By Dean Houghton

UNDERGROUND LIVESTOCK

There's a strange world lurking below the soil surface

Leonardo da Vinci lamented back in the 1500s that man fails to appreciate the intricate life of the soil. "We know more about the movement of celestial bodies than about the soil underfoot," he wrote.

Fast-forward 500 years, and not much has changed. "I think it is still fair to say that we know more about outer space than we do about the organisms living in the soil," says Ray Weil, University of Maryland professor of environmental science and technology. "Soil microbes are notoriously hard to culture," he points out. "Scientists have grown less than one percent of these species in a Petri dish."

New frontier. Thanks to advances in technology, modern scientists are now addressing da Vinci's concerns. "Researchers can now use molecular tools to track these microbes, such as extracting their DNA from soils," Weil points out. "The number of scientific papers on the ecology of soils has been going up exponentially. It's a new frontier."

And what a vast frontier it is. Every farm harbors these "underground livestock" by the billions. Even the most dedicated Corn Belt crop farm supports thousands of species of underground livestock—and the total weight of these underground animals could reach a couple of tons per acre, easily matching the weight of above-ground domestic livestock in an intensely managed grazing system.

ALL SCANNING ELECTRON MICROSCOPE IMAGES: BYRON LEE, AAFC, LETHBRIDGE RESEARCH CENTRE

►**Right:** Spikes and spines on this soil mite give a hint about life below the soil's surface—it's a jungle down there.

►**Top:** Francis Yeatman uses cover crops to boost soil biology. ►**Above:** Creatures in the springtail family facilitate the breakdown of soil organic matter.

The world of underground livestock isn't for the faint of heart. Sprinkled throughout this story are scanning electron microscope images of various members of the soil mite family, animals that are approximately the size of the period at the end of this sentence. The images reveal bodies covered with armor and spikes, a hint that, in fact, it's a jungle down there.

The world below. Weil revised the most widely used soils textbook, *The Nature and Properties of Soils*, which he coauthors with Nyle Brady, a Cornell University professor emeritus. A passage in that textbook describes the world of underground livestock in terms that sound more like a science-fiction novel.

"If our bodies were small enough to enter the tiny passages in the soil, we would discover a world populated by a wild array of creatures all fiercely competing for every leaf, root, fecal pellet, and dead body that reaches the soil," according to the passage. "We would also find predators of all kinds lurking in the dark, some with fearsome jaws to snatch unwary victims, others whose jellylike bodies simply engulf and digest their prey."

Biological farming. The world under the soil surface may be unfamiliar, but some farmers are beginning to harness the power of these underground livestock. "Agriculture is facing economic and environmental challenges," says Francis Yeatman, who provides consulting services to a wide range of farmers in South Africa, extending from dairy farms to vineyards. "We are entering a new era where we have to farm smart, and the changes we're making are based mainly on soil biology."

He summarizes his approach as reducing tillage; increasing soil cover and organic matter; balancing soil nutrients; and using environmentally friendly sprays and fertilizers.

Soils that are healthy have a good balance of physical, chemical, and biological characteristics, Yeatman points out. Physical soil structure is critical in vineyards, so he carefully selects permanent and seasonal cover crops in order to help build the soil.

"Use of these crops has increased water infiltration, reduced soil erosion, and moderated soil temperatures," he says. "We do regular soil and tissue samples so we can provide the exact nutrients needed, and our changes in the kind of fertilizers and sprays that we use have increased the amount of earthworms and soil microflora and microfauna. Together with altered tillage and use of cover crops, the system has provided remarkable improvements in soil structure and associated root growth."

Yeatman has typically complemented his nutrient feedings with added bacteria to stimulate uptake and help regulate disease vectors. He's altering that approach. "We're now working with the soil ecology, making sure we provide a food source, and we're finding that we can affect the number of bacteria and fungi. All they are waiting for is the right food source, and the number of bacteria and benefi-

►**Right top:** Like fungi, the *Actinomycetes* bacteria family grows hyphae. These bacteria produce the "earthy" smell of freshly turned soil. ►**Far right:** Carefully chosen blends of cover crops can boost microorganisms as well as provide improvements in physical characteristics of the soil.

PHOTO: DAVID SCHARF

THE NUMBERS GAME

		Agricultural soils	Prairie soils	Forest soils
Per teaspoon of soil (one gram dry)	BACTERIA	100 million to 1 billion	100 million to 1 billion	100 million to 1 billion
	FUNGI	Several yards (Dominated by vesicular-arbuscular mycorrhizal fungi)	Ten to hundreds of yards (Dominated by vesicular-arbuscular mycorrhizal fungi)	Several hundred yards in deciduous forests, one to forty miles in coniferous forests (dominated by ectomycorrhizal fungi)
	PROTOZOA	Several thousand flagellates and amoebae, one hundred to several hundred ciliates	Several thousand flagellates and amoebae, one hundred to several hundred ciliates	Several hundred thousand amoebae, fewer flagellates
Per square foot	NEMATODES	Ten to twenty bacterial feeders, a few fungal-feeders, few predatory nematodes.	Tens to several hundred	Several hundred bacterial and fungal-feeders, many predatory nematodes
	ARTHROPODS	Up to one hundred	Five hundred to two thousand	Ten to twenty-five thousand, many more species than in agricultural soils
	EARTHWORMS	Five to thirty, more in soils with high organic matter	Ten to fifty, arid or semi-arid areas may have none	Ten to fifty in deciduous woodlands, very few in coniferous forests

TABLE: NRCS SOIL BIOLOGY PRIMER

►**Above:** Underground livestock affect soil fertility and productivity, as biological processes are responsible for about 75% of the available nitrogen and 65% of the available phosphorus in the soil. ►**Left:** Soil mites such as this *Ametrop* species process crop residue into soil organic matter.

cial fungi such as mycorrhizae just take off."

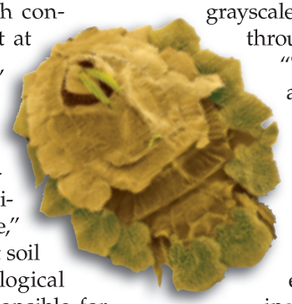
Microorganisms are so abundant in the world below that scientists have a hard time finding words to describe the extensive diversity. Grab a handful of healthy soil, for example, and you are holding more biodiversity—just in the bacterial community—than exists in all the animals of the Amazon basin.

Fresh soil. Those bacteria provide a wide range of soil services. Actinomycetes is a bacteria that, like fungi, grows filament-like hyphae. This species is responsible for the "earthy" smell of freshly turned, healthy soil, and it degrades stubborn components of soil organic matter, such as cellulose.

Soil biology is a complex subject. Living in the soil are plant roots, viruses, bacteria, fun-

gi, protozoa, algae, mites, nematodes, worms, ants, maggots, insects and grubs, and larger animals. The USDA's Natural Resources Conservation Service offers an excellent Soil Biology Primer, available by navigating to the soil biology tab from *soils.usda.gov/sqi*.

Jill Clapperton, a soil-health consultant and principal scientist at Rhizoterra based in Florence, Mont., points out that the soil flora and fauna are connected in the soil food web. "These activities stabilize soil aggregates, building a better soil habitat and improving soil structure," she says. "Soil organisms affect soil fertility and productivity. Biological processes in the soil are responsible for about 75% of the available nitrogen and 65% of the available phosphorus in the soil. In fact, soil fertility is largely dependent on the processing of various organic residues or soil organic matter through the soil food web."



In her previous work with Agriculture and Agri-Food Canada at the Lethbridge Research Centre, Clapperton took an extremely close look at some of those important recyclers of organic matter—soil mites. (The scanning electron microscope images were made in grayscale, with the colors arbitrarily added through photo editing software.)

"These soil mites are classified as detritivores," she points out. "They are omnivores, they eat fungi, bacteria, organic matter, and each other. They recycle things in the top 2 inches of soil."

These animals break organic matter into smaller pieces, their excrement is important for building soil structure, and they burrow to create microsites within the soil. "This is how the cycle works," Clapperton adds. "One animal moves in, modifies the habitat, stimulates microbial activity and recycling, and boosts nutrient transfer to the roots. Of course, we also need predators to feed on bacteria and fungi to keep them in balance. This active predator/prey relationship is part of the important web connection in the soil."

►**Above:** Soil mites act as important recyclers of organic matter. ►**Left inset:** Protected from attack by intricate armor plating, this soil mite bores through soil, modifying habitat.

►**Above:** Strange animals from the world below the soil surface, these closeup views of the elongated *Himinothrus* (top) and the rounded *Galumnas* demonstrate the diverse range of body types found within the soil mite family.

Boosting life in the soil has long been a goal for veteran no-tiller David Brandt, Carroll, Ohio. He keeps a close eye on earthworms, perhaps the most important member of the soil macrofauna, as they loosen soils with their burrowing while improving fertility.

Diverse mix. Brandt says he has recently noticed a boost for soil microorganisms when he has used cover-crop blends. "When we use a three-way mix of cover-crop species, we think there is about three times as much activity from the microorganisms," he says. "You can see it in the soil structure, the crop looks healthier, and we are getting more water infiltration. That's worth something—we think it is part of the payback for investing in covers."

He is starting to use biological soil testing to get a handle on the impact of his cover crops on the soil life. Brandt also is nutrient testing the grain he produces. "We want to see if we can impact the amount of nutrients being put into the kernel," he says. "We want to prove that we're producing a premium product."

Biology of the soil may have been largely ignored throughout history, but South African soil-health consultant Yeatman believes that it offers many practical payoffs that will bring it to the forefront for the future. "We are finding ways to mineralize the vast amounts of phosphorus that are locked up in soils," he says. "We are finding ways to feed populations of microorganisms that will help suppress pathogens. When you see farmers around the world cutting costs by boosting their soil biology, it gets very exciting." ■

More images at JohnDeere.com/Furrow

►**Above:** David Brandt says diverse cover-crop mixes help boost microorganism activity in his soils.