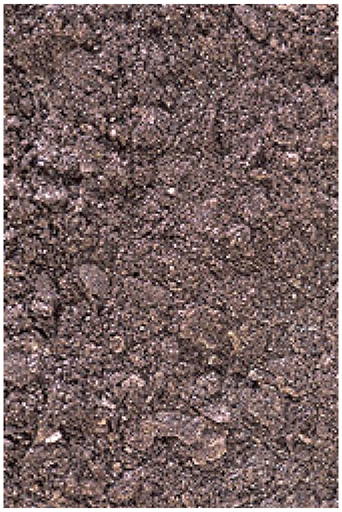
Glomalin: Hiding Place for a Third of the World's Stored Soil Carbon

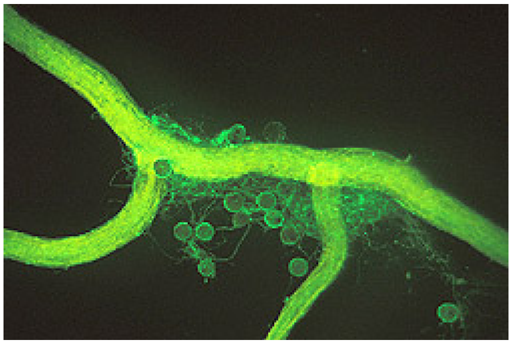
A sticky protein seems to be the unsung hero of soil carbon storage.



Glomalin, extracted from undisturbed Nebraska soil and then freeze-dried.
(K9969-2)

Until its discovery in 1996 by ARS soil scientist Sara F. Wright, this soil "super glue" was mistaken for an unidentifiable constituent of soil organic matter. Rather, it permeates organic matter, binding it to silt, sand, and clay particles. Not only does glomalin contain 30 to 40 percent carbon, but it also forms clumps of soil granules called aggregates. These add structure to soil and keep other stored soil carbon from escaping.

As a glycoprotein, glomalin stores carbon in both its protein and carbohydrate (glucose or sugar) subunits. Wright, who is with the Sustainable Agricultural Systems Laboratory in Beltsville, Maryland, thinks the glomalin molecule is a clump of small glycoproteins with iron and other ions attached. She found that glomalin contains from 1 to 9 percent tightly bound iron.



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.
(K9968-1)

Glomalin is causing a complete reexamination of what makes up soil organic matter. It is increasingly being included in studies of carbon storage and soil quality. In fact, the U.S. Department of Energy, as part of its interest in carbon storage as an offset to rising atmospheric carbon dioxide (CO_2) levels, partially funded a recent study by lab technician Kristine A. Nichols, a colleague of Wright's. Nichols reported on the study as part of her doctoral dissertation in soil science at the University of Maryland.

That study showed that glomalin accounts for 27 percent of the carbon in soil and is a major component of soil organic matter. Nichols, Wright, and E. Kudjo Dzantor, a soil scientist at the University of Maryland-College Park, found that glomalin weighs 2 to 24 times more than humic acid, a product of decaying plants that up to now was thought to be the main contributor to soil carbon. But humic acid contributes only about 8 percent of the carbon. Another team recently used carbon dating to estimate that glomalin lasts 7 to 42 years, depending on conditions.

For the study, the scientists compared different chemical extraction techniques using eight different soils from Colorado, Georgia, Maryland, and Nebraska. They found that current assays greatly underestimate the amount of glomalin present in soils. By comparing weights of extracted organic matter fractions (glomalin, humic acid, fulvic acid, and particulate organic matter), Nichols found four times more glomalin than humic acid. She also found that the extraction method she and Wright use underestimates glomalin in certain soils where it is more tightly bound than usual.

In her Beltsville laboratory, soil scientist Sara Wright examines a soil aggregate coated with glomalin, a soil protein she identified in 1996.
(K9972-1)

Soil scientist Sara Wright (foreground) and technician Kristine Nichols use nuclear magnetic resonance to examine the molecular structure of extracted soil organic matter constituents.
(K9971-1)

In a companion study, Nichols, Wright, and Dzantor teamed up with ARS chemist Walter F. Schmidt to examine organic matter extracted from the same soils under a nuclear magnetic resonance (NMR) imager. They found that glomalin's structure differs from that of humic acid—or any other organic matter component—and has unique structural units.

In a current study in Costa Rica, partly funded by the National Science Foundation, Wright is using glomalin levels and root growth to measure the amount of carbon stored in soils beneath tropical forests. She is finding lower levels of glomalin than expected and a much shorter lifespan. "We think it's because of the higher temperatures and moisture in tropical soils," she explains. These factors break down glomalin.

Forests, croplands, and grasslands around the world are thought to be 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.

How Does Glomalin Work?

It is glomalin that gives soil its tilth—a subtle texture that enables experienced farmers and gardeners to judge great soil by feeling the smooth granules as they flow through their fingers.

Arbuscular mycorrhizal fungi, found living on plant roots around the world, appear to be the only producers of glomalin. Wright named glomalin after Glomales, the taxonomic order that arbuscular mycorrhizal fungi belong to. The fungi use carbon from the plant to grow and make glomalin. In return, the fungi's hairlike filaments, called hyphae, extend the reach of plant roots. Hyphae function as pipes to funnel more water and nutrients—particularly phosphorus—to the plants.

"We've seen glomalin on the outside of the hyphae, and we believe this is how the hyphae seal themselves so they can carry water and nutrients. It may also be what gives them the rigidity they need to span the air spaces between soil particles," says Wright.

Technician Kristine Nichols checks the progress of corn plants growing in containers specially designed for glomalin production.
(K9973-1)

Dried samples of undisturbed soil (top row) and material left after extractable organic matter has been removed (bottom row). Although minerals are the most abundant components of soil, organic matter gives it life and health. Soil samples from left to right are from Maryland, Nebraska, Georgia, and Colorado.
(K9974-1)

As a plant grows, the fungi move down the root and form new hyphae to colonize the growing roots. When hyphae higher up on the roots stop transporting nutrients, their protective glomalin sloughs off into the soil. There it attaches to particles of minerals (sand, silt, and clay) and organic matter, forming clumps. This type of soil structure is stable enough to resist wind and water erosion, but porous enough to let air, water, and roots move through it. It also harbors more beneficial microbes, holds more water, and helps the soil surface resist crusting.

Scientists think hyphae have a lifespan of days to weeks. The much longer lifespan of glomalin suggests that the current technique of weighing hyphae samples to estimate fungal carbon storage grossly underestimates the amount of soil carbon stored. In fact, Wright and colleagues found that glomalin contributes much more nitrogen and carbon to the soil than do hyphae or other soil microbes.

Rising CO_2 Boosts Glomalin, Too

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.

They did a 3-year study on semiarid shrub land and a 6-year study on grasslands in San Diego County, California, using outdoor chambers with controlled CO_2 levels. When CO_2 reached 670 parts per million (ppm)—the level predicted by mid to late century—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, instead of from higher atmospheric CO_2.

"You're in the driver's seat when you use techniques proven to do the same thing as the higher CO_2 that might be causing global warming. You can still raise glomalin levels, improve soil structure, and increase carbon storage without the risks of the unknowns in global climate change," she says.

Putting Glomalin to Work

Wright found that glomalin is very manageable. She is studying glomalin levels under different farming and ranching practices. Levels were maintained or raised by no-till, cover crops, reduced phosphorus inputs, and the sparing use of crops that don't have arbuscular mycorrhizal fungi on their roots. Those include members of the Brassicaceae family, like cabbage and cauliflower, and the mustard family, like canola and crambe.

"When you grow those crops, it's like a fallow period, because glomalin production stops," says Wright. "You need to rotate them with crops that have glomalin-producing fungi."

In a 4-year study at the Henry A. Wallace Beltsville (Maryland) Agricultural Research Center, Wright found that glomalin levels rose each year after no-till was started. No-till refers to a modern conservation practice that uses equipment to plant seeds with no prior plowing. This practice was developed to protect soil from erosion by keeping fields covered with crop residue.

Glomalin went from 1.3 milligrams per gram of soil (mg/g) after the first year to 1.7 mg/g after the third. A nearby field that was plowed and planted each year had only 0.7 mg/g. In comparison, the soil under a 15-year-old buffer strip of grass had 2.7 mg/g.

Wright found glomalin levels up to 15 mg/g elsewhere in the Mid-Atlantic region. But she found the highest levels—more than 100 mg/g—in Hawaiian soils, with Japanese soils a close second. "We don't know why we found the highest levels in Hawaii's tropical soils. We usually find lower levels in other tropical areas, because it breaks down faster at higher temperature and moisture levels," Wright says. "We can only guess that the Hawaiian soils lack some organism that is breaking down glomalin in other tropical soils—or that high soil levels of iron are protecting glomalin."

It's Persistent and It's Everywhere!

The toughness of the molecule was one of the things that struck Wright most in her discovery of glomalin. She says it's the reason glomalin eluded scientific detection for so long.

"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 says. "No other soil glue found to date required anything as drastic as this."

"We've learned that the sodium hydroxide used to separate out humic acid in soil misses most of the glomalin. So, most of it was thrown away with the insoluble humus and minerals in soil," she says. "The little bit of glomalin left in the humic acid was thought to be nothing more than unknown foreign substances that contaminated the experiments."

Once Wright found a way to capture glomalin, her next big surprise was how much of it there was in some soils and how widespread it was. She tested samples of soils from around the world and found glomalin in all.

"Anything present in these amounts has to be considered in any studies of plant-soil interactions," Wright says. "There may be implications beyond the carbon storage and soil quality issues—such as whether the large amounts of iron in glomalin mean that it could be protecting plants from pathogens."

Her recent work with Nichols has shown that glomalin levels are even higher in some soils than previously estimated.

"Glomalin is unique among soil components for its strength and stability," Wright says. Other soil components that contain carbon and nitrogen, as glomalin does, don't last very long. Microbes quickly break them down into byproducts. And proteins from plants are degraded very quickly in soil.

"We need to learn a lot more about this molecule, though, if we are to manage glomalin wisely. Our next step is to identify the chemical makeup of each of its parts, including the protein core, the sugar carbohydrates, and the attached iron and other possible ions." Nichols is starting to work on just that.

"Once we know what sugars and proteins are there," says Nichols, we will use NMR and other techniques to create a three-dimensional image of the molecule. We can then find the most likely sites to look for iron or other attached ions.

"Researchers have studied organic matter for a long time and know its benefits to soil. But we're just starting to learn which components of organic matter are responsible for these benefits. That's the exciting part of glomalin research. We've found a major component that we think definitely has a strong role in the benefits attributed to organic matter—things like soil stability, nutrient accessibility, and nutrient cycling."

As carbon gets assigned a dollar value in a carbon commodity market, it may give literal meaning to the expression that good soil is black gold. And glomalin could be viewed as its golden seal.—By **Don Comis,** Agricultural Research Service Information Staff.

This research is part of Soil Resource Management, an ARS National Program (#202) described on the World Wide Web at http://www.nps.ars.usda.gov.

Sara F. Wright and Kristine A. Nichols are with the USDA-ARS Sustainable Agricultural Systems Laboratory, Bldg. 001, 10300 Baltimore Ave., Beltsville, MD 20705; phone (301) 504-8156 [Wright], (301) 504-6977 [Nichols], fax (301) 504-8370.

"Glomalin: Hiding Place for a Third of the World's Stored Soil Carbon" was published in the **September 2002** issue of *Agricultural Research* magazine.

Last Modified: 2/26/2014