I would now like to formally begin today's conference, and introduce Dr. Holli Kuykendall.

Thank you very much, Eddie. Thank you for your support with the ATT system. This is Holli Kuykendall. I'm the webinar coordinator here at the East National Technology Support Center for USDA NRCS. And our webinar co-coordinator today is David Lamm. He is the team leader for the National Soil Health and Sustainability Team.

Welcome to today's webinar presentation. I'm going to let David introduce the topic and the speaker. But I wanted to make sure that everyone is aware that we are offering CEUs for today's presentation. We have CEUs for the American Forage and Grassland Council, Certified Crop Advisors, Conservation Planner, Society of American Foresters, Society for Range Management, and the Wildlife Society. The ENTSC will submit your professional CEUs for all of those different societies, with the exception of Conservation Planner. And we ask that all conservation planners submit on their own for their state-specific program.

At the end of today's presentation, you'll return back to the webinar portal to complete step two, which offers a brief post-test. You'll be able to enter your certification credentials, and you'll receive, by email, your training certificate.

I want to thank the Southern Regional Extension Forestry Group for helping us with the webinar portal. This is their product, and we are partners with them in being able to offer our conservation webinars through the webinar portal system. They provide great support, and we really appreciate it. So David, with that I'm going to turn the presentation over to you.

OK, thank you, Holli. And again, I want to welcome everybody. Again, this is David Lamm. I work out of the Tech Center here, and do most of my work around the topic of soil health. And I'm really excited about today's topic, because it's one of those things-- had I known then what I know now, I would have been a lot better district conservationist, having worked in Northeast Indiana for 25 years.

Before we get started with Jim, when I introduce him, I do want to remind folks that it's all things soil health this week. We do have another webinar scheduled for Thursday. And what we're going to be talking about is using the core NRCS conservation practices for enhancing soil health. And then we're going to go through-- I got three-- you're not going to listen to me drone on. I actually have three state-level folks. Barry Fisher from Indiana, Joel Moffett from Colorado, and Gordon Mikell from South Carolina will be talking about what they're doing at the local level, and how they're using NRCS conservation practices to enhance soil health on their farms that they're working on there.

So let me move on to today's topic, The Biology of Soil Compaction. As I mentioned, as district conservationist, I worked next to Ohio for 25 years and spent the last portion of my days there figuring out how to no-till using tillage. Paring soil to no-till using tillage. And the whole concept of biology and relating it to soil compaction never entered my mind. And had I known Jim Hoorman at the time and he'd been able to educate me, we would have done a lot greater things than what we are able to achieve.

So with that, let me introduce Jim. Jim is the Extension Educator/Specialist in Putnam County for Extension Service there. He's been an extension educator for about 22 years. In his spare time, he's also an assistant professor at the Ohio State University there in Columbus. And when he has a few extra minutes on his schedule, he is working on his Ph.D. work in environmental science. He's trying to figure out the benefits of cover crops and how much [INAUDIBLE] leaching and run off, and all those [INAUDIBLE]. And besides that, Jim is coming around the country. He does a lot of public speaking. Very strong advocate for soil health. So with that in mind, Jim, I'm going to shut up and let you take over and educate us on the biology of soil health.

OK. All right. Well, we're going to talk about the biology of soil compaction. They asked me to put my mug up there, so that's what I looked like about seven years ago. I probably got a few more gray hairs since then. This is actually taken, I believe, on Steve Groff's farm when I visited there.

So let's get into it. When we look at a soil, an ideal soil should be composed of these different components. About 45% of it is mineral. That's just really ground-up rock. So you look at sand, silt, and clay. What's the difference between sand, silt, and clay? It's just the size. So sand is, of course, the largest, and sand will break down into silt, and silt breaks down into clay.

When I was taking some classes, they used to say that sand is just a clay factory. It will eventually break down. But as you look at this, about 5% of it should be organic matter. That's in an ideal soil. Now that would be in a clay soil. If you have a silty soil, you're probably looking at-- maybe 2% is a really good number. Possibly 2 and 1/2. You might even get it up to three, just depending on the soil. But 50% of that soil should be pore space. And if we're saturated, that would give us-- in a foot of soil-- almost six inches of water. But generally, we assume that it's about 50% water, so in an ideal soil, we should be able to store about three inches of water in that top foot. So this gives you an idea.

Now, I'd like to say that organic matter is extremely important. It's like the brains and your heart. It controls so many things. It's a buffer for a number of different things. And it's really important when we're talking about soil compaction and soil structure.

Here's some common bulk densities. When you look at uncultivated, undisturbed woodlots, for example, we should have somewhere between a bulk density of 1 to 1.2, maybe 1.3. And when we talk about bulk density, the lower the number, the less dense it is. So what we're looking at is-- and this is all in metric units. We've got grams per centimeter cubed. So what we're doing is we're looking at the weight divided by the volume. And we're measuring the solid portion of that. So 1 to 1.2-- that's going to give us roughly about 50% pore space. 1.3--

And the question I have to ask you is what is the highest bulk density which you can have? The answer is 2.65. So if we're around 1.3 divided by 2.65, that means about 50% of that is pore space, and about 50% of that is in the solid phase.

And so as we look at some of these different bulk densities, you go to a cultivated clay and silt loams, we can get up to 1.5, 1.7. Cultivated sandy loams-- actually, sand is a little denser, so we'll see it actually rise a little bit. It can be a little lower or a little [INAUDIBLE]. It's 1.3 to 1.7. And then you continue, as we get down to concrete, it's about 2.4.

Now, this was some information that came about-- that I found, I guess-- was that root-limiting, for most soils, is about 1.6 grams per centimeter cubed. It's root-restrictive at about 1.8. So if you look at some of these, when we get into this compacted glacier till, we're above 1.9. And any time you get above 1.8, you're definitely going to have your roots go off at a right hand angle. They won't be able to penetrate that. They don't have enough force.

Well, actually, we've got some new information. And this is now by soil texture. And you can see that those numbers apply to the sand, but when you get to silty soils, actually the ideal bulk density should be less than 1.4 in order to have those roots penetrated. And once we get greater than 1.65, it's too high, and the roots won't be able to-- it will restrict the roots.

And for clays, this number may seem a little low, but it's actually 1.1 or less is the ideal bulk density for root growth. Once we get above 1.47, the roots are going to be restricted in how much they grow.

So we're starting to see some of these numbers come out. Here's typically what we see when we plow the field. And we talk about the plow pan. Generally what happens-- in an undisturbed soil, the bulk density will gradually rise. And it will gradually get a little bit-- the number will increase. But when we have a plow pan-- you'll see here about seven, eight, nine inches-- we're reaching a bulk density of 1.9. So what typically happens is a corn root will go down through that a soil profile. When it hits this compacted zone, those roots will go off at a right-hand angle. So we're really restricting how much water, how much nutrients a plant can get when we do that.

I've seen this demonstrated quite well in Minnesota. We had a farm out there that we visited. And they had very nice soils. It was very dark. A lot of organic matter. But unfortunately, they plowed both their corn and their soybeans. And they had a very restricted layer there about seven inches down. They were complaining that they couldn't get more than about 135 to maybe 150 bushel of corn in most years. And it was because of the lack of moisture and the lack-- those corn roots would go down to that compacted layer, go off at a right-hand angle, and when it got very dry out, the soil-- that corn could not produce. Now it probably had the capability of going at least 180 to 200 bushel, but because of this compacted layer, it was restricted in how much yield it would go-- how high it would go.

And when we're looking at soil organic matter, we like to talk about, again, the density. And soil organic matter has a very low density. You're looking at about six grams per centimeter cubed. Versus if we look at, say, the average of a typical soil might be 1.45. Again, we're looking at that bulk density, to mass divided by the volume, so the weight divided by the volume. Soil organic matter has a lot less density than the soil, so it has more space for air and water. Every pound of soil organic matter can hold about 18 to 20 pounds of water.

So we like to use a sponge to represent what that soil organic matter looks like. And actually we've got a nice picture here. And this came from Brady and Weil's. On the left you'll see organic matter. You can see the black spaces in there. Those are the voids where air and water can be stored. On the right-hand side, we've got an electron microscope of clay particles. And look at how they stack up. They're much denser. They're much tighter together.

And so, we can actually-- clay can hold some water, but it won't hold nearly as much water as what the organic matter holds.

So just to take a look at some of those properties, here's compacted soil characteristics. And so the density we typically see- it's not uncommon to see 1.6 to 1.8 on clay soils, versus, say 1.45 on a regular soil. Compacted soils have higher density than the regular soils, so again they have less space for air and water storage. Dense soils act like road or pavement. They, a lot of times, will result in flash floods.

So what happens is-- think of an accordion. And when you stretch out that accordion, you've got a much wider area. But when you compact it, what you're doing is you're getting rid of-- the part that we're losing is all the pore space. And as we lose pore space we have less room for air and water to get into the soil.

So also, a common thought here, or thing we need to recognize, is that dense soils have much less microbial and biological life in it. Typically, the microbial life that we'll see in these dense soils is mainly going to be the bacteria, because they are extremely small.

The fungus, which send out these hyphae and this net, have a much tougher time moving through these dense soils. And typically, dense soils-- they're dense because they've been tilled, and we've lost soil structure. And that's also detrimental to these mycorrhiza fungus. So we'll talk a little bit about that as we get into soil structure.

So here are three soil compaction factors. Most of us are aware that heavy equipment, because of their weight, will compact the soil. But did you know that rain and gravity also compact the soil? So if we get, for example, say, a 30 to 35 mile per hour rain, that has a tremendous force. And when that rain hits the soil, it can actually compact the soil. So let's say we used to plow the fields. And we would kind of fluff it up. And then once the rains would come, and the combination of rain and gravity would then make that soil settle back down, and it would become much more dense.

There's also something-- we'll show that in just a little bit-- what's going on there with the soil structure.

But is there a visual way to measure soil compaction? Well actually, I noticed this coming home from school when I was taking some of my Ph.D classes. That as I was going down the road, I noticed that wherever we had a fence row or a woodlot, or even a pasture, it's not uncommon now that we're actually driving down into our fields. And there was an elevation difference there anywhere I went out and measured it. And I had a couple professors I brought this up, and they said, well, that was soil erosion. I said, that's not possible. Six to nine inches of a soil erosion would mean that we would be in the subsoil. They said, well it's, probably soil that blew over onto the fence row. I said, well, I took the measurements on the lee side of a woods, away from the prevailing winds.

And so we were typically seeing six to nine inches of elevation difference. And we got to looking through the literature, and yes, this is about how much soil our soils have compacted. So what's happened is, is with the tillage-- and you'll see this especially on the end rows. And if you're next to the woods-- at least in Northwest Ohio-- we typically now will see water running off of the woods onto our end rows, because we've actually compacted our soil.

Think of that-- again, think about how we can shrink that soil. We're taking all that pore space out, and what's happening now is the water tends to stand on our end rows around the wooded areas. And the water actually moves out of those areas.

Well, if 50% of that area-- of this six to nine inches-- should have been void space, that would equal three to four and a half inches of additional water storage capacity, or least air and water that we could maybe store in that soil. Is that significant during a drought? And the answer is yes, it is extremely significant. So we need to be thinking about that.

Here's a very common chart that's been used by a lot of people. This shows the soil organic matter and available water-holding capacity. This is in inches of water per one foot of soil. So if I have 1% soil organic matter and I have sandy soil, I can store one acre-inch per foot of soil. If I have a silt loam, I can almost store two. So it's 1.9. Your silty clay's about 1.4.

As we increase the organic matter in these different soil textures, you'll notice I can get up to 5% organic matter. That might be a little difficult in a sand, but if I could reach that I, could store about two and a half inches of water per foot of soil. In a silt loam, almost four, and in the silty clay loam, almost three. Again this is per foot of soil. So, if I have a three-foot soil profile, typically what happens is that the soil surface will have a little bit more organic matter, and then it will decrease as we go down. So let's say I have 1 and 1/2% I gain at the top. Say in the [INAUDIBLE], and then [INAUDIBLE] next foot I gain about 1/2%. With every additional 1% organic matter, I'm going to be gaining, on average, almost three acre-inches of water.

And that is tremendously important, especially in our drier regions. But the silty loam soil, I can almost gain two inches. So that's almost the equivalent of three inches. It's actually about 5.7 with that 1% additional organic matter. So that's extremely important. And hopefully we can take advantage of that by adding roots to our soil and adding the organic matter.

Soil-inherent properties. When we look at the available water in the soil-- you look at the sand-- the available water is just the difference between field capacity and the permanent wilting point. At field capacity, our soils are basically saturated. And you'll notice here with the sand, there's not as much of a difference. Where we gain the most is with a loamy soil. A loamy soil is a mixture of sand, silt, and clay. That is also high in organic matter. That's where we have the most available water.

And as you look at the clay, actually we have-- at field capacity-- we have quite a bit. But those clay particles hold on to that water. Water is a bipolar molecule, and it has positive and negative charges. And so that clay, having a negative charge, holds on to that water. So there the permanent wilting [INAUDIBLE] up tremendously. We have a little less available water to that plant.

So it is-- available water is largely an inherent soil property. So what can we do about it? Is there anything we can do? Well, there is one thing we can do. We can add organic matter. So as you look at some of these soils-- and this is some information from Ohio-- you'll notice when we have a drought-- we had a major dry period here in 2012-- it is related to weather. A 200 bushel of corn crop needs approximately 22 inches of plant-available water.

In Ohio, we typically receive 19 to 23 inches of water from April through September. However, it's not too often that we raise 200 bushel corn. Now, this last year, we actually did that. But we had a tremendous amount of water-- rainfall-- this summer. So rain makes grain. The more rain you have-- but if you're lacking for rain, what about getting that water from the soil profile? And the question you have to ask yourself is, do I have the soil structure in place so that when it rains, that water slowly infiltrates into the soil? And then can I store it? And the way to store that is by improving your soil structure and also increasing your organic matter.

Again, every 1% organic matter can hold anywhere from one to two acre-inches of water. One pound of organic matter can hold 18 to 20 pounds of water. So you have to think about what's going on with your soil structure.

Dynamic properties-- this infiltration. I can remember when we had this dry period. The farm right across from me had been tilled. He tilled it two or three times. We got an inch of rain, and my guess is probably he absorbed no more than maybe a quarter of an inch of it. The other three-quarters ran off. It happened to run on my field. [INAUDIBLE] Thank you very much. Because I had no-till, and I had some cover crops there, the water infiltrated.

But take a look at this. Where you plow the surface, and you have a cultivated field with a bare surface, water infiltration rate after one hour. This is in acre-inches per hour. This is some Ohio data. It's about 0.26.

Now take a look at no-till. And most people assume that no-till's always going to be better. But once you take away that organic matter, what we call that armor, as Jay Fuhrer likes to say, that armor on top of the soil, that really decreases the amount of water infiltration.

Now when we get it up to 40% cover, we actually almost double where we plowed it. We're up to 0.46. And if we have 80% cover, we can actually go four times higher. So we have four times more water infiltration where we have no-till and cover.

And that's what we're talking about. We're starting to talk about this ecological farming. The goal is not to till your soil. Long-term no-till. I like to call it eternal no-till. That would be our goal. Along with live crops year-round. That's what we're calling ecological farming.

And the reason this works so important is because it very closely mimics Mother Nature. So if you think of a woods, or a forest, or a long-term grass that's been, maybe, in pasture, those very closely mimic Mother Nature. We have live roots there year round, and because of that, we'll have better water infiltration. We should also have higher storage because that residue prevents the soil from crusting. As we get the better infiltration, then, and we add organic matter to that soil, we should be able to store a lot more water.

Let's take a look at some common practices that have a negative impact on soil health. Here's a soil that has very little structure. A common practice-- in northwest Ohio anyway-- is we will do rotational tillage. We will no-till it one year, and then the following year, we'll go through and do some light tillage on that. And when you do the tillage, what you do is you add oxygen to the soil, and by adding that oxygen to the soil, you burn up the organic matter. And so what we'll see is that the water, then, because we have poor soil structure, the water will pond on the soil surface.

And the other problem is on the right. Once that water starts to pound, it starts to gain speed, and pretty soon we start to lose a lot of nutrients that are flowing off that soil.

Here's a field-- a long-term no-till versus a rotational tillage. These fields were just less than a quarter of a mile apart. Same rainfall event on May 15. We got 3/4 of an inch of rain. And you'll notice on the left-hand side, where we have long-term no-till and strip-till corn. We have a little better soil structure. The water was able to be absorbed. Just 3/4 of an inch of rain, and look how much ponding we have on this field on the right-hand side.

And at this time, I might talk just a little bit about-- think about these soils. These are clay soils. These are typically [INAUDIBLE]. And so if you can imagine-- I like to do this demonstration with bricks and sponges and we'll try to do this. Now, you have to imagine that you have a brick in one hand and a sponge in the other. Both are about the same size. So which one's denser? Well, we all know that the brick is denser. And if I were to stick them both in water, which one would hold more water? You know, it's interesting-- the brick will actually absorb water, but the sponge will absorb tremendously more water because it has a more porous soil structure.

So let's think about how we made that brick. We took subsoil, which is clay. And we put it in the furnace. We burned off the organic matter. And we dried it. Now my question to you is, what do farmers do when they till their soil? They turn over the soil. They bring the clay to the surface. They let the sun dry it-- burn off the organic matter. And guess what? So what do we call a brick laying on top of the soil? We call it a clod.

You've probably all seen farmers that have done this. They will get their fields extremely fine. They'll work it a number of times. When we get a heavy rainfall, what happens? It will crust, and it'll get just like a brick. So let's think [INAUDIBLE]. The clay has a negative charge. And if I have two bricks, and I put them side by side, since the clay has a negative charge, if I add a positive ion, like calcium, magnesium, or potassium, those two bricks are going to set up like a brick wall.

We call these individual soil particles microaggregates. And a little bit, we'll talk about macroaggregates, and we'll explain what's going on there.

Here's some data, and I'll show you a field that we have in northeast Ohio, where we had a conventionally-tilled field. And you'll notice the water coming off of that is very dark. It has a brown color.

It's taking a lot of nutrients with it. On the right-hand side, we have a no-till field. And you'll see the clear runoff coming from this no-till field. This is where they put on an excessive amount of a simulated rainfall to show what the difference in the color.

Actually we've done this experiment for the last 30 years in northeast Ohio. Where we had this conventionally-tilled field, we had a total of over 1,500 inches of runoff. How much runoff do you think we had where we established a no-till field 30 years ago? We had a total-- over that 30 years-- of seven inches of runoff. A tremendous difference in the amount of runoff coming off the field.

And something that we could do to actually increase this no-till field would be if we were to add a cover crop to it, and very closely mimic Mother Nature. We could actually add a tremendous amount more of organic matter to that field. And we could store a lot of the water that we would apply to that no-till.

Generally, with no till fields-- I'll show you a slide in a little bit-- they have very big macropores. The water can get into the soil very quickly. But the key part is that we're missing that extra organic matter in order to store that water long term. So I'll demonstrate that in a little bit.

Saving nutrients in the soil is related to the speed of water. If I double the speed of water, how many more nutrients can be lost? And as you look at this slide, it's exponential. It goes from 2 to the 6th power. So if I go from 1 mile per hour to 2 miles per hour, I actually increase the amount of nutrients that can be lost, because of the speed and energy that's stored in that water. I can lose 64 times more nutrients. If I go from 1 to 4, I'm up to 128. From 1 to 8, 256. If I go in some of our road ditches, we actually have water that's running somewhere between 20 and 30 miles per hour. I could be losing almost 1,000 times more nutrients with that water.

So our goal now is to use no-till with the cover crops in order to slow that water down, increase that infiltration rate, get the water to move down through the soil, take away its energy, and as it slows down, it will start to drop any nutrients that are there.

Plus, If we have live roots there, my question to you is, what do live roots absorb? They absorb soluble nutrients like nitrogen and soluble phosphorus-- soluble reactive phosphorus. So by having those live roots there, we increase organic matter content, we slow that water down, and we have the opportunity, then, to absorb a lot of those nutrients.

This is a slide that I produced. When we're seeing what we're seeing here in Ohio, we're starting to see the flashiness. We all know what a flash flood is. We're saying that the same thing in the northwest Ohio, because we have such poor soil structure on a lot of our acreage. When it rains, the water washes off the surface that's very saturated in nutrients. And typically, what happens-- it gets into our ditches and our streams very quickly. You'll see this dirty water. And so what happens is the water goes up very quickly, and then it drops very quickly.

And where we have this ecological farming, where you have woodland, or pasture, or you have something living and growing year round, typically what happens is the road ditch or the stream will slowly start to come up. The water will be much clearer. It'll stay at that level for a longer period of time. [INAUDIBLE] slowly drop.

And we can actually show that on a hydrograph. So on the right-hand side, we have this conventional farming. And actually the area that is in the hatched area is the same under both of these. So what happens is, under a conventional farming system, the higher this hydrograph, the more flooding occurs. So most of this water will leave, say, in about two to three days.

Where over here, where we have the ecological farming, the no-till and the cover crops, we'll actually have the same volume of water, but it takes several days for that water-- the hydrograph isn't it nearly as high. So we have a lot less flooding. That soil can actually absorb that water. And [INAUDIBLE].

One of the things-- a common misperception among our farmers is, we need to get rid of that water as soon as possible. The answer is, that's only partially true. We just need to get enough water so that that plant can survive. We do not want completely saturated roots. But if we have even just an inch of free board there, where those roots can get some oxygen, that plant can survive having that water. And that water can slowly go through that soil profile. It slowly goes through the soil profile. We can absorb a lot more nutrients.

And it's not uncommon-- I hear this all the time. We will get a one- or two-inch rainfall, and within a week, farmers will be coming to me saying, you know, I wish we had another rain. I said, well, didn't you just get one to two inches? And they said, yeah, but it all ran off.

Well, what we need to do now is look at some of these natural processes. By increasing our water infiltration, adding organic matter to the soil, we can store a lot of that water. Because Mother Nature doesn't always give us the amount of water exactly at the time we need it. Organic matter is a way that can help us with it. It can act as a buffer in the soil for both nutrients, water, temperature, pH, and cation-exchange capacity.

If you look at where most of the water is taken up by these plants, this also relates to the nutrients. It's almost exactly the same. 40% of it's going to come within that top six inches. Another 30% will probably come in that next six inches. We're getting at about 30% of our water below one foot.

Now if you have a very porous soil-- this would be for a clay soil-- if you have a very porous soil where you have more sand, this triangle probably is a little more aggressive. It may actually go down that three to four feet in the soil. So where we have more pore space, the roots can get down a little bit deeper and pull water from deeper in the soil. But this is some data that came from a typical clay soil.

What about those hot dry summers? As we're looking at corn production, I put this in here because this is a really important. We just came out of a drought. At 75 degrees Fahrenheit, we use about one acre-inch of water per week . When you add 10 degrees Fahrenheit, for every 10-degree increase in temperature, we double our water requirements. So at 85 degrees, we need two inches. At 95 degrees-- this is the soil temperature-- we need about four inches of water per week for the corn. So heat and drought together very quickly increases your yield loss because of this detrimental effect on the soil.

So I think at this time, we were going to take some questions, David, if you have some. I think we're about halfway through the presentation.

OK, yeah, I do have a couple questions, Jim. Does the thickness of the compacted layer have a role? I mean, does it have to be an inch thick, two inches thick, before you start to restrict root growth?

Well, generally what will happen-- let's just assume it's at least an inch deep-- all roots will find planes of weakness. So the thicker that zone is, the more difficulty these small roots-- and what I like to say these small roots are is, if I'm going to drill through concrete, do I start with the big bit, or do I start with the small one? We typically will use a very small bit and pre-drill a hole. And so when we have grass cover crops that have very fine roots, they can find small planes of weaknesses.

Now, the thicker that compacted layer is, and the denser it is, the harder it is for that root to squeeze through and try to-- And once it squeezes through, what will happen is, the next plant-- if it's a corn plant, or a soybean plant that follows it-- they follow the same planes of weaknesses. They'll follow the same root, and they'll gradually start to break up that soil compaction. They'll come together, and then they'll expand, and they'll gradually kind of wedge that crack open a little bit, and they'll start to break down that compacted zone. So it does-- the deeper-- if you have a very thick compacted layer, it's going to be much tougher for you to make improvements if it's just a shallow one.

And I'll come back to something that's occurring, now. How many people are doing vertical tillage? Vertical tillage is where we go maybe two to three inches deep. We just lightly fluff that soil. Guess what? We're finding a tillage pan. It may not be quite as dense as this hard pan that I talked about, this plow pan, but we're finding that these tillage pans are restricting water infiltration. And that's very, very important. Because as we restrict that water infiltration, we're going to have more of that water run off the surface. If that water starts to pick up speed, it's going to take-- we've got saturated-- we typically have more nutrients-- are in that zone, and as that water picks up speed, it's going to take a lot of this valuable nutrients with it. So it's important how thick it is.

I had another question related to that-- was the use of the penetrometer. Is there a-- [INAUDIBLE] just could explain how you might be able to use that and pick up these compacted layers, and maybe their measurement--

Typically, I think, if I remember right, and this is going back a little ways. We used to use a penetrometer. Usually they'll give you inches per square foot, I think, or what is it? Pounds per square inch. That's what it is. Pounds per square inch. I got to remember because I haven't used a penetrometer-- And I think the number that sticks in my mind is about 250 to 300 is a very dense soil. That's kind of related to that 1.6 and that 1.8. So you want it to be less than 250. Once it gets over 300, then the roots cannot penetrate it.

So if you're using a penetrometer, they are very sensitive. But they do give you a lot of information. You can use one of those-- penetrate your soils-- take a look at what the-- how that will go down through your soil profile. If you can push it down and have very little resistance, then you have a very porous soil and obviously that is what we're looking for. So farmers have used those.

Let me ask-- I've got two quick questions. Someone wanted to suggest-- a couple people suggested a fourth method of compaction would be grazing. Do you have any comment on that?

Yes. If you overgraze, you can compact the soil. Typically where we mob graze, and we only keep them on for a very short period of time, we don't see as much compaction. But for example, if the cows are all following each other, and--

I hate to bring this up, but let's say that you-- think about a high-heeled shoe. A woman-- a 120-pound lady in a high heel with a spike on it has a tremendous amount of compaction. Matter of fact, the pounds per square inch is greater than an elephant. Because you've got all that weight just on that little spike, and that's putting tremendous force on a small area of soil. So with the hooves, if you've got, let's say, a 1,000 pound animal-- we'll just use 1,000 pounds. And you've got four hooves. And I don't know what the area is. Think about how much weight-- you've got 250 pounds in that small area. And if you have a lot of animals doing that, you can compact soil.

Now let's go back to my bricks. Remember the brick and the sponge. The more organic matter that you add to a soil-- think about if I had two bricks and I put a sponge in between there. I can compress those, and if I have organic matter, it will actually decompress those-- So I can put weight on those bricks, press them together, and that sponge has any rigidity to it-- if it's a normal sponge-- it will actually allow that soil to [INAUDIBLE] just about like that accordion. It will pull back apart again.

So it's very important. If you over-graze a soil, what happens? I've got a picture, I believe, that's coming up. You'll find out that you'll have a lot less roots. You'll have a lot less organic matter. Typically, we get about 50% growth above ground, 50% below ground. That's at maturity. But if you have, say, three to four inches of grass growing above ground, you may have 21 to 30 inches of roots. And that can help. If you've got animals grazing that, it's just like that brick with that sponge. They can actually-- it cushions. Organic matter cushions the blow. As long as they don't stay there and continually go over it. If they graze that way down and then the roots die off, pretty soon you're going to find that that soil what will become compacted. So the key thing is don't overgraze your pastures.

I think we'll hold any more questions 'til the end there. So why don't you go ahead and proceed, there, Jim.

All right. So this is something that typically farmers will see. They will see these compacted layers where they go on these ruts in the field. And if you have a situation like this, how do I handle it? Well, probably the best thing to do is, rather than-- you can see as you look across this picture, there are some rutted areas, but it's not the whole field. Just-- if you have to do tillage to level these out, only do the tillage right where the ruts are, and leave the rest of the field alone. And unfortunately, most of our farmers, once they get started, they think that they have to have to do the whole field.

So as we're looking at these dynamic properties-- this rooting volume-- the thing that I wanted to call your attention to-- here on the right, we have a no-till field that has a lot of roots in it. Compare that to the structure on the left. It looks almost like a concrete block. So it's all related to the arrangement of the soil particles, the root development, the water infiltration.

Some interesting facts. Compaction can reduce your yields up to 60%. I just got some data from Australia. Tim [INAUDIBLE] said where he went to controlled traffic, he was able to increase his yields anywhere from 10 to 40%. So this 60% would be where we really severely compacted our field year after year.

The other thing is, compaction has been shown to persist for up to nine years in a field. Just natural freezing and thawing will start to break up some of those layers of compaction, but it can persist for quite a long period of time.

As we look at increasing that root volume, we're going to now talk about aggregation-- soil aggregation-- and aggregate stability. All these promote biological activity. They increase the organic matter. No-till is a good way, but no-till with a cover crop is even better. We want to prevent that slope compaction, and in order to prevent that, you need to stay off soils that are wet.

Where we have controlled traffic, or managed traffic, the first time after you till a soil, or the first time you run across that soil, 80% of the soil compaction from that wheel traffic is going to occur with [INAUDIBLE] first pass. So tillage is a short-term solution. Generally it lasts only about a year.

If you want long-term solutions, you've got to add roots to your system. And the best way to add roots is to grow your main crop-- follow that up with the cover crop. The goal is to have live crops growing year-round, 12 months out of the year if at all possible.

Let's take a look at how these ruts-- how they form. Here's a tractor wheel. And notice with the weight, I'm pushing down onto that soil, but there's also soil underneath it. So what happens is, a lot of the soil gets moved to the side. But there's already soil there. So what typically happens is that we'll start to form this typical hump. So this little bit of a hump in the soil. So typically, if we're going level, we'll have a little bit of a hump. And then we've got our deep rut, a hump, and then the soil will level off.

And it's interesting. If I take a disc, and I actually disc that-- If you've ever disked shut a rut, you'll notice that it seems like you've lost soil. What you've actually done is you've compressed that soil, and that loss is that 50% loss of void space. So compacted soils tend to have less void space.

Typical soils that we have now probably have lost any where from 25 to 35% of their void space in the soil.

But let's take a look at this root. This is an oilseed radish-- a tillage radish, I believe, in this case. Roots actually do the same thing-- they take up space. And so we've got this big root. It pushes down, it pushes this soil to the side, and then it physically lifts the soil. So roots compact the soil, but they compact the soil with a purpose. And we'll show you what's going on here.

So we've actually taken some measurements on soil compaction. This was done on Dave Brandt's farm, southeast of Columbus, Ohio. And here's what we found. Out in the open field, compared to where we had the radishes, compaction decreased by greater than 40%. So things like oilseed radish, sorghum sudan grass, annual ryegrass, cereal rye. These are all very good plants that can be used to decrease soil compaction. We generally say that most of these roots can penetrate the soil about a foot of soil. If the soil's very compacted or has very poor soil structure, we can gain about a foot per year. So that's why it takes a little bit longer. If I'm going to use roots, I may be able to penetrate about a foot per year. If I have poor soil structure all the way down-- say three feet deep-- it may take me two to three years to break that soil up and to improve that soil structure.

Here's what the roots and the fungi-- the hyphae-- do. You'll notice these are clay particles, and these are the roots. They realigned these clay particles. We call these individual clay particles-- we call them microaggregates. And these may be a combination of-- there may be a little bit of roots in there, a little bit of organic matter. But as we realign these, we will compact them together. And then what will happen is a root will give off some root exudates. And we'll get some glomalin from the mycorrhizal hyphae. And what we will form is something called a macroaggregate.

So if you want to see what a microaggregate looks like, they're about the size of a small piece of sand-- maybe a piece of gravel. Just dig up some soil in your lawn. Dig it up and kind of shake it, and you'll see these little soil pats that are all attached to the roots. Those are macroaggregate.

So here's a question I always like to ask my farmers. I say, if you have a lot of clay in your soil, wouldn't you like to have some sand and gravel? And Mother Nature has a way to do that. If you can grow more roots in there, you can actually form these macroaggregates. That will let air and water go down through your soil. Now the interesting thing is, these are all-- these macroaggregates have these polysaccharides and all these microbial waste around them. They're actually insoluble. That means they're coated with this material, and the water will actually be shed off there.

It's interesting-- inside these macroaggregates is stored a tremendous amount of carbon. And these macroaggregates serve two functions. If I take a macroaggregate and take one of these pats, put it between my fingers, I can turn it into a microaggregate. That's what happens when you till the soil. And we all know when we till the soil, that's going to be like those bricks. They're going to set up just like a brick wall, so it's going to form a crust.

These macroaggregates may only last for a couple weeks-- a couple months-- a very short period of time. The microbes use the glues and all of these wastes. And that is their food source. So they're continually being formed and reformed in the soil, but if you don't have live roots there, you're going to lose them after a couple months. And that's what causes our soils, then, to lose its soil structure. So live roots are very key to having good soil structure.

Here's the bacteria. They're associated more with the microaggregates. They're breaking these down. 40 to 60% of the soil microbial biomass is associated with these microaggregates, and that's where the bacteria is. They're the ones-- 90% of the bacteria are linked to this clay. And that's why, in very poor-structured soils, we have a lot more bacteria than we do fungus. If we want to increase the fungus, we have to stop the tillage. We can't over-fertilize. Too much fertilizer and tillage kills off the fungus. The fungus are going to give you that glomalin.

And so here's what this macroaggregate looks like. These very small gray ones are the microaggregates. This macroaggregate is all these pulled together. And then it's kind of got this-- either glomalin, or these polysaccharides coating them all together in a microbial waste. That's what helps to form these macroaggregates. If I till the soil, this will break open, and very quickly, the microbial population, especially the bacteria, will consume all these polysaccharides. And all I'll be left with is microaggregates. And that's why our soil then starts to-- we start to have poor soil structure.

These are these mycorrhizal fungus. You'll notice how they infect-- this is a corn root. And look at the size of them. These are about 1/10 the size of a root hair. These mycorrhiza can actually explore 20% of the soil. A corn root by itself can only explore 1% of the soil.

And what these mycorrhiza do is they're like a freight train. They're bringing back water, bringing back soluble nutrients-- nitrogen, sulfur, phosphorus-- all these micronutrients back to the corn plant. The corn plant, in exchange, is feeding these mycorrhiza and giving them sugars in order to survive.

Where we have too much tillage-- too much phosphorus-- then we tend to have less microbial biomass in the mycorrhizal fungus. And here's a mycorrhizal fungus. Which one is it? It's actually the white ones. Sometimes they'll be a little bit yellow. Just in a handful of soil, we can actually have several miles of these mycorrhizal fungus. That root hair is actually a little bit brown. And these mycorrhiza will tend to be yellow or white.

And when they die, or when they start to-- if one of them is broken off, what happens is this glomalin, or glomulin, that's what surrounds this soil particle, and that's what gives our soils good soil structure. So this is going to help to form those macroaggregates. So when I go and dig in a soil that's very healthy, and the soil just crumbles, that means it has a lot of fungus-- a lot of these macroaggregates in the soil.

Building soil is like building a house. The architecture is Mother Nature. We have the plants. We have the sand, silt, and clay, which is our foundation. The roots are going to be the frame for our house. The nails are going to be the humus. The lag screw will be the phosphorus. We've got braces-- that's going to be the nitrogen and the sulfur. The polysaccharide is kind of like the insulation or the glue. And the glomalin is kind of like the house wrap.

And then we have this roof. So let's take a look at this.

Here's a typical house. We start with our foundation. If you're in a room, just look at the pore space that you have around you-- all the air. Why is that there? Because generally we tend to have wood studs in a house. And so that wood is going to be attached to our foundation. If this is a brick wall, we're going to use the phosphorus lag screws to attach that together.

Carbon, by itself, is almost like spaghetti. It's very flexible. But when I add double or triple bonds, and I also add some nitrogen and sulfur to it, it has rigidity. And so those are going to act like the places in the soil. They're going to give our soil room. That we add more pore space. The nails are kind of that long-term humus that's been around for 10,000 years.

The glomalin is kind of like the glues in the house wrap around the house.

And then we have our roof. Now it's very important that you have a thick layer of organic matter on top of your soil. So imagine if every other year, we had a tornado come through. This tornado's called tillage. If the roof came off of my house, what would happen to the interior of my house? If I can't get that roof replaced for a while, we're going to get rain inside the house, and my house is going to start to rot out. The wood will rot out, and my house will collapse.

What happens in the soil? It's not too much water. It's too much oxygen. Too much oxygen causes the organic matter to be oxidized. It's burned up. It's just like if you have a wood stove. If I open the damper, fire's going to burn brighter, and we're going to lose all that carbon-- will go out the smokestack.

Same thing happens in soil. You put too much oxygen in there, we're going to lose it. So it's very important that we have a thick layer of residue on the soil surface to keep the amount of oxygen and carbon dioxide in the soil in the proper proportion.

And so oxygen and carbon dioxide are inversely related. Carbon dioxide is heavier than the oxygen. As one goes up, the other goes down. So if I open a soil up, all the carbon dioxide to escape. And I'm going to have more oxygen. The microbes are going to flourish, and they're going to eat up all these glomalins and polysaccharides and glycoproteins. All the glues that I need in my soil to give me good soil structure.

Here's what happens when we break open those macroaggregates. You'll notice the carbon dioxide being lost-- the oxygen coming in. And so we end up-- we go from a macroaggregate to microaggregates. Microaggregates are the ones that set up like a brick wall. Those are the ones that are going to form your clods in your soil.

Wrong way, sorry about that. So what about if I have cold no-till soils? Typically farmers will tell me that when they start to farm, they're starting in no-till, their soils are cold and wet. When I talk to long-term no-tillers, they tell me their soils are warm and moist.

So what's the difference? Well, imagine this-- is you come out of the winter, and you went from a conventional-till field, to a no-till field. Did you get rid of all your soil compaction? Probably not. So what you've got, typically, is you'll have zones. You'll have a lot more water. So we come out of the winter-- is we have this water stored in the soil profile. Probably a saturated soil profile. Water holds the heat. It also holds the cold. So it takes 10 times more energy to warm up water than what it does air.

If I have very good-- if I put in a nice cover crop, and I can break up those compacted zones-- get that water so it will drain through that soil, I actually can induce a little bit more oxygen into that soil. And by doing that, I will warm that soil quite quickly.

Now, didn't I just say oxygen in that soil might be a bad thing? Here's the thing. Remember we told you that those macroaggregates were insoluble, and most of the carbon is tied up in there? If we can control this, what will happen is they will slowly break even open. It's not like we have the a big rush of air. When you go through and do tillage, you're really disrupting those macroaggregates. You're breaking them open. But now that we're using roots, we're a little more gentle. We're not going breaking open those macroaggregates as much. And even though we've got a little more oxygen in there, we're not putting all those forces on there to break those macroaggregates.

Now let's go out another two, three years. And let's say we're starting to get some residue on top of our soil. What color is to residue when it's down? It turns black. And black will absorb the heat. It will help to warm your soil.

Let's go out another two, three years. Let's say now we're starting to get a thicker layer of residue. And when you do that, what happens in the middle of a compost pile? It actually starts to heat up. Actually, it's very difficult to get thick layer of residue. Because most long-term no-tillers tell us they have so much biological activity that that residue actually breaks down quite quickly. It's only these conventional farmers that are having that trouble breaking down their residue.

Are we getting close on time, David?

Yeah, Jim. I think if you're about at a point there, we might want to to wrap it up, unless--

All right. We'll make this the last one. As you look at your crop rotation, drilled soybeans have a poor root system. They have a thicker-- when you're following drilled soybeans with corn, that has a thick root system-- that's part of the reason why no-till suffers, especially that corn. If we can add a cover crop in between there, we can actually help that corn to break up those compacted zones.

So you've got to look at the percentage of time you have live roots. Does no-till have more live roots than conventional tillage? Not by itself. It's not until you add that cover crop. What's missing in the no-till? You've got to have live roots.

So this is basically a biological problem. You've got to have live roots in your soil to have good soil structure. All right.

All right, Jim, thanks. That's a lot of information, there, and again, I wish I had heard this about 10 years ago. And I would've been a lot more successful in my career out in the field.

I do have a few questions here I want to follow up on. A question about what's the role of earthworms? Do they mess up the compaction? Or have you got a comment on that?

Earthworms are extremely good at helping to form macroaggregates. And so I'm glad you asked that, because I actually have a couple pictures. You might want to tell people the slide set is available. A lot of the pictures-- not all of them are self-explanatory, but I'll explain two of the pictures that we're looking at.

What happens is, when you've gotten macropores, just by themselves, sitting in a no-till situation, with earthworms. The problem that we're getting is, we're getting a lot of very fast water infiltration. The water moves down through the soil profile very quickly. It takes a lot of soluble nutrients. And then a lot of those nutrients may be lost out the [INAUDIBLE].

But when we add a root, what we do is we add a root to that profile. And that's going to slow that water down. It acts like a biological plug. And it will move the water-- think of macropores as superhighways moving things very quickly. Now we're going to move that water into the micropores, and the biopores, and where the roots are. And then the roots can absorb that nitrogen, absorb that phosphorus, and reprocess it. So what we've done is disrupted some of these natural cycles in the soil.

Earthworms have been-- they've claimed that they're a problem. Actually, if you put them with live plants, they're not an issue. It's not an issue.

What about use of controlled traffic, and precision ag, and that type of system? Have you had experience with that?

Yes. What we're seeing is, where we use the controlled traffic. As I said, Tim-- I believe his name is Tim Robinson-- from Australia. He's been doing this for a number of years now. And Randall Reeder at Ohio State has some data.

What were finding out is that it is a little more compacted in that wheel track. But then outside of that wheel track will be down around-- bulk density in the wheel track may be 1.5 to 1.7. Just a small zone. But outside of that wheel track, it'll be about 1.1 to 1.3 grams per centimeter cubed.

So we're getting the exact-- what we want to. We want to have that good soil structure. And we're seeing yield increases of anywhere from 10 to maybe as much as 40%, or theoretically it's possible to get as much as 60% yield increase just by using that controlled traffic.

OK, good. Two more questions, then I'll let you go, Jim. I know you've already made one presentation today, and this is on top of that. So we appreciate your energy here.

A question about crops. You mentioned some good crops for residue-- or not residue, but roots. We have alfalfa-- would that be considered-- what are some of your-- give me your top five or six that you recommend.

Well, let me just go to that real quick. Here's some other information that we had. This is what subsoiling does. If you're doing conventional, you're going to get about a 3 to 10% yield increase by doing subsoiling. Without the subsoiling, if you're no-tilling, you're actually going to get a decrease. And so subsoiling will do just immediate changes, whereas the cover crops are going to be long term.

So I think I'm getting to that. Here's all the different soil resistance to compaction. And here's the best one. Continuous no-till, controlled traffic, cover crops. There's my slide.

The best cover crops to fight soil compaction are the sorghum sudan, the annual rye grass, and the cereal rye. If you're going to grow the sorghum sudan, let it grow up as a forage. Let it get about three feet tall. Either mow it off or harvest it. The reason we do that is because you get five to nine times more roots. That's a 500 to 900% increase.

If I'm going to use brassicas, use the radishes. Don't use the turnips because they're shallow-rooted.

For the legumes-- whoops, sorry about that. Use the hairy vetch, then the cowpeas, the red clover, and the winter peas. If you've got surface compaction, use buckwheat, and for deep compaction, you can also use the sunflowers. So those are some of the ways you can fight your soil compaction. So I actually got done here. That slide set is available if somebody wants to look at it. Most of those last slides are pretty much self-explanatory

OK. Well, I think I'm going to cut it off there, Jim. And again, I appreciate your effort. And I just thought and pondered that usually a woods left in the northern-- northeast-- or western Ohio farm was there because it was too wet. And now you're telling me because they're draining out of the woods into the cropland. Wouldn't our grandfathers be embarrassed about that?

It's interesting because we are now actually driving off-- when we go into our fields, farmers are noticing that there is an elevation difference. They are actually driving down into their fields. And that is due to the poor soil structure. As much as it is-- I mean what we call soil compaction-- a lot of that is actually poor soil structure.

Well, Jim, you've done a great job of it. Got a few comments here and the folks appreciate your effort. Very thorough and complete. And again, I want to thank you for your effort here. And I appreciate your time in this presentation.

As far as the participants, I want to remind everybody-- there are handouts, and the presentation is available at the conservationwebinars.net site, and if you want to get credit for this-- CEUs for whatever certification you're going after, you'll have to go back there, and there's very good instructions at the site. So with that, I'm going to call it a quit. And again, Jim, I appreciate your effort, and I look forward to seeing you next week out in Omaha.

Yes, we will see you there.

OK. And we'll call this quits for today. And I look forward to Thursday's webinar. Hopefully a lot of you could join us then too. Take care.