to destroy AMF, GRSP levels were still able to reach and maintain a steady state in the soil. On the other hand, non-AMF microbial residues were shown to decline during the same period.

In 2006, soil scientists looked closely at how tillage affects soil characteristics, including GRSP and mycorrhizae populations. Samples were taken from a field in a five-year crop rotation divided into four different tillage systems including no-till, reduced tillage, chisel-plow and conventional moldboard plowing.

Both studies confirmed that while tillage depletes AMF and stops the development of new GRSP, the GRSP levels reached before tillage commenced were not impacted due to its recalcitrance.

"Total glomalin concentration increased when soils were subjected to Reduced Tillage and No Tillage compared with Conventional Tillage and this increase was related to C content. Glomalin-C as a proportion of total soil C remained almost constant among treatments (ca. 5%) and no relationships were found between glomalin levels and AM fungal variables,"

Effects of tillage systems on soil characteristics, glomalin and mycorrhizal propagules in a Chilean Ultisol.

> Even more striking, additional studies have found that the best way to increase AMF levels isn't through conservation practices but through application of mycorrhizal inoculants.

"Inoculation with AM fungal inoculum leads to a higher increase in AM fungal colonization (29%) than other agriculture practices including shortened fallow (20%) and reduced tillage (7%),"

https://nph.onlinelibrary.wiley.com/doi/full/10.1111/j.1469-8137.2005.01490.x

## 4 Big Mycorrhizal Inoculant Take-Aways Relevant to Soil Carbon in Mainstream Agriculture

1. Mycorrhizae are the main pathway of carbon into soil.
2. GRSP is a tillage-proof repository of stored carbon.
3. Mycorrhizal inoculation is more effective than conservation practices at boosting AMF colonization in soil.
4. Mycorrhizal inoculants sequester and permanently store SOC for farmers using a variety of farming practices.

## Tips for Choosing a Mycorrhizal Inoculant that Builds Carbon Permanence

Like any input applied on a farm, successful incorporation of mycorrhizae into farm practices requires understanding the key differentiators between products and how those apply to a grower's specific needs.

At Groundwork BioAg we strongly recommend farmers and agronomists consider the following key points when selecting a mycorrhizal product, especially if they are pursuing the positive benefits of carbon permanence.

### Read the Label

There are two relevant categories of mycorrhizal fungi: endo- and ecto-mycorrhizae. Ecto-mycorrhizae associate with woody plants (trees and bushes) and offer no value for other commercial crops. For row crops, farmers need to use endo-mycorrhizae, or AMF.

**Some on-the-shelf mycorrhizal inoculant products contain the wrong type of mycorrhizal species, or minuscule amounts of the right kind!**

### Concentration Equals Results

The best way to ensure a high ROI when using mycorrhizal inoculants is by applying a concentrated product with high potency. Concentration levels among competing products vary widely, from as few as just one to ten spores (or propagules) per gram to concentrations of thousands or more. High concentrations are especially critical for cost-effective inoculation when using mycorrhizal inoculants as a seed treatment prior to planting.

**For the best field results in commercial agriculture, choose a highly concentrated inoculant. At Groundwork BioAg we recommend applying no less than one million propagules of endomycorrhizal fungi per acre of row crops.**

### Define Your Soil Health Needs

Glomus intraradices, recently renamed as Rhizophagus intraradices, is one of the primary endomycorrhizal species active in Groundwork BioAg's Rootella products and known to benefit most crops at some level. But site-specific conditions affect the rate of responsiveness. For instance, Glomus intraradices has a strongly positive response when used in challenging soil conditions, such as low water and organic matter content, deficient soil phosphorus and nitrogen levels, high toxicity and acidic or alkaline conditions.

**Understanding the site-specific needs of soil to support optimal crop production enables an informed decision when choosing a mycorrhizal inoculant.**

### Mycorrhizal Inoculants Should be Easy to Use

Mycorrhizal inoculants should be formulated with the end user in mind. Usage techniques and methodologies should not limit a farmer's ability to adapt mycorrhizae to the needs of their ever-changing production cycle.

**Choose a mycorrhizal inoculant that accommodates your desired application method - be it wet or dry seed treatment, in-furrow treatment, soil mixing, or anything else.**

Responding to demand from mainstream agriculture, Groundwork BioAg's Rootella® mycorrhizal inoculants are produced to easily integrate into commercial farm operations. Rootella offers a highly concentrated inoculant, critical to achieving high efficiencies at low application rates and for successful performance when used as a seed treatment. All Rootella products are OMRI-listed and suitable for use in organic farming. For more information or to request a sample, visit www.rootella.com.

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