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Soil microenvironments – revealing biological and chemical processes via imaging

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The complexity of soils extends from the ecosystem-scale to individual microenvironments, where micro-scale interactions between microbiota, organic matter (OM) and mineral particles are thought to control the long-term fate of soil carbon and nitrogen. It is known that such biogeochemical processes show disproportionally high reaction rates within nano- to micro-meter sized isolated zones (‘hot spots’, e.g. rhizosphere) in comparison to surrounding areas. However, the majority of soil research is conducted on large bulk (> 1 g) samples, which are often significantly altered prior to analysis and destructively analyzed. Thus it has previously been impossible to study elemental flows (e.g. C and N) between plants, microbes and soil in complex environments at the necessary spatial resolution within an intact soil system.
Especially the high sensitivity and lateral resolution of nano-scale secondary ion mass spectrometry (NanoSIMS) offers one smart approach to study the composition and fate of organic matter at biogeochemical interfaces of biological, organic and mineral soil microscale structures. Especially the possible imaging of stable isotopes (e.g. 13C, 15N) at high resolution enables the direct tracking of microscale processes via experiments using stable isotope enrichment. However, NanoSIMS can only provide meaningful results if applied in concert with other imaging (e.g. focused ion beam (FIB-SEM), micro-CT) and classical analytical techniques (isotopic and elemental analysis) to both integrate different spatial scales and multiple layers of information. Most notably classical bulk analyses are the backbone to connect the imaging of microscale soil features and phenomena active at Pedon and ecosystem scale. Exemplary a range of studies on properties and processes at soil microenvironments with increasing complexity will be presented, reaching from microaggregates to intact rhizosphere and soil cores.