In-Situ mapping of biogeochemical gradients in the rhizosphere of rice plants (*Oryza* sp.) and consequences for iron plaque formation

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Rice is traditionally grown on water-logged soils that are characterized by low redox potentials. Rich in organic carbon and ferric iron minerals in the soil matrix, these settings create optimal conditions for microbial iron(III) reduction and therefore saturate the system with reduced ferrous iron (Fe(II)). Rice plants have evolved a strategy to release O_2 from their roots to prevent iron toxification in these ferrous iron-rich environments, by so called radial oxygen loss (ROL). ROL causes Fe(III) plaque formation on the rice root surfaces, which significantly increases the sorption capacity for nutrients and contaminants, such as toxic metals, in paddy soils. Furthermore, these conditions create an ideal habitat for microaerophilic Fe(II)-oxidizing bacteria, proposed to contribute significantly to iron cycling in the rhizosphere. Although a few studies focused on the mechanisms for iron plaque formation directly on the roots, no holistic approach considered the peripheral geochemical gradients within the entire rhizosphere – a dynamic reaction zone for biogeochemical redox processes.

Here we developed an experimental set-up that allows the non-invasive visual observation of iron plaque formation and in-situ measurements of geochemical parameters (O_2, Eh, pH, $Fe(II)_{aq}$) that establish around rice roots as a function of time. Post-hoc image processing revealed Fe(II) oxidation and Fe(III) mineral formation zones in the rhizosphere, while in-situ microsensor measurements spatially localized and chemically quantified gradients for pH and O_2 in the mm- and μM-range. Geochemical hot-spots were identifed around the root tips suggesting a high turnover-rate for Fe(II) and a potential habitat for microaerophilic Fe(II)-oxidizing bacteria. The iron minerals formed on and around the roots were identified as ferrihydrite, lepidocrocite and goethite using Mössbauer spectroscopy and X-ray diffraction and differences to purely abiotic iron mineral formation processes could be identified. These findings support our hypotheses that plant-induced oxidation reactions, iron mineral plaque formation and other geochemical processes are not only limited to the root tissue surface but affect a wider area in the rhizosphere, subsequently implying their importance as a reaction zone for sorption and redox processes in rice paddy soils.