Study reveals stable soil moisture variability within fields, opens door for satellite remote sensing

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One of the experimental fields shortly before planting in early May. [Remote sensing signals can provide reliable estimates of soil moisture without vegetation cover during non-growing seasons. Credit: Yi Yang

A multi-institutional study led by University of Illinois and Agroecosystem Sustainability Center (ASC) scientists concluded that, although soil moisture varies significantly both within a single field and from field to field due to varying soil properties and different management practices, soil moisture distribution relative to the field average remains consistent across time within each field.

Their results were published on April 26 in the *Vadose Zone Journal.*

Over three years, the team used sensor measurements and a high-density campaign to reveal that the drier areas remain the drier areas and the wetter areas remain the wetter areas. The study also deduced this finding, reliable estimations of high-resolution soil moisture could be made by integrating optical and active microwave remote sensing, and modeling, instead of relying on infield measurements.

"Our ultimate goal was to improve our understanding of soil moisture variability," said principal investigator Bin Peng, an ASC scientist and an assistant professor in the Department of Crop Sciences. "We wanted to understand the controlling factors of those variabilities and how those variabilities can be reflected in satellite remote sensing data."

"The current satellite-based soil moisture products are too coarse to meet the requirements for agricultural applications," noted Yi Yang, the study's first author and a doctoral student in computational ecohydrology.

"We found that the spatial pattern of soil moisture variability is not changing over the season. In other words, drier areas tend to stay drier and wetter areas tend to stay wetter. We can use this knowledge to estimate the pattern of the spatial variability of soil moisture, and then estimate high-resolution soil moisture products."

The research team also included Kaiyu Guan, founding director of ASC and a professor in the department of Natural Resources and Environmental Sciences; Ming Pan, a senior hydrologist at Scripps Institute of Oceanography at the University of California-San Diego; Trenton Franz, a professor of hydro geophysics at the University of Nebraska-Lincoln; Michael Cosh, a researcher at the U.S. Department of Agriculture's (USDA) Hydrology and Remote Sensing Laboratory and Carl Bernachhi, a core ASC scientist at USDA and a professor in the Department of Crop Sciences and Plant Biology.

The team conducted field campaigns in three 85-acre fields and set up continuous field stations in 30 other fields from 2021 to 2023.

A container in the field housing the data logger connected to soil moisture sensors and communication equipment transmitting data via cellular network. Credit: Yi Yang

"Most of our efforts were to improve our understanding of soil moisture variability using field experiment data, and we are also striving to test if our improved understanding can really be useful for remote sensing retrieval," Yang said.

He noted that taking regular field measurements are too expensive, too labor intensive and not scalable.

"We can get the relative dry-wet pattern within a crop field through optical remote sensing," Peng said.

"Therefore, you don't have to go to the field and replicate the data collection. Our experiment confirmed that because the relative pattern is stable, once you get two or three images from optical satellite sensors to confirm the wetter and drier pattern, you can fill in the temporal gap. This opens a new pathway for high resolution remote sensing retrieval."

Peng said the study provides a roadmap for studying soil moisture variability in cropland, which until this point had been lacking both measurement and reliable remote sensing capabilities. That pathway combines optical remote sensing data with shortwave infrared spectral bands, active microwave remote sensing, and modeling.

High-resolution soil moisture data will be valuable to the farmer for more precision irrigation. It could also be used to understand greenhouse gas emissions or carbon intensity of agricultural production, which are closely related to soil oxygen and water conditions as they directly affect biochemical reactions and microbial activities.

"We should build upon the knowledge discovered here to develop a high-resolution soil moisture product," Guan said.

"We laid out our roadmap for mapping high resolution soil moisture over cropland using multi-source satellite remote sensing and modeling data. The first stream of information gives within field soil moisture variability, and then the second stream gives the absolute soil moisture temporal changes. We can then integrate them with modeling to map every field across the Midwest or even across the globe."

More information: Yi Yang et al, Within-field soil moisture variability and time-invariant spatial structures of agricultural fields in the US Midwest, *Vadose Zone Journal* (2024). DOI: 10.1002/vzj2.20337

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