Episode 3: What is soil organic matter, really?
Full transcript

Hi everybody. Welcome back to the Priming for Production Podcast. I'm Natalie Lounsbury and this is the third episode, third out of four that I'm devoting to the all-important soil organic matter.

To start off, I'm going to take you back to the first episode with this little bit from Johannes Lehmann from Cornell University to remind you why we're spending so much time on this topic.

> ***Johannes- soil organic matter is one of the, if not the, foundation of soil functioning, soil fertility, soil everything. It's the foundation of soil health and how carbon and nutrients cycle in soil. So understanding soil organic matter is really fundamental to understanding soils.***

For the first two episodes, I talked about some of the ways soil organic matter controls a lot of the physics, biology, and chemistry of soil. I also talked about the carbon cycle and the balance between photosynthesis and respiration on controlling soil organic matter levels.

Our understanding of soil organic matter is undergoing something of a revolution right now. Seriously, it is. And what's exciting is that I was able to talk with some of the people who are at the forefront of that revolution. So everything I presented in the last two episodes is real. It's not changing, and that's why I presented it that

way. Soil organic matter does all the things we always thought it did- it provides increased water holding capacity, resistance to compaction, better nutrient cycling and nutrient retention, all those good things. What is changing is our understanding of what soil organic matter actually *is*—on a molecular level—and why and how it sticks around in soils. This is important if we're now at a point where we recognize how important organic matter is and we want to build it. There's quite a bit of history and terminology in this episode, and I apologize for that in advance. If you don't want to listen to the entire episode, I'll give you the take home message right at the top that answers the question of what is soil organic matter?

> ***Johannes- Everything was a plant at some point. Some of it still looks like a plant, like a small leaf fragment, which is typically around 10, 20, 30% of the soil carbon. The rest was a microbe not too long ago, or will be a microbe not too long in the future. The soil organic matter is constantly transformed by microorganisms.***

This may be very different from what you've heard in the past about organic matter. I'm guessing that many of you associate organic matter with a word that I haven't yet uttered. It may have felt conspicuously absent, and that is **humus**. It's lovely, satisfying word, but what, really, is humus?

> ***Johannes- Humus is a term that was coined a few hundred years ago in the context of soil organic matter and was born out of the observation that one can extract quite a bit of brown substance from a peat when shaking it with a certain solution.***

Rewind… What is he talking about? This is where the history comes into play. The year was 1786. Exciting discoveries like photosynthesis were fresh and new, and a curious scientist in Germany by the name of Francois Charles Achard decided to investigate peat in a bog and he observed that:

> ***Johannes- So experimentalists were obtaining this brown soup and they found that this has properties that they didn't expect it to have and generated a series of arguments that these brown substances extracted***

> ***from soil would be humic substances and further classified… they came up with that term, humic substances further humic acids, fulvic acids, humins that can be obtained by various techniques from soil. You shake the soil with sodium hydroxide, which is a solution that has very very high pH***

I'm going to interrupt Johannes for a second here to make a couple of points. The pH we're talking about for this soil extraction is very high, extremely alkaline, like Drano. The mechanism is actually the same as Drano- you add this alkaline material to the organic junk like hair stuck in your pipes-- I know, gross-- and it dissolves it.

> ***Johannes: and by exposing the soil with sodium hydroxide, you deprotonate the organic matter and you make a lot of things soluble that would never be soluble in the soil solution. And then, you acidify it after you have extracted it out of the soil and that recombines the molecules in unexpected ways. And that product, that extraction product, is called humic substances.***

Are you having chemistry flashbacks? Nightmares? Don't worry about deprotonation and recombining molecules and all of that. The point here is that this extraction procedure changed the very nature of the organic substances in soil. They were basically creating a new organic product.

The problem is that for hundreds of years, it was assumed that what was extracted by these procedures was actually what was present in soil, that this WAS soil organic matter. Scientists thought plant materials going into the soil were transformed into humic substances or humus in the soil over time through a process called "humification" and then once they reached this humified state they kind of stayed that way, but what we're learning now is that a transformation was happening during the extraction itself.

> ***Ray- people thought that's what they had extracted out of the soil- turns out that's what they made with this very alkaline extract.***

That's Ray Weil, whom you'll remember from the last episodes, from the University of Maryland.

It's as if some scientists wanted to study hair, but instead of looking at hair straight off our heads, they obtained the glop from a pipe cleaned out with Drano, and then studied that. This seems silly to us because it would be easy to get real hair and look at it. The issue with looking at soil organic matter in its natural state is that it's hard to get at it—impossible until recently—without somehow extracting it first. So people extracted it, and what they ended up with through extraction was an altered material.

When I first learned about soil organic matter, I learned about humic substances. I'm sure many of you did, too. This is the model that existed in textbooks. It was really ingrained. I've spent a lot of time looking at factsheets, websites, and just about any place where there's a description of soil organic matter and I see references to humic substances or humic and fulvic acids all the time. When Ray was revising his textbook recently, he was forced to address changes in our understanding of soil organic matter.

> ***Ray- As you know I've just finished revising my textbook, and one of the things I had to make major changes to was the way I talked about organic matter and humus because there have been major advances that have been going on for probably 20 years, but most soil scientists and agriculturalists that really didn't get into the nitty gritty of the chemistry were still operating on concepts of organic matter that are probably half a century out of date.***

There were certain notions about the properties of these extracted humic substances that shaped what we believed about soil organic matter for generations. Because of what they were extracting, people thought that there were these long-lasting, large, stable, compounds that organisms wouldn't consume and that this is why carbon persisted in soil for such a long time. A word you'll hear a lot if you

start digging into this is "recalcitrant." It basically means hard for microbes to decompose. But these beliefs haven't held up to evidence.

> ***Johannes- The observations have not really stacked up to the premise that these are large recalcitrant molecules. It's an interesting phenomenon where the concept of humus and humic substances was a product of a certain extraction procedure that someone did 250 years ago.***

Until recent decades, however, we didn't have technology that could let us see the real chemical composition of unaltered soil organic matter so we relied on these extractions. As analytical tools have advanced, people like Johannes have started looking directly at organic matter in soils, not at the alkaline-extracted proxy, to see what kind of molecules are there and where they're located in the soil. What they're observing has changed the way scientists are thinking about what soil organic matter is and why it persists in soil.

> ***Johannes- We're slowly converging on a model that looks quite different from the humification model. There's no resynthesis to a large molecule that is intrinsically persistent and recalcitrant in soil, that can be built up to form more organic matter, which means also when you want to have more organic matter in soil, you need to manage the flow of carbon rather than accrue a certain type of carbon that is supposedly recalcitrant. Which actually jibes very well with what farmers observe all the time. If I till more, if I destroy aggregates, if I do something that promotes organic matter mineralization, if I destroy the protection of carbon in soil, then I see less carbon over time. So I think it is intuitively, we are in tune with that view of a progressive degradation of organic matter to smaller and smaller molecules, but we still have to overcome this, in part still lingering scientific model, but definitely a very deeply ingrained popular view of humification and the formation of this stable humus.***

So if soil organic matter isn't the humic substances that many of us were taught it is, what is it? Scientists are finding that the compounds in soil are smaller, simpler, and recognizable compounds compared to what was observed from these alkaline

extractions. Here's the same bit I played at the top of the episode about what soil organic matter really is.

> ***Johannes- Everything was a plant at some point. Some of it still looks like a plant, like a small leaf fragment, which is typically around 10, 20, 30% of soil C. The rest was a microbe not too long ago, or will be a microbe not too long in the future. The soil organic matter is constantly transformed by microorganisms. The microorganisms themselves, the living microorganisms, make only a very small portion of the total carbon, usually less than 10% is in living microorganisms at any given time, but the other 90%, the largest part of that, was a microorganism not so long ago.***

This is a very different picture of soil organic matter than the previous paradigm of humic substances, but new research strongly supports the idea that soil organic matter is dominated by dead microbial cells and simple microbial products. To learn more about this, I spoke with someone who has studied the role of microbes in processing organic matter.

> ***I'm Cynthia Kallenbach, a post-doctoral fellow at Colorado State University with the Innovation Center for Sustainable Agriculture.***

For her dissertation research, Cynthia did kind of a proof-of-concept experiment in the lab to see whether she could get microbes to create soil organic matter that resembled soil organic matter from a real, field soil.

> ***Cynthia-So we took two different types of clay, pure clay, there was no carbon, there was no microbial community associated with the clay. We mixed sand with clay and then we took inoculum from a field soil in Michigan that was a prairie soil and just inoculated it with that community. We weren't that interested in who was there, what the community was, we just wanted to add some microbes to these pure clays.***

> ***Then we gave the community glucose, which is basically a sugar, a simple sugar, and we gave them glucose every week for 15 months and we just followed the development of the soils over time, the microbial community that grew from this inoculum into a more established community.***

They chose glucose not just because it's easy for microbial communities to consume, but because microbes in a field soil may see a lot of glucose coming out of plant roots.

> ***Cynthia- We know more and more that the exudates and the compounds that are leaking out of roots are the main energy supply for microbes and a lot of that exudate material is glucose.***

They also gave the microbes other nutrients, like nitrogen, phosphorus, and sulfur, that they need to survive, creating the conditions for them to thrive.

> ***Cynthia- We looked at chemistry of the soil organic matter and the amount of this new soil organic matter we were accumulating. What was nice about the set-up is that glucose is rapidly utilized by microbial community. It doesn't stick around in the soil generally. And using some analytical chemical techniques, we could look at soil organic matter chemistry to determine that the glucose wasn't sticking around and the carbon we were building was coming from these microbial inputs.***
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> ***In the end, after 15 months, we had about 1% soil carbon. We see that in a lot of agricultural soils, that level of carbon concentration. So it's a lot over a very short period of time.***

If you remember back to last episode when I said organic matter is about half carbon, this translates to nearly 2% organic matter that the microbes had built up in the soil over 15 months. This is similar to what a lot of agricultural soils have. Granted, this was on a lab bench and not in the field so this certainly is not 100% translatable to the field.

> ***Cynthia- Well these are idealized systems. There were no limitations to the microbial community so we really tried to create a system where the microbial community could thrive and really build up biomass and in fact our microbial biomass concentrations were extraordinarily high, stuff you would never find in any cultivated soil. So we were generating a lot of these microbial products.***

They were also starting from zero organic matter, a situation that doesn't really exist in the natural world. Despite the short time frame, the organic matter that they accumulated was really similar in terms of its chemical composition to what they saw in a natural field soil. The microbial transformation of glucose led to a lot of proteins, lipids, polysaccharides, and nitrogen-bearing compounds just like the field soil.

> ***Cynthia- There were statistically some differences in some of the compounds, but it definitely was starting to resemble what we would see in a natural field soil in terms of the number of compounds, the complexity of that chemistry and the relative abundance of certain groups. That was really interesting to us, that we could get the same level of chemical complexity and diversity that we see in a natural field soil.***

Cynthia was able to create this soil organic matter really fast, but in natural soils, we know that some of the organic carbon has been around a really long time. We know this from a method called carbon dating, which measures the amount of carbon 14, which is naturally occurring radioactive carbon. Measuring carbon 14 can give us a good sense of how old the carbon in organic matter is. So how does this notion of soil organic matter as a constantly evolving substance jibe with the data showing that some carbon in soils is hundreds or even thousands of years old?

> ***Johannes- carbon dating is a very valuable tool, but the only thing it can say is that this carbon was fixed by photosynthesis into organic matter at a certain time in the past. That doesn't mean that it has been in this form since that time. So it could be that the leaf that fixed the CO_2 200 years ago, that that carbon is still in the soil, but it's not in the form it was fixed***

> ***in. It might have undergone numerous transformations in the soil. It's still that carbon, but it might have been a microorganism a thousand times in the past and died again and adsorbed to a clay particle being sandwiched between two clay particles for a few decades, then broken up again because the clay particles dissolve, then eaten by a microbe. Then it became an organic substance in the microbe, the microbe died, that molecule is again adsorbed to another clay particle, again sandwiched between two clay particles, stays there for another few years. And so on and so forth***

Natalie (in interview)- It just hasn't yet made it to CO_2

> ***Johannes- That's all that it says. There is a false conclusion that we draw from something being old that it's also recalcitrant. Something being old means only that it's old. That it has been fixed by photosynthesis a long time ago. That's all that it says. So it could have cycled a long time between microorganism and adsorbed to a clay particle and back and forth.***

So even the *old* carbon in soil can undergo transformations. That's not to say some carbon doesn't stick around longer than other carbon, depending on factors like how appetizing it is to organisms and where it ends up in the soil. We'll talk more about these things in the next episode.

Let me get back to the word humus for a moment. When people talk about humus, it evokes many of the old understandings of organic matter-the humic substances notion that hasn't held up to investigation. It's a word that people are very attached to and honestly it's a really nice word to say. "Soil organic matter" doesn't roll off the tongue in quite the same way.

> ***Johannes-There are a lot of feelings associated with the term humus, and it has been used for hundreds of years and millennia before somebody had the idea to use sodium hydroxide as a soil extractant, but it was very often used in the term of soil itself, whereas after the discovery that you could***

> ***extract a lot of organic matter with sodium hydroxide, it was used for the organic fraction and specifically that presumably very stable part of soil organic matter that we then called humus and then can characterize further with different extractions by alkaline solutions.***

Because I think it's impossible to separate the word humus from all that it has come to be associated with, I choose not to use the word and instead just to say soil organic matter. This is totally a matter of personal opinion, but I thought I would explain why you won't hear me say it.

The emerging model of soil organic matter is very optimistic about building back organic matter that we've lost, and this is in line with what farmers like Steve Groff are seeing and what Ray discussed at the end of last episode about how organic matter levels can increase rapidly when you make a radical change. Cynthia is careful not to take the results of her research too far, but it's nonetheless pretty exciting.

> ***Cynthia-We can start to think that maybe we can actually build carbon faster than we previously thought. And in fact, if we start to look at C14, radiocarbon carbon dating which has long been our golden method for estimating carbon age, we actually find that some of the most stable carbon is fairly new. You can imagine that those microbes are constantly contributing to that stable carbon pool. It doesn't necessarily take centuries for that carbon to end up there.***

This is a good place for me to recap a little from this episode. Soil organic matter is really important for all the reasons we always thought—it affects the physics, biology, and chemistry of soil as I discussed in the first episode. What is changing is our understanding of what soil organic matter actually is. Because it was hard to extract and look at organic matter without changing its very nature, we used to think there were these complex humic substances in soils that took a really long time to accumulate and stuck around for a long time because of their chemical composition. We now realize that the organic matter in soils is largely compounds

from dead microbes, and that it doesn't have to take a long time to accumulate organic matter in soil.

The question is: how do we create the perfect conditions in the field for microbes to do their jobs turning over and storing away more organic matter?

In the next episode, the final installment in this organic matter series, I'm going to get into this question of the conditions for soil carbon storage, so tune back in. I'm also going to talk in a later episode about some of the ways we can measure **different** soil carbon pools to see whether our management practices are having an effect.

Oh, and one final note about humic substances that I didn't want to include in the original main discussion because it was already confusing enough. Some of you may have seen products available that are called humic and fulvic acids. How do these products relate to soil organic matter? Remember how I said people would subject the soil to a series of alkaline and acid extractions and the products of these extractions were called humic substances? People also did this to other organic materials like low-grade coal. So most of those products you see on the market as either humic or fulvic acids are extracted from some organic material like low-grade coal. They're a product of a specific extraction procedure. Studies in greenhouses have shown that they can have a positive effect on plant growth. But these substances should not be confused with what is actually present in soil organic matter, and they are definitely not a cost-effective way to build organic matter in soil.

As usual, you can get the full transcript of this podcast on the website, soilpodcast.com. I'd also love it if you'd stop in and give me some feedback on the podcast there too! This podcast was made possible by a grant from Northeast Sustainable Agriculture Research and Education. In order to keep programs like this possible, we need to hear from you! So once again, check out soilpodcast.com.

I want to thank Johannes Lehmann at Cornell University, Ray Weil at the University of Maryland, and Cynthia Kallenbach at Colorado State for their time

and insights. Also, I'd like to thank Markus Kleber of Oregon State University for sharing some of his thoughts on this topic with me. And thanks to you for listening.