

61. Tracing the Influence of Mineralogy, Microbiology, and Exudate Chemistry on the Stabilization of Root-Derived Carbon

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Project Goals: Our project (Mapping soil carbon from cradle to grave: drafting a molecular blueprint for C transformation from roots to stabilized soil organic C) focuses on a fundamental understanding of C cycling in soil as mediated by soil microorganisms and their interactions with plants. Our work investigates how the interactions between soil minerals and microorganisms affect C sorption and stabilization in soil, particularly in the rhizosphere. Through our research we seek to provide a mechanistic understanding of the conversion of root-derived C to stabilized soil C, clarify the impacts of microbial activities on soil C sequestration, and substantially expand our understanding of molecular regulation of terrestrial C cycling.

Mineral surfaces provide sites for carbon stabilization in soils, protecting soil organic matter (SOM) from microbial degradation for up to thousands of years (Mikutta et al., 2006). While plants provide the primary supply of carbon to soils, minerals are central controllers of the ultimate fate of that carbon. Free plant carbon in soil may quickly be metabolized by microbial communities and released back to the atmosphere (CO₂, CH₄), while carbon that associates with mineral surfaces has the potential for long-term storage. However, we know that not all mineral-associated carbon is protected from microbial degradation for long time periods. Our previous work tracking plant carbon into soil under elevated atmospheric CO₂ showed that while soil minerals initially stabilized new plant-derived carbon, naturally occurring plant and soil dynamics resulted in loss of carbon from soil minerals and a subsequent pulse of CO₂ to the atmosphere. Thus, soil minerals hold a conditional potential for long-term carbon stabilization.

In more recent experiments, we followed the fate of ¹³C-labeled plant-derived carbon in soil microcosms incubated with three minerals representing a spectrum of structure and reactivity: quartz, kaolinite, and ferrihydrite-coated quartz. These minerals, which were isolated in mesh bags to exclude plant roots but not microorganisms, were extracted and measured for total C and ¹³C atom% after 1, 2, and 2.5 months incubation. At 2.5 months, the quartz had the least mineral-bound C (0.40 mg-g⁻¹) and ferrihydrite the most (0.78 mg-g⁻¹). Ferrihydrite and kaolinite also accumulated more plant-derived carbon (3.0 and 3.1%, respectively) based on ¹³C isotopic tracing. These results, which we coupled with Fourier Transform Infrared Spectroscopy (FTIR) and ¹³C-Nuclear Magnetic Resonance Spectroscopy (NMR) analysis of the chemical character of mineral-associated SOM, suggest that more reactive minerals have a higher potential to associate with simpler compounds, which otherwise may have been easily degraded by microbes. Through extraction of cells from the mineral surfaces and preliminary quantification of DNA (PicoGreen), we see that on all minerals, a significant portion of the associated carbon is from living or recently living microbial bodies, emphasizing the importance of microbial biomass not only in the breakdown of SOM, but as a component of SOM.

Despite the importance of plant roots as a conduit for carbon substrates that may eventually become mineral stabilized, certain root exudates may actually destabilize mineral associated SOM, liberating carbon for microbial degradation. We conducted a study with ¹³C-labeled individual exudate solutions pumped through artificial roots into soil rhizotrons. With the addition of the common root exudate oxalic

acid, 75-95% oxalic acid C was released as CO₂. Accounting for carbon use efficiency (CUE) and expected biological oxygen demand (BOD), 50% of CO₂ released was not, in fact, from oxalic acid metabolism, but rather from priming of carbon already in the soil. Analysis of mineral-organic complexes and soil pore water (NanoSIMS, STXM/NEXAFS, and LDPI-MS) indicate this carbon was 'old carbon' released from mineral surfaces. Thus, despite the importance of plants in supplying carbon to soils, 'priming' may release carbon from mineral-organic complexes, such that it is microbially available. Our research shows that both soil mineralogy and the chemical character of plant-derived compounds are important controls of mineral stabilization and destabilization of soil carbon.

References

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