

Manganese availability regulates Mn(III)-driven organic matter degradation at oxic-anoxic interfaces

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Reactive manganese (Mn) phases have recently emerged as a critical driver of organic matter degradation in soil and sediment environments, affecting both CO₂ emissions and carbon storage. Recent evidence suggests that oxic-anoxic interfaces act as critical hotspots for the formation of reactive Mn(III) species and associated organic matter degradation. Yet, the extent to which microbially-mediated, Mn(III)-driven organic matter oxidation depends on Mn availability remains largely unknown. In this study, we quantified how variations in Mn bioavailability affect rates and pathways of Mn(III)-driven organic matter degradation along oxic-anoxic interfaces. To this end, we established soil redox gradients in diffusion reactors and varied the Mn(II) supply toward the oxic-anoxic interface. Over a 12-week incubation, we quantified variations in Mn(II) oxidation rates, microbial abundance and gene expression, and organic matter degradation across the redox gradient. Pore water analyses, Mn XANES, and wet-chemical extractions indicated that Mn(III) formation at the oxic-anoxic interface peaked after 4 weeks of incubation and increased with increasing Mn availability. Quantitative PCR showed greater fungal:bacterial ratios with increasing Mn availability, while metatranscriptomics illuminated presumed Mn(II)-oxidizing enzyme dynamics. Carbon XANES, microbial respiration rates, and phenol oxidation potential assays showed that organic matter degradation increased with Mn availability, with peaks coinciding with Mn(III) formation at the oxic-anoxic interfaces. Combined, our results showed how Mn availability regulates microbial Mn(II) oxidation rates along oxic-anoxic interfaces and thus the potential for Mn(III)-driven organic matter degradation. Our findings suggest that ecosystem-scale Mn bioavailability controls the extent to which oxic-anoxic interfaces act as hotspots for Mn(III)-mediated organic matter degradation.