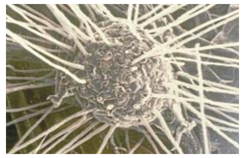

The soil carbon connection

In the final article in series on mycorrhizae fungi's role in agriculture, the authors make the connection between atmospheric carbon dioxide and different forms of stable soil carbon, glomalin and biochar.

The element carbon is the essence of all life, past and present on our planet. The term "organic" in its most basic definition means anything that includes the carbon atom in its composition. All living tissue, including that of plants, is comprised entirely of carbon-based molecules so it stands to reason that the availability of carbon is of utmost importance in any ecosystem. Thus, most plants and other below-ground beneficial organisms are highly dependent on carbon stored in their ecosystem: the soil.

The predominant source of carbon in soils is driven by a cycle involving carbon dioxide gas, a component of air (0.039% by volume) and the growth and decomposition of plants. Ultimately, the energy of the sun powers this cycle. Plants capture carbon dioxide (CO_2) from the atmosphere, converting the carbon into tissue and other organic components by means of photosynthesis.

Many of these compounds and the associated carbon become incorporated in the plant's root system, soil respiration or in the adjacent populations of soil organisms such as bacteria and fungi. As the plants die, their tissues decompose, primarily through the actions of soil micro-organisms. Some of the carbon returns to the atmosphere as CO_2 gas to continue the cycle, while some becomes stored in the soil in the form of long-lasting, chemically-stable residues such as humus (see the August 2011 article in this series) and a special mycorrhizal-produced substance called *glomalin*. Under ideal circumstances, the carbon bound in these unique compounds can last in the soil for decades up to hundreds of years or more.

Carbon is at the core of a soil's chemical and physical viability for plant growth. Carbon compounds improve root and mycorrhizal development, facilitate the absorption of plant nutrients and serve as a source of nitrogen, phosphorus and sulfur. They also often dictate the physical properties of soil that determine its resistance to erosion and the critical availability of water and air. This stored carbon is essential to support biological activity, plant productivity and, in the case of farming, sustained profitability. It is well documented throughout history that numerous civilisations have perished basically due to their failure to maintain adequate soil carbon and the resulant loss of agricultural productivity.

As we will learn later in this article, soil can be a powerful means by which to accumulate carbon reserves in the form of organic matter. Land management practices such as no-till, winter cover crops, biological inoculants, perennial pastures, and manure and compost inputs are all methods known for their ability to increase soil-stored carbon. Over time, if farming activities result in soil carbon loss exceeding replacement by the natural rhythms of root and mycorrhizal activity, decay and recycling, production will likely decline.

We discussed the properties and significance of humus in the last mycorrhizae series article but there is another critically important carbon-storage substance in soils called glomalin. Loaded with carbon, glomalin is a sticky, organic glue-like substance produced exclusively by arbuscular mycorrhizal fungi. United States Department of Agriculture scientist Dr Sara Wright discovered glomalin in 1996, naming it for Glomus, the mycorrhizal fungal group that produces it.

These fungi are found worldwide and will colonise more than 80% of all terrestrial plants. It is theorised that the mycorrhizal fungi produce glomalin on the outside of the hyphal filaments to seal them from leaking as they transport nutrient solutions back to the root cells. Scientists also speculate that glomalin provides sufficient rigidity to allow the tiny filaments to bridge voids and the air spaces among soil particles without collapsing.

The soil surrounding plant roots colonised by mycorrhizal fungi rapidly accumulates soil glomalin, thus sequestering air-derived organic carbon and stimulating soil productivity. Technically a glycoprotein, the relatively stable glomalin molecule is made up of 30%-40% carbon, resists decomposition for up to 42 years and can comprise up to 40% of the total carbon found in soil. It has been estimated that all the soil on Earth contains about 1.58 trillion metric tons of carbon; therefore, the contribution of soil carbon to this total by mycorrhizal fungi could be as much as 630 billion metric tons. This exceeds the 611 billion metric tons estimate for all the carbon stored in the entire world's terrestrial vegetation.

Wright's discovery of glomalin has initiated a comprehensive reassessment of the role of organic matter as it relates to carbon storage and soil quality. Glomalin binds organic matter with particles of sand, silt and clay to form carbon-rich aggregates. The accumulation of such aggregates creates the uniform, granular structure indicative of healthy topsoil. Aggregation created by glomalin also contributes to a soil's ability to hold water without eroding and helps prevent carbon loss throughout the soil matrix.

Glomalin increasing with rising CO_2

In other studies, Wright and researchers from the University of California at Riverside and Stanford University documented that that increased atmospheric CO_2 levels stimulate mycorrhizal fungi to produce more glomalin. The studies were conducted in semi-arid shrubland and on grasslands in San Diego County, California, US, using outdoor chambers with controlled CO_2 levels. At CO_2 levels of 670 parts per million (ppm) – the atmospheric level predicted for Earth by some scientists by the end of this century – mycorrhizal fungal hyphae grew three times as long and produced five times as much glomalin as fungi on plants growing in an atmosphere with today's ambient level of 370ppm of CO_2. Scientists continue to study this phenomenon in the hope of learning more about how the fungi and glomalin may help mitigate the effects of greenhouse gasses and global warming.

A little-understood and archaic method of carbon management, known as biochar, has been recently resurrected. Biochar is charcoal produced by special pyrolysis processing of biomass feedstocks such as wood waste, crop chaff, manures, green waste or waste paper. Although modern research on biochar is in its infancy, the technology is nothing new. Ancient civilisations in the Amazon Basin of South America utilised biochar (also known as *terra preta*) to sustain soil fertility in tropical croplands. Still highly productive today, some soil samples from this region date back more than 6000 years.

Biochar incorporated into soil can act as an extremely stable conditioner and fertility enhancer while effectively storing carbon for up to thousands of years. Furthermore, the pyrolysis manufacturing process can produce bio-oil and syngas – potential alternatives to fossil fuels.

Biochar meets mycorrhizae

Biochar and mycorrhizae – two "hot" research trends among agronomy scientists – are beginning to converge in an effort to help address the various challenges posed by global warming, alternative energy production and modern non-sustainable agricultural practices.

As described above, mycorrhizal fungi's significant role in long-term CO_2 sequestration is an ongoing research endeavor. The many soil health and plant growth benefits from these ubiquitous plant symbionts are already well-documented but burgeoning knowledge related to the glycoprotein glomalin has created a whole new realm of soil knowledge. The United States Department of Energy is currently funding studies to determine glomalin's promising potential to offset atmospheric CO_2.

So where is the convergence? Biochar and mycorrhizae both augment soil sustainability and they both implement substantial long-term carbon sequestration. The bonus is that combining these two remedial agents apparently compounds their cumulative beneficial properties into a powerful "2 + 2 = 5" soil scenario. In other words, the sum of the benefits exceeds that of each of the contributors.

Researchers say biochar contributes to pro-mycorrhizal soil environments via multiple mechanisms:

- Biochar appears to modify soil pH, cation exchange capacity (CEC) and waterholding capacity, creating a more favorable environment for mycorrhizal colonisation and activity.
- Biochar seems to promote microbial populations, which further stimulate mycorrhizal performance.
- Biochar may favourably influence the complex chemical communications between plants and mycorrhizae and may vitiate certain inhibitory compounds.
- The myriad, tiny pores on biochar particles may serve as physical "shelters" for mycorrhizal hyphae and various symbiotic bacteria, protecting them from damage and microbial predators.

So far, the majority of studies indicate that mycorrhizae-colonised plants grown in biochar-treated soils significantly out-perform non-biochar controls.

Much more research is needed but perhaps the soil management tools of the future will include both mycorrhizal inoculants and biochar amendments – a combination simultaneously addressing three vital global issues: agricultural sustainability, atmospheric CO_2 mitigation and alternative energy needs.

Find out more:

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WA trial links biochar, mycorrhizae and organic nutrients

It's only one trial, but the results highlight the connectivity between mycorrhizae fungi, biochar and lower levels of plant available nutrients for increasing wheat yields. University of WA agronomist Zakaria Solaiman, with colleagues from the WA Department of Agriculture, compared wheat grown in conjunction with different rates of biochar made from oil mallee trees and with two different fertilisers: typical soluble fertiliser applied at 55 and 30 kilograms per hectare and a mineral (organic) fertiliser containing mycorrhizae inoculum applied at 100kg/ha.

A summary of the results demonstrate two key outcomes. The mycorrhizae-inoculated fertiliser produced higher root colonisation than the uninoculated soluble fertiliser and as the biochar rate increased so did the percentage of root colonisation, Table 1.

Secondly, wheat yields with soluble fertilisers were not influenced by biochar rate, except at six tonnes/ha and 30kg/ha of fertiliser. In contrast, with the mineral fertiliser wheat yield was significantly improved at the lowest biochar application rate of 1.5t/ha compared to no biochar. Higher rates of biochar did not lift yields any higher.

Solaiman concludes that the improved yield associated with biochar and mycorrhizae inoculation in the trial (which was conducted in a low-growing-season rainfall year) may have resulted from the mycorrhizae fungi hyphae improving water supply to the plant roots and reducing drought stress and loss of grains.

Find out more:

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Table 1: Mean root colonisation (% root length colonised) by arbuscular mycorrhiza fungi in the field experiment in June and September. Irrigated subplots received 20mm of irrigation in August. Values significantly different from no biochar application are shown in bold

	Biochar rate (t/ha)	June %	September Irrigated %	September Unirrigated %
		Soluble fertiliser		
55kg/ha	0 (4 pass)	0	2	0
	3	1	6	5
	6	9	13	3
30kg/ha	0 (4 pass)	0	1	0
	3	6	17	3
	6	7	22	3
		Mineral fertiliser		
100kg/ha	0 (4 pass)	24	15	32
	3	12	**46**	23
	6	**47**	**45**	**62**

Table 2: Yield and yield components of wheat at harvest in the field experiment. Values significantly different from no biochar application are shown in bold

	Biochar rate (t/ha)	Yield (kg/ha)	Screenings (%)	Small grain (%)
		Soluble fertiliser		
55kg/ha	0 (1 pass)	1792	2.8	22
	0 (4 pass)	1872	3.1	14
	1.5	1797	2.1	17
	3	1889	1.9	15
	6	1809	2.2	21
30kg/ha	0 (1 pass)	1875	1.6	48
	0 (4 pass)	1961	1.9	26
	1.5	1885	2.1	**16**
	3	1788	3.0	18
	6	**2305**	2.0	19
		Mineral fertiliser		
100kg/ha	0 (1 pass)	1350	3.0	29
	0 (4 pass)	1408	3.0	16
	1.5	**2032**	2.0	18
	3	**2018**	2.1	20
	6	**2010**	2.8	16