1487

Denizens of the Soil: Small, but Critical

by Andy Moldenke, Research Entomologist, Oregon State University, Corvallis, Oregon

Very few people really understand how soils work. I'd like to give three illustrative examples of how soil arthropods, soil microbes and roots work together as a combined system in the real world. The first example is of onion production. Basically, the plant is incapable of taking up any phosphorus at all from the soil unless it has mycorrhizae on the roots. With mycorrhizae, the roots pick up lots of phosphorous. The growth of the onion plant depends upon the number of arthropods called springtails living in the soil. Springtails function by eating the tips of the mycorrhizae which stimulates the mycorrhizae to grow, dissolve more of the soil around it, and feed it to the plant. As you increase the number of springtails in the soil, the plant grows faster until there are so many springtails that they eat all the mycorrhizae. Then growth drops to zero again.

Andy Moldenke

Penknife oribatid mite

The second example is from oak forests in Europe. When oak trees live on sandy soil they grow very slowly. They don't make many leaves so there's not much litter at the end of the year. But the litter that does come down year after year piles up very thick. Most of the nutrients are in the litter layer, unused, not part of the biological growth of that ecosystem. On the other hand, oak trees that grow on clay soil grow very fast and have lots of leaves. But when the leaves hit the ground they decompose very rapidly and make a very thin litter layer. In fact, all of those nutrients in that ecosystem are bound up into the tree growth itself.

An oak tree puts lots of chemicals in its leaves called phenols that prevent caterpillars from destroying the trees. When the leaves die and enter the litter on the ground, all those chemicals are still in the leaf. When a millipede or an earthworm comes along and starts to eat that leaf, the pH changes and the phenols polymerize and form a great big plastic rubbery mass killing the millipede. However, on clay soil, a little springtail lives in the soil. At night, before it comes up to feed on the litter, it fills its belly with inorganic clay particles. Then it comes up to eat fungi and leaves and litter. The inorganic clay particles in the gut prevent the polymerization from taking place and the springtail lives and grows happily. As a result, the nutrients in that ecosystem cycle; they don't pile up on the ground. The moral of the story is that the productivity of that entire forest ecosystem is basically the result of one little arthropod in that soil.

The last example is another one from oak forests in England. Joe Anderson went out in oak forests in England and brought all the different soils back to the lab. He sterilized those soils killing the bacteria, fungi, arthropods, worms, etc. Then he added back to the soil all of the bacteria and fungi that normally lived in that soil. The only thing missing were all the little arthropods. Those fungi and bacteria release a certain amount of nitrogen, (x). Now, in another pot he put the same litter with the fungi and bacteria that normally are there and put in an oak seedling. What did he find? He found exactly the same amount of nutrients (x) because the oak tree seedling didn't do anything. Then, he took another pot and added a millipede. What happened? The amount of nutrient recycling went up ninefold. Then he ran the experiment a fourth time, with both a millipede and an oak seedling. There was no extra nutrient building (x), but the growth of the seedling oak tree was four times what it was when there weren't any arthropods present. The activity of those arthropods affected the rates of decomposition, and all of that extra nitrogen went directly into the growth of the plant.

Anderson has taken many many soil types and many different kinds of vertebrates in that experiment. What he's found is that the rate of nutrient turnover is dependent upon the soil type, but within any given kind of soil type, it's really independent of how many bacteria and fungi you have in that system. It's actually independent of the <u>kind</u> of arthropod or invertebrate you put in there. It's only dependent on how many of them are there. They can be tiny little oribatid mites or great big oribatid mites, it doesn't make any difference.

Soil invertebrates are system catalysts. They don't do much of anything chemically in the processing that takes place in the soil, but they regulate the rate of decomposition and the rate of nutrient recycling. They do that by crushing up the resources and the living microbes that are in the soil, by mixing the organic and the inorganic components of the soil, and by driving the complex processes of microbial succession. They feed on the current microbial crop, and by their own feces they provide for a new and different type of microbial succession to take place.

Now what's the punch line of the story here? The punch line is that dirt isn't dirty, soil isn't soiled, litter isn't garbage. There's something missing in the way we use those words; it's the living component that's missing. The upper layers of soil, which are the only ones that are important in growing plants and trees and everything else, are alive. Litter and topsoil are, in fact, biologically the most diverse part of any terrestrial ecosystem. They are also the most chemically diverse part of any ecosystem. In our forest soils in the Blue Mountains there are literally hundreds of

Continued on page 4

Denizens cont.

Continued from page 3

species of arthropods in every square meter of soil. There are literally hundreds of thousands of individual arthropods per square meter of soil. These are all things you can see walking around in your hand; they've got eyes they've got legs, they get hungry, they get tired, they lust after their mates, they do little mating dances, they have behavior. These are not bacteria, they are not amoebae, these are rather highly complicated organisms.

You can find a variety of these critters any time you go out and take a shovelful of dirt. The most common things in the soil are oribatid mites, and the variation among mites is amazing. The biggest one is the size of a period on a printed page; the smallest one is 1/250th of an inch in length. There is a long-legged oribatid mite. There is a flat-backed, aircraft-carrier oribatid mite. There are oribatid mites that have great big ostrich plume feathers all over their bodies.

There are about 250,000 oribatid mites in every square meter of soil. One is called a pen-knife oribatid mite. When it's attacked, it folds up like a turtle. One is what I call a stegasaurus oribatid mite. The mite itself is very small and has big, moveable flat plates covering the body. Some of them have basically bombay doors: flexible wings that they can retract their legs into. One even has a special trap door that comes up and protects the entire bottom of the face, all the little appendages for eating. There is another oribatid mite that has a cannon on the side of the body. It shoots a sticky goo when attacked. There is one that hides by covering the whole top of the body with mud that it cements on top.

Oribatid mites are fungal feeders. They eat fungal hypha with great lobster-like claws. A fungal hypha is like a piece of spaghetti with a skeleton on the outside. So the mite has to crush it and crack it open with shears and then jab them into its mouth like you would spaghetti. Another species feeds by inserting the whole feeding aparatus into the breathing pores on the pine needles. When they feel a fungal hypha, they grab it. As they pull one chelicera, the other one goes in and it all works hydrostatically. There are also some oribatids that suck bacteria through straws. Huge muscles that work the suction cup inside the mouth attach to the back of its head.

The other major group of soil dwellers are springtails. There are about 100,000 per square meter out in the forest. They're called springtails because they have this tail at the end of the body that normally is held underneath under very high blood pressure. When attacked, they have a little clamp which releases and catapults the springtail way up into the air. A springtail that may be 1/12th of an inch long can jump maybe a yard away. A very effective device. Another springtail is all covered with scales like the wings of a butterfly.

Now springtails and oribatid mites are just two things in the soil. Any meter of soil has lots and lots of things that live in it. Bright, red bdellid mites are not only in the soil. They are used in biological control in many parts of the world. In Oregon we use them heavily in the pear industry down in Ashland and Medford. There are pseudoscorpions, skunk spiders, centipedes, and snail-feeding beetle.

The point that I want to make is that all the upper layers of the soil are biogenic. The microstructure of the soil is fashioned by arthropods and worms, and therefore the major chemical and physical properties are directly under biocontrol. Every chemical and physical property of soils is basically driven by the surface:volume ratio of the particles that make it up. The upper layers of soil are composed of the living bodies of countless invertebrates, fungi, and bacteria, and the skeletons of all the dead ones as well.

Oregon State University is actually the first place in the U.S. where researchers have actually made slides of soil and looked at them. We found that even deep down in the soil all of it is made up of invertebrate feces. Most things eat the manure or feces of the other things. The total nutrient content of the soil is actually of secondary importance. Also of secondary importance is whether the nutrients are immobilized in the organic debris or whether they're immobilized in the inorganic phase down in the mineral soil. The critical parameter is how dynamic soil-converting processes are. In other words, how many dung beetles do you have in the system, and how many species do you have in that system? Now, when I occasionally teach a lecture to forest groups in ecology at OSU, the first thing I do when I come in to the board is I write "BPGT." I write those on the board at the beginning of a lecture and I tell everyone at the beginning that they are supposed to be able to tell me what that means. I'll tell you what it is and make a long story short: "Bug Poop Grows Trees."

I want to finish up by giving you three facts for your consideration, because you've probably never thought like a root before. I want you to think like a root. The first fact is that plant roots are only passive sponges. They can do nothing themselves. They can do no decomposition;

Continued on page 5

Andy Moldenke

Stilt-legged mite with shed larval skins on back

Denizens, cont.
Continued from page 4

they can effect no process of nutrient solubility; they can make no chemical change in the soil. The second point is that soil chemical transformations—the decomposition, the mineralization, and the recycling—are actually caused by the extracellular digestion of the secreted enzymes of bacteria and fungi in the soil. There are some abiotic changes that take place in the soil, freezing and thawing and drying, but those generally take place at times when they're not terribly useful to the plants. The third point is that absorption of nutrients is directly dependent upon the cell's surface area. In all soils, anywhere you are in the world, the surface area of soil microbes is millions, billions, zillions times that of plant roots. Plant roots are at a competitive handicap to get those nutrients.

So in the real world, how does it work? How do plants grow? On the one hand in the real world, you have a plant that's got a lot of energy from photosynthesis but it needs nutrients to grow. On the other hand you have a soil microbe that's got lots of nutrients but it needs energy to grow.

Now there're two solutions to the problem. The first solution is soil critters—anything from protozoa to the two-foot long Oregon earthworm. Nutrients are either pooled in dead plant cells in the soil or in the tissue of the living microbes themselves. Each time one of those invertebrates feeds, it alters the physical state of those nutrients usually by crunching it up with its jaw. It exposes those nutrients to new kinds of microbes in its own gut. It extracts its own little percentage as tax. The invertebrate grows and then it defecates, and for a few seconds or at most a few minutes there are soluble nutrients available to the community at large. As soon as they're grabbed up they are immobilized again. Now remember everybody in the soil is eating everybody else's pre-packaged resources. This process is going on all the time. Sooner or later some of those nutrients are going to be released close enough to a root that the root can grab it.

The second solution to that problem is an incomplete solution: a mycorrhizae. A mycorrhizae is a symbiosis between a fungus and a plant root. The fungus makes an attachment to the plant root and grows out into the soil. As it grows out into the soil, the plant pumps fuel into the mychorrhiza (sugars fixed in photosynthesis), the mycorrhiza dissolves its surroundings, and what it doesn't want it sends to the plant root.

There are several living species that live in the soil, each one responding to its own set of environmental variables, its own unique web. We can use that information as indicator species. If you bring me back a vial full of soil from an area I've studied, I can tell you the time of year you took that sample. I can tell you the stage of forest succession. I can tell you the altitude you took it from. I can tell you the overstory canopy. I can probably tell you something about the understory canopy. I can tell you whether it was from a north-facing slope, east-facing slope, etc. If you took it from Sisters and the Ponderosa Pine forest there, I could tell you how far it was from the nearest tree trunk, whether that tree trunk was alive or dead, or whether it was a juniper or a Ponderosa Pine. I can tell you that because of the species composition of that soil community.

So the structure of the actual community can give useful information if you take the time to decipher. For instance, if you ask what happens if we fumigate stumps to control the root rot? What does it do to the whole ecosystem? How far does it go out away from that stump and does it last for weeks, months, years, or for decades? What about broadcast burning? Do the effects last for two or three years, five or ten years, twenty years, fifty years, one hundred years? You can answer those questions with this kind of information.

The second useful thing I think we can do is to look at the notion of a keystone species. Of all the hundreds of species out there, are there some that play a crucial role in an important ecological pathway? One species that can't be substituted for by any other?

Nitrogen-fixing bacteria, do something unique, something that can't be substituted for. Another example of that is the cyanide-producing millipede that is so common in western Oregon. All the nutrient transfers take place in the soil itself, from one fecal particle to another fecal particle and pass it down that chain of succession. But how do you get from a dead leaf on the ground to a fecal particle? Well, that's the role of the cyanide-feeding millipede in our forest. There's really only one common millipede in that whole forest system from southern Alaska all the way to northern California. Basically every single leaf, both deciduous and coniferous, that falls on the ground, actually goes through the gut of that one species of millipede before it even enters the soil ecosystem. So there you have one species that does something that can't really be substituted for by anything else. It's a keystone.

There are a few morals I'd like you to get.

First, soils are alive. They are biogenic. All the upper layers are in fact nothing but living critters or the feces of living critters.

Second, soil arthropods are the regulators in most soil processes. They are the system catalysts that drive the microbial processes of chemical excitement. All of those processes would stop if we didn't have the critters here feeding upon them.

Third, soils are by far the most biologically diverse part of any terrestrial ecosystem.

Fourth, by monitoring the types of diversity that are there you can learn how an ecosystem is functioning. We can generate useful information on different time scales and spatial scales that is different from what you can learn by looking at soil cores or tree rings.

Last, we need to start to use our eyes and examine the world we live in. We will see what a really neat world we live in and just maybe we will stop treating soil as if it were dirt.