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Probing the Fate of Siderophores in Soils through Gallium X-ray Absorption Spectroscopy

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Approximately one third of global land area is covered by high pH, alkaline soils that are deficient in one or more essential elemental nutrients, potentially limiting the productivity of agricultural crops. Nutrient deficiencies, especially iron (Fe), can stem from the insolubility of the metal, preventing their dissolution and limiting bioavailablity. Iron deficiency causes anemia in more than 2 million people worldwide, especially affecting woman and children. This health crisis has been exacerbated by the need to increase yield of crops, which has prioritized overall yield above micronutrient nutritional content. To combat Fe deficiencies, plants, bacteria, and fungi have developed specific uptake strategies, such as the production of siderophores, a structurally diverse class of strong Fe(III) complexing agents exuded to facilitate the solubilization and uptake of essential nutrients from soils. Historically, tracking the fate Fe-siderophore complexes in soils has proven difficult because of the abundant iron phases in soils. To solve this issue, we are using gallium (Ga) complexes with the model siderophore desferrioxamine-B (DFOB) to probe siderophore fate in soil environments. We conducted experiments to study the sorption of Ga-DFOB complexes to the surfaces of common soil minerals. Extended X-ray absorption near edge structure (EXAFS) spectroscopy analysis showed that Ga was separated from the siderophore by ferrihydrite and birnessite, but intercalated as a whole complex into montmorillonite clay. Spatially resolved X-ray fluorescence analysis of Ga-DFOB reacted with a Casville soil revealed hotspots where Ga or Ga-DFOB complexes associated with specific minerals. This work is improving our understanding of siderophore function to determine factors limiting micronutrient uptake in crops to aid in the development of better management strategies to improve crop yields and nutritional content. Future work will focus on expanding to other siderophores to see how different structures affect sorption and fate in soils.

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