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Advanced 129Xe NMR techniques for examining soil meso- and microporosity and its role in hosting soil organic matter

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Particle size fractions of natural soils (allophanic Andosol and fire-affected Arenosol), as well as organo-mineral mixtures that compositionally model these soils were investigated by means of 129Xe NMR of adsorbed xenon and 13C CPMAS NMR with the aim of evaluating (i) the meso- and micropore environments and (ii) interaction mechanisms between the mineral and organic soil components. Fine porosity could only be observed after the removal of soil organic matter (SOM) that pointed toward a close association between the mineral- and organic soil phases. Iron induced broadening of the 129Xe resonances was not directly proportional to the concentration of Fe oxides that was explained by their masking with organic matter. In the allophanic Andosol, the broadened appearance of the 129Xe NMR patterns was interpreted in terms of: (i) restricted pore access within the phase of aluminosilicates due to their intimate association with SOM that makes those organic species particularly resistant to the chemical oxidation and (ii) inclusions of the islands of poorly crystalline Fe oxides into the allophanic compounds. Most probably, formation processes of an Andosol include co-precipitation of the Al- together with the Si- and Fe species leading to the complex (hydr)oxides consisting of two (or more) phases. In the particulate organic matter (POM) fractions of the Arenosol, we were able to identify micropores thus highlighting the advanced potential of 129Xe NMR spectroscopy in interrogating soil polymeric organic structures, as compared to the N2 adsorption method. There, we observed up to 4 signals indicating the presence of phases varying by their pore environments, e.g. charred residues with micropores (140-150 ppm), coarser phases of root litter of varying decomposition degrees (0-12 ppm). In the mineral fine particle size fractions of the Arenosol, the abundance of the charred species interacting with clay minerals was revealed. To summarize, the 129Xe NMR spectroscopy of adsorbed xenon can successfully be used in a combination with methods more traditional for soil science to achieve an extended understanding of microstructural properties of soil pores and their role in carbon sequestration.

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