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Work begins to decode the chemical language of fungi

Below the ground lie vast, living networks that connect entire forests. These hidden systems, formed of fungi, serve as a conduit for nutrients and information in ways that scientists are only beginning to understand.

Now a $7.5-million grant will enable a team of researchers, led by UC Santa Barbara's Holly Moeller, to investigate these systems in greater depth than ever before. Moeller and her colleagues at UCSB, UC Davis and North Carolina State University will work to unravel the chemical signals produced by fungi, what environmental cues they relate to and how to detect them. Ultimately, they plan to produce devices to capture these signals in the wild.

A forest's hidden connections

Humans have long known that fungi perform crucial functions in ecosystems, especially decay and nutrient recycling. More recently, we've come to appreciate that certain groups, known as mycorrhizal fungi, form extensive underground networks with plants and each other. "These fungi attach to a plant's root system, and they can daisy chain trees to one another," said Moeller, a professor in the Department of Ecology, Evolution, and Marine Biology.

The fungal threads, or hyphae, extend the reach of root systems and can transfer water, carbon and nutrients between plants. They can also transmit information. This enables plants to sense what's happening to their neighbors, such as signals from an insect attack, Moeller explained.

Fungal networks are constantly sensing a host of environmental conditions and activities — from soil chemistry and nutrient availability to disturbance and plant response — and responding in their own chemical language. "Being able to eavesdrop on that fungal information gives us a way to leverage the fungi as sensors about the environment," Moeller said.

Stimulating growth

Studying fungal growth directly in a forest is challenging because most activity happens underground. "In a real forest, we can't easily see hyphae," said chemist Thuc-Quyen Nguyen, director of UCSB's Center for Polymers and Organic Solids. "And digging up soil to observe the fungi can destroy the very networks we want to study."

The first step is the tricky task of culturing these fungi in the lab. Unlike their decomposing counterparts, which are often happy to grow in a petri dish, mycorrhizal fungi grow in the soil and only in association with their plant partners. That's where the expertise of Nguyen and materials scientist Angela Pitenis comes into play. "Our goal is to create synthetic materials that mimic the mechanical properties of soils to encourage fungal growth," said Associate Professor Pitenis.

The team has honed in on hydrogels, a broad group of hydrated polymer networks that includes soft contact lenses. These materials more readily lend themselves to manipulation than real soils.

The group has to consider a lot of parameters when developing their gel — charge, salinity, ions, acidity, conductivity. But that also means they have the ability to tweak a lot of variables to cultivate different fungal networks as well as control their growth rate and direction. Pitenis and Nguyen are working together to develop soft, conductive materials to direct fungal growth and fine tune the gel to different fungi.

The synthetic soil will form the basis for a device to cultivate and examine mycorrhizal networks. This aspect of the project will be led by Moeller’s group, which has extensive experience growing young trees in the greenhouse, colonizing them with fungi and measuring how the fungi affect the plants' growth. She and Laura Bogar — a former UCSB postdoc, now an assistant professor at UC Davis — are both growing young trees together with mycorrhizal fungi to understand how fungi transmit signals across tree networks.

A fungal Rosetta stone

Which brings the team to their second task: Translate what these fungi are saying. “One of the biggest challenges is that fungus-tree communication is invisible,” said Kevin Garcia, an associate professor at North Carolina State University. Soil fungi release a complex mixture of volatile compounds, which scientists still know very little about.

Garcia’s group is investigating fungal genomes to learn how environmental stimuli correlate with gene activation and the chemicals a fungus produces. The group at NC State University will use genetic manipulation of soil-forest fungi to validate the roles that specific genes play in volatile compound production. This will give the team a better understanding of the relationship between fungal signals and different environmental conditions.

At UC Davis, Bogar and Professor Cristina Davis are identifying and characterizing these chemicals, including the signals fungi may exchange with plants before the partners ever touch. “The hope is that these fungi are all speaking somewhat related languages,” Moeller added, “because they all have to be talking to the plants.”

That said, none of the scientists believe the fungi are striking up subterranean conversations; it’s more akin to insects communicating via pheromones.

Image



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Under the forest floor, fungi like these chanterelles connect their host trees into a vast biological network.

Wiretapping the forest

This fascinating work begs the question of how the team plans to actually detect these signals. “Right now we don't have any straightforward way to ‘hear’ the chemical conversations between forest trees and fungi,” Bogar said. “It happens underground, in tiny quantities, and can change really fast.”

Davis and Mitchell McCartney, director of UC Davis’s BioMEMS Laboratory, are developing new technology that moves chemical sensing away from the traditional, large benchtop equipment into handheld, wearable and portable sensors. For instance, they’ve created a wearable device that monitors the skin chemistry of people with different health conditions. Now they’re extending this kind of technology to work on mycorrhizal hyphae.

The team envisions a small sensor that can be deployed in the forest, clamped to a plant's root system. After a few days, the fungi would extend their hyphae into the

gel-filled compartment inside, and the device would provide a live readout of the network’s chemical signals. “This feels like a sci-fi project to me,” said McCartney. “It's exciting to combine digital technologies with biological approaches.”

Fungi are deeply intertwined with the environment around them, and scientists want to take advantage of that. “We're seeking to wiretap that fungal system to gather some of the information that the fungi already had,” Moeller said.

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