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Fractal characterization of the intra-aggregate pore heterogeneity in macro-aggregates from contrasting land use and management treatments

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Soil aggregates play a key role in a number of soil processes, and are considered to be of particular importance for soil carbon sequestration. However, lack of measurement and analysis tools has hindered progress in understanding the mechanisms by which complex internal aggregate structures influence various soil processes. Recent advances in computed tomography allow addressing internal heterogeneity of soil aggregates at micron resolutions. Aggregate images can then be subjected to a variety of data analyses techniques that will allow estimation and evaluation of the complexity and heterogeneity of the intra-aggregate pore and solid structures. Fractal analysis is one such tool. However, the nature of some fractal measures when they are applied to pore distributions, e.g., box-counting dimension, is such that it can be substantially affected by the total porosity. This influence of porosity on fractal dimension values limits its usefulness as a measure of heterogeneity of the pore distributions. Standardization of the fractal dimension values so as to eliminate the influence of the initial pore voxel numbers on the heterogeneity assessment can greatly increase applicability of fractal analysis in soil image studies. The objectives of this study are (i) to develop a technique to standardize the box-counting fractal dimension with respect to the total number of pore voxels; (ii) to use the computed tomography scanning and fractal analysis tools to examine the characteristics of the intra-aggregate pore space in macro-aggregates (4-6 mm in size); and (iii) to compare heterogeneity of intra-aggregate pore space in macro-aggregates from the same soil subjected to long-term contrasting management practices, namely conventional tillage, no-till, and native succession vegetation. Intact soil aggregates 4-6 mm in size have been selected from long-term ecological experiments located in Michigan, USA (LTER). Three-dimensional images of the aggregates have been obtained at the Advanced Photon Source (APS), Argonne National Laboratory (ANL), IL, with resolution 14.6 μm. The proposed method of standardizing box-counting fractal dimension allowed obtaining information on heterogeneity of pore voxel distributions without bias generated by the effects of the total pore numbers. The results indicated that in the studied Alfisol, macro-aggregates under long-term conventionally tilled (chisel plow) management had greater number of pore voxels (>15 μm) than the aggregates under 20 years of no-till and aggregates under 20 years of native succession vegetation. Large pores (>120 μm) prevailed in the aggregate interior, but their distributions were more heterogeneous in the exterior parts; while 30-75 μm pores were equally abundant, although more heterogeneous in the interior than in the exterior parts of the aggregates. Overall, greatest heterogeneity in pore voxel distribution was observed in aggregates from native succession, followed by those from no-till, and the highest uniformity observed in conventionally tilled aggregates. Observed differences in pore voxel numbers and fractal characteristics are consistent with differences in magnitudes and variabilities of a number of processes occurring in soil aggregates, including microbial activity, nutrient availability, and carbon sequestration.