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Quantitative imaging of cation adsorption site densities in undisturbed soil

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The vast majority of present soil system models assume a homogeneous distribution and accessibility of cation adsorption sites (CAS) within soil structural units like e.g. soil horizons. This is however in conflict with several recent studies finding that CAS in soils are not uniformly but patchily distributed at and below the cm-scale. It is likely that the small-scale distribution of CAS has significant impact on the performance of these models. However, systematic approaches to map CAS densities in undisturbed soil with 3-D resolution that could lead to respective model improvements are still lacking. We therefore investigated the 3-D distribution of the CAS in undisturbed soils using X-ray scanning and barium ions as a contrast agent. We appraised the validity of the approach by comparing X-ray image-derived cation exchange coefficients (CEC) with ones obtained using the ammonium acetate method. In the process, we evaluated whether there were larger CAS concentrations at aggregate and biopore boundaries as it is often hypothesized. We sampled eight small soil cores (approx. 10 ccm) from different locations with contrasting soil texture and organic matter contents. The samples were first saturated with a potassium chloride solution (0.1 mol per liter), whereupon a 3-D X-ray image was taken. Then, the potassium chloride solution was flushed out with a barium chloride solution (0.3 mol per liter) with barium replacing the potassium from the CAS due to its larger exchange affinity. After X-ray images as well as electrical conductivity in the effluent indicated that the entire sample had been saturated with the barium chloride, the sample was again rinsed using the potassium chloride solution. When the rinsing was complete a final 3-D X-ray image was acquired. The difference images between final and initial 3-D X-ray images were interpreted as depicting the adsorbed barium as the density of barium exceeds the one of potassium by more than 2 times. The X-ray image-derived CEC correlated significantly with the ones found from the ammonium acetate method. Our results confirm that the CAS are heterogeneously distributed in space, however without a clear relation between the CAS density and the location of the imaged pores. We are convinced that the here proposed approach will strongly aid the development of more realistic soil system model.