The Rhizosphere: The Secret Life of Soil

Beneath our feet is an ecosystem so astonishing that it tests the limits of our imagination.
It's as diverse as a rainforest or a coral reef. We depend on it for 99% of our food, yet we scarcely know it.
Soil.

Under one square meter of undisturbed ground in the Earth's mid-latitudes there might live several hundred thousand small animals. Roughly 90% of the species to which they belong have yet to be named. One gram of this soil – less than a teaspoonful – contains around a kilometer of fungal filaments.

When I first examined a lump of soil with a powerful lens, I could scarcely believe what I was seeing. As soon as I found the focal length, it burst into life. I immediately saw springtails – tiny animals similar to insects – in dozens of shapes and sizes. Round, crabby mites were everywhere: in some soils there are half a million in every square meter.

Then I began to see creatures I had never encountered before. What I took to be a tiny white centipede turned out, when I looked it up, to be a different life form altogether, called a symphylid. I spotted something that might have stepped out of a Japanese anime: long and low, with two fine antennae at the front and two at the back, poised and sprung like a virile dragon or a flying horse. It was a bristletail, or dipluran.

As I worked my way through the lump, again and again I found animals whose existence, despite my degree in zoology and a lifetime immersed in natural history, had been unknown to me. After two hours examining a kilogram of soil, I realized I had seen more of the major branches of the animal kingdom than I would on a week's safari in the Serengeti.

But even more arresting than soil's diversity and abundance is the question of what it actually is. Most people see it as a dull mass of ground-up rock and dead plants. But it turns out to be a biological structure, built by living creatures to secure their survival, like a wasps' nest or a beaver dam. Microbes make cements out of carbon, with which they stick mineral particles together, creating pores and passages through which water, oxygen and nutrients pass. The tiny clumps they build become the blocks the animals in the soil use to construct bigger labyrinths.

Soil is fractally scaled, which means its structure is consistent, regardless of magnification. Bacteria, fungi, plants and soil animals, working unconsciously together, build an immeasurably intricate, endlessly ramifying architecture that organizes itself spontaneously into coherent worlds. This biological structure helps to explain soil's resistance to droughts and floods: if it were just a heap of matter, it would be swept away.

It also reveals why soil can break down so quickly when it's farmed. Under certain conditions, when farmers apply nitrogen fertilizer, the microbes respond by burning through the carbon: in other words, the cement that holds their catacombs together. The pores cave in. The passages collapse. The soil becomes sodden, airless and compacted.

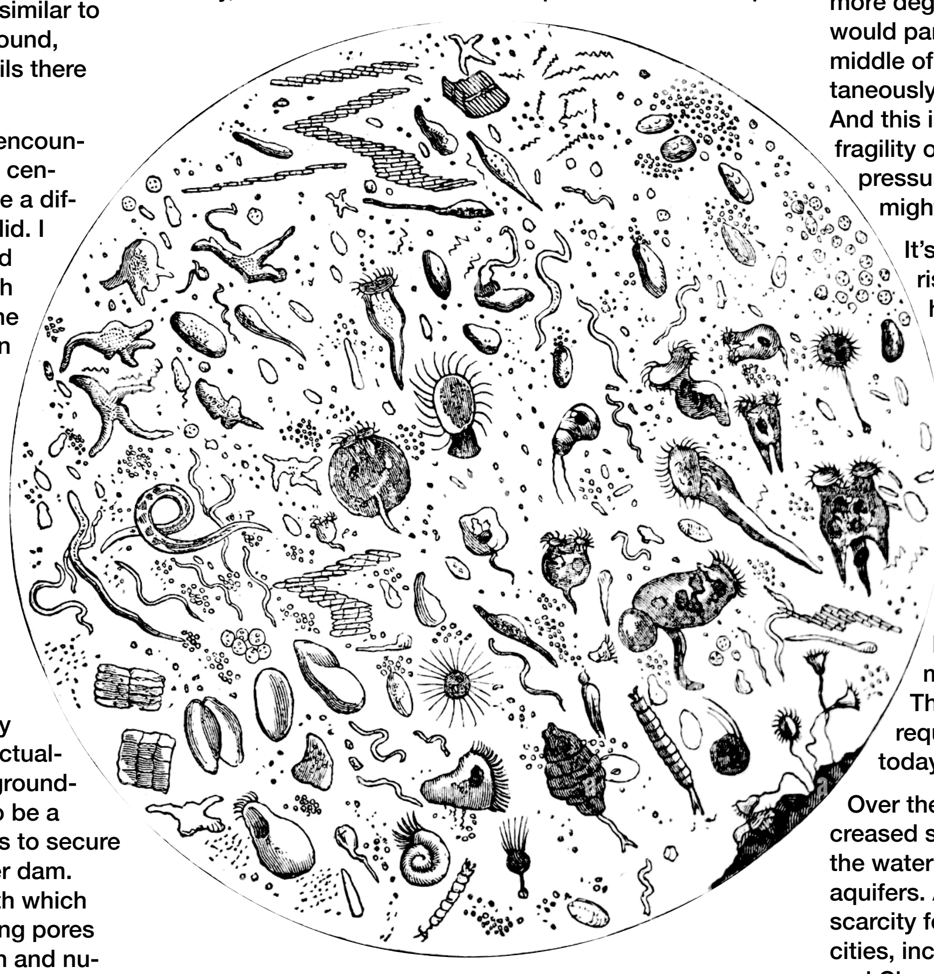
But none of the above captures the true wonder of soil. Let's start with something that flips our understanding of how we survive. Plants release into the soil between 11% and 40% of all the sugars they make through photosynthesis. They don't leak them accidentally. They deliberately pump them into the ground. Stranger still, before releasing them, they turn some of these sugars into compounds of tremendous complexity.

Making such chemicals requires energy and resources, so this looks like pouring money down the drain. Why do they do it? The answer unlocks the gate to a secret garden.

These complex chemicals are pumped into the zone immediately surrounding the plant's roots, which is called the rhizosphere. They are released to create and manage its relationships.

Soil is full of bacteria. Its earthy scent is the smell of the compounds they produce. In most corners, most of the time, they wait, in suspended animation, for the messages that will wake them. These messages are the chemicals the plant releases. They are so complex because the plant seeks not to alert bacteria in general, but the particular bacteria that promote its growth. Plants use a sophisticated chemical language that only the microbes to whom they wish to speak can understand.

When a plant root pushes into a lump of soil and starts releasing its messages, it triggers an explosion of activity. The bacteria responding to its call consume the sugars the plant feeds them and proliferate to form some of the densest microbial communities on Earth. There can be a billion bacteria in a single gram of the rhizosphere; they unlock the nutrients on which the plant depends and produce growth hormones and other chemicals that help it grow. The plant's vocabulary changes from place to place and time to time, depending on what it needs. If it's starved of certain nutrients, or the soil is too dry or salty, it calls out to the bacteria species that can help.



Take a step back and you will see something that transforms our understanding of life on Earth.

The rhizosphere lies outside the plant, but it functions as if it were part of the whole. It could be seen as the plant's external gut. The similarities between the rhizosphere and the human gut, where bacteria also live in astonishing numbers, are uncanny. In both systems, microbes break down organic material into the simpler compounds the plant or person can absorb. Though there are more than 1,000 phyla (major groups) of bacteria, the same four dominate both the rhizosphere and the guts of mammals.

Just as human breast milk contains sugars called oligosaccharides, whose purpose is to feed not the baby but the bacteria in the baby's gut, young plants release large quantities of sucrose into the soil, to feed and develop their new microbiomes. Just as the bacteria that live in our guts outcompete and attack invading pathogens, the friendly microbes in the rhizosphere create a defensive ring around the root. Just as bacteria in the colon educate our immune cells and send chemical messages that trigger our body's defensive systems, the plant's immune system is trained and primed by bacteria in the rhizosphere.

Soil might not be as beautiful to the eye as a rainforest or a coral reef, but once you begin to understand it, it is as beautiful to the mind. Upon this understanding our survival might hang.

We face what could be the greatest predicament humankind has ever encountered: feeding the world without devouring the planet. Already, farming is the world's greatest cause of habitat destruction, the greatest cause of the global loss of wildlife and the greatest cause of the global extinction crisis. It's responsible for about 80% of the deforestation that's happened this century. Of 28,000 species known to be at imminent risk of extinction, 24,000 are threatened by farming. Only 29% of the weight of birds on Earth consists of wild species: the rest is poultry. Just 4% of the world's mammals, by weight, are wild; humans account for 36%, and livestock for the remaining 60%.

Unless something changes, all this is likely to get worse – much worse. In principle, there is plenty of food, even for a rising population. But roughly half the calories farmers grow are now fed to livestock, and the demand for animal products is rising fast. Without a radical change in the way we eat, by 2050 the world will need to grow around 50% more grain. How could we do it without wiping out much of the rest of life on Earth?

Just as farming is trashing crucial Earth systems, their destruction threatens our food supply. Sustaining even current levels of production might prove impossible. Climate breakdown is likely, on the whole, to make wet places wetter and dry places drier. One more degree of heating, one estimate suggests, would parch 32% of the world's land surface. By the middle of this century, severe droughts could simultaneously affect an arc from Portugal to Pakistan. And this is before we consider the rising economic fragility of the global food system, or geopolitical pressures, such as the current war in Ukraine, that might threaten 30% of the world's wheat exports.

It's not just the quantity of production that's at risk, but also its quality. A combination of higher temperatures and higher concentrations of CO_2 reduces the level of minerals, protein and B vitamins that crops contain. Already, zinc deficiency alone afflicts more than a billion people. Though we seldom discuss it, one paper describes the falling concentrations of nutrients as "existential threats".

Some crop scientists believe we can counter these trends by raising yields in places that remain productive. But their hopes rely on unrealistic assumptions. The most important of these is sufficient water. The anticipated growth in crop yields would require 146% more fresh water than is used today. Just one problem: that water doesn't exist.

Over the past 100 years, our use of water has increased six-fold. Irrigating crops consumes 70% of the water we withdraw from rivers, lakes and aquifers. Already, 4 billion people suffer from water scarcity for at least one month a year and 33 major cities, including São Paulo, Cape Town, Los Angeles and Chennai, are threatened by extreme water stress. As groundwater is depleted, farmers have begun to rely more heavily on meltwater from glaciers and snowpacks. But these, too, are shrinking.

A likely flashpoint is the valley of the Indus, whose water is used by three nuclear powers (India, Pakistan and China) and several unstable regions. Already, 95% of the river's flow is extracted. As the economy and the population grow, by 2025 demand for water in the catchment is expected to be 44% greater than supply. But one of the reasons why farming there has been able to intensify and cities to grow is that, as a result of global heating, glaciers in the Hindu Kush and the Himalayas have been melting faster than they've been accumulating, so more water has been flowing down the rivers. This can't last. By the end of the century, between one- and two-thirds of the ice mass is likely to have disappeared. It is hard to see this ending well.

And all this is before we come to the soil, the thin cushion between rock and air on which human life depends, which we treat like dirt.

While there are international treaties on telecommunication, civil aviation, investment guarantees, intellectual property, psychotropic substances and doping in sport, there is no global treaty on soil.

The notion that this complex and scarcely understood system can withstand all we throw at it and continue to support us could be the most dangerous of all our beliefs.

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