Journal of Contaminant Hydrology 279 (2026) 104905

Contents lists available at ScienceDirect

Journal of Contaminant Hydrology

journal homepage: www.elsevier.com/locate/jconhyd

Soil dissolved organic carbon governs the transport of polyethylene terephthalate microplastics in heterogeneous soil systems

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A R T I C L E I N F O

Keywords:
Microplastics
Polymer type
Soil colloids
Transport
Dissolved organic carbon (DOC)

A B S T R A C T

The fate and transport of microplastics (MPs) in heterogeneous soil systems remain poorly understood. This study systematically investigated the transport behaviors of three distinct MP polymers, polystyrene (PS), polypropylene (PP), and polyethylene terephthalate (PET), with twelve representative Chinese soil colloids using saturated column experiments packed with quartz sand. Without soil colloids, PS and PP exhibited high transport with breakthrough mass recoveries ranging from ~70 to 90%. Notably, the introduction of various soil colloids exerted a negligible impact on the transport of PS and PP, suggesting their transport is largely independent of soil mineralogy. In contrast, individual PET displayed significantly lower transport (recovery ~10%) in the absence of colloids. However, PET transport was markedly facilitated by the presence of soil colloids, with recoveries surging to ~60% depending on the soil type. To decipher the underlying drivers, an XGBoost machine learning feature importance analysis was employed, identifying dissolved organic carbon (DOC) as the predominant soil physicochemical property governing PET transport. This finding was further corroborated by scanning electron microscopy (SEM), which revealed a stable PET-DOC interaction mechanism that enhances PET transport. Our findings underscore that MP transport in terrestrial environments is not solely determined by polymer identity but is governed by a critical interplay with soil DOC. These insights are essential for accurately assessing the environmental risks of MPs, particularly in agricultural soils characterized by fluctuating organic matter levels.

1. Introduction

With the rapid growing use of plastic products, the total global polymer plastics production reached 413.8 Mt. in 2023 as reported by Plastics Europe. Among them, large amounts enter soil systems (Sedlak, 2019). Microplastics (MPs), with sizes smaller than 5 mm (Alimi et al., 2018; Hernandez et al., 2017; Ivleva et al., 2017) accumulate in soil with modern production and living activities, and it has been reported that the total amount of MPs released into soil each year may be 4–23 times that of the oceans (Nizzetto et al., 2016). The rapid production and usage of plastics have made MPs a great challenge for soil safety. The fate and transport of MPs have been recognized as the essential and crucial aspect in evaluating and assessing their ecological effect. Polystyrene (PS), polyethylene terephthalate (PET), and polypropylene (PP) were selected as representative MPs due to their high global production (Geyer and Law, 2017), widespread use in consumer products, and frequent detection in soil environments (Zhang et al., 2018). These polymers exhibit distinct physicochemical properties with different densities, hydrophilicities and hydrophobicities (Andrady, 2017), which may lead to different interactions with soil components.

To date, numerous studies have focused on the environmental behavior of MPs in terrestrial environments, including their aggregation and transport (Dong et al., 2018; He et al., 2020; Hou et al., 2020; Liu et al., 2019; Tan et al., 2021). The transport of MPs is influenced by several factors, including the physicochemical properties of both the plastics and the porous media (He et al., 2020; Hou et al., 2020; Jiang et al., 2021; Tan et al., 2021), solution chemistry (Hou et al., 2020; Liu et al., 2019; Tan et al., 2021) and the presence of co-transporting

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https://doi.org/10.1016/j.jconhyd.2026.104905
Received 19 January 2026; Received in revised form 19 February 2026; Accepted 2 March 2026
Available online 3 March 2026