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Elemental and isotopic imaging to study biogeochemical functioning of intact soil micro-environments

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The complexity of soils extends from the ecosystem-scale to individual micro-aggregates, where nano-scale interactions between biota, 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') 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 analysed destructively. 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. By using nano-scale secondary ion mass spectrometry (NanoSIMS) in concert with other imaging techniques (e.g. scanning electron microscopy (SEM) and micro computed tomography (μCT)), classic analyses (isotopic and elemental analysis) and biochemical methods (e.g. GC-MS) it is possible to exhibit a more complete picture of soil processes at the micro-scale.

I will present exemplarily results about the fate and distribution of organic C and N in complex micro-scale soil structures for a range of intact soil systems. Elemental imaging was used to study initial soil formation as an increase in the structural connectivity of micro-aggregates. Element distribution will be presented as a key to detect functional spatial patterns and biogeochemical hot spots in macro-aggregate functioning and development. In addition isotopic imaging will be demonstrated as a key to trace the fate of plant derived OM in the intact rhizosphere from the root to microbiota and mineral soil particles. Especially the use of stable isotope enrichment (e.g. $13CO_2$, 15NH4+) in conjunction with NanoSIMS allows to directly trace the fate of OM or nutrients in soils at the relevant scale (e.g. assimilate C / inorganic N in the rhizosphere). However, especially the elemental mapping requires more sophisticated computational approaches to evaluate (and quantify) the spatial heterogeneities of biogeochemical properties in intact soil systems.