Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.38105

A thermodynamic framework for quantifying alkalinity lost to surface buffering during enhanced weathering in acidic tropical soils

BRIAN ROGERS AND KATE MAHER

Stanford Doerr School of Sustainability

Surface buffering represents a major alkalinity sink during enhanced weathering in acidic tropical soils. In these systems, exchangeable acidity and the surface proton reservoir constitute large buffering pools that must be neutralized before sustained alkalinity export can occur. Although this sink is reflected in the limited depth penetration of pH increases following agricultural liming, quantification is more challenging in enhanced weathering contexts, where depth-integrated buffering must be estimated across entire soil columns and diverse soil systems. Here, we present a transferable thermodynamic framework linking routine soil test measurements to the surface buffering processes governing alkalinity consumption. The approach constrains a surface complexation model of proton-reactive organic matter and metal-oxide functional groups using the change in pH-dependent surface charge between native soil pH and pH 7, quantified as the difference in cation exchange capacity measured at these two pH values. This constraint enables prediction of integrated alkalinity demand associated with exchangeable acidity and pH-dependent surface deprotonation, yielding a thermodynamically consistent estimate of alkalinity consumption. Application of the framework to 2,347 acidic tropical soils from the Kellogg Soil Survey Laboratory shows that variability in surface buffering is systematically associated with organic matter content and short-range-ordered Fe and Al oxides, whereas bulk clay content is not predictive of buffering capacity. Depth-integrated calculations indicate that buffering capacity persists approximately linearly through at least the upper 2 m of the soil column, implying that acidic tropical croplands collectively contain billions of lime-equivalent tons of neutralizable acidity within the upper meters of the soil profile. Reactive transport simulations further indicate that surface buffering dominates alkalinity consumption during early to intermediate stages of enhanced weathering deployment. Together, these results suggest that a substantial fraction of added alkalinity may be internally consumed before persistent export occurs. By linking routine soil test measurements to thermodynamic behavior, this framework provides a mechanistically grounded, operationally scalable method for standardized estimation of surface-based alkalinity consumption and establishes depth-integrated surface buffering as a primary control on the fate of added alkalinity in acidic tropical soils.