

Quantum Sensing in the Rhizosphere: Utilizing Nitrogen-Vacancy Centers to Track Metals and Radicals in the Root Environment

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Investigating rhizosphere biogeochemistry presents significant challenges due to its complexity, dynamic nature, and inaccessibility within soil. Existing bioimaging techniques face trade-offs between resolution, invasiveness, and detection limits, limiting their effectiveness in capturing the chemical interactions occurring within this environment. Our novel approach to investigating rhizosphere biogeochemistry utilizes nitrogen-vacancy (NV) defect centers in diamond nanoparticles or “nanodiamonds” (NDs) as in-vivo probes. NV centers are nonbleaching fluorescent electronic spins that are highly sensitive to nearby paramagnetic species, such as oxygen- or carbon-centered free radicals and metal species including iron, manganese and gadolinium. In abiotic environments, the concentration of paramagnetic species can be measured from the strength of the optically detected magnetic resonance (ODMR) spectra of the NVNDs.

We have successfully incorporated NVNDs (100-300 nm in size) into the roots of model grass species *Brachypodium distachyon*. Confocal imaging confirms uptake into all areas of the root, including the root tip, root hairs, epidermis, cortex, and the vascular cylinder. We designed and constructed transparent soil-analog microfluidic chips for real-time in-situ imaging of roots incorporating NVNDs and have demonstrated that ODMR spectra can be measured from NVNDs within the root environment. We are calibrating the sensitivity of the rhizosphere ODMR signal for known concentrations of chemical analytes, starting with gadolinium. This NVND quantum sensing platform holds great promise in particular for revealing the transport and fate of environmentally persistent free radicals produced by wildfire and their impact on rhizosphere biogeochemistry.