New research shows practices from the past will be key to future soil carbon solutions

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Sometimes to go forward, you must go back.

A new study from Colorado State University's Department of Soil and

Crop Sciences and and the Graduate Degree Program in Ecology found that regenerative practices—including integrating crop and livestock systems—were successful as long-term carbon storage solutions.

The paper, "Restoring particulate and mineral-associated organic carbon through regenerative agriculture," was recently published in *Proceedings of the National Academy of Sciences* (*PNAS*). The study was led by ecology Ph.D. candidate Aaron Prairie, along with two co-authors: research scientist Alison King and M. Francesca Cotrufo, professor of soil and crop sciences and Prairie's advisor.

Their research presented a global systemic meta-analysis looking beyond the impact of regenerative agricultural practices on total soil organic carbon (SOC) alone, instead looking at two main pools.

Not all soil carbon is created equally

The regeneration of SOC in agricultural soils is one of the most realizable, nature-based solutions available to mitigate global warming and sustain food productivity for the future. Over the past two years, Prairie looked at studies featuring experiments analyzing the effects of regenerative agricultural practices compared to conventional or control practices and how these different practices increase SOC. Rather than just looking at total soil organic carbon, he broke it up into particulate organic carbon (POC) and mineral-associated organic carbon (MAOC).

"That's important because they behave very differently in soil," said Prairie, noting that POC cycles faster, creating different implications for management and carbon sequestration.

Cotrufo first demonstrated that two functionally different pools of carbon are formed through different processes and her former Ph.D. student, Katherine Rocci, showed they respond differently to global

changes.

"This analysis is the first one to demonstrate the differential impact of regenerative practices on both the particulate organic matter and the mineral associated organic matter," Cotrufo said. "There has been meta-analysis before, but on a small subset of management, and only looking at the total carbon. We found that if we study POC and MAOC separately, we can better inform management about what different conditions promote better outcomes."

A confirmation of regenerative agriculture

One of the most important findings Cotrufo noted is that regenerative practices have an overall positive impact on SOC pools.

"There are a lot of nuances and variables across the studies that need further research," she said. "But it's a big call for agriculture to move towards a regenerative management model."

Especially when these practices are combined, Prairie noted.

"We know that they all work individually, but this study also showed the huge potential for the stacked effects even more," he said.

Decades ago, to increase productivity and lower production costs, the industry largely separated animal production from crop production, focusing on specialization.

"We have increased productivity, but that has come at a huge cost to the environment," Cotrufo said.

The study showed tremendous potential to greatly increase SOC pools through synergistic interactions between multiple practices, such as

polyculture farming, cover cropping, integrated crop-livestock systems and even tillage.

While helpful for plant growth, conventional tillage can also lead to erosion and loss of soil nutrients. But when other regenerative practices are in place, it's possible, Prairie said.

"Tillage has a much less negative effect on soil carbon if you are doing things like cover crops and polyculture and other sorts of regenerative practices," he said.

Patience

Another finding is that like all good things, increasing SOC takes time.

Prairie said his analysis shows that impacts from regenerative practices don't begin showing up in terms of soil carbon until approximately six years after implementation.

That's a problem because most SOC programs—including carbon markets, which allow farmers and ranchers to sell "carbon credits" equal to the amount of carbon dioxide their land has sequestered—quantify SOC change in a five-year-timeline. which means they aren't going to capture this benefit of regenerative agriculture.

"You have to set the system in motion for plants, microbes and soil minerals to work to regain that organic matter," Cotrufo said. "It's not a quick fix."

Looking to the past for agriculture's future

This type of integrated management model was typical before the

industrialization of agriculture, Cotrufo said. The farmers in the 1800s and early 1900s had small operations that were diversified. Some producers are returning to that model and demonstrating how that can be effective in regenerating soil carbon today.

This analysis opens the door to looking at regenerative agriculture in new ways, Prairie said.

"It shows that there's a lot that we don't understand about specific mechanisms of carbon formation and that more research needs to be done into the combination of these different practices and their viability," he said.

From there, targeted interventions at a regional scale would be possible to further research why a specific combination of cover crops works better than another, or why a specific timing or variety garners improved results.

"This paper shows that regenerative integration and regenerative principles definitely work," Cotrufo said. "Optimizing them for context is where we need to work next."

Cotrufo also noted that this is the first time during her career that she's had a Ph.D. student's work published in *PNAS*, a fact that's made even more notable because the two-year data project required Prairie to learn data analysis on the job.

The dataset will also be part of a new modeling consortium, allowing the data collected to live beyond this project.

"There was a big learning curve to decipher how to structure the data, the best way to skim papers," Prairie said. "If you don't have a framework to start with, it feels daunting. But looking at it now, it's very

rewarding for me, especially because so much work went into this, and I want it to be used beyond this study; I want it to be useful."

More information: Aaron M. Prairie et al, Restoring particulate and mineral-associated organic carbon through regenerative agriculture, *Proceedings of the National Academy of Sciences* (2023). DOI: 10.1073/pnas.2217481120

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