Episode 4: How does soil organic matter stick around?
Full transcript

Hi everybody. Welcome back to the Priming for Production podcast. I'm Natalie Lounsbury and this is the fourth and last episode devoted entirely to soil organic matter. In the previous episodes, I talked about what soil organic matter does for your soil, where it comes from, and what it really is. But we haven't yet talked about *how* carbon is stored in soils and the reasons why some soils store more carbon than others, which is important if we want to build organic matter.

> ***Stephanie- Carbon is designed to be used, so the fact that soils store so much carbon is really interesting to us.***

That's Stephanie Yarwood from the University of Maryland again.

What she means, of course, is that carbon is food just waiting to be eaten by hungry soil organisms. So why doesn't it all get eaten? Part one of today's episode is about the physical environment in soil that allows carbon to stay protected from hungry organisms and thus allows organic matter to build up in soil.

Part two of today's episode is about the organisms themselves and how different microbial communities in soil can affect carbon storage because of how efficient, or inefficient, they are at using carbon. We know when microbes get ahold of carbon that they consume it, some of it goes toward their cells and some of it gets respired, but not all microbial communities are equally efficient at this process. So,

NORTHEAST SARE Sustainable Agriculture Research & Education
UNIVERSITY OF MARYLAND 1856 DEPARTMENT OF ENVIRONMENTAL SCIENCE & TECHNOLOGY

how does the microbial community itself affect whether a soil is gaining or losing organic matter?

First, let's talk about the soil physical environment. It's crazy, even though we're on episode four already and this podcast is about soil, I've focused so much on organic matter that you might forget that the mineral component of soil is the backbone of everything. This mineral component is made up of different sized particles—sands are the biggest, you can see them with your naked eye and they make a soil gritty, then silts are the intermediate sized particles and they give the soil that smooth feeling like flour when you touch it, and finally clays are the smallest particles. You can't see them with you naked eye, but you can feel them in soil because they make it kind of sticky. The ratio of sand to silt to clay make up the texture of a soil, and there's nothing you can do to change the texture. A sandy loam when you buy the farm will be a sandy loam when you sell you sell the farm. Texture itself is really important for determining how much organic matter a soil has.

> ***Johannes-texture has been shown for a long time- finer texture has higher organic matter than coarse, sands have a lot less carbon than clay soils.***

That's Johannes Lehmann of Cornell University again.

This probably isn't news to you. You probably already knew that sand doesn't hold organic matter very well, especially if you've got a sandy field and a not-so-sandy field on your farm. Soils with more silt and clay generally have higher organic matter. There's a lot of chemistry involved in how clays and organic matter interact. At the end of the day, there's nothing you can do to change the texture of your soil, so I don't want to spend much time on these interactions, but I will say that it has to do with those negative and positive charges on clay minerals that Ray mentioned back in episode one when he was talking about cation exchange capacity. All you need to know is that the texture makes a big difference when it comes to how much organic matter is in a soil, and sandy soils do not hold onto organic matter as well as soils with more clay and silt. That is not to say you're stuck with the organic matter level you have just because of the texture; that's not at all the case. In theory, there is a maximum amount of organic matter that a soil can have, a sort of saturation point, but you can pretty much be guaranteed that an agricultural soil is not at that point.

> ***Johannes- That kind of saturation concept makes a lot of sense. But in reality, most soils are so far from that saturation that even with enormous additions of organic matter, you're not observing a saturation of soil carbon because the soils can still accrue carbon and we would need to add so much that we will not observe it in field soils.***

Okay, so you can't change the texture of a soil, how much sand, silt, and clay there is, but what you *can* change, and what can help build organic matter in soils, is how all the sand, silt, and clay particles come together to form **aggregates**. Aggregation is important for storing organic matter because it protects it from hungry microbes. Remember, microbes can eat just about any kind of organic matter.

> ***Stephanie- Microbes have been around millions of years. They can figure out a way to break it down. But in an aggregate, a microbe might never see it.***

Carbon tucked deep inside an aggregate, or sandwiched between two clay particles, is *physically protected*. It's not consumed by microbes because they just can't get to it. I asked Stephanie to take us on a tour of the soil as if we were in the Magic School Bus. If you don't know the Magic School Bus, it's this series where the crazy teacher Ms. Frizzle takes the kids around in a school bus to explore different things like the human digestive system, the Solar System, you name it. I don't think they ever went to the soil, though.

> ***Stephanie- So you're in your Magic School Bus and you're very small, an aggregate is going to look like Mt. Everest. Well, the carbon is hiding inside Mt. Everest. As a microbe, it's unavailable and so therefore you start to be able to store carbon away because the microbes can't eat it.***

> ***They can't find it to eat it. You till, and break it all up, break Mt. Everest up, and all of a sudden there's the carbon.***

This explains why turning over a forest or prairie soil leads to a dramatic and rapid decline in soil organic matter. Not only are you busting open aggregates and exposing carbon that microbes previously couldn't get to, you're also giving them more oxygen, which we know they need for respiration. This allows them to consume carbon much faster.

There's a lot we can do to affect aggregation in soil, not just in a negative way by destroying aggregates like when we till, but actually building aggregates, too. Aggregation is a dynamic process that involves everything in the soil from the microbes and fauna to the minerals and water, but I think it's fair to say that roots are at the center of it. If you've ever pulled up some plant roots, you've probably observed aggregation in action, happening before your very eyes. You see those crumbs of soil stuck to the roots. That soil right around the roots is called the rhizosphere and it is the hotbed of activity in the soil. It's where most of the active microbes are hanging out.

> ***Stephanie- The reason that microbes are in the rhizosphere is because plants are inherently very leaky. They're leaking out carbon. As a root grows through the soil it's a wash of carbon coming out from photosynthesis. The microbes for the most part are eating these small sugar molecules that are coming out.***

So the microbes are in the rhizosphere taking advantage of all the carbon the roots are leaking out, which means the soil fauna are hanging out there taking advantage of all the microbes. The roots, fauna, and microbes are exuding compounds that act as kind of a glue to stick soil particles together and form aggregates. Inside these aggregates they're trapping organic matter in the form of dead microbial cells and all the other things we talked about in episode three that make up organic matter.

There's something else important happening around the roots, and that's the activity of mycorrhizal fungi. Mycorrhizae are different from fungi that get carbon by breaking down organic matter; instead, they associate with living plant roots and receive carbon directly from the plant. Here's Charlie White from Penn State.

> ***Charlie-Mycorrhizae are a beneficial soil fungus that creates an association with plant roots and the plant provides energy to the mycorrhizal fungus in exchange for nutrients that the mycorrhizae extract from the soil.***

Mycorrhizae are fascinating for a lot of reasons and we could spend a long time talking about them, but they're especially important when it comes to soil aggregation and carbon dynamics.

> ***Mycorrhizae do a number of things for soil. Their filamentous hyphae growing out through the soil really help to generate stable aggregates. Mycorrhizae are a very efficient way to take carbon out of the atmosphere, move it through the plant, into the plant roots, into the mycorrhizae and then stabilize it in the soil in substances like polysaccharides, which are essentially just imagine sticky sugars, think about a cinnamon bun with that sugar glazing on it. That's kind of what a polysaccharide is like in the soil. Those can be stabilized on soil mineral surfaces, and it's one of the ways carbon is sequestered in soils is through that mycorrhizal association.***

So the roots themselves are contributing to aggregation through their exudates, and the carbon they supply to microbes and mycorrhizae also gets used to glue soil particles together, trapping and physically protecting organic matter. Scientists have shown that the carbon from roots tends to stick around longer in the soil than carbon from leaves and stems.

> ***Johannes: Roots seem to have a greater efficiency in turning into protected organic matter than shoots have. The proportion of soil carbon being root derived and derived from above ground biomass is typically tilting toward root derived organic matter.***

There are a couple of reasons for this, but one of them is that root carbon is more likely to get incorporated into an aggregate either directly or soon after it has been incorporated into a microbial cell.

Speaking of the microbial cells, it's about time for me to move on to the second part of this episode. For this, I'm going to move away from the physical environment, how the texture and aggregation of soil affects organic matter storage, and turn back to the microbes themselves. For this, I talked with Cynthia Kallenbach of Colorado State about a different experiment she conducted to try to understand a phenomenon she and her colleagues observed in a long-term field experiment in Michigan.

They had two systems that had been in place for years- both based on a corn-soybean-wheat rotation. The first system, for lack of a better term I'll call it the conventional system, received inorganic fertilizers and pesticides. It was a tillage-based system. The second system was an organic system that included a red clover cover crop after wheat and did not receive inorganic fertilizers. The organic system also had slightly higher tillage because of cultivation for weed control. Neither system received any manure or compost, so all of the carbon going into the systems was coming directly from plants. The conventional system significantly out-yielded the organic system and the researchers estimated that the total carbon inputs were higher. Despite higher carbon inputs in the conventional system, the organic system had higher soil organic matter and this led the researchers to ask why?

> ***Cynthia- There needs to be some way to account for how we're getting more storage of the same or fewer inputs. This has to be something to do with how the microbial community is processing that carbon and utilizing that carbon, at least that's what we hypothesized. The fate of carbon that you add to the system is highly dependent on what the soil microbial community is doing with that carbon.***
>
> ***When the soil microbial community utilizes that carbon, some of it is used for building microbial biomass and its used to meet their energy and***

> ***nutrient needs and in that process of metabolizing that carbon, some of it gets released back into the atmosphere as carbon dioxide, so it's kind of an input output cycle of carbon. But it's the microbes that might be controlling how much gets allocated to their own microbial biomass vs. how much gets respired as CO_2 back into the atmosphere.***

If more carbon gets allocated to the microbial biomass and less gets respired, then there's more carbon that can get protected on mineral surfaces or inside aggregates.

In this case, there was more carbon going into the conventional system, but apparently a lot more of it was getting respired and ending up in the atmosphere, not in the soil. In the organic system, there was less carbon going in, but more of it was sticking around in the soil.

> ***Cynthia-So you can think of it as humans, we need to eat to survive, we're eating food to maintain our metabolism and we all have different metabolism and we all use food differently. Some of us have allergies to food and some of it metabolize it really quickly, but whatever we don't use, we're also breathing out as carbon dioxide and the microbes are doing the same thing.***
>
> ***So we hypothesized that it was something about the microbial community that was causing these differences in the soil organic matter, in terms of how they were using the carbon that was being added through crop residues.***

They took some of each soil out of the field and back to the lab, where they fed the microbes some glucose, which is a simple sugar that is exuded by roots, to see what the microbes would do with it. What they found was that the microbial community in the organic system's soil was more efficient at processing glucose. That is, as they were building their microbial biomass, they respired less carbon dioxide for every unit of carbon they incorporated into their cells than the microbes from the conventional system did. Basically, the microbes from the organic system's soil had a really efficient metabolism, or carbon use efficiency.

Now I definitely don't want to turn this into an organic vs. conventional conversation. It just happened to be that was the long-term experiment they had set up there. One of the obvious problems with such a comparison is that there were a lot of differences between the two systems so it's hard to say exactly which were responsible for changes in the microbial community's carbon use efficiency. First, the use of a red clover cover crop, which by no means is a practice limited to organic farming. Second, the use of inorganic fertilizers in the conventional system, and third, the use of slightly more tillage in the organic system for weed control. So I asked Cynthia, can you really determine which of these factors led to the increased carbon use efficiency in the organic system?

Cynthia-we can't be certain because there were all of these factors present, but we can speculate and based on what we know about how microbes respond to different management practices, and we do know that microbial communities are really sensitive to changes in carbon supply and that's one of the key factors that also influences their carbon use efficiency. But in the end it's gonna be hard to say that it's just due to maybe this cover crop and not the use of fertilizers.

What's interesting about the year round cover is that it's affecting system in so many different ways. So when you add a cover crop, you are now giving a supply of carbon to the microbial community in the winter. This is really important because agricultural systems, unlike forest systems, are really carbon limited. We tend to supply enough nitrogen to the microbial community because we're trying to meet crop plant needs, and there's a limited supply of carbon. So in the winter, the microbial community can be kind of carbon starved.

Natalie- So normally people might think of the winter as kind of a dead time with not a lot of activity, so you're saying the microbes are active in the winter when it's really cold.

> ***Cynthia- They are active. In fact, I was at a conference this week and there was a talk by someone at Berkeley, Steve Blazewicz and he was showing they were getting a lot of microbial activity at soils just above freezing point.***

If there are no plants in the field over the winter, there are no roots pumping out those delicious exudates. If microbes want to eat something, they have to eat something slightly harder to metabolize than the simple sugars and other compounds that roots exude. Cynthia and her colleagues think that maybe the microbial community adjusts to having year-round carbon supplies by taking a slow and steady approach to carbon consumption, whereas perhaps the microbes in the conventional system are adapted to more of a feast-or-famine scenario so they really chow down while they can, which ends up being less efficient and they blow off more as carbon dioxide. It's a microbial version of stress eating.

> ***Cynthia-Stress factors can induce lower carbon use efficiency such as drought, sometimes when we see warmer temperatures in the soil and we get soil warming and the microbes aren't used to that we can see a decrease in the carbon use efficiency, and then the supply of carbon itself can have a really strong effect on that community's carbon use efficiency.***

Back in episode two Stephanie talked a little bit about carbon use efficiency, and how much carbon gets respired back into the atmosphere.

> ***Stephanie-We know that depending on the microbe, type of C, it can be a lot or a little, but anywhere from 25% to 75% of the C is respired back into the atmosphere, and the rest is incorporated. That's a big span. For instance, if it's a small compound, like root exudates, they seem to incorporate more and blow off less as CO2, if it's a piece of straw, they actually have to put a lot more energy into getting at it, and they're looking for nitrogen also, and these other compounds and so they're getting rid of a lot of excess carbon, doing it. So it depends a little bit on what it is, in the system.***

What Cynthia and her colleagues are doing is using this concept of carbon use efficiency to explain why different farming systems might increase carbon more than others. It's not just about how much carbon is getting added to a system, it's also about how that carbon is processed once it gets into the soil.

At the end of the day, it's impossible to tease out whether it was the year-round plant cover and the steady supply of carbon inputs in the organic system, or the fertilizer and perhaps pesticides in the conventional system, but whatever it was, there was a fundamental difference in how the microbial community processed carbon between these two systems. Even though there was higher tillage in the organic system, something we generally associate with more rapid carbon loss, the microbes there were more efficient at using carbon to build their bodies and subsequently keeping more of the carbon in the soil. This contradiction highlights the complexity of the interactions between the soil microbial community, carbon inputs, and the physical environment in the soil. All of these aspects influence how much carbon is stored in a soil.

So should you manage a soil to physically protect carbon in aggregates? Yes, aggregation is good no matter how you slice it. It's good for water dynamics, good for resistance to erosion, and good for building soil organic matter. Should you manage a soil for an efficient microbial community? Sure, but we're still not quite clear on how exactly you can do that. Keeping a year-round living root system may be a key component to both building aggregation and maintaining an efficient microbial community.

> ***Johannes-I think roots are a very important part of adding carbon to soil and we're not managing below ground plant material very well with that in mind. We're thinking about "are we adding the crop residues? How are we adding it? When are we adding it? How much can we remove? But we're rarely thinking about any below ground root management with soil improvement in mind.***

As I wrap up this four part series on soil organic matter, I hope some of this is making sense and is in line with what you've seen in your own fields.

Underpinning it all is the concept of how much carbon goes into your system vs. how much goes out. If you want to build soil organic matter, you need to be thinking about both sides of this equation. This may be the end of the episodes devoted entirely to organic matter, but you can be sure that we'll touch on this topic quite a bit in the future. I hope this has given you the foundation to be thinking about organic matter in a way that maybe you didn't before. If the gears are turning, then that's a good thing. But if something doesn't make sense or you have questions, feel free to send me an email. You can reach me and you can also get a full transcript of this episode if you go to www.soilpodcast.com, where I also hope you'll be kind enough to provide some feedback.

Thanks as always to the guests in today's episode, Johannes Lehmann of Cornell University, Stephanie Yarwood of the University of Maryland, Charlie White of Penn State University, and Cynthia Kallenbach of Colorado State University. This podcast was made possible by a partnership grant from Northeast Sustainable Agriculture Research and Education.