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X-ray analyses of representative elementary volumes for pore network connectivity measures in undisturbed soil columns

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Soil samples with a volume of approximately 100 mL are commonly used for measuring soil properties needed to parameterize continuum models of transport processes in soils. The necessary assumption that the sampled soil volume corresponds to a representative elementary volume (REV) has only been occasionally tested. Furthermore, the few studies so far have focused on bulk properties such as porosity and bulk density and have not investigated the scale-dependence of pore-space connectivity, which is fundamental for transport properties such as the permeability of soil. In this study, we investigated the scale-dependence of morphologic properties of the soil pore-space in 25 undisturbed soil columns sampled from five different depths (8, 23, 33, 53 and 73 cm) from a field site in southern Norway (Skuterud). The analyses of scale-dependence were conducted on regions of interests of dimensions 4 x 4 x 4 cm3 from binarized X-ray images with a resolution of 40 microns. We focused our evaluation on imaged porosity and five measures of pore-space connectivity, i.e. percolation probability, percolating porosity, critical pore diameter, connection probability and the Euler-Poincaré number. As pore network connectivity is scale-dependent and because the connectivity of large pores has a very strong impact on the soil permeability, we conducted our analyses considering three contrasting minimum pore diameters, namely 80, 250 and 500 microns. Our results show individual scaling-characteristics of all investigated measures for all 25 soil samples. Plateau-regions in the scale-relationships, which occurred at scales between 2 and 4 cm, were only observed for the imaged porosity for the samples taken from depths of 8 and 33 cm. This indicates that the soil volume of 64 cm3 did not constitute a REV for the connectivity measures. The scaling-characteristics for the analyses with different minimum pore diameters were similar for the porosity, but diverged significantly for the connectivity measures, with the larger pores showing poorer connectivity. These results call into question the suitability of 100 mL samples for measuring properties that strongly depend on the connectivity of larger soil pores, (e.g. permeability) and also suggest that scale-effects deserve more attention in the modelling of soil systems.