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Responses of subsoil organic matter contents and physical properties to long-term application of increasing amounts of manure

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Application of farmyard manure (FYM) is common practice to improve physical and chemical properties of arable soil and crop yields. However, studies on effects of FYM application mainly focussed on topsoils, those in subsoils have been rarely been addressed so far. We, therefore, investigated the effects of a 36-year application of different FYM rates (0, 50, 100, 200 Mg ha^{-1} a^{-1}) on organic carbon (OC) contents of a Chernozem in 0−30 cm (topsoil) and 35−45 cm (subsoil) depth, and its effects on soil structure and hydraulic properties in subsoil. X-ray computer tomography was used to analyse the response of macropore system (≥ 19 µm) and the distribution of particulate organic matter (POM) to different FYM applications. Based on morphological characteristics, POM was subdivided into a fresh and aged fraction. Image-derived POM volumes were related to contents in total OC (TOC) and water-extractable OC (WEOC) in order to differentiate between possible input sources of soil OC below the plough horizon. We show that manure application of up to 50 Mg ha^{-1} a^{-1} caused increases in TOC and WEOC contents only in the topsoil, whereas rates of ≥ 100 Mg ha^{-1} a^{-1} resulted in TOC enrichment also at deeper depth. In subsoil, the increase in POM (aged and fresh) and WEOC was more marked than that in TOC, indicating that POM and soluble OC may have facilitated the subsoil TOC enrichment. The subdivision of TOC into different OC sources shows that most of the increase was due to fresh POM, likely by roots. The increase in subsoil TOC went along with increases in macroporosity and macropore connectivity, possibly due to the stimulation of bioturbation. We neither observed increases in plant-available water capacity nor in unsaturated hydraulic conductivity. Our study shows that only very high applications of FYM over long periods can increase OC stocks of arable subsoil, but this increase is largely based on fresh, easily degradable POM and accompanied by high C losses.