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New Mechanism of Carbon Sequestration in Soils

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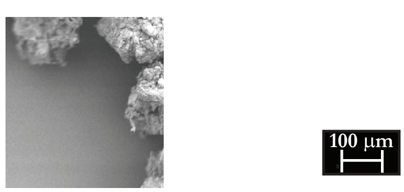
Carbon flow through soil organic matter (OM) is essential to the functioning of terrestrial ecosystems. This phenomenon has recently attracted great interest due to concerns about global warming caused by increases in carbon dioxide and other greenhouse gases, and the potential for using soil as a sink for carbon (C) released into the atmosphere by human activity. This research suggests that in many soils the key to maximizing C sequestration is soil aggregate formation and stability. Soil microaggregates (defined as water-stable aggregates in the 100-250 um size range) have a greater capacity to protect carbon against decomposition compared to macroaggregates, as demonstrated by their many-fold slower C turnover times. This study has focused on understanding mechanisms underlying the long residence times in soil microaggregates. Carbon stabilization in soil had been proposed to result from several processes, including (1) the inherent recalcitrance of the organic molecular structure, (2) intimate association with silt and clay particles, or (3) physical protection in pores inaccessible to degradative bacteria (pore size exclusion).

This research supports a novel mechanism for C-sequestration in microaggregates that has profound implications for C protection in soil. A method based on ultra-small angle x-ray scattering (USAXS) of synchrotron x-rays at the Advanced Photon Source at Argonne National Laboratory allows us to determine the total pore size distribution of the microaggregate, and to distinguish the extent and size distribution of pores that are entirely filled with OM versus partially filled or empty (air- and water-filled) pores. Changes in the extent and pore-size distribution of OM-filled pores were evaluated at two long-term field manipulations: a chronosequence of tallgrass prairie restoration (Fermilab, Batavia, IL; Mollisol) and a 30-year comparison of till/no-till cultivation at two levels of nitrogen inputs (University of Kentucky; Alfasol). Prairie restoration,

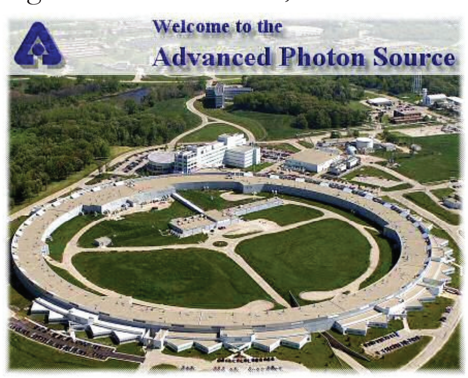
Representative soil microaggregates



Soil carbon sequestration capacity may be far greater than currently believed, but it is strongly linked to land management practices that promote organic matter accrual and a stable microaggregate structure.

decreased tillage, and increased fertilizer inputs resulted in a systematic increase in the fraction of pore space entirely filled with OM. Virgin prairie soils had >80 percent of their porosity filled with OM, but in the prairie restoration chronosequence it took 9 years to build up to 20 percent of porosity filled with OM, and 24 years to reach 70 percent. No tillage not only increased OM content but also doubled the fraction of porosity entirely filled with OM.

Since these micropores are still large enough to accommodate small bacteria and exoenzymes, size exclusion cannot be the mechanism of OM protection from degradation. It is postulated that C sequestration is via the simple filling of the pores resulting in spatial and kinetic limitations. Once a pore is filled with OM, bacteria can easily access only the OM in the small area of the pore throat. At the same time, diffusion of enzymes excreted by soil organisms through the OM matrix is very slow. The pore filling reduces diffusional paths between soil organisms and their food, and increases the tortuosity of those paths. In addition, the OM filled pores retain more water, thus restricting oxygen movement and slowing decomposition.



Advanced Photon Source, Argonne National Laboratory

Impact

This new mechanism suggests the potential for OM storage in soil is larger than generally thought because it is neither limited by the surface area of minerals nor dependent on strong sorption by these surfaces. Another critical implication is that agricultural management and land use can significantly alter the extent of C sequestration. Practices that promote OM accrual (e.g., prairie restoration or reduced tillage) promote pore-filling by OM which further enhances carbon preservation. Conversely, disruption of high OM soils (e.g., via cultivation) is known to result in rapid loss of soil carbon; our results suggest that the mechanism of such rapid degradation of OM is disruption of the OM-protective pore structures. Once lost, rebuilding recalcitrant OM is initially slow as evidenced by results of the prairie restoration chronosequence. Essentially, the greater the OM build-up in microaggregates, the more stable is the stored carbon, as long as a stable microaggregate structure is maintained. Further research into the dynamics of microaggregate formation that leads to pore-filling by OM may suggest strategies to hasten the rate of carbon sequestration.

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