**Episode 2*: Where does soil organic matter come from?***
Full transcript

Hi everybody, welcome back to the Priming for Production podcast. I'm Natalie Lounsbury and I'm looking forward to continuing with the soil organic matter theme. This is the second of four episodes I'm devoting to organic matter. Last episode, we talked about the effects organic matter has on physical characteristics like water dynamics, how it serves as food for the organisms that cycle nutrients like nitrogen in soil, and how organic matter increases cation exchange capacity, which holds onto positively charged nutrients like calcium, potassium, and magnesium.

So I hope I convinced you that building organic matter will have a payout, but I didn't get into ***how*** you can build organic matter. And I'm still not ready to tell you how you can build organic matter partly because there's no single answer and partly because I'm a really strong believer in the basics and we're not done with the basics. We still haven't talked about **where** soil organic matter comes from, which is the topic of today's episode.

Alright, so here we go.

It all starts with the carbon cycle.

So far, we've mostly been talking about soil organic matter, but often people talk about soil carbon. I want to clarify what the relationship between soil carbon and soil organic matter is so we're all working from the same understanding. For this I turned back to Professor Ray Weil, at the University of Maryland.

> ***Ray- So this can be kind of confusing. I think traditionally people, especially farmers, talk about organic matter in their soil. That's the black stuff that you can see. That's what holds water, it holds nutrients, it's something you can conceptualize. Carbon is an element. It turns out that most of the carbon in humid region soils is there as part of organic molecules.***
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> ***The two reasons we're now talking more about carbon now is that first of all, carbon is what's usually measured. So in the lab when they do soil tests by most methods, what they're actually measuring is carbon and then they are multiplying by some fudge factors to get organic matter. And then carbon is what cycles throughout the world in the carbon cycle, part of which has huge impacts on climate change. So in the last three decades climate change has become a big focus of science and the carbon cycle is a big part of that and the soil carbon therefore feeds into that so scientists have tended to talk more about the carbon in soil.***
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> ***Fortunately, all you need to do is realize that organic matter is roughly half carbon.***

*Natalie- and what's the other half*

> ***Ray- the other half, you know, these are organic molecules, what makes a molecule organic, by the way, is the carbon in it. That's by definition, an organic molecule is one that's made of carbon. And usually it's a chain of carbon, so sugar is a very simple organic molecule, it's a chain of carbon with hydrogen and oxygen on it, and so is alcohol. So basically most of the organic molecules, most of us, if you take away the water, we're mostly made of carbon, oxygen, and hydrogen with some other elements thrown in, you know, nitrogen is one of those.***

Nitrogen is found in lots of compounds in plants like proteins and chlorophyll. There's a pretty good amount of nitrogen in organic matter in general, but you don't find it in all organic compounds. There's also sometimes sulfur, and phosphorus too. The ratio of these elements to one another varies from one compound to another. Remember how last episode I said that when soil organisms consume organic matter they can make nitrogen, sulfur, and phosphorus available for plants? It's because when they consume organic matter, they're not just consuming carbon, they're also consuming these elements.

So sometimes people will talk about soil organic matter, and sometimes people will talk about carbon. They're related because carbon is the backbone of soil organic matter, but it's important to remember that soil organic matter has more than just carbon in it.

Okay, getting back to the carbon cycle.

Carbon is at the core of two processes that make life on earth possible: photosynthesis and respiration. These processes are essential to understanding soil organic matter, so even though I know everyone has heard of photosynthesis, I want to spend some time talking about it anyway.

> ***Ray- The concept of photosynthesis and respiration being two sides of the same coin, being in relationship with each other, and hopefully being in some kind of balance, this is kind of one of the fundamental things that makes our planet work, makes life on our planet work.***

Plants, algae, and some bacteria too, use energy from light, take carbon dioxide out of the atmosphere, combine it with water, and produce carbohydrates, which become their living tissue. In the process, they give off oxygen into the atmosphere. So, light, carbon dioxide, and water in, and oxygen out. This, of course, is photosynthesis.

Some of the carbohydrates from photosynthesis will be used to form the above ground plant parts that we see, like the leaves and the stems, while some will go to the roots. A surprisingly large fraction actually sort of leaks out of the roots in the form of what are called root exudates.

> ***Ray- Plants provide the connection between the above ground world and the below ground world. They funnel the sunlight energy through photosynthesis and funnel it down and out the roots.***

If there were no counter process to photosynthesis, all the plant material that had ever been photosynthesized in all of history (well, since plants have been around anyway) would still exist in or on top of the soil. But we all know that's not how it works. Plant materials get eaten. Leaves, sticks, and even logs don't stick around. Things decompose.

And this is because of respiration, which is the quite literally the opposite of photosynthesis.

During respiration, organisms get energy from carbon compounds and release carbon dioxide and water. Along the way, they use oxygen. So, oxygen and carbon compounds in, carbon dioxide and water out. The process is similar whether we're talking about ourselves in our above ground world getting energy from potato chips and corn dogs or most soil organisms in their below ground world. In both worlds, much of the carbon that gets consumed gets respired back into the atmosphere as carbon dioxide.

> ***Ray-Well microbes, just like us, heaven forbid if every bite we took- all the carbon in my breakfast this morning built more of me, we would get really fat really quick. If you ate a dry pound of rice, say, which is probably about half carbon, a half a pound of rice, you gained a half a pound of weight, we would get really fat. So most of what we eat, we breathe out. We either don't digest it, we won't get into that. But most of the carbon that we actually digest, we burn for energy and we breathe it out as carbon dioxide. And that's exactly what the soil organisms are doing, too. Fungi tend to be a little more efficient, bacteria a little less efficient in terms of how much growth they get out of the carbon that they're eating.***

One big difference between us and soil organisms is that they can, as a whole, consume a much more diverse range of carbon compounds than we can. Here's Johannes Lehmann, from Cornell University:

> ***Johannes- decomposers do prefer certain type of organic matter for energy generation because it's just easier to metabolize, but they can metabolize almost anything that you put in front of them if they're given the time to adapt to it and if they have no other choices.***

In other words, they can be picky eaters but at the end of the day, they'll eat what they're given. Just how do soil organisms eat such a diverse range of carbon compounds? I'm going to focus in on the microorganisms here, not to discount the importance of the larger critters in soil, but as Ray said last episode:

> ***Ray-The biochemistry is being carried out almost all by the microorganisms. The chemistry.***

So how do these microorganisms consume carbon, and carry out all the biochemistry?

Here's

> ***I'm Stephanie Yarwood. I'm an assistant professor of soil microbiology and the University of Maryland. I study microbial ecology in lots of different environments including agricultural systems.***
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> ***A microbe is just a single cell. Single cells have different ways to do that, but most of them actually send out an enzyme into the environment, and that breaks down a compound small enough to where they can take the carbon compounds into their own cell. You might think about it like what we do as humans is we ingest carbon and then in our stomachs we break it down, so we internally break things down and then we release what we can't use, and absorb what we can use. Microbes don't have a stomach.***

> ***They basically break things down around them and then absorb those nutrients into them. When I was a kid I was fascinated with starfish because starfish basically can invert their stomach into a clam shel and digest it alll. And now I study microbes, which kind of do the same thing.***

Microorganisms may eat a little differently than we do—they break down compounds outside their cell and then bring it into their cell where they can get energy from it—but they still follow a similar process to us humans. They consume carbon, some of it goes toward building their cells, and the rest gets respired back into the atmosphere as carbon dioxide. How much goes toward building their cells and how much gets respired is a pretty big area of interest.

> ***Stephanie-That's one of the things we're trying to model a lot. We're trying to understand exactly when they're breaking things down, how much of that gets recycled back into the atmosphere? The values, we it in microbiology is carbon use efficiency. We know that depending on the microbe, depending on the type of carbon, it can be a lot or a little, but anywhere from 25% to 75% of the carbon is respired back into the atmosphere, and the rest is incorporated. But 25-75 is a big span, and that shows you how varied it is depending on what it is.***

Depending on which microbe it is, and what the carbon compound is, anywhere from 25-75% of the carbon they consume, and remember, organic matter is about half carbon, gets respired back into the atmosphere and the rest gets incorporated into microbial cells. Microbes eventually die, and their cells may serve as food for other organisms, and so respiration, the process that consumes carbon in soil, goes on and on and on.

To sum it up, plants photosynthesize, creating carbohydrates, and soil organisms respire, creating carbon dioxide that goes back to the atmosphere where plants can then use it, again, for photosynthesis.

There's one more little thing about photosynthesis and respiration. We usually think of plants as the photosynthesizers, but they actually respire, too. They have to use the carbohydrates from photosynthesis along with the nutrients, like nitrogen and phosphorus they've taken up from the soil to make more complex compounds, like the nitrogen containing proteins and chlorophyll that I already mentioned. To get the energy to do this, they use carbon just like we do, and some of it gets respired. Obviously, on the whole, plants fix more carbon through photosynthesis than they respire, but I just didn't want to overlook the fact that plants respire too. It's why they need oxygen. It's why you can't have a saturated soil when it comes to most plants, or they'll die.

For the rest of this podcast, when I talk about respiration, and I will talk about respiration again, I'm generally talking about soil organisms consuming carbon compounds and releasing carbon dioxide; often when people think about this process they think about it as decomposition, or breaking down organic matter.

Alright, so on the one hand, if we had *only photosynthesis* in this world, we'd have millions of years of fresh, undecomposed plant material stored up in our soils and we know that's not the case. On the other hand, if soil organisms kept up with plants and decomposed all the carbon that was ever photosynthesized, we'd have no soil organic matter. And we know that's not the case, either. We have tons of soil organic matter. In fact, soil organic matter has more carbon in it than all the plants on earth right now. Why and how soils store organic matter is the topic of episode 4, but I'm not done with the topic of this episode, which was where does soil organic matter come from? At the most basic level, soil organic matter comes from carbon that was photosynthesized by plants, but hasn't been respired back into the atmosphere by soil organisms.

In other words, all organic matter in the soil was originally, at some point, fixed by photosynthesis. This is true even if you're talking about systems in which you've added manure or compost. That carbon originally came from photosynthesis, too. In the case of manure, it was just processed through an animal, which used some of the carbon for energy, some for building its body, respired the bulk of it back into the atmosphere and left some of it for us in the form of manure.

The amount of organic matter that exists in a specific soil is a function of how much organic carbon has gone into the soil either directly from photosynthesis in place or from inputs like manure vs. how much has been respired by soil organisms. Remember back to last episode when I said there's kind of this paradox between needing to build organic matter for all the good things it does like increase water holding capacity and cation exchange capacity while also needing microbes to consume organic matter to get all the benefits it provides? Resolving this paradox all comes down to balancing the amount of carbon that goes into soil, the carbon inputs, and the amount of carbon that gets respired.

Historically, we've tended to increase the amount of respiration in our agricultural soils without providing adequate carbon inputs in return.

> ***Ray- If we take a natural soil under natural vegetation, it will have reached (if it's been around for a long time) it will have reached an equilibrium where the inputs from forest or prairie or the marsh are pretty much balanced by decomposition and so organic matter will have leveled off at a pretty high level.***
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> ***Now the farmer comes along and clears trees or the grass and tills the soil and immediately, the organic matter starts declining. This is one of the problems of agriculture, is that it takes a natural system that's reached a dynamic balance, let's say, and it messes that all up. It does that in a number of ways.***
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> ***Organic matter declines quite drastically in the first few decades, in fact in the first couple of seasons that a soil is cultivated.***

This decline shows that the carbon inputs and the carbon outputs are out of balance. The soil organisms are respiring a lot more carbon than is being added back to the soil whether that's via photosynthesis or manure.

> ***Ray- A lot of this organic matter was not decomposing simply because it was physically in locations that were inaccessible and as soon as you till it,***

> ***that changes it and it disappears very quickly. There have been many studies have followed organic matter content of soils from the time prairies were first plowed or the forest was first cleared. These show that typically half the organic matter in soil of the upper foot or so is lost during first several decades, twenty, thirty, forty, maybe fifty years and then things start slowing down, the loss starts slowing down and you reach new plateau at a much lower level. This is a less productive soil- holds less water, infiltrates less, has less microbial activity, it's cycling fewer nutrients, it requires more inputs. Our history in Midwest is you could plow soils and grow for a decade or so without much fertilizer or manure because you were basically mining the nutrients from soil. Once you get to lower level, you're no longer getting a lot of those nutrients being released, the accessible organic matter is decomposed.***

This sounds like a total downer, but I'm not going to end the episode on that low note. In fact, what I want to end on is this very optimistic note:

> ***Ray- The nice thing, the hopeful thing, is that it'll bounce along staying there, maybe drifting down or if you're doing a good job farming maybe drifting up, but we know that if you make a radical change, it will rebound even faster than it degraded.***

Radical changes to bring soil organic matter closer to its natural levels can take several different forms. If you think about organic matter levels as being driven by the balance between photosynthesis and respiration, you can imagine that management practices that increase photosynthesis and decrease excessive respiration can help. Steve Groff is a farmer and cover crop consultant in Pennsylvania. His two key management practices are no-till and cover crops.

> ***Steve- I started no-till back in 1982 and those fields that I started in '82 are still no-till to this day. They are now gone from 2% organic matter to almost 5% organic matter over the last 30 something years. That is a noticeable change and that's just because of management. Management has done that.***

Natalie-that's not huge additions of manure and compost, that's direct plant matter.

> ***Steve-No, Correct. And no disturbance of the soil to burn up organic matter. We're keeping it. We're storing it and keeping it.***

I'll get back to Steve in the future to talk more about cover cropping. His management strategies may not work for every farm, but they're a great example of managing photosynthesis and respiration to increase soil organic matter.

Let me just recap what we talked about today: where does soil organic matter come from? I know I'm so redundant, but it all originally comes from photosynthesis. It's processed by soil organisms, who respire a lot of it back into the atmosphere, but a lot of it sticks around in the soil. Next episode we'll talk a little about the history of our understanding of soil organic matter and how our emerging understanding is really exciting in terms of building back degraded agricultural soils.

Tune into the next episode as we keep going on this soil organic matter theme.

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