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Potential of combined neutron and X-ray imaging to quantify local carbon contents in soil

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Soil organic carbon (SOC) is of key importance for soil functioning. It strongly impacts soil fertility, greenhouse gas emissions, nutrient retention, and contaminant degradation. The soil pore network determines how oxygen, water and nutrients are transported and exchanged in soil, and the architecture of the soil is therefore equally fundamental to soil functions. For a thorough understanding of the microbial habitat, the soil pore network architecture needs to be evaluated alongside with the spatial distribution of SOC, but the challenge ahead is the 3-D visualization of organic carbon at the micro-scale. At present, such visualizations are undertaken using staining agents, but their non-specific binding to other features in the soil aggravates evaluation of organic carbon at the micro-scale.

In the present study, we investigated the potential and limitations of using joint white-beam neutron and X-ray imaging for mapping the 3-dimensional organic carbon distribution in soil. This approach is viable because neutron and X-ray beams have complementary attenuation properties. Soil minerals consist to a large part of silicon and aluminium, elements which are relatively translucent to neutrons but attenuate X-rays. In contrast, attenuation of neutrons is strong for hydrogen, which is abundant in SOC, while hydrogen barely attenuates X-rays. When considering dried soil samples, the complementary attenuation for neutrons and X-rays may be used to quantify the fractions of air, SOC and minerals for any imaged voxel in a bi-modal 3-dimensional image, i.e. a combined neutron and X-ray image.

We collected neutron data at the IMAT beamline at the ISIS facility and X-ray data at the I12 beamline at the Diamond Light source, both located within the Rutherford Appleton Laboratory, Harwell, UK. The neutron image clearly showed variations in neutron attenuation within soil aggregates at approximately constant X-ray attenuations. This indicates a constant bulk density with varying organic matter and/or mineralogy. For samples with identical mineral composition, neutron attenuation data of sieved and repacked soil samples exhibited a large coefficient of determination (R^2) in a regression between volumetric SOC content and neutron attenuation (0.9).

Even larger R^2 (0.93) were obtained when the volumetric clay content was also included into the regression. However, when comparing soil samples with different mineralogy, R^2 dropped to 0.24 and 0.37, depending whether the clay content was considered or not. To improve the method, it is necessary to include specifics of the soil mineralogy. Here, analysing the time-of-flight neutron attenuation data collected at the IMAT beamline will provide further insights. In summary, our approach yielded promising results. We anticipate that quantitative 3-D imaging of organic carbon contents in soil will be possible in the near future.