Ask a Biologist vol 022   Topic: Soil & Microbes   Guest: Ferran Garcia-Pichel

You Say Dirt, I Say Soil   -

What could possibly be the difference between a cup of dirt and a cup of soil?   Dr. Biology talks with microbiologist Ferran Garcia-Pichel about why he avoids the dirty word and prefers to say soil. Could it be there is more in a cup of dirt - excuse me a cup of soil than meets the eye?

Transcript

Dr. Biology: This is Ask-a-Biologist, a program about the living world. I'm Dr. Biology. Let's pretend I'm your next door neighbor. Your doorbell rings and you see me standing there with an empty measuring cup. But instead of asking for the typical cup of sugar or maybe a cup of flour, I ask if you could spare a cup of soil. You have to keep in mind now that you're living next door to Dr. Biology.

Now you're thinking to yourself, "A cup of soil?" And you say, "You mean a cup of dirt." No, actually I'm looking for a cup of soil. Now you're confused. You're thinking, "What's the difference?" And you ask, "What is the difference between a cup of soil and a cup of dirt?"

And so begins our adventure into what may seem to a dirty subject. But in fact, that cup of soil I want to borrow is filled with tiny living organisms that have their own tiny food web that has a big impact on all living things. To help us explore the world of soil and the microorganisms that make it their home is our guest scientist, Ferran Garcia-Pichel, a professor in the School of Life Sciences at Arizona State University.

He's a microbiologist that's been doing some very cool research with some special microbes called cyanobacteria. If you look at the name, you'll see that it begins with 'cyan', which is the name of a particular color of blue, and it turns out to be hint about the organism.

He's also been looking into some other microorganisms called extremophiles. And maybe we'll see what these extreme organisms have to do with life on earth, and what they have to do with maybe life on other planets. Welcome to the show, Professor Garcia-Pichel.

Ferran Garcia-Pichel: Hello everyone.

Dr. Biology: OK, Ferran. Is it OK if I call you Ferran?

Ferran: Please.

Dr. Biology: I've brought in a cup of soil. [shaking sound of dirt in container] You can hear it. Now tell me what's the difference between a cup of soil and a cup of dirt?

Ferran: Well it's just really a matter of language. But in a way, if you look at the etymology of these words, then really it's not a cup of filth. It is a cup of a complex mixture of living and non-living materials, minerals, and microorganisms; degrading organic matter that composes this thing we call soil. And so that's why I'm so adamant about not calling it dirt.

Dr. Biology: Right, it's these microorganisms that make it so important. Actually it was interesting. I was looking at a little information on the web, and they were estimating that in a gram of soil, I will use the word you like to use, that there can be as many as a billion microorganisms. If you do the math, it's pretty interesting because in an eight-ounce cup of soil, you end up with over several hundred billion microorganisms in that single cup, which is pretty cool.

Now you do a lot of work with soils. And in fact, there are a lot of different kinds of soils. For example, what would be the difference between a cup of soil in the desert Southwest, and say a cup we get from the coast, or maybe even my own backyard?

Ferran: Yes, like everything in this life, soils come in all different sorts and colors. And mostly they vary in their biological potential and their percentage composition between living and non-living components. So if you go to certain soils in the Arctic tundra, they're mostly composed of organic material. Whereas if you look at very poor soils in very arid regions, they would be composed mostly of inorganic minerals.

And then there are also things in between. So if you go to most typical soils that we care about, our agricultural soils of course are very important for everybody, these are halfway in between. You have soils with richer biological components, and forest soils, for example, and then soils that are typically poorer in the biological component than arid areas.

Dr. Biology: Like the desert.

Ferran: Like us. In the Southwest, we have relatively poor soils that are very arid, they have low components, and they are relatively slow in turning over in their activity because they're limited by the lack of water. So if you irrigate them, they can turn into richer soil. If you go higher in elevation, say for example, high into the mountains of Arizona, you start getting richer soils, more typical of Midwestern latitude forests.

Dr. Biology: Right. So if I want to grow a garden, it's better to have soil that has this organic material, the microbes that are in there, than say in the desert, where I have, as we said earlier, maybe just dirt. It has no microbes. It's basically inorganic material.

Ferran: Well only that minerals are not necessarily filthy either.

Dr. Biology: True.

[laughter]

Ferran: So it may not still be dirt, it may be an inorganic soil. In any event, that's right. So essentially a soil is a complex system that is not in what we call a steady state. It's evolving just like many other systems, in the long-term, from the original mineral soil that comes from weathered rock, and slowly matures into soils that become rich in organic matter that promote the growth of plants that are important, perhaps for agriculture, our gardening and so on.

Dr. Biology: Hum, now back to these microbes that we know are in this cup of soil. How do they fit into the food web? What's their role basically?

Ferran: Well we can think about it in two different levels. One, you can think about the part of the biota that we cannot really see with our naked eyes do in the soil itself. And essentially what they do is in most soils that have an important input from organic matter in plant litter, their main role essentially, is to transform that organic matter, to decompose it into it's original components, CO_2 and water, in regards to the carbon part of it. And in so doing, they couple this activity with other transformations. That activity cannot be done by itself.

Essentially they're burning that organic matter. They have to burn it with something, typically that would be oxygen, in what we call the atmosphere of the soil. But when they run out of oxygen, they can use alternative fuels, and those are actually what this transformation gears, what we call the bio-geochemical cycles that happen in the soils.

So sometimes, these activities of transforming organic matter are ingrained into the cycles of other elements, like nitrogen or iron. And so cycles that are ingrained to other cycles then drive many of their elemental cycles of the different elements in nature in those soils.

Dr. Biology: So one of the things we could say is that they not only break down the organic material, but in doing so, they release the water and the CO_2, right?

Ferran: Right.

Dr. Biology: They also release the nitrogen that was basically tied up, right?

Ferran: They would consume particular compounds in other cycles. For example, to burn this organic matter they either use oxygen if it's present, but when they run out of it they may start using nitrate. So then they would respire or breathe just like we do, but they would breathe something else.

In so doing--they for example, one of the consequences of this process is that this nitrate that is present in the soil, is now transformed into nitrogen gas that gets lost to the atmosphere. So, in a way it impoverishes this process called, "Denitrification." It impoverishes the soil in terms of it's nitrogen capacity.

Then other microbes then may be needed, that they're able to return this nitrogen from the atmosphere into the soil. Only microbes can do this process. So, that's why microbes are so important also in returning some of these nutrients from the soil. This is a particular problem for us in the Southwest and other arid areas of the world, where nitrogen is a very important limiting nutrient for the fertility of soils and agriculture, and agricultural activities.

So some of the microbes are these nitrogen fixtures, that we also happen to study in our laboratory.

Dr. Biology: Oh, OK.

Ferran: So, it's all engrained. Nothing happens by itself, it's all a big complex clockwork.

Dr. Biology: Yes, yes. A clockwork, right. Like in this case a cycle. Here we've got microbes that are responsible for decomposing organic material, which is breaking down say, dead plants. They release the nitrogen into the atmosphere. Then we have other microbes that are able to help bring the nitrogen back into the soil, so new plants can grow.

It truly is a full-cycle, and part of the food web. While we're talking about the food web, let's talk a little bit about the soil food web. There's all these different organisms, and cast of characters so to speak. There's some things you can see, and so therefore we think they make up most of this food web.

So there are nematodes, and arthropods, and there will be the fungi, and there's the plants--you go through all that, and then there's one little section that says, "Bacteria." So it looks like there's a whole lot of these other things, and just a little bit of the bacteria. Is that what's really going on in the soil?

Ferran: Well, that's sort of a human tendency we have. We have very visual organisms ourselves. We tend to believe very much, or think that what we can see is important, and truly is. Obviously, the importance of plants for soils cannot be discounted.

Yet those more morphologically, seemingly boring organisms that are beyond the reach of our eyes, have not only the lion share of the biomass, the total mass of organic compounds that are in the soil, but also they carry out most of all the diversity in chemical reactions, in transformations that constitute the clockwork of the soil--and what drives the maturation, formation of the soil, and so on.

So essentially as we microbiologists tend to think, "We could think of an Earth without plants or animals, but we could not think of an Earth without microbes."

Dr. Biology: That's kind of what I was going to ask you, if we had to substitute or remove some of those things from the food web. If we removed the bacteria, we'd be in really deep trouble, right?

Ferran: If we removed the bacteria, we would have possibly not have a very efficient way of extracting nutrient from the mineral components, so plants could not get a good handle. There would be no way of carrying certain necessary transformations, like nitrogen fixation--and again any productivity, any plant leaf, that would not be essentially degraded.

So all of those elements would be tied up in all that biomass, and there would be no new growth. So the renewal is certainly founded on the presence of bacteria, so that the eco system is sustainable.

Dr. Biology: So, without bacteria could we have life on earth?

Ferran: Without bacteria? Well, that's almost a philosophical question. I guess one could go in that direction, but certainly not life in any way that would be similar to what we know today as life.

But certainly we've had for most of the duration of Earth's history, we've had complete eco system, and biogeochemical cycles, and a life-supporting planet, without macro-organism--and that's for the lion's share of Earth's history.

The eco systems with macro-organisms are actually relatively new in the history of Earth, so the other is correct.

Dr. Biology: Right, the macro-organisms. Those are like--well you and I, and all the plants and animals, and things that we can see with just our eyes vs. the microorganisms, that we typically need a microscope to see. Those are the things that have been around a long time, and you and I are relatively recent in living things in the eco system. Well, that's interesting.

Now you spend a lot of time researching a particular bacteria called, cyanobacteria. What got you interested in this organism?

Ferran: Well, so it's not a bacteria, it's a group of bacteria. So it's not just a single bacterium, it's a class of bacteria. all right? So these organisms are interesting, because first of all they are essentially the inventors of photosynthesis.

Photosynthesis as we know as plants today, essentially was invented by these organisms. They are the only microorganisms that are capable of that type of metabolism, of that transformation. In addition to this, many of these cyanobacterial which are very common even today, in the open oceans they represent a large proportion of all the carbon that is fixed in the world--is fixed by cyanobacteria in the ocean.

Another characteristic of the cyanobacteria, is that they seem to be dominant in extreme environments. I always had a tendency to study these extreme environments, because things seem to be simplified when things get extreme.

So I felt like we had a chance to better understand systems, in that they're still functional at the extremes but they lose part of the complexity. So we had a better chance to start understanding bacteria in natural systems as they work, if we look at the extremes. By extreme, we mean environments that are so extreme in their environmental parameter, that they limit the amount of organisms that can live under those particular circumstances.

Dr. Biology: Right. It can be things--extremes in temperatures or extremes in pressure. We'll get to talk a little bit more about that.

Well another thing that we've learned from some of your research, at least I've learned from reading about your research, is sunscreens. The curious thing about that of course, is we talk about that all the time. Especially if you live in the Southwest desert, we want to protect ourselves against damage from the sun. It turns out that maybe there's a story that these little bacteria could tell us all about, and we could make use of.

Ferran: Yes, this is a very long interest of mine. Essentially, it all stems from the same interest in understanding these extreme environments, and these groups of organisms that are common in it. It also comes from the study of cyanobacteria and from really old research that I did during my PhD work.

While I was visiting some desert sites and marine sites in Baja, California, in Mexico, in the late 1980s, I noticed that many of the cyanobacteria that grew in this high, very dry environment - exposed to a lot of ultraviolet radiation from the sun, without an ability to be able to repair any damage because of the lack of water - displayed very strange colorations.

And so we started studying this, and we actually found out that microbes produce a new class of sunscreen to protect themselves from the extreme nature of the environment in deserts, just like where we live.

So that opened up a whole new area of research for us into microbial sunscreens. We have been studying the sunscreens from cyanobacteria at the physiological and the biochemical level. And now we're trying to crack the molecular and genetic basis for the biosynthesis of sunscreens in cyanobacteria as well.

Dr. Biology: So is there going to be an advantage for humans down the road? We always want to get back to us [humans], for some reason or another.

Ferran: Yes. We are basically, if I may use the redundancy here, basic scientists. We don't necessarily aim at finding an application immediately. That doesn't mean we don't care, but we have not realized the importance of going after questions that may not necessarily have an application. But that doesn't mean that we're not aware of the potential; we try to pursue it if we happen to find it.

In this case, the molecules that were discovered in the sunscreens of cyanobacteria have been later found to be unique molecules, in terms of their composition and their effects on human health. Some of these molecules have been shown to have an anti-cancer activity, anti-inflammatory activity, in addition, to their ability to act as sunscreen.

So yes, we have patented these things together with our colleagues in the biomedical community. And yes, there is potential application for this research in medicine and human health. Not that we would be pursuing, as basic scientists, this to the end, but we've opened up these avenues so that applied scientists can make use of them. And that's really the value of basic science in the long run.

Dr. Biology: Yes, that's a really important point, and I don't think we've really talked about that on our show. There are two areas in science. There's a basic research area, and there's applied research. It turns out that the basic research is looking for the fundamental things that are going on in the world and how they work.

Applied research often uses the information that's gathered from basic research to move it on to things that could be a product or a medicine. And they're very important, both basic and applied. So I'm glad that you brought that up. It's something we really haven't talked about here, and I do think it's important.

Ferran: Yes, I think it's important also to point to the bridging between the two. Actually it is incumbent upon the basic scientist, when they see something that may be obviously interesting, to bring the research up to a level where it can be picked up by the more applied side of things.

Dr. Biology: Right, Right. And quite frankly, the basic research is the fun part, because it seems like that's when your curiosity gets to run amuck. You get to think, "Wow, that's cool. Why is it doing that? And how is it doing that?" And that's pretty much what you've been doing with the bacteria, right?

Ferran: Yes, I consider myself very lucky for this. In this part of science where you just follow your inklings and try to answer questions for the sake of knowledge. I consider myself very lucky to be able to do this. Even though of course, it may not earn as easily the recognition of the general public as discovering immediately applicable new medicine.

Dr. Biology: Right. Actually Ferran, this is a really good topic. We have an emeritus faculty member, Winifred Doane, who discovered the adipose gene. For those who haven't heard the word 'adipose', it means 'fat'. So it's the 'fat' gene. She discovered this gene in Drosophila, which are fruit flies, 50 years ago, and it lay dormant. It was basic research.

Recently, it's been picked up because a new group is working with it using mammals, basically some rats. It's got this rebirth, but it came about from her early research. It didn't necessarily take off right away, but 50 years later, now it's become really important.

Ferran: Yes, it is also incumbent upon us in the scientific community to make the public aware of the importance of basic research, and to essentially build up this knowledge repository, where then people with an applied inkling can go and draw from. And the larger the repository, the bigger the chances that those applied efforts will succeed.

Dr. Biology: Right, a giant library.

Ferran: It's a matter of increasing the chances of success. That's really what basic research does for applied research.

Dr. Biology: Yes, this giant library of knowledge that you don't necessarily use right away, but if it's there later on, you can pull it off the shelf and start working with it.

Ferran: Exactly.

Dr. Biology: I think that's perfect. We talked about soil. I have my cup of soil, and so now we're into a cooking mode. Maybe I need a little bit of salt. Salt is a spice, and like most spices, just a little bit of salt is good. If you get too much salt, it can really ruin food. Well it also turns out a little bit of salt in the environment is also good for us. But you get way too salty of an environment, and most things can't live there.

You actually have been doing some work with some of these organisms that live in incredibly salty environments, and you started talking about some of the extremes. I like to use the word that's been coined awhile back, 'extremophiles'. Can you talk a little bit about these organisms that live in this really salty world?

Ferran: Yes, as you have indroduced not many bugs can live under very extremely salty conditions. And so that offered us a model to study ecological principles with ecosystems that had a very limited amount of members, and so that was the reason why we started doing this. Essentially, the biology of extremophiles, in this case, microbes that like to live in extreme conditions of salt are called 'halophiles', from halite, which is essentially the Greek name for salt.

So in this case we studied communities of evaporating ponds mostly in salt producing companies. And in those salt evaporation ponds you can see them actually when you fly into San Francisco. In the bay, you see some wonderful examples of red, pink and green colored ponds. Those are all colored by these halophilic microorganisms that leave concentrations of salt where very few organisms can live.

Actually, you have a very good example in using salt to preserve food. The point is, and the analogy is even larger than this, in food science, we preserve food by going to the extremes. Either we cool things down, or we salt things up, or we dry things up or heat things up. Essentially, by going to the extreme, we limit the amount of organisms that can, then, spoil food. That's the idea.

Yes, we have studied the organisms that can live in essentially saturation conditions for sodium chloride. Essentially, it's table salt dissolved in water until water will not take up any more, and they can still live there. It's very interesting also to study the mechanisms they have and how different they are to cope with the circumstances.

Dr. Biology: Well, and that has to do with life on Earth. It turns out that extremophiles is kind of an interesting study because we can actually move out of our solar system. We can actually be explorers now, so sometimes people would call you maybe an astrobiologist?

Ferran: Yes. The study of extremophilic microbiology has been very important for the development for the signs of astrobiology. Essentially, in astrobiology, people try to figure out if they can detect, or at least predict, the presence of living organisms, or life, outside of our only known example, our planet. In this regard, of course, conditions in other planets are, in general, not very close to the ones we have on Earth, at least today.

Therefore, studying Earth's systems that are a little bit different than the norm, these extreme environments, the hope is here that we can then perhaps predict or understand (A) the limits of life and (B) how life differs in terms of possibilities or also their imprints in those environments so we can then detect or predict the presence of living organisms in planets that are outside of our own. So essentially, it widens our horizons as how we understand the possibilities and effects of life.

So essentially in that regard, yes, I have been involved in projects in astrobiology before, together with other faculty at ASU. Signs of extremophilic microbiology have been very important in the development of astrobiology.

Dr. Biology: I like to ask three questions from my scientists...

Ferran: Three more questions.

Dr. Biology: [laughs] Right. Three more questions. When did you first know you wanted to be a biologist or a scientist?

Ferran: Well, I'm afraid I'm going to have to let you down a little bit here. I was not a precautious microbiologist, that's for sure. I think I knew from very early on that I wanted to go into some academic pursuit.

I always liked the environment and being able to do academic work, but I doubted until very late, at least relatively late, compared to others, between going into biology, physics, or philosophy, which were my three choices at the time. So, I guess it was a little bit by the turns of life that eventually I ended up in a microbiology lab and I enjoyed it very much. Things sort of snowballed from there.

Dr. Biology: It fell into place.

Ferran: Yes.

Dr. Biology: Well, now that you've figured out what you want to be...

Ferran: Not that I have a lot of choice anymore...

Dr. Biology: We hope you still have a choice, because I'm going to take away all your biology and science. You're not going to be able to be a scientist. What I want to know is what would you be if I took all those away? You can't be a scientist, and you can't be a biologist.

Ferran: Hmm. How about a performer?

Dr. Biology: A performer?

Ferran: Yes. Some singer or actor.

Dr. Biology: Singer or actor? Great!

Ferran: Yes, something like that, I guess; an artist of some sort. I don't know. I really haven't given it much thought, but I guess I can see myself leading a bohemian life.

Dr. Biology: That creative side, it's actually...

Ferran: Yeah, I guess so.

Dr. Biology: ...something that we...

Ferran: Something creative. I guess you hit the crucial point there.

Dr. Biology: Well, we've mentioned many times on the show that science is a process of being creative. People often think of science as not being creative, but I often say that we design experiments, and the word 'design' is used for a reason. You seeing things that are occurring in nature and wondering how they do it and why they do it, and creating experiments to find the answer, it takes creativity.

Having you say that you would like to be an artist or performer or actor makes perfect sense to me. All right, you are actually going to be a good candidate for this last question. What advice do you have for someone who would like to be a biologist?

Ferran: You mean some useful advice that's not too cheesy?

Dr. Biology: "Useful" is good, but let's say "words of wisdom"?

Ferran: "Words of wisdom". The truth is if they want to be a biologist, they should pursue it; it's so simple. They should just enjoy the path as they get there. Essentially, if they're not enjoying it as they get there, maybe it's not the path for them. I know that sounds a little cheesy, and it's not a "Be All You Can Be" sort of thing, but that's really what it is. It's really no secret; you don't really need much wisdom for this. Do you?

Dr. Biology: No. Would you recommend, if it's a younger student, do you recommend that they take any kinds of classes, for example, that help them be prepared?

Ferran: Oh, surely. There is no way, in any discipline nowadays, not just in biology, there is no way to be successful and compete and get your kicks from it, but to work hard and achieve a level of proficiency because the field is very competitive and you need to be successful to be happy at it; there's no question. You need to make progress and you need to be competitive and that takes hard work. The only good side about it, of course, is that preparation is fun in itself.

That was my point; if that hard work is not fun at the same time, then maybe it's not the hard work that you need, and you need some other hard work. I don't think there's escaping from the hard work. If that particular one is the one that's alleviated by the pleasure you get out of it, that's probably means you've found your path and you should just continue on.

Dr. Biology: Right. The fact is that if you do things that you enjoy, then it really isn't work, whether it's hard or not, you still enjoy it. Ferran, I want to thank you for joining us here today.

Ferran: Yes, thank you for having me here. It's been a pleasure.

Dr. Biology: OK, now that we've had a chance to explore our cup of soil, I hope you'll understand why we didn't say, "It's a cup of dirt," at least according to our guest scientist, Ferran Garcia-Pichel. The "Ask-a-Biologist" program is produced on the campus of Arizona State University. Even though we don't broadcast live, you can still send us your questions using our companion website. The address is: askabiologist.asu.edu, or you can just Google the words, "Ask-a-Biologist". I'm Dr. Biology.