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From Sea to Land: Setting a Size Definition of Plastics for Soil Ecosystem Studies

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ABSTRACT

In soil studies, the current definition of microplastics as particles <5 mm was adopted directly from marine research. To our opinion, a more precise and differentiated size definition is needed to focus studies on specific challenges plastics cause for soil ecosystems. As relevant soil functions such as water, carbon, and nutrient retention and provision are mainly controlled by soil structure, biota, and chemical processes dominantly appearing in the micro- to nanoscale, we suggest adapting size ranges of plastics to the respective process scales in soil ecosystem studies. Even more, we expect that larger particles will not be incorporated into soil until they reach a size threshold compatible to soil structure (<1000 µm, depending on soil properties). Redefining plastic sizes in accordance with soil processes and the International System of Units (SI) should be implemented to focus research. A unified definition of microplastics (1–1000 µm) and nanoplastics (1–1000 nm) will set a standard to further allow relating plastic sizes across research disciplines.

1 | Opinion

The initial concern and popularization of the term "microplastics" originated from ocean and marine research; however, there is now an increasing focus on soils as potential accumulators of plastic pollution. Consequently, the transition of microplastics research from sea to land has brought practices not relatable to soil-specific research questions, and the current accepted definition of microplastics (<5 mm) is misleading when designing studies evaluating effects on soil life and processes. Even the first mentions of "microplastics" in 2004 were in reference to fibers ≈20 µm in diameter (Thompson et al., 2004), which is much smaller than the current broad definition. The current size definition originated from the first proceeding of the National Ocean and Atmospheric Association, which aimed to choose a unified size definition of "microplastics" debris and provided a practical solution to include the larger mesh size of marine nets (Arthur et al., 2009). This proceeding itself suggests a redefinition to microscopic polymer fragments with future scientific advancement, which is now needed, as the current definition is outside the scope for soil research. Here, we aim to improve the definition of environmentally relevant plastic particle sizes that may potentially harm soil quality and suggest a reclassification of plastic sizes used in soil studies.

Plastic research in soil has focused on its effects on biota, as well as physical and chemical processes (Pérez-Reverón, et al., 2023). Before entering the soil, plastics must fit within the pore system of soils or be incorporated by mixing animals (Figure 1; macroplastics range). This explains why researchers do not

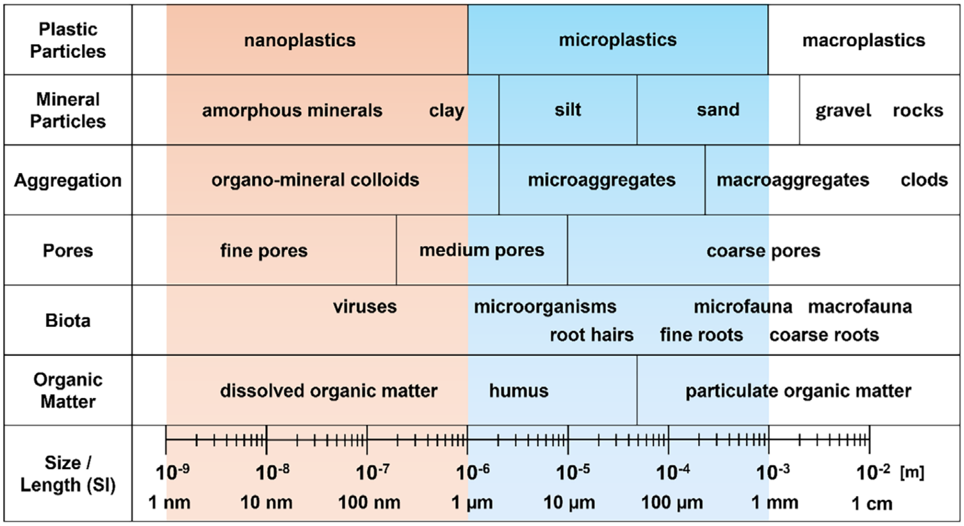

FIGURE 1 | Plastic sizes are displayed on a scale with soil components to highlight their relevance to soil materials and biota. The range where most interactions between soil fauna and roots appear is highlighted in blue (1–1000 µm), whereas most chemical and physical processes occur in red (1–1000 nm). We suggest matching the process scale to the plastic size in soil ecosystem studies.

find large concentrations of millimeter-scale plastics in soils (Jia et al., 2024). As most soil particles and functions occur below 1 mm, a larger definition inclusive of microplastics up to 5 mm is inappropriate for most soil studies. For plastic particles to affect soil biota, they must be within a size range capable of interacting with the respective organism or their environment. Only for macrofauna, such as earthworms, 5-mm particles might cause physical injuries. Organism health is most likely affected by plastics at the micrometer- to nanometer-scale, where sorption behavior and uptake to cells occur (Arthur et al., 2009; Pérez-Reverón, et al., 2023). Therefore, it is recommended to fit the scale of an experiment on soil fauna to the relevant size range of plastics (Figure 1).

Research on soil quality involves soil processes that occur below the millimeter-scale, such as water retention, soil aggregation, chemical interactions between organic and inorganic matter, pollutant interactions, and microbial processes (Totsche et al., 2018). Within the micrometer-scale, plastic incorporation into biopores, other pore spaces, and stable soil aggregates is likely to occur first (Figure 1; blue microplastics range) (Totsche et al., 2018). Then, physicochemical degradation and biological changes result in transformed nanoplastics with largely unknown surface characteristics, transport, accumulation, and implications for complex interactions in soil (Figure 1; red nanoplastics range), for example, the uptake into plant cells (Pérez-Reverón, et al., 2023). Hence, defining and utilizing plastics across an overly broad size range can misrepresent their effects and reduce the robustness of reviews and compiled data.

Although it is important to consider input of "macroplastics," these will not incorporate and interact in soil systems until degrading into microplastics and nanoplastics (Jia et al., 2024; Pérez-Reverón, et al., 2023). A more efficient approach for plastic research in soil science would be to adopt size definitions already established for understanding soil processes and functions (Figure 1). All processes related to soil formation involve the formation of and reaction with particles <2 mm (Totsche et al., 2018). The size definitions common in soil research of mineral particles (sand, silt, and clay) and physical aspects (soil aggregation and pore size) utilize the established International System of Units (SI) and could be directly used to define plastics in soils. A standard classification of plastics by particle diameter length can unify various fields studying "macroplastics" (>1 mm, $>10^{-3}$ m), "microplastics" to the micrometer-scale (1–1000 µm, 10^{-3}–10^{-6} m), and "nanoplastics" to the nanometer-scale (1–1000 nm, 10^{-6}–10^{-9} m). In practice, the size definition of plastics will be the minimum length of the plastic particle that can freely pass through a sieve or defined mesh, meaning that if fibers are longer than they are wide, they will be classified reflective of their width and not their length. Therefore, for soils, the size classification of plastics will remain as the smallest dimension possible for plastic particles to fit through a sieve due to their oblong, non-uniform shapes.

As plastics transport and accumulate across air, water, and soil, they fragment and fractionate into a smaller size, leading to yet unknown complex mixtures and effects in all environmental compartments. With these definitions, we want to support the two main goals of plastic research in soil science: to relate plastic sizes to soil processes and functions relevant to soil quality and to enable bridging gaps between research disciplines such as hydrology and atmospheric science. When studies are comprehensively reviewed, the size definition of microplastics needs to be unified as to not falsely relate studies where experimental microplastics differ magnitudes in size. We defined here microplastics (1–1000 µm) as being most relevant for soil functions such as physical stabilization of soil (aggregation), water, carbon, and nutrient retention; and nanoplastics (1–1000 nm) as most relevant for soil processes, such as organic and inorganic matter interaction, including pollutants and toxic effects. For soil biota, the relevant size of plastic particles would be those that interact directly or indirectly with the respective biota of interest. For macroplastics of greater size (>1 mm), transportation away from soil is more likely than incorporation until specific soil processes are met (Jia et al., 2024). Therefore, this refocus and redefinition of microplastics and nanoplastics will emphasize effects at the environmentally relevant size range of soil life and processes.

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