

Freida Blostein: Hi, my name is Freida Blostein, and I'm here with my co-hosts, Emily Crossette and Nicholas Medina, we're all doctoral students and fellows in the Integrated Training and Microbial Systems or ITiMS program at the University of Michigan.

Nicholas Medina: ITiMS is a program funded by the Burroughs Wellcome Fund and is dedicated to training students to investigate microbial sciences, using mathematical modeling, population sciences and laboratory techniques.

Emily Crossette: So Freida, Nicholas and I all study microbes and microbial communities, although we each do so in different systems and fields. I'm an environmental engineer and I study microbes in land applied manure and biosolids, which are resources which are recovered through waste treatment.

Nicholas Medina: While I study interactions between microbial communities, invertebrate activity and soil structure as an ecologist.

Freida Blostein: And I'm an epidemiologist studying how commensal microbes of different body sites, like the oral microbiome, can influence human health and disease.

Freida Blostein : So one thing we wanted to do in this podcast was play this kind of fun microbial game where we'll give you hints about a specific microbial species or genus throughout the podcast, and you can try and guess what it is before the end of the episode. So here's your first clue. The species name of this microbe means waxy in Latin and refers to the appearance of its colonies.

Emily Crossettee: It was actually at an ITiMS's retreat where we met Dr. Jo Handelsman, who broke some earth shattering news for us.

Dr. Jo Handelsman: The average rate of soil erosion across agricultural land is about 10 times the rate at which it produced, which doesn't give us very long for having productive agricultural land. And in many areas that will be it already is a crisis.

Emily Crossette: And that inspired this podcast series. In this three episode miniseries, we'll be addressing the soil crisis, the science of soil and some exciting scientific developments that may help ameliorate this crisis.

Freida Blostein: So first, let's talk a little bit about why soil is important and what's going wrong. And who better to ask than the pioneer in microbial sciences who sparked our interest initially, Dr. Jo Handelsman.

Freida Blostein: Dr. Handelsman is the director for the Wisconsin Institute for Discovery at the University of Wisconsin, Madison. She also served for three years as the associate director for science at the White House Office of Science and Technology Policy under President Obama.

Dr. Jo Handelsman: Well, soil is something that we depend on for first and foremost, probably most people would think of food production. And that's probably the single most direct effect of losing soil, is that we lose our capacity to produce food because ninety five percent of our food supply comes directly or indirectly from crops. And the other one is water quality, generally drinking water quality and all kinds

of water quality because soil is the biggest filter for water on Earth and we depend on the soil to process water that is contaminated at the surface. And by the time it gets to our groundwater, it tends to be a lot cleaner. And that's because of the action of the soil. If we don't have topsoil with all the nutrients and organisms that are acting on the water as it percolates through, then we're not going to have clean water. So there are several environmental and health issues that interface very directly with soil loss.

Freida: Before we talked to Dr. Handelsman, I could've guessed that soil was important for food production, but I'd never really thought about how important it could be for water quality too - but that makes a lot of sense.

Nicholas: Yeah, it really underlines for me how interconnected our environment is.

Emily: Yes! And how fragile the system is and how delicate the balance is between soil health and water quality!

Freida: Speaking of fragile, Dr. Handelsman also told us how soil and the microorganisms in soil intersect with something I worry a lot about... climate change.

Dr. Handelsman: It also is the biggest repository for carbon on Earth in terrestrial environments, contains between two and three times as much carbon in the atmosphere and probably about the same, roughly two to three times as much as all the plants and trees on earth contain. So as a storage house for carbon, it's incredibly important for climate change and both and can play a positive and a negative role. If we release the carbon that's in the soil, that can have obviously a negative effect, but it also has the capacity to hold more carbon than it currently does. The soil has some other potential to contribute to climate change. One of the things we found in recent years is that as areas that are under permafrost have begun to melt and and thaw, microorganisms that normally are quiescent and not very metabolically active are starting to release methane, which is a very powerful greenhouse gas, is about 20 times more effective as a greenhouse gas than carbon dioxide. And so release of methane is a very concerning problem. And as we warm the earth, more soils will thaw and more methane producing bacteria will essentially wake up and produce methane and then that will worsen the problem. So it's a truly vicious cycle of the behavior of soil microorganisms and climate change.

Emily: So soil can either be a huge force for preventing climate change... or part of the vicious cycle that enhances it.

Nicholas: Climate change is complicated. And soil is complex! That's why we need whole fields of scientific study to understand them.

Freida: Well, I'm super concerned about climate change, and I also love food and water.. Like, basically every human should..... So I'm pretty convinced that soil is really important.

Nicholas: Important AND vulnerable. We have a problem, which is that we are losing our soil at unprecedented rates. Dr. Handelsman alluded to that previously, but let's hear what she has to say more specifically.

Dr. Handelsman: So the challenge is holding onto our soil in the face of increasingly severe and frequent weather in the Midwest, in particular in this country. It washes the soil away or makes it vulnerable to wind erosion, which blows it away.

Nicholas: Dr. Handelsman mentions two types of erosion here, wind and water erosion. And these terms refer to the underlying action causing erosion. But regardless of how erosion is happening, it has devastating effects on the soil, breaking down the structure of the soil. And when the nutrient rich, topsoil is lost, there can be ecosystem wide shifts and loss of plant roots that help protect the soil from erosion to begin with.

Emily: So this becomes a compounding process, and different types of soil can be more or less vulnerable to these types of erosion.

Freida: Soil structure, soil types, what do these terms even mean?

Nicholas: Soil structure refers to the arrangement of solid parts of soil and the pore space between them is determined by how the solid pieces and the soil clump bind together and aggregate, which is influenced by the organic material, often microbes, that are a part of soil as well. Soils can be made of different proportions of inorganic material like sand or clay, and often that's what we mean when we refer to different soil types. We'll talk about this a little bit more in our second episode, too. So if you're intrigued, stay tuned.

Freida: And speaking of seconds, here's the second clue for microbe of the episode. Although rare, a variant of this bacterial species has acquired plasmids that enable it to produce anthrax, a deadly toxin.

Freida: OK, so that explanation of soil structure makes sense to me. And also I think I understand erosion a little bit better too.. Erosion takes away topsoil which can impact which plants can grow, which can lead to even more erosion. And of course, this isn't actually the first time we've had an erosion crisis in the United States, right?

Dr. Handelsman: That's right. And in the Dust Bowl, it was the Oklahoma, Kansas area that was so devastated by that. And it was precipitated by the way the soil was managed that made it vulnerable to erosion. And what happened was that it was precipitated specifically by a drought that made the soil very dry made it susceptible to wind erosion. What we're dealing with in the upper Midwest is more often water erosion, but the change in weather is precipitating a change in that kind of erosion and increasing the intensity of water erosion.

Nicholas: The Dust Bowl is such a serious issue that it actually made it into FDR, his famous fireside chats.

FDR (Fireside chat audio): I shall never forget the fields of wheat so blasted by seeds that they cannot be harvested. I shall never forget the field of corn stunted fields. And what the sun left the grasshoppers consumed. I saw a brown pasture, but would not keep a cow on 50 acres. Yet I would not have to think for a single minute that there is a permanent disaster in these drought regions, or that the picture I saw meant depopulating these areas. No cracked earth, no blistering sun, no burning wind, no grasshoppers are a permanent match for the indomitable American farmers and stockmen and their wives and

children who have carried on through desperate days and inspire us with their self-reliance, their tenacity and their courage.

Freida: Time for another microbe clue. This microbe is not all bad. It actually can enhance plant growth partially through the natural production of antibiotics, which inhibit the growth of plant pathogens.

Freida: The Dust Bowl was incredibly grim... and the effects were pretty far reaching. I just read an article from 2015 which showed that individuals exposed to soil erosion during the dust bowl were less likely to finish college and more likely to experience health problems and poverty later in life - especially if they were exposed in utero which means they were exposed. before they were even born*.

Nicholas: If soil erosion has been happening in the United States since the 1930s, why don't we have any solutions? Like FDR was saying, isn't there something farmers can do to increase the quality of their soil?

Emily: Well, one of the approaches to repair soil is applying biosolids from wastewater treatment plants or manures. These amendments are rich in nitrogen, phosphorus and organic carbon, which can help rejuvenate soil and fertilize crops.

Freida: Are biosolids, like, poop?

Emily: That's a good question. Poop is actually the original soil amendment but biosolids today are treated byproducts from wastewater treatment plants. You can actually really think of them like microbe poop because microbes in wastewater treatment plants eat our waste that we flush down the toilet and then when they get so fat, they settle out of the wastewater. We collect those settled solids and further treat them and concentrate them before applying them to land. Since my dissertation research explores the microbial communities in land applied manure and biosolids, I was curious about Jo's perspective on its role in soil health.

Emily: So as an environmental engineer, I particularly study the land application of biosolids and manure for agricultural production, and it seems like, you know, this is an important resource recovery pathway that keeps kind of the loop of, you know, we take the carbon plants are taking that fixing carbon from the atmosphere. We harvest those plants, we consume them, and then they go back into our waste streams and then we reapply them to soil. Where are the losses still coming from? And why isn't land application returning organic carbon to the soil through these waste streams enough?

Dr. Handelsman: Well, there are several reasons for that. One is no process is, of course, 100 percent efficient. So at each step in that process, we're losing carbon to either the atmosphere or to make human tissue, for example, if you're eating those products or in the waste that results even from the agricultural the crop process. But the other thing is that we're not reapplying the biological material to most of our farmland and we're using chemical fertilizers, which are made at very high cost of fossil fuels, and that also leach much more easily than biological materials nutrients do. Which means that they end up contaminating groundwater or surface water, lakes and rivers and streams. And then the final reason is that the soil itself is being physically removed at rates faster than, than even with reapplication of biological material, we can regenerate because it's physically washing away with hard rainfalls. And so that then takes it into first rivulets in the field and then two rivers and then eventually to

the Mississippi River. And that deposits a lot of the soil and nutrients from the soil down in the Gulf of Mexico.

Emily: And keep in mind, when this soil washes away, it has some downstream effects, literally.

Dr. Handelsman: So one of the consequences of soil and nutrients from soil being deposited in the Gulf of Mexico is the hypoxic zone that has resulted. That's a 7,900 square acre area of the Gulf of Mexico that is free of oxygen because it has been contaminated with nutrients that cause algal blooms. And when those algae run out of nutrients and die, other organisms decompose them and use oxygen in the process. And they essentially suck all the oxygen out of the water. And that has had devastating effects on the ecology of the Gulf of Mexico and also practical issues of loss of fishing and shellfish industries in that area.

Freida: Ah! Again, everything is connected! Soil erosion doesn't just hurt farmers and food production... the deposited soil ends up in the ocean and hurts the fishing industry and ocean ecology too!

Nicholas: Yeah, soil is in a crisis, and it's a big problem... for everyone.

Emily: And clearly, land application alone is clearly not the solution.

Freida: So where does that leave us? What can we expect going forward as we continue to lose soil - more food insecurity?

Dr. Handelsman: Well, absolutely. If we can't produce food, then food insecurity is enhanced. And so I think that's the prediction of the next decades of loss of soil. If that reduces our farmland productivity, then clearly that's going to lead to food insecurity and probably worse than insecurity, it will lead to real food shortages. We're not quite as flush with food as we like to believe in this country. We have stockpiles of food that are a lot lower than many people would like them to be. So we're a lot closer to being on the edge of being food insecure than, I think, our everyday lives and the amount of food that we waste would suggest. But with the loss of soil that working close to the edge of our needs, I think is going to end up being much more severe and we're going to be hard pressed to produce more than we need and perhaps in a few decades as much as we need. And that's just the United States. I mean, other countries like India and China are suffering erosion at even four to ten times the rate that we are. So some countries are going to run out of soil much more quickly. And which is why it's so important for the United States to act quickly and set a model for the rest of the world. But we don't seem to be developing policy to do that.

Freida: And just so I can panic appropriately, is this all happening right now?

Nicholas: Basically, it's definitely an urgent situation. This is what Dr. Handelsman had to say.

Dr. Handelsman: The expectations, I think, are hard to predict in terms of a timeframe because we don't know how fast we will be eroding soil in the future. But we've done some projections. When I was in the White House, my group calculated if it was eroding at this rate, then when would we run out of soil? And clearly, the average rate of soil erosion across agricultural land is about 10 times the rate at which it's produced, which doesn't give us very long for having productive agricultural land. And in many areas that

will be it already is a crisis. There are areas, large tracts of land that have already lost all of their topsoil. Ohio has lost enough that they're starting to see it eating into their crop yields. And in the next 10 years, I think we're going to see a pretty large expansion of those areas that are affected by soil loss. And they're there. They will be affected in their ability to produce crops. If it increases, as the weather prediction would suggest it will, then I would say we're going to be in a pretty serious crisis mode by mid century, 2050 or so.

Emily: Well, this is pretty grim. Why is this not big news? And what are farmers, scientists, environmentalists and politicians doing to mitigate this looming crisis? Can we fix the problem quickly enough to prevent the kind of catastrophe that Dr. Handelsman is talking about?

Freida: Right. We need solutions. But this conversation also made me realize how much there is about soil that I just don't know. So before we start talking about solutions, I think we need to really dig deep into the science of soil.

Emily: Oof

Nicholas: Stayed tuned for episode two, where we'll learn more about how microbes live in soil and what they do that helps all the soil crisis.

Freida: And we will make some more terrible puns! And our final microbe clue is that this bacteria is actually Dr. Handelsman favorite microbe.

Nicholas: Do you have a favorite microorganism or metabolism?

Dr. Handelsman: Well, it's so hard to pick because there's so many great ones. But I guess I would have to say *Bacillus cereus*, which I've worked on for about thirty five years now, would have to be my favorite just because it is such an interesting organism that has kept us busy and intrigued for so many years. And every time we study some new aspect, we uncover unexpected characteristics. It's also an underappreciated organism because some bacillus serious strains cause food poisoning. And so people think of it as a food toxicant. But in fact, it's one of the most ubiquitous and abundant organisms in the soil and pretty important for the soil. So once again, just one slice of a microbe that people have contact with through horrible toxicology, the food poisoning process, makes them judge an entire species. So I'm just a little bit protective and defensive of *Bacillus cereus* because it's really, it's a great organism.

Nicholas: We are so grateful to our guest, Dr. Jo Handlesman, for her time and expertise, without which we wouldn't have been able to create this podcast.

Emily: This podcast also wouldn't be possible without the Burroughs Wellcome Fund, which supports the ITiMS program.

Freida: And that concludes this first episode of the ITiMS soil podcast. We really hope you enjoyed it and learned something new - I know that I certainly did! This podcast is a three episode series, so tune back in for the 2nd episode on the science of soil, and the 3rd episode on some possible soil solutions.