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Analysis of Soil Structure Turnover with Garnet Particles and X-Ray Microtomography

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Matter turnover in soil is tightly linked to soil structure which governs the heterogeneous distribution of habitats, reaction sites and pathways in soil. Thereby, the temporal dynamics of soil structure alteration is deemed to be important for essential ecosystem functions of soil but very little is known about it. A major reason for this knowledge gap is the lack of methods to study soil structure turnover directly at microscopic scales. Here we devise a conceptual approach and an image processing workflow to study soil structure turnover by labeling some initial state of soil structure with small garnet particles and tracking their fate with X-ray microtomography. The particles adhere to aggregate boundaries at the beginning of the experiment but gradually change their position relative to the nearest pore as structure formation progresses and pores are destructed or newly formed. A new metric based on the contact distances between particles and pores is proposed that allows for a direct quantification of soil structure turnover rates. The methodology is tested for two case studies: (1) soil compaction of a silty loam soil in steps of 1.1, 1.3 and 1.5 g/cm^3 and (2) wetting/drying cycles at different bulk densities in the same soil. We demonstrate that the analysis of mean contact distances provides genuinely new insights about changing diffusion pathways that cannot be inferred neither from conventional pore space attributes (porosity, mean pore size, pore connectivity) nor from deformation analysis with digital image correlation. This structure labeling approach to quantify soil structure turnover provides a direct analogy to stable isotope labeling for the analysis of matter turnover and can be readily combined with each other.