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Soil cation storage as a key control on the timescales of carbon dioxide removal through enhanced weathering

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Significant interest and capital are currently being channeled into techniques for durable carbon dioxide removal (CDR) from Earth's atmosphere. A particular class of these approaches — referred to as enhanced weathering (EW) — seeks to modify the surface alkalinity budget to durably store CO_2 as dissolved inorganic carbon species. Here, we use SCEPTER — a reaction-transport code designed to simulate EW in managed lands — to evaluate the throughput and storage timescales of anthropogenic alkalinity in agricultural soils. Through a series of alkalinity flux simulations, we explore the main controls on cation storage and export from surface soils in key U.S. agricultural regions. We find that lag times between alkalinity modification and climate-relevant CDR can span anywhere from years to many decades, with background soil cation exchange capacity, agronomic target pH, and fluid infiltration all impacting the timescales of CDR relative to the timing of alkalinity input. There may be scope for optimization of weathering-driven alkalinity transport through variation in land management practice. However, there are tradeoffs with total CDR, optimal nutrient use efficiencies, and soil nitrous oxide (N_2O) fluxes that complicate attempts to perform robust time-resolved analysis of the net radiative impacts of CDR through EW in agricultural systems. Although CDR lag times will be more of an issue in some regions than others, these results have significant implications for the technoeconomics of EW and the integration of EW into voluntary carbon markets, as there may often be a large temporal disconnect between deployment of EW and climate-relevant CDR.