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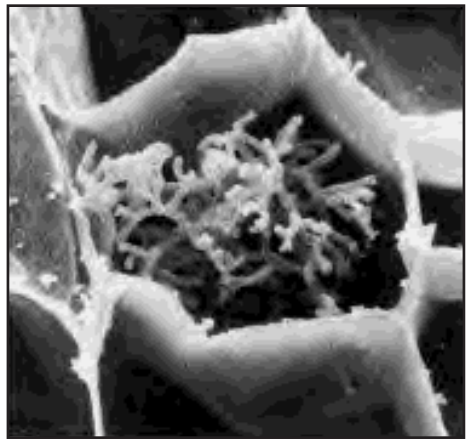
Glomalin: Hiding Place for a Third of the World's Stored Soil Carbon

By Don Comis
Information Staff, USDA-ARS
[Reprinted from Agricultural Research*, September 2002]*

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.

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 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.



This arbuscule in a root cell facilitates the exchange of energy from the plant to the fungus ... but whoever would have thought that this symbiotic fungus helped store a lot of soil carbon?

The 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. 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

See Mycorrhizae Produce, page 2

Vitazyme Boosts Almonds in California

By Paul W. Syltie, Ph.D.

The San Joaquin Valley of California is one of the world's prime almond producing areas, yielding nearly 1 billion pounds of the tasty nuts in 2002. Amongst the hundreds of almond producing farms in this fertile valley is the farm of Dan and Tom Rogers near Madera, about 30 miles northwest of Fresno.

After years of above-average almond yields, reflecting their good management practices, the Rogers' brothers, led by their father T.C. ("Chip") Rogers, decided to embark on a new direction; moving towards biological principles rather than continuing the traditional pathway of conventional almond production practices. This led them to adopt the use of a "Radiant Energy Force" (REF) unit to treat their irrigation water as it came out of the well or canal. The device purportedly adds electrons to the water, giving it a degree of negative charge, and also "imprints" the water with frequencies that counteract various pathogens —

Vitazyme treated almonds on the Rogers' Farm showed greater maturity in mid-July then the untreated controls. Note the larger size as well.

See Vitazyme Helped Income, page 3

Mycorrhizae Produce the Glomalin

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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 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 the 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 — especially 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 air spaces between soil particles," says Wright.

Here we see vesicular-arbuscular mycorrhizae hyphae reaching out into the soil around roots, channeling nutrients back to the plant. The fibers are coated with glomalin, a major storehouse of soil car-

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 warmer climates. 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

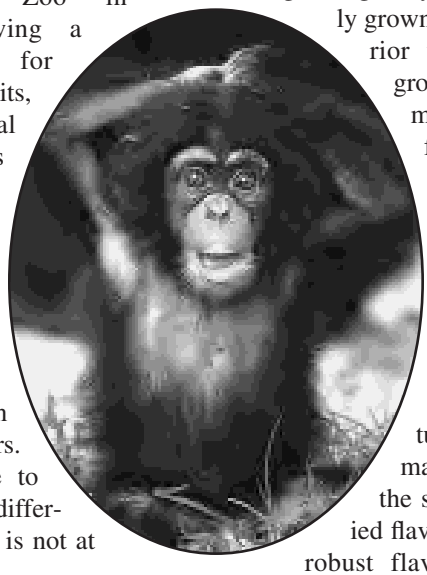
See Glomalin Is Remarkably, page 6

Monkeys Go Ape Over Organic Foods!

Organic Means Better Eating

By Paul W. Syltie, Ph.D.

A January 27 Agence France-Presse release stated that monkeys at the Copenhagen Zoo in Denmark are showing a marked preference for organically grown fruits, rejecting traditional pesticide-treated foods fed by zookeepers. According to Neils Melchiorsen, keeper of the zoo, "For one reason or another the tapirs and chimpanzees are choosing organically grown bananas over the others. Maybe they are able to instinctively tell the difference, and their choice is not at all random."



The chimps are able to tell the difference between organic and regular fruit, and when given a choice between them ... they systematically choose the organic bananas, which they eat with the skin on," said Melchiorsen. "But they peel the traditional bananas before eating them."

This tidbit of information adds to the growing body of data that organically grown foods are indeed superior to the conventionally grown, pesticide and commercial fertilizer treated fare. The differences may be subtle, related to intrinsic composition differences in minerals, vitamins, sugars, protein, or other components that are detected by the taste buds of well-tuned animals ... or they may be obvious, such as the sweetness and full bodied flavor of the produce. The robust flavor of an organically grown apple is hard to deny, nor is the exquisite sweetness and aroma of organically grown sweetcorn. The majority of feeding studies comparing organic to conventional foods shows a benefit in favor of the organic types. Pesticide residues are drastically reduced in these foods as well, and with their reduction a lesser risk of diseases associated with such chemicals.

More will be related in coming issues of *The Vital Earth News* on this important issue of organic versus conventional food quality . . . so stay tuned. The facts in this debate will likely lead to some massive turnovers in consumer decision-making in the near future as it is discovered that food quality — and thus our personal health — is directly related to how our food is grown. □

The Four Surefire Rules for Success

Number 1. Show up.
Number 2. Pay attention.
Number 3. Ask questions.
Number 4. Don't quit.

Bob Gilbert, *Bits and Pieces*

Vitazyme Helped Income Rise $700/acre!

Continued from page 1

such as Fusarium species — that infect the root systems of the trees. Both effects enhance tree health and growth, and have benefitted nut yields.

Besides using this device, the Rogers since about 1999 have begun utilizing Vitazyme on a regular basis, along with two local products from Bio Inc. These products are Ceres, applied at 2 gallons per acre in the fall and 1 gallon per acre in the spring, and Liquicomp, applied at 1 gallon per acre in the fall and 2 gallons per acre in the spring. Vitazyme is applied at 13 oz per acre twice, in early May and again in mid-June.

The fertility program that the Rogers use is adjusted annually to match the needs of the trees, but in general involves the application of 75 units of nitrogen in November after harvest, and another 75 units of nitrogen in the spring. Other fertilizers used are mixed formulations such as 4-8-8 (% N-P_2O_5-K_2O), and UN32, CAN17, and 0-0-25 (ammonium thiosulfate). As Tom stated, "The longer we have been using your product [Vitazyme] and the Bio Inc. products the more we realize we need to learn about soil health and how it affects fertilizers."

Watering is scheduled as needed according to an irrometer, which measures the soil moisture content. Typically irrigation is done every 6 to 10 days with sprinklers beneath the leaf canopy. To insure good pollination — so critical for nut set — two to three bee hives per acre are placed in the orchard, and additional pollen is sprayed at blossom time to insure a good set. An REF unit has also been placed on the sprayer to assist in good leaf contact, and has resulted in reduced pesticide use.

Dan, Tom, and Chip are very pleased with the results of their conversion to more biologically sound practices with

See Natural Methods Improve, page 7

Heavy yields of almonds have resulted from Vitazyme use on the Rogers Farm, since 1999 when use began.

Note the large size of these freshly shelled Vitazyme treated almonds. Nut quality has improved since 1999.

15-Minute Soils Course

Lesson 17:

The Incredible Array of Soil Organisms

In Lesson 2 we looked briefly at the array of microorganisms that populate the rhizosphere [root zone] of plants. In this lesson we will look more deeply into the wide array of organisms that populate a soil.

Daniel Dindal's *Soil Biology Guide* (Wiley, 1990) contains nearly 1,300 pages of soil organisms, so it is obvious that only a tiny fraction of all of these organisms can be included here. Most major groups are included in this lesson.

Soil Bacteria. It has been said that almost any known bacterium and a good many more can be found in the soil. However, only a relatively few types attain high population levels, of 10,000 to 100,000 or more per gram of soil. They vary greatly in shape, size, degree and type of mobility, and food source required, and can adapt to nearly any environment.

Actinomycetes. A diverse but major group of bacteria that are filamentous and often branched, having short and rudimentary hyphae and extensive, branched, narrow mycelia. They are usually aerobic, saprophytic mesophiles, consume organic matter, and thrive under moderate temperatures. These organisms produce antibiotics, like streptomycin, and also produce the "earthy" odor of soil (the chemical geosmin).

Soil Fungi. All are heterotrophic; i.e., they feed on outside carbon sources, so are saprophytic, parasitic, or symbiotic. These organisms include the highly beneficial and mutualistic mycorrhizal fungi, of which there are several varieties: vesicular-arbiscular, endo-, orchid, and other types that utilize plant energy and grow hyphae from the roots into the soil, and then return nutrients to the roots (see Lesson 2).

Soil Algae. Simple or multicellular photosynthetic organisms that live mostly near the soil surface, so as to intercept sunlight energy. They vary tremendously in shape, size, and appearance. One type is blue-green algae, (cyanophyta) which more resemble bacteria that contain chlorophyll. Cyanophyta also fix nitrogen, so are highly important in agriculture.

Soil Protozoa. Single-celled organisms that are more complex and larger than most bacteria, fungi, and algae cells, and live mostly in surface soil layers. Some are amoeba-like, and others have flagella or cilia, so can move rapidly.

Slime Molds. Amoeboid-like cells that eat bacteria and bits of organic matter, especially in moist leaf litter and rotting wood.

Viruses. Tiny parasites of living cells that are present for all types of soil organisms.

Turbellaria. Flatworms (flukes), tapeworms, planaria, and others adapted to wet soil situations.

Nematodes. Aquatic roundworms, but they can live on the films of water in soils or inside the tissues of roots. Most species are nonparasitic and harmless, but some are very damaging. Over 12% of the production of major food crops is destroyed by nematodes.

Gastropods. Snails and slugs are found in many soil situations, especially under wet and shady conditions. Some will eat vegetation.

Enchytraeidae. Pale-colored worms that are especially common in cold, highly organic soils.

Lumbricidae. Earthworms comprise this group, of which there are many types. They are highly useful in developing soil structure, and facilitating air and water movement. In some situations they comprise 80% of total soil biomass, or up to 2,000 lb/acre.

Tardigrades. Tiny eight-legged, shielded creatures that feed on microbes, and can endure extended periods of drought.

Araneida. True spiders that live in the spaces within leaf litter, and are mostly predators.

Mesostigmata. Tiny tick-like creatures that live in litter and soil and prey on small organisms.

Other Groups. Insects (at least 15 major groups live in soils, from the egg to adult stages), **Pseudoscorpionida** (scorpion-like creatures), **Prostigmata, Astigmata, Orbatida,**

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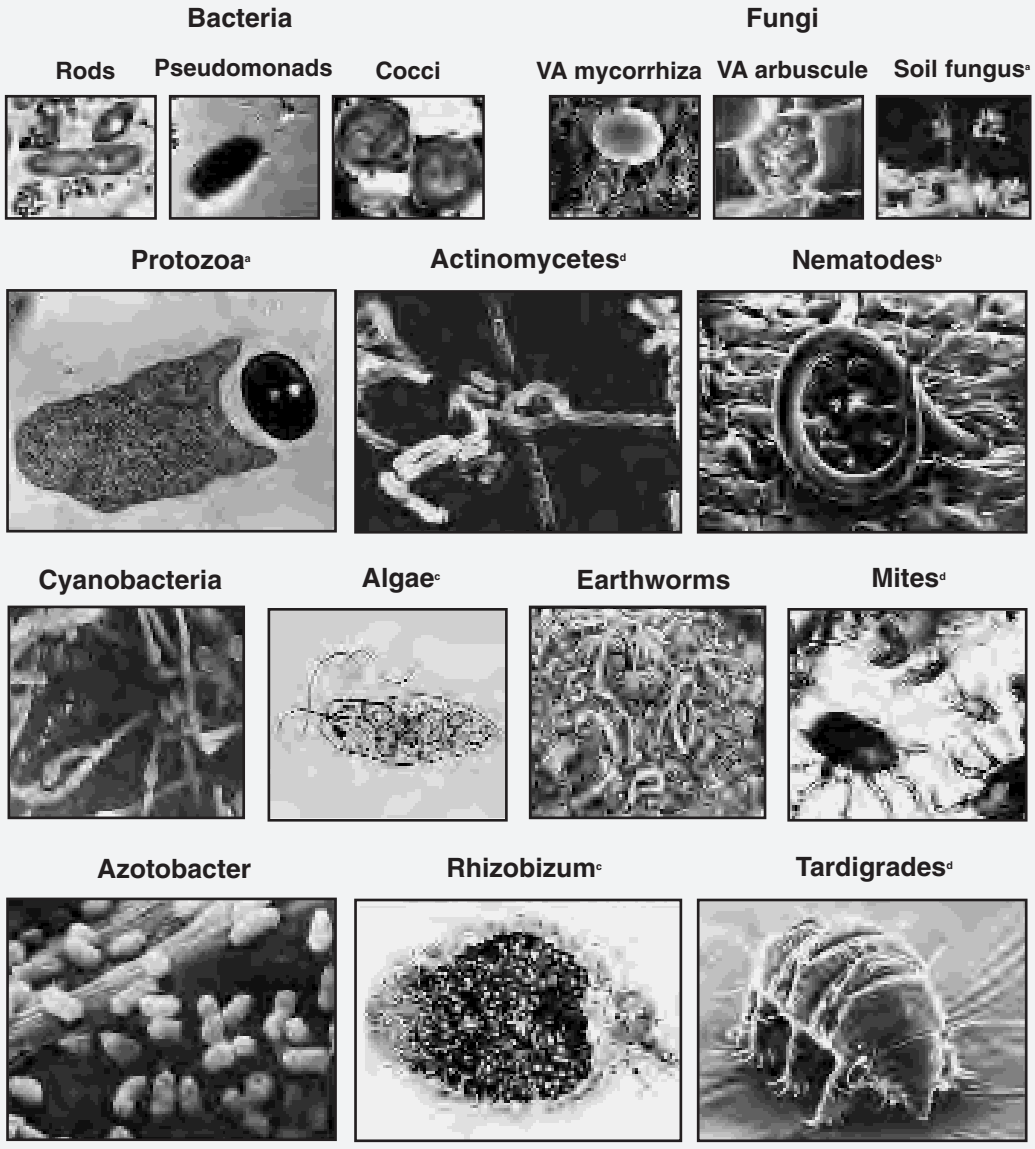
15-Minute Soils Course

Typical Rhizosphere Organisms



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Isopoda, Chilopoda, Diplopoda, Pauropoda, Symphyla, Mammals (gophers, badgers, voles, moles), and **Crustaceans** (crayfish).

The primary functions of these various organisms are complex and interrelated. Thankfully, most are beneficial. Many of them break down fresh organic remains to small bits, and eventually to plant-utilizable mineral and nitrogen forms. Protozoa and some nematodes feed on bacteria and fungi, and their excretions provide plant food. Predation among the various species is vigorous, and serves to limit an overgrowth of any one type. This activity is especially vigorous in the rhizosphere, where energy-rich compounds are secreted by the roots.

See How Much You Learned

1. The following groups of organisms are important:
a. Bacteria b. Fungi
c. Algae d. All of these

2. Soil protozoa are known to feed on soil bacteria. T or F

3. How many pounds of earthworms can live in a good soil? up to _____.

4. Which of these organisms is especially able to survive long periods of drought?
a. Earthworms
b. Tardigrades
c. Gastropods
d. Araneida

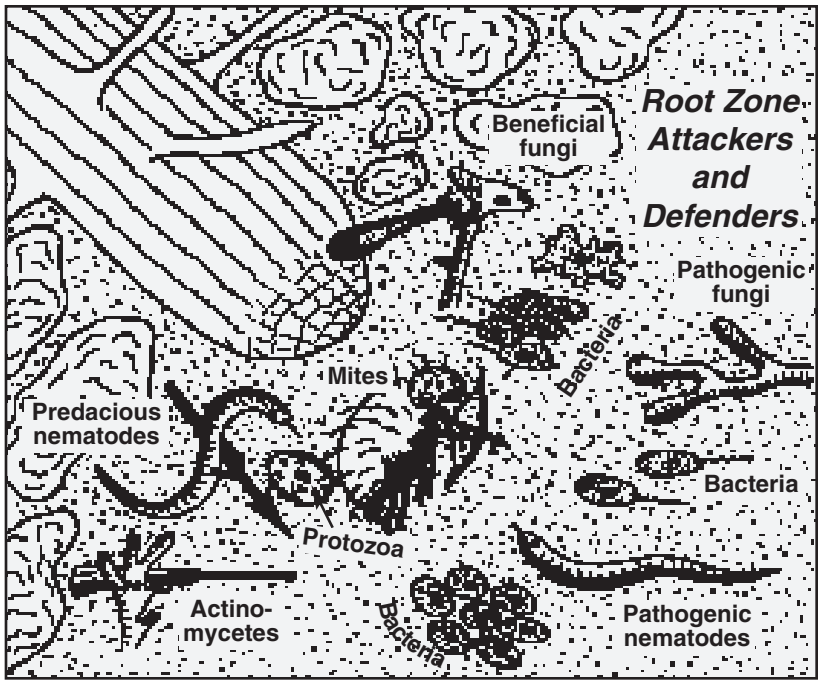
5. What organisms give soil its earthy smell? _____.

6. Cyanobacteria are also able to fix atmospheric nitrogen. T or F

7. Phototrophic, rods, cocci, anaerobes, and gram positive all characterize various types of _____.

Answers: 1. d; 2. T; 3. 2,000 lb; 4. b; 5. actinomycetes; 6. T; 7. bacteria.

The War of Soil Beneficials & Pathogens



By Paul W. Syltie, Ph.D.

This rather humorous but remarkably truthful figure has been taken from *How Soils Work, A Study Into God-Plane Mutualism of Soils and Crops* by this writer. The battles amongst beneficial and pathogenic organisms in the soil beneath our feet is not unlike the conflicts we can more easily notice in the above-ground portions of plants: aphids versus ladybugs, or wasps versus cabbage loopers.

The key to making natural plant diseases and pest control work — as within affairs of animals and men as well — is to encourage *mutualism*. This term implies encouraging organisms or behaviors that complement and support one another, such as a honey bee pollinating a flower or mycorrhizal fungi growing from a plant root. Each benefits the other, and in many cases neither could survive without its counterpart.

To learn much more about the battle beneath your feet, and the ways soils and plants interact, order a copy of *How Soils Work* from Xulon Press at (866) 909-2665 (188 pages, $13.95). □

Glomalin Is Remarkedly Persistent!

Continued from page 2

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 0.07 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.

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 attached iron and other possible ions." Nichols is starting to work on just that.

"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. □

Natural Methods Improve Almonds

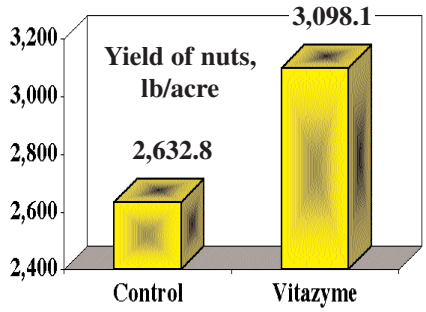
Continued from page 3

their almonds. They have noticed an improvement in soil health, as evidenced by better tilth (faster water infiltration and percolation) and greater earthworm activity in late winter and early spring.

Year	Production lb/acre
1992	2,231
1993	2,608
1994	2,717
1995	2,413
1996	1,366
1997	3,071
1998	1,625
1999	3,650
2000	2,593
2001	3,027
2002	3,025

Production for the two main almond varieties — Nonpareil and Carmel — has been tracked over many years, and shows an exciting trend since the biological innovations have been initiated in about 1999. Production since 1992 is shown in the table on the left. If the bad years of 1996 and 1998 are deleted (the springs had poor weather and pollination was restricted), then the pre-1999 production averaged 2,608 lb per acre, and production in 1999 and after averaged 3,074 lb per acre, an increase of 466 lb per acre. If the price of almonds is $1.50 per pound, then this increase under biological methods amounts to about $700 per acre! For 45 acres of mature almonds this would yield $31,500 more total income.

Yield Results in a 1997 Trial



A test with Vitazyme on the Nonpareil and Carmel almonds in 1997 on the Rogers farm produced excellent increases in production. Note the graph to the left. Vitazyme has proven to be an excellent enhancer of crop production of all sorts, nut crops responding very well to this powerful biostimulant that improves soil fertility, plant health, yields, and net income. ☐

Farm Kid's Exposure to Dirt Makes Them Healthier

According to the *New England Journal of Medicine*, a study at the Institute of Social and Preventive Medicine in Basel, Switzerland, showed that farm kids are healthier than city kids. That finding flies in the face of efforts of urban dwellers to protect their children from germs and filth found in rural environments. However, a common bacterial toxin found in less-than-pristeen settings such as around farmyards, animal pens, and even on dirty floors may help protect children from developing allergies and asthma.

Apparently the endotoxins produced by bacteria — which toxins are very common around farm animals — may stimulate the developing immune system to tolerate many environmental irritants that trigger allergies. Thus, farm kids who have been exposed to pets, farm animals, and dirt in their early childhood have improved immune systems and are at lower risk to develop allergies and asthma. Perhaps cleanness and sterility of the developing child's environment can be carried too far, as this study implies. ☐

"Cultivators of the earth are the most valuable citizens. They are the most vigorous, the most independent, the most virtuous, and they are tied to their country, and wedded to its liberty and interests by the most lasting bonds."

Thomas Jefferson

Statement of Purpose

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