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Quantifying and visualizing soil macroaggregate pore structure and particulate organic matter in a Vertisol under various straw return practices using X-ray computed tomography

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ABSTRACT

The structure of soil pores plays a crucial role in determining the distribution and retention of particulate organic matter (POM) within soil aggregates, yet the specific effects of different straw return practices on POM stabilization through soil pore structure remain poorly understood. This study aimed to quantify and visualize soil macroaggregates POM distribution and pore structure using advanced X-ray computed tomography (CT) and image processing techniques under three straw return practices: no-tillage with straw mulching (NTS), traditional rotary tillage with straw incorporation (RTS), and deep plowing with straw incorporation (DPS) in a Vertisol. A total of 27 soil aggregates (4–6 mm) from soil depths of 0–10, 10–20, and 20–40 cm were analyzed at an 8-μm resolution. The results showed that NTS significantly increased POM content and surface area density in the 0–10 cm soil layer compared to RTS. In contrast, DPS was most effective in deeper soil layers (20–40 cm), maintaining high POM content and promoting the development of extensive and well-connected pore networks, as evidenced by significantly higher connected porosity and mean breadth density of POM. Additionally, strong positive correlations were observed between POM content, connected porosity, and pore connectivity ($P < 0.05$). These findings highlight the importance of selecting appropriate straw return practices to optimize POM retention and enhance soil C storage, particularly in the context of sustainable soil management in Vertisols.

1. Introduction

Soil organic matter (SOM) is generally separated into two major fractions: particulate organic matter (POM) and mineral-associated organic matter (MAOM) (Cotrufo et al., 2019). POM, primarily derived from plant material and microbial byproducts, ranges from 53 to 2000 μm in size and plays a crucial role in soil C cycling due to its high carbon to nitrogen (C/N) ratio and lower density compared to MAOM (Lavallee et al., 2020). As a labile fraction of soil organic carbon (SOC), POM serves as a sensitive indicator of soil quality changes induced by management practices (Chan, 2001; Cotrufo et al., 2019; Guo et al., 2019). Within soil aggregates, POM is physically protected from biodegradation, which is a crucial for soil C protection (Kravchenko and Guber, 2017). Recent studies suggest that this physical protection within soil aggregates may play a more significant role in C sequestration than previously recognized (Kan et al., 2022; Rabbi et al., 2020).

The structure characteristics of soil pores are a key determinant of the protection and decomposition of POM within soil aggregates (Kravchenko and Guber, 2017). For instance, Wang and Hu (2023) reported that POM protection in alpine ecosystems was positively correlated with < 15 μm pores, while 15–30 μm pores might promote POM decomposition. Ananyeva et al. (2013) found that POM accumulation correlated with 15–37.5 μm pores, whereas decomposition correlated with 37.5–67.5 μm pores in soil macroaggregates from long-term native succession vegetation. Similarly, Toosi et al. (2017) observed that POM in macroaggregates under long-term land management was less decomposed in areas where either small (13–32 μm) or large (136–260 μm) pores were abundant. Liang et al. (2019) demonstrated that in the undisturbed natural soil aggregates, >100 μm pores were more effective in protecting POM than in promoting its decomposition. In contrast, Gao

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