# Soil Life & Carbon

## Answers to Global Warming in Our 'Root Cellar'

*by Mike Amaranthus, Ph.D.*

*Root system of a rye crop inoculated with compost tea and mycorrhizal fungi — this area is rich in feeder roots, soil organisms and soil carbon.*

From the food we eat, to the air we breath, to the clothes we wear, humans depend on the thin covering of the earth's surface we call soil. Arguably this thin and fragile layer of living topsoil is the Earth's most critical natural resource. Soil is literally the "root cellar" for the planet, a storage area that feeds us and protects us in emergencies. It nurtures life in both forest and field and carves intricate paths that link the health of the land, sea and atmosphere.

Lately there has been tremendous attention given to carbon sequestration. Five to ten years ago, few had heard of or cared about the concept. Carbon sequestration has suddenly become a hot topic because carbon in the air combines with oxygen to become carbon dioxide, a greenhouse gas that contributes to global warming.

Soils are key players in the process of storing (sequestering) and recycling carbon. According to Canada's Department of Agriculture and the Environment, soils contain more than all the carbon in the atmosphere and three times more than is stored in all the Earth's vegetation. Soil microbes break down decaying plant and animal matter in the process of creating fertile soils, and healthy soils containing billions of beneficial microorganisms and vigorous root systems have become an important carbon sink, binding up carbon that might otherwise enter the atmosphere.

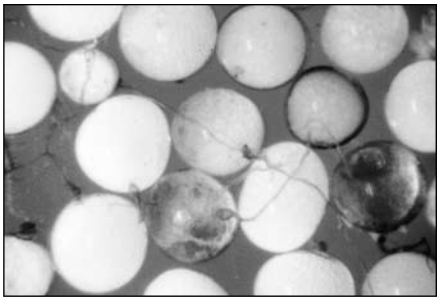
The carbon absorbed from the atmosphere by plants and animals can take several paths before it re-enters the air as carbon dioxide. When a plant or animal dies, it is broken down by soil microorganisms. As the microorganisms consume the organic matter, they release some of the carbon into the atmosphere in the form of carbon dioxide. Some is destined for longer-term storage in roots and in the bodies of plant-eating or carnivorous animals. Animals then return more of the carbon to the atmosphere as $CO_2$ through respiration, although some will be stored within their bodies until they die and decompose. Finally, as plants and animals decay, instead of escaping as carbon dioxide, a significant portion of their carbon becomes part of the organic component in soils through the activities of essential soil organisms. These beneficial microorganisms work to produce a substance known as humus, a stable, rich component of soil that is the color of dark chocolate and loaded with carbon.

### HISTORY LESSON

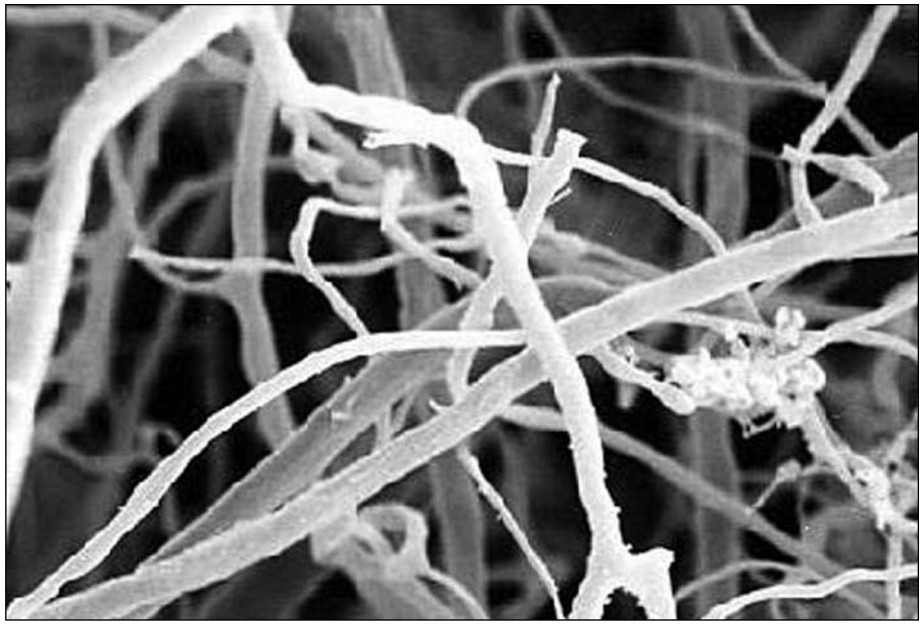
When frequent tillage is introduced, long chains of carbon that are the essence of humus are converted into carbon dioxide, which releases into the atmosphere. Soil depleted of the humic fraction is more prone to erosion, loss of microbial diversity and a breakdown of structure and can support fewer animals and plants. "Organic matter is the elixir of microbial life in the soil," explains Dr. Dave Perry, professor and ecologist at Oregon State University. "It holds water, preventing drought and floods, it supports the living soil organisms that hold the key to sustainable plant growth, and it is a reservoir of carbon that plays a key role in global climate change."

Soils can contain a wide range of organic matter. Most topsoils range from 1 to 20 percent organic matter. The best agricultural lands have loamy topsoil in which there is a high concentration of organic matter. Some of the richest in the world were found in the Great Plains of the central United States, where perennial grasses, their roots systems and associated soil organisms over thousands of years built up deep layers of carbon-laden topsoil. They form continuously, but very slowly. Only about one inch of soil is formed every 500 to 1,000 years, so loss of good topsoil is a serious issue that has led to the rise and fall of civilizations.

The great early civilizations of Mesopotamia, for example, arose because of the richness of their soils, and collapsed because of declines in soil quality. Poor



*Endomycorrhizal spores such as these are deposited beneath the soil surface and do not rapidly recolonize agricultural sites once they have been lost.*



*Mycorrhizal filaments in the soil extract nutrients and water and leave deposits of carbon-rich glomalin.*

land management and excessive irrigation caused soils to become increasingly degraded and unable to support the Fertile Crescent civilizations. Ancient Greece suffered a similar fate. The philosopher Plato, writing around 360 B.C., attributed the demise of Greek dominance to soil degradation: "In earlier days Attica yielded far more abundant produce. In comparison of what then was, there are remaining only the bones of the wasted body; all the richer and softer parts of the soil having fallen away, and the mere skeleton of the land being left." What Plato likely did not recognize is how much carbon had washed away from these Greek soils.

In the New World, similar processes were unfolding. Harvard Professor Sylvanus Morley concluded back in the 1930s that the great Mayan Civilization of Mesoamerica collapsed because they overshot the carrying capacity of the land. Deforestation and erosion exhausted their resource base. Mayans died of starvation and thirst in mass, and others fled once-great cities, leaving them as silent warnings for generations to come.

UCLA professor Jared Diamond, author of the books *Guns, Germs and Steel* and *Collapse*, argues that most inhabitants of Easter Island in the Pacific died because of deforestation, erosion and soil depletion. In Iceland, farming and human activities caused about 50 percent of the soil to end up in the sea, explains Diamond, concluding, "Icelandic society survived only through a drastically lower standard of living." Not surprisingly, the practice of destroying soils by torching watersheds or salting farms and fields has been employed by armies in warfare from the time of Alexander the Great to Napoleon.

Today, we are facing many of the same issues: removal of native vegetation, over-harvest, dwindling supplies of fresh water, overworked soils and sprawling population growth. Our poor management of the land has resulted in serious warning signs. Widespread agricultural pollution of lands and seas, accelerated topsoil loss, damage to fish and aquatic life, pesticide buildup in our bodies, and rapidly declining nutritional value of food have become environmental problems of immense importance that are directly related to soil. Now is the time to bring attention to the critical role our management of soil plays in another environmental issue of great significance: global climate change.

## FIRST LESSON

How do we stop the degradation of our soils? The answers can be found in nature below the soil surface in our "root cellar." A favorite habitat of microbes is near and in the roots of plants. Although many of them live throughout the soil, up to 100 times more live close to the roots of plants.

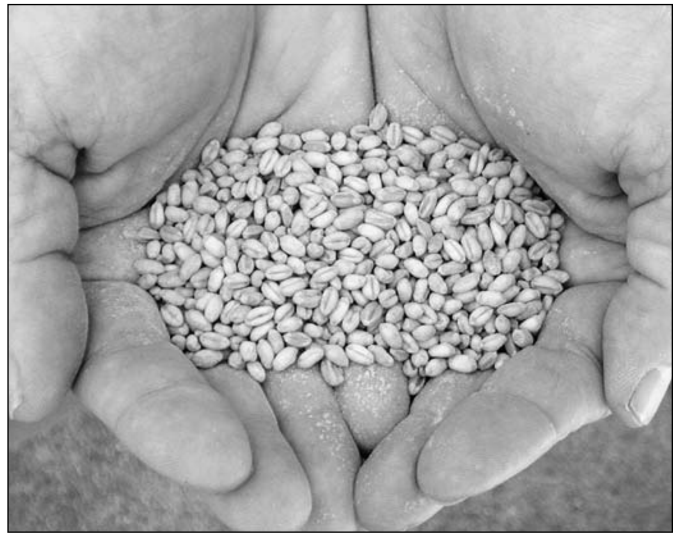
This area near the roots is called the rhizosphere, the thin layer of soil surrounding the roots. Some microbes have such a close relationship with plants that they actually live *inside* the plant, such as beneficial mycorrhizal fungi. Their threads penetrate into the root and secure sugars provided by the plant to fuel their growth. In exchange, these same filaments radiate out from the root into the surrounding soil where they capture nutrients and water and transport these materials back to the plant. It is estimated that mycorrhizal fungal filaments explore hundreds to thousands of times more soil volume than roots alone.

Endomycorrhizae, also known as arbuscular mycorrhizae, are the symbiotic association of fungus and root that occur on more plant species than all other types of mycorrhizae combined. They have been observed in the roots of more than 1,000 genera of plants representing some 200 families. It has been estimated that more than 85 to 90 percent of the estimated 400,000 species of vascular plants in the world form arbuscular mycorrhizae. These include most grains, vegetables, fruit and nut trees, vines and turf grasses.

Benefits of mycorrhizae include:

- Improved nutrient and water uptake;
- Improved root growth;
- Improved plant growth and yield;
- Reduced transplant shock;
- Reduced drought stress.

Some modern agricultural practices reduce the biological activity in soil.



*A granular mycorrhizal inoculant (left) and a mycorrhizal inoculant coating on wheat seed.*

Certain pesticides, chemical fertilizers, intensive cultivation, compaction, organic matter loss, and erosion adversely effect beneficial mycorrhizal fungi. An extensive body of laboratory testing indicates that the majority of intensively managed agricultural lands lack adequate populations of mycorrhizal fungi. Farming widespread areas affects the plant/mycorrhizal relationship in two fundamental ways. First, it isolates the plant from beneficial mycorrhizal fungi available in natural settings. Second, it increases a healthy crop's need for water, nutrients and soil structure.

Once lost from a farm, endomycorrhizal populations are slow to recolonize unless there is close access to natural areas that can act as a source of mycorrhizal spores. Endomycorrhizal fungi do not disperse their spores in the wind, but must grow from root to root or be dispersed by animals, so close proximity to healthy and undisturbed natural sites may be necessary. Normally though, farmers seldom have the opportunity to grow their crops immediately adjacent to undisturbed natural ecosystems.

Inoculating farmland soils with mycorrhizal fungi before, during or following planting can improve crop establishment, growth, yield and carbon sequestration. Mycorrhizal inoculants are available in liquid, powder and granular forms and can be sprinkled onto roots during transplanting, banded beneath seed, used as a seed coating or watered in via existing irrigation systems. The goal is to create physical contact between the mycorrhizal inoculant and the crop roots, and the type of application depends upon the farmer's equipment and needs. Inoculants that are concentrated and contain several species of mycorrhizal fungi produce the best results. The cost of inoculation generally ranges from $7 to $17 per acre.

## CARBON-RICH SUPERGLUE

Mycorrhizae also perform another service for the ecosystem that has only recently come to light. The USDA published a report by Don Comis on work by Sara F. Wright and Kristine A. Nichols that suggests a substance called glomalin, discovered by Wright in 1996, does indeed "glom" onto a large amount of carbon. The glomalin molecule is made up of 30-40 percent carbon and represents up to 30 percent of the carbon in soil. It is a natural superglue that binds organic matter to mineral particles in soil. It also forms soil clumps — aggregates — that improve soil structure and keep other soil carbon from escaping. It is in fact glomalin that gives soil its tilth — a subtle texture that enables experienced farmers to identify great soil by feeling for the smooth granules as they flow through their fingers. Glomalin is relatively stable in soils, lasting anywhere from seven to 42 years.

Endomycorrhizae form with nearly all the important agricultural plants (with the exception of the brassicas). Glomalin (produced by the endomycorrhizal fungal group *Glomus*, hence the name) is produced by endomycorrhizal fungi established on a plant's roots. The fungi produce glomalin from carbon they trade for other nutrients and water, apparently to seal themselves and gain enough rigidity to carry materials across the air spaces between soil particles. Sara F. Wright's discovery of glomalin is causing a complete reexamination of soil organic matter. It is increasingly being included in studies of carbon storage and soil quality.

## $CO_2$ & GLOMALIN

In an earlier study, Wright and scientists from the University of California at Riverside and Stanford University showed that higher $CO_2$ levels in the atmosphere stimulate the fungi to produce more glomalin. A three-year study was done on semiarid shrub land, and a six-year study was conducted on grasslands in San Diego County, California, using outdoor chambers with controlled $CO_2$ levels. When atmospheric $CO_2$ reached 670 parts per million — the level predicted for the middle to late 21st century — mycorrhizal fungal filaments (hyphae) grew three times as long and produced five times as much glomalin as fungi on plants growing with today's ambient level of 370 ppm.

Longer hyphae help plants reach more water and nutrients, which could help plants face drought in a warmer climate. The increase in glomalin production helps soil build defenses against degradation and erosion and boosts its productivity. Wright says all these benefits can also come from good tillage and soil management techniques rather than higher atmospheric $CO_2$. “You can still raise glomalin levels, improve soil structure, and increase carbon storage,” she notes.

Forests, croplands and grasslands around the world are potentially valuable for offsetting carbon dioxide emissions from industry and vehicles. In fact, some private markets have already started offering carbon credits for sale by owners of such land. Industry could buy the credits as offsets for their emissions. The expectation is that these credits would be traded just as pollution credits are currently traded worldwide. Although such plans risk abuse by industrial polluters and are thus controversial, the importance of our crops, forests and grasslands in offsetting the environmental damage caused by human technology is unquestionable.

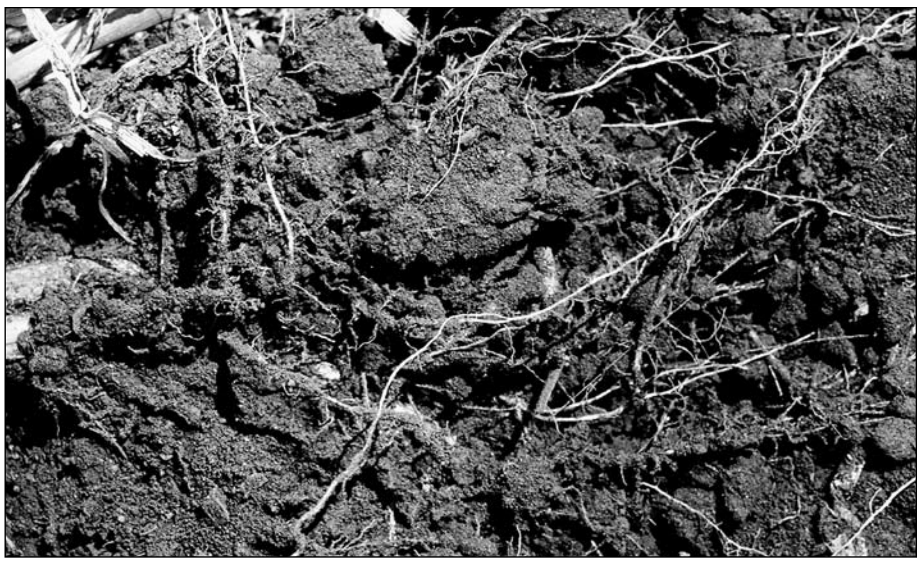
## SECOND LESSON

Today most human food comes from legumes, oilseed crops and cereal grains. It is estimated that 80 percent of agricultural land is occupied by these crops. These human staples are relatively high in protein and calories and easy to store and transport, thus making them attractive to both consumers and producers. However, these annual crops must be grown from seed every year, generally using fossil-fuel intensive cultivation and fertilization methods. To maintain annual yields, farmers are faced with growing input costs for seed, fuel, fertilizer, pesticides and herbicides. All these practices, including tillage, consume or release large amounts of carbon dioxide into the atmosphere. In addition, erosion and runoff from these intensively cultivated lands can pollute freshwater supplies and degrade the soil.

Data from the Rodale Institute’s long-running comparison of organic and conventional cropping systems confirms that organic methods are far more effective at removing carbon dioxide from the atmosphere and fixing it as beneficial organic matter in the soil. Data from 23 years of continuous research in side-by-side fields is conclusive: the organic system has shown an increase in soil carbon of 15-28 percent, compared to *no increase* in the non-organic system. Dr. David Douds of the Agricultural Research Service suggests that healthy mycorrhizal fungi populations in organic systems are key to the increase in soil carbon. In addition, a recent study of energy inputs conducted by Dr. David Pimentel of Cornell University found that organic farming systems use just 63 percent of the energy required by conventional farming systems, largely because of the massive amounts of energy required to synthesize nitrogen fertilizer.

and diseases were almost nonexistent. Over time prairie soils built and maintained deep and carbon-rich productive topsoil. It is a soil legacy that helped make America prosperous.

Compared to perennial grasses, annual crops such as wheat, corn, sunflowers and sorghum have relatively shallow root systems. The vast majority of annual roots are confined to the top foot of soil. These root systems die after harvest, leaving non-vegetated soil exposed to erosion of precious topsoil. Perennial root systems, on the other hand, commonly exceed 6 feet in depth and maintain this living tissue year-round. This allows perennial grasses to be resilient in the face of extremes of environment



*A glomalin-rich soil inoculated with beneficial soil organisms.*

This is big news. Organic farming with help from mycorrhizal fungi can take massive amounts of carbon dioxide out of the air. If all 160 million acres of corn and soybeans in the United States were converted to organic production, the reduction in atmospheric $CO_2$ could translate to:

- 57.7 million cars off the road (25 percent of nation’s cars!);
- 773 billion car miles not driven.

Let’s look at nature’s “root cellar” as an example of how the system works — for example, a native tall-grass prairie in the Midwest. These prairie systems were productive year after year and needed no fertilizers, pesticides or herbicides. Pests and to sprout into action when warm temperatures, water and nutrients become available. Deep perennial grass-root systems and associated mycorrhizal fungi reduce fertilizer losses, conserve water, and boost the soil’s storage of carbon. Roots and mycorrhizal fungi pump carbon-rich plant sugars such as glomalin into the soil, feeding beneficial soil organism that conserve and access soil nutrients.

Perennial roots themselves become a root cellar of stored carbon. Deep root systems capture and utilize more rainwater than shallow root systems, thus reducing off-site movement of water and nutrients. In addition, perennial grasses do not have to be planted every year, thus reducing consumption of fuel by farm machinery. Perennial root systems and associated mycorrhizal fungi tie up soil resources, discouraging invasions of weeds. Pesticide, herbicide and fertilizer use is greatly diminished, which again lowers the amount of fossil fuels needed on the farm. Greater root depths, longer growing seasons for roots and mycorrhizal fungi let perennials sequester carbon at a rate 50 percent higher than an annually cropped field.

For all of these reasons, plant breeders both in the United States and internationally have initiated breeding programs to develop wheat, sunflower, sorghum and intermediate wheatgrass as perennial grain crops. While still in the early stages, plant geneticists such as Wes Jackson in Kansas are making progress. The Land Institute, a nonprofit founded by Jackson, has discovered that of the 13 most widely grown grain and oil seed crops, 10 are capable of hybridization with perennial relatives. The widespread production of high-yield perennial grain crops, if successful, could have a major positive impact on both the environment and the sequestration of carbon in the root cellar.

## CONCLUSIONS

Hidden underground in our planet's root cellar, nature has given us a template to help us resolve a variety of serious environmental issues, including global warming. Often overlooked and underappreciated, the living soil holds the key to the future. Vigorous long-lasting root systems and associated tiny fungal threads can accumulate and store vast amounts of carbon. Are we destined to relive the mistakes of previous civilizations or are we wise enough to learn from natural systems? It's time to examine our root cellar for solutions.

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