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Connectivity and percolation of pore networks in a cultivated silt loam soil quantified by X-ray tomography

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The connectivity of macropore networks is thought to exert an important control on transport processes in soil. However, little progress has been made towards quantifying these effects for natural soils in the field, partly because of the experimental difficulties but also because the concept of connectivity lacks a unique mathematical definition. To investigate this question, X-ray tomography was used to measure pore volume, size distribution and connectivity at an image resolution of 65 microns for 64 samples taken in two consecutive years in the harrowed and ploughed layers of a silt loam soil a few weeks after spring cultivation. Three different connectivity metrics were evaluated and compared: one local metric, the Euler number, and two global measures, the connection probability and the probability of percolation (the fraction of the porosity which is continuous across the sample). The connection probability was found to be a good measure of the long-range connectivity (i.e. continuity) of the pore networks. In contrast, the Euler number was not a sensitive measure of global connectivity, although all samples with negative Euler numbers did percolate. We also found that the way connection is defined in the image analysis (either by 6 or 26 nearest neighbours) did not influence the calculations of percolating porosity. The results also demonstrate that harrowing has a clear homogenizing effect on the distribution of the pore space. However, a comparison with random field simulations and the evidence of small percolation thresholds shows that the macropore system developed in the recently harrowed soil was far from completely random or disordered. In some samples, more than one pore cluster percolated, while in others the percolating cluster was not the largest one. Nevertheless, the macropore networks in this cultivated silt loam soil displayed some key features predicted by percolation theory: a strong relationship was found between the percolating fraction and the imaged porosity, with a percolation threshold of ca. 0.04 to 0.06 m3 m-3 and a value of the critical (universal) exponent close to the theoretical value of 0.41 in the harrowed layer. A percolation threshold was less clearly identifiable in topsoil that had not been recently tilled, although this difficulty may probably be attributed to finite size sampling effects in this layer, which showed a more ordered (structured) distribution of the pore space. We suggest that a percolation-based approach may provide a sound conceptual basis for describing the transport properties of macropore networks in soil.