Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.26363

Thermal Stability and Composition of Iron-Bound Organic Carbon in Mangrove Soil

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Mangroves forests are among the most efficient soil organic carbon (SOC) sinks, with iron (Fe) oxides gaining increasing attention with their role in SOC stabilization. However, the mechanisms underlying Fe-SOC remain unclear. To address this, we analyzed the mineral-associated organic carbon fraction from pristine mangrove soils at depths of 0–10, 40–50, and 80–100 cm. Samples underwent Fe sequential extraction, with Fe and organic carbon (OC) concentrations measured at each step. Fourier Transform Infrared Spectroscopy (FTIR) and Thermogravimetric-Differential Scanning Calorimetry (TG-DSC) were conducted between extraction steps to assess the contribution of Fe fractions to organomineral interactions and SOC stability.

Progressive Fe extraction led to a decrease in OC, as evidenced by reduced intensities of organic bands in FTIR spectra (Figure 1a). Simultaneously, the exothermic region associated with organic matter oxidation expanded and shifted to higher temperatures (Figure 1b), reflected by higher thermal stability (DSC-T_{50}; Figure 2a) and increased energy density (ED; Figure 2b). This suggests that the remaining OC (not bound to Fe) became more thermally stable.

This finding aligns with the "bioenergetic framework" and the emerging paradigm of soil organic matter persistence, which propose that organic matter is continuously processed, decomposed and oxidized by microbial communities. Oxidation enhances chemical reactivity, facilitating organomineral interactions, particularly with Fe oxides through ligand exchange reactions. We found a positive correlation between DSC-T_{50} and the CH:COO^- ratio (Figure 2a), indicating that as Fe-bound OC was removed, the remaining OC (not bound to Fe) became more thermally resistant and less oxidized. Similarly, the C:N ratio increased with Fe removal (Figure 2b), further supporting that Fe-bound OC is more processed by microorganisms.

Our findings highlight Fe's key role in stabilizing a relatively labile SOC fraction in mangrove soils, challenging conventional assumptions about Fe-bound OC stability. These insights improve our understanding of carbon cycling in coastal ecosystems and have important implications for blue carbon strategies, conservation, and climate modeling.