Unearthing the impact of moisture on soil carbon processes

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A soil core sample taken from a NEON site in Colorado, one of approximately 400 samples tested for this study. Credit: Adrian Gallo.

The ground below your feet contains some 2,500 gigatons of carbon, approximately three times the amount of carbon held in our atmosphere and four times more than is stored in every living thing—trees, ants, whales, and humans included—on our planet.

Despite this, the dynamics that drive soil carbon cycles are less understood than the dynamics of other carbon stocks.

Now, researchers from across Virginia Tech, in collaboration with scientists with the U.S. Department of Agriculture's Forest Service, the National Science Foundation's National Ecological Observatory Network (NEON), and other universities, are offering a new perspective on those processes, revealing that moisture is a critical driver in the regulation and sequestration of soil carbon stocks.

"We're demonstrating, at the molecular level, that there is a big split in how carbon in soil is cycled between humid and arid soil systems," said Brian Strahm, a professor in the College of Natural Resources and Environment's Department of Forest Resources and Environmental Conservation and a primary investigator in this research. "This is useful in allowing us to imagine two fundamentally different models of how carbon is concentrated and moves within soil."

These findings, published in *Proceedings of the National Academy of Sciences*, are at odds with the group's initial expectation about what factors make soil efficient at sequestering carbon.

"The big takeaway is that most of the things we thought we knew about soil carbon were wrong," said Kate Heckman, a research biological scientist for the Forest Service and the lead author of the paper.

"Our initial hypothesis centered on the importance of certain kinds of soil minerals that we assumed were important in carbon persistence, or how long carbon stays in soil. We also thought that temperature patterns across the sites would be a strong regulator of carbon age, but we didn't see the signals we expected to see associated with either temperature or soil minerology."

A continent's span of soil samples

To gain understanding about the interrelation between soil carbon and moisture, the group utilized core samples collected by NEON, an observation network that is working to collect long-term ecological data across the North American continent to better understand how ecosystems are changing.

As part of that effort, the facility has installed hundreds of in-ground sensors to monitor soil dynamics. The meter-deep cores that they dug—400 of which were utilized in this study—offered researchers a critical snapshot of thousands of unique soil "horizons," or layers of soil that show different characteristics based on age and composition.

"Opening the cores was like seeing different parts of the country through an 8-by-200-millimeter soil snapshot," said Adrian Gallo, who was tasked with doing many of the initial core analyses and who recently completed his Ph.D. in soil science at Oregon State University. "It was not uncommon to open up the cores and think, 'What on earth is happening here with the colors and rocks and roots?' And then I'd have to look at aerial imagery, topography maps, and soil descriptors from nearby locations to help me understand the landscape history."

Starting with those core samples, researchers used a combination of radiocarbon and molecular composition analyses to reveal the relationship between the abundance and persistence of carbon in soil and the availability of moisture in the region where the samples were taken.

"I focused specifically on how decomposition of soil carbon might differ across large-scale climate gradients," said Assistant Professor Angela

Possinger, who studies soil science in the School of Plant and Environmental Sciences in the College of Agriculture and Life Sciences. "We ended up dividing the sites into systems that can be broadly grouped as 'humid' and 'arid' climates, which goes together with many other differences in ecosystem and soil properties. This division ended up helping us better describe the differences in decomposition rates across the U.S."

Associate Professor Brian Badgley, also of the School of Plant and Environmental Sciences, aided in the data interpretation, particularly in considering the biological implications of these findings. He said the research fills a knowledge gap in our understanding of soil microbiology on a wide scale.

"The gap between the way we analyze soil microbial communities using samples of only a few grams, to the regional and global scales in which carbon cycling is often considered, represents an immense challenge," said Badgley. "The identification of continental subsystems in this work provides an exciting conceptual framework for how we can consider microbial processes across a vast landscape."

Lead author Heckman, who worked with researchers at Michigan Technological University, hopes that scientists will build on these findings. One future investigation area she suggests would be manipulation studies of field and croplands, which would allow scientists to see first-hand how changing moisture impacts soil carbon processes.

"Soil organic carbon is being considered as one of the more promising carbon capture and sequestration approaches we have, and understanding the role moisture plays in that process is critical to helping us realize that potential." Heckman said. "My hope is that this study encourages a lot of our science community to examine the role of moisture in the terrestrial carbon cycle."

Strahm stresses that it is critical for scientists investigating global carbon to understand that different soil systems require different models to predict changes in soil carbon stocks.

"We cannot use the contemporary view and model to predict how these soil systems will change in the future," said Strahm, who is an affiliate professor of the Global Change Center. "When we predict systems to get wetter or drier, we're moving systems from one bucket to another. But that kind of shift carries all kinds of implications, so an appreciation of two distinct systems will be a critical conceptual leap."

More information: Katherine A. Heckman et al, Moisture-driven divergence in mineral-associated soil carbon persistence, *Proceedings of the National Academy of Sciences* (2023). DOI: 10.1073/pnas.2210044120

Provided by Virginia Tech

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