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Modeling interactive effects of Mn, N, and warming on soil carbon storage

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Terrestrial carbon (C) cycling models typically quantify soil C storage as a function of broad environmental parameters (e.g., climate and vegetation) and do not incorporate geochemical factors. However, C cycling is coupled to biogeochemical cycling of major and minor nutrients through multiple processes (e.g., C fixation, soil respiration, mineral stabilization). For example, the redox-active micronutrient manganese (Mn) stimulates enzymatic degradation of leaf litter by fungi and may decrease soil C stocks; however, these interactions are poorly understood at the ecosystem-scale. Here, we used a new coupled Mn-C biogeochemical model developed in PFLOTRAN to examine the influence of Mn cycling on soil C storage in a representative temperate forest. Bioavailable Mn(II) in soil solution was modeled as a function of biotic and abiotic birnessite dissolution and increased with decreasing soil pH. Plant uptake of Mn then increased with decreasing pH to generate Mn-rich leaves. Subsequent Mn enrichment in leaf litter promoted enzymatic oxidation of lignin and decreased recalcitrant litter remaining in the organic horizon. As a consequence, our simulations demonstrate that increased Mn cycling through vegetation decreased C storage in organic horizons, increased C storage in mineral horizons, and reduced total soil C stocks. Furthermore, we explored how Mn-induced changes to C storage interacted with two prominent human impacts on soils, N deposition and warming, that are known to increase and decrease C stocks, respectively. Nitrogen enrichment increased C stocks by inhibiting Mn-dependent lignin degradation, muting the effect of Mn-enhanced degradation at low pH. Warming stimulated decomposition and reduced C stocks in strongly acidic soils where Mn was readily bioavailable. Conversely, warming increased C stocks in moderately acidic to circumneutral soils as soluble Mn was depleted over decadal timescales and became limiting to decomposition. We propose that depletion of bioavailable Mn or other cofactors that are critical to decomposition could limit the response of organic C stocks to warming over time and should be considered in terrestrial C models. Our simulations provide a framework for coupled biogeochemical models and demonstrate their importance in predicting soil C storage.