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Beyond Weathering: Combining Organic and Inorganic Soil-Based Carbon Drawdown

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Enhanced rock weathering (ERW) is gaining traction as a carbon dioxide removal strategy, yet most carbon accounting frameworks emphasize inorganic carbon formation and alkalinity export while largely neglecting soil organic carbon (SOC) responses. This imbalance may misrepresent net carbon outcomes in agroecosystems, where mineral amendments interact with dynamic biological and geochemical processes. A mechanistic understanding of coupled soil organic and inorganic carbon (SIC) dynamics is therefore essential for accurate monitoring, reporting, and verification.

We present an integrated framework linking mineral weathering, microbial processes, and carbon stabilization pathways across temporal scales. Fresh silicate inputs introduce reactive surfaces and base cations that promote organo–mineral associations via cation bridging, Fe/Al (hydr)oxide precipitation, and secondary mineral coatings. These processes influence the efficiency of CO_2 capture during dissolution and alter SOC stabilization potential. Concurrently, microbial communities actively regulate weathering through organic acid production, ligand-promoted dissolution, and shifts in carbon use efficiency under elevated pH and nutrient availability. Feedbacks among respiration, dissolved organic carbon (DOC) mobilization, and mineral transformation may lead to priming, stabilization, or transient SOC losses. Abiotic controls—including redox transitions and reactive oxygen species generated during mineral reactions—further complicate carbon fate, particularly during early-stage disequilibrium following deployment.

We translate these mechanisms into environmental and agronomic context, highlighting how soil texture, mineralogy, hydrology, and management “dials” (e.g., tillage, cover cropping, grazing, organic amendments) govern whether systems are dominated by SIC formation, SOC stabilization, or additive storage. We also identify missing processes in current land surface and reactive transport models, including SOC feedbacks, nutrient–weathering coupling, hydrological transport of alkalinity and DOC, and nonlinear management interactions that challenge scaling efforts.

We integrate emerging field observations from an ongoing two-year study across California pasture and cropland systems in Mediterranean climates. High-frequency gas, aqueous, and solid-phase measurements capture inorganic and organic carbon fluxes at field scale. Preliminary isotopic and dissolved inorganic/organic carbon data indicate active mineral weathering and evolving carbon partitioning, while baseline microbial biomass and density fractionation analyses provide constraints on SOC pool dynamics. Together, these efforts aim to refine mechanistic understanding and improve predictive confidence in ERW carbon accounting.