

Redox Fluctuations Control Coupled Iron-Carbon Cycling and Microbial Community Structure in Tropical Soils

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Project Goals: This Early Career research examines the genomic potential and expression of tropical soil microorganisms as they experience shifts in soil temperature, moisture, depth and oxygen availability. Associated fluctuations in redox potential are proximal controls of mineral-organic matter interactions in humid, tropical soils. By tracking the degradation and fate of organic ¹³C labeled compounds during shifts in soil redox status, this work will improve our understanding of microbial metabolic flexibility, and how microbial processes affect the fate of organic carbon in wet tropical systems. The mechanistic understanding produced by this research will also improve the predictive capacity of mathematical models that forecast future tropical soil carbon balance.

Wet tropical soils alternate frequently between fully oxygenated and anaerobic conditions, constraining both the metabolism of tropical soil microorganisms and the mineral-organic matter relationships that regulate many aspects of soil C cycling. Tropical forests are predicted to experience a 2–5°C temperature increase and substantial differences in the amount and timing of rainfall in the coming half century. Yet we have a poor understanding of how soil microbial activity and C cycling in these systems will respond to such changes in environmental variability. Using a 44-day redox manipulation and isotope (¹³C) tracing experiment with soils from the Luquillo Experimental Forest, Puerto Rico, we examined patterns of tropical soil microorganisms, metabolites and soil chemistry in soils exposed to different redox regimes: static oxic, static anoxic, high frequency redox fluctuation (4 days oxic, 4 days anoxic), or low frequency redox fluctuation (8 days oxic, 4 days anoxic). Replicate microcosms were harvested throughout the incubation to assess how changes in redox oscillation frequency altered microbial community structure and activity, organic matter turnover and fate, and soil chemistry.

Microbial community structure was strongly affected by patterns of O₂ availability in soils incubated under different redox oscillation treatments. Communities from static anoxic soils became enriched in many Proteobacteria and Firmicutes taxa relative to the initial community, while soils that experienced either fluctuating or constant O₂ exposure retained a similar community composition to the native soil (measured at the start of the experiment). At the same time, the concentration and molecular composition (measured by FTICR-MS) of DOC shifted, corresponding to O₂ availability. DOC and Fe²⁺ concentrations were positively correlated for all four redox treatments and increased within minutes following a switch from oxic to anoxic conditions. Prolonged anoxia led to the reductive dissolution of Fe oxides, and a corresponding increase in DOC availability. Several members of the microbial community belonging to

Proteobacteria, Acidobacteria, and Firmicutes that are capable of iron oxidation, reduction (or both) were significantly enriched under anoxic conditions, suggesting the observed changes in Fe cycling were at least partly driven by microbial activity. However, in soils where redox conditions oscillated, the overall crystallinity of iron oxides increased.

We used molecular scale spectromicroscopy and secondary ion mass spectrometry (SEM/STXM/nanoSIMS) high-resolution imaging to trace the fate of added ^{13}C plant litter and compared the chemical composition of the pure ^{13}C -litter vs ^{13}C -organic matter found in the soils after incubation under oxic, anoxic, and oscillating conditions. Overall, the static oxic soils exhibited the highest gross soil respiration (CO_2 flux), however, ^{13}C -litter derived respiration was highest in static anoxic soils, suggesting decomposition of pre-existing SOM was O_2 -limited in the anoxic soils. Chemical alterations of the added ^{13}C organic matter (relative to the added substrate) were dependent on redox treatment. In general, anoxic soils tended to accumulate aromatic compounds compared to the oxic soils.

Taken together, these data illustrate how microbial community activity (i.e. oxidation of carbon and reduction of iron or other acceptors) and Fe-C coupling may control redox-driven biogeochemistry in humid tropical soils. These results, along with parallel studies of biogeochemical responses (pH, P availability), suggest a highly responsive microbial and geochemical system, where the frequency of low-redox events controls exchanges of C between mineral-sorbed and aqueous pools. Our findings highlight the need for a more explicit representation of soil redox dynamics in our understanding of C cycling in dynamic tropical forest ecosystems.

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