Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.36356

Resolving Structural Controls on Particulate Organic Matter Occlusion and Mineralization in Soil Using Stable Isotope Tracing and Synchrotron-radiation X-ray CT

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The transformation of plant-derived particulate organic matter (POM) into more persistent mineral-associated organic matter (MAOM) is thought to involve a critical yet unresolved step - the physical occlusion of POM within soil aggregates (oPOM) – which may protect POM from decomposition and promote associations with minerals. Competing hypotheses suggest that (H1) microbial processing of fPOM drives its occlusion by increasing its chemical affinity for minerals, or (H2) occlusion is driven by early aggregation processes, with decomposition proceeding within aggregate pores.

We tested these hypotheses by incubating three soils (smectitic Mollisol, illitic Alfisol, kaolinitic Ultisol) exhibiting differing aggregation patterns, with $^{13}C^{15}N$-enriched plant litter. We frequently measured $^{13}CO_2$ and destructively sampled after one week, one month, and three months to determine $^{13}C^{15}N$ in fPOM, oPOM, and mineral-associated fractions. We complemented isotope analysis with synchrotron X-ray CT at the Advanced Photon Source to quantify temporal change in intra-aggregate architecture and POM distribution within aggregates, which may be related to POM transfer among fractions and mineralization.

Within one week, litter-$^{13}C^{15}N$ constituted ~10 and ~20% of clay C and N in all soils, respectively, indicating rapid and substantial sorption of litter-derived compounds, supporting H1, that litter (fPOM when first added to soil) is microbially processed prior to occlusion. However, litter-$^{13}C^{15}N$ was also incorporated into the oPOM fraction within one week, and tended to decrease over time, which supporting H2 and indicating that both mechanisms may operate concurrently.

X-ray CT provided additional soil-specific insights. In the Mollisol, porosity increased one week after litter addition (~32% vs 29%) but decline after one and three months, consistent with H2. In contrast, porosity in the Alfisol and Ultisol increased only after three months. This suggests that the dominance of early vs. late POM occlusion and decomposition depends on soil structural properties. Ongoing work investigates how microbial assimilation of litter-$^{13}C^{15}N$ influences its cycling into oPOM fractions. We are also using dual-energy scans of iodine-stained aggregates to more precisely identify POM and OM coatings within the mineral matrix and relate them to bulk isotope and mineralization data, improving our understanding of the role of soil structural features in organic matter cycling.