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Research papers

Linking saturated hydraulic conductivity and air permeability to the characteristics of biopores derived from X-ray computed tomography

Zhongbin Zhang[a], Kailou Liu[b], Hu Zhou[a], Henry Lin[c], Daming Li[b], Xinhua Peng[a,*]

[a] State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, CAS, Nanjing, 210008, China
[b] National Engineering and Technology Research Center for Red Soil Improvement, Jiangxi Institute of Red Soil, Nanchang 331717, China
[c] Department of Ecosystem Sciences and Management, Pennsylvania State University, University Park, PA 16802, USA

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ABSTRACT

The different types of soil macropores (e.g., biopores and non-biopores) vary in the conductivity of water or air due to the difference in the 3D pore characteristics. The objectives of this study were to reveal which types of macropores and which macropore characteristics played the most important roles in regulating water or air flow. Intact soil columns sampled from the subsoil of a long-term fertilization experiment were scanned by medical X-ray computed tomography (CT), and subsequently, saturated hydraulic conductivity (K_s) and air permeability at −12 cm water potential (K_{a12}) were measured. The 3D characteristics of macropores were then analyzed with image analysis. The biopores and the percolating biopores that connected the top and the bottom of a soil column were separated for the biopore-dominated samples (with percolating biopores) and their 3D characteristics were also quantified. Our results showed that the mean macropore diameter of the limiting layer (MDLL) presented the best relationships with K_s and K_{a12} compared with the other macropore characteristics for all the samples. The biopores and percolating biopores contributed 27.8–74.5% and 3.26–64.4% of the volume of total macropores, respectively, for the biopore-dominated samples. The hydraulic radius, mean diameter, compactness, global and local connectivities, and MDLL of biopores, especially those of percolating biopores, were generally larger than those of total macropores. The global connectivity (Γ) of biopores performed very well for estimating K_s and K_{a12}. The MDLL of percolating biopores could predict K_s much better than the MDLL of biopores and total macropores. Moreover, the performance of MDLL for estimating K_{a12} was as good as the MDLL of biopores but was much better than the MDLL of total macropores. The findings of this study reveal that the MDLL is a more useful parameter in estimating saturated hydraulic conductivity and air permeability at low water potential than the other CT-derived pore characteristics.

1. Introduction

Soil macropores can conduct water and air preferentially in soils to facilitate root growth (Devitt and Smith, 2002; Katuwal et al., 2015; Colombi et al., 2017). Meanwhile, surface applied agro-chemicals such as fertilizers and pesticides can be transported to deeper soils and even to groundwater via macropores, resulting in low use efficiency of these chemicals and a higher potential of groundwater pollution (Coquet et al., 2005; Jarvis, 2007; Zhang et al., 2014). Soil macropores consist of different pore types from different biological or non-biological origins, such as earthworm burrows, root channels, cracks and inter-aggregate packing voids. These types of macropores vary in size, shape, orientation, and ability to conduct water and gas (Ringrose-Voase, 1996; Abou Najm et al., 2010). Biopores are reportedly much more continuous and effective in transporting water, solutes and air than non-biopores (Koestel and Larsbo, 2014; Zhang et al., 2018). Luo et al. (2008) found that the macropore network by itself cannot arbitrarily be equal to a preferential flow network, since only a small fraction of the macropores, especially the highly continuous biopores in the subsurface, are active in transporting water and solutes.

Soil pore structure governs how fast water, air, and solutes can enter and move through soils (Vervoort et al., 1999; Uteau et al., 2013; Paradelo et al., 2016). Many researchers have tried to link soil pore characteristics and hydraulic conductivity or air permeability (Logsdon et al., 1990; Dexter et al., 2004; Deepagoda et al., 2011; Larsbo et al., 2014; Koestel et al., 2018). Dexter and Richard (2009) proposed a simple model for estimating saturated hydraulic conductivity with the pore size distribution by assuming soil pore space as bundles of capillaries of different radii. The widely used Kozeny-Carmen equation predicts saturated hydraulic conductivity with porosity, tortuosity and

* Corresponding author.
E-mail address: xhpeng@issas.ac.cn (X. Peng).

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