frontiers | Frontiers in Environmental Science

TYPE Editorial
PUBLISHED 05 October 2022
DOI 10.3389/fenvs.2022.1040756

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OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to
Toxicology, Pollution and the
Environment,
a section of the journal
Frontiers in Environmental Science

RECEIVED 09 September 2022
ACCEPTED 13 September 2022
PUBLISHED 05 October 2022

CITATION
Filella M, Turner A and Scott J (2022),
Editorial: Plastics in the environment:
Understanding impacts and identifying
solutions, volume II.
Front. Environ. Sci. 10:1040756.
doi: 10.3389/fenvs.2022.1040756

Editorial: Plastics in the environment: Understanding impacts and identifying solutions, volume II

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KEYWORDS

plastics, environment, pollution, impacts, effects

Editorial on the Research Topic
Plastics in the environment: Understanding impacts and identifying solutions, volume II

Our first collection of Frontiers articles highlighted the broad diversity of environmental problems caused by the mismanagement of plastics in different settings, and the many challenges that scientists, managers, regulators and stakeholders face in addressing these problems (Filella et al., 2021). This, second series essentially deals with plastics in soils and the degradation of plastic (and in particular, expanded polystyrene). Improving the circularity and management of plastics in soils requires an understanding of their presence, impacts and degradation pathways.

The problem of plastic pollution was identified in the scientific literature several decades ago, with a clear focus on plastics and microplastics in the marine environment. However, research regarding its impacts on terrestrial ecosystems and human health began to emerge more recently (Rillig, 2012), with recognition that most plastics are produced, used and disposed of on land. Thus, whilst it has often been generally accepted that the ocean represents the ultimate sink for plastic contamination, this perception is changing with the realization than soils can become long-term storage reservoirs of plastics. Although estimations can be found in the literature, the existing mass of plastic in soils remains poorly understood (Stubbins et al., 2021), and a rigorous comparison of the respective amounts of plastics in oceans and soils is not possible at present.

Most of the attention regarding plastics in soils has focused on agricultural settings and applications. According to a recent FAO report (FAO, 2021), agricultural value chains used 12.5 million tonnes of plastic in plant and animal production, and 37.3 million tonnes of plastic in food packaging in 2019 (Figure 1A). Although there have been efforts to increase productivity and efficiency and reduce waste in all agricultural sectors, plastics

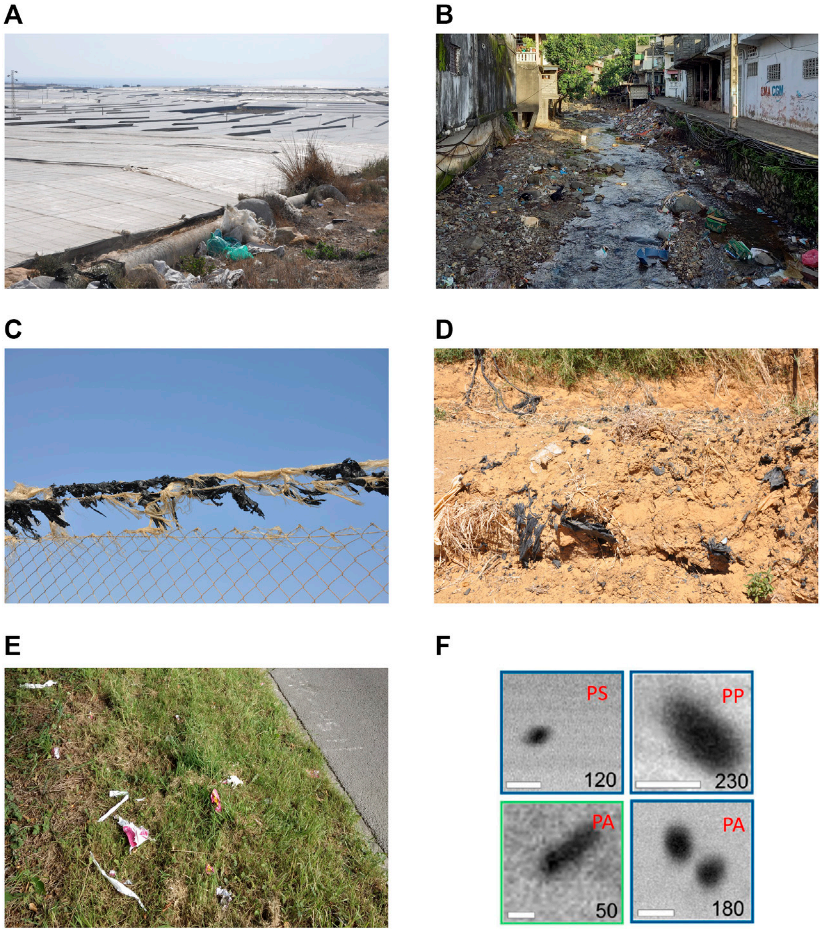

FIGURE 1
(A) Greenhouses in Campo de Dalías, Spain (February 2022), where an estimated area of 20,000 ha is covered with plastic. The largest concentrations of greenhouses around the world are found in two areas, with 80% in the Far East (China, Japan, Korea), and 15% in the Mediterranean basin. **(B)** Mutsamudu, Comoros (March 2022). The lack of adequate garbage collection in urban areas is a source of soil plastic pollution across the world. In low-income countries, over 90% of waste is often disposed in unregulated dumps or openly burned (www.worldbank.org). **(C)** Agricultural plastics transported by wind and captured and damaged by wire fencing in Campo de Dalías, Spain (February 2022). **(D)** Low density polyethylene plastic film mulch after harvest of strawberries in Huelva, Spain (June 2022). The rest of the mulch film is buried in the soil, making complete removal impossible and resulting in significant plastic accumulation. **(E)** Plastic litter at the side of a road in Plymouth, United Kingdom (July 2022). Mechanical clearing of the vegetation enhances the fragmentation and mobility of traffic-related waste and more general urban litter. **(F)** Nanoplastics in four agricultural soil samples identified by scanning transmission X-ray microscopy (Foetisch et al., 2022). PA, polyamide; PP, polypropylene; PS, polystyrene. Scale bars are in nm.

remain a major source of soil contamination because of their persistence and the lack of systematic collection and sustainable management protocols.

There are three principal routes by which plastic contaminants enter agricultural soils. Firstly, and in common with non-agricultural soils, external plastics are derived from general littering, poorly managed waste disposal practices, and wet and dry atmospheric deposition (Figures 1B,C). Secondly, plastics are derived from the *in situ* littering, damage and degradation of agricultural plastics (Figures 1A,D). Thirdly, plastics (and especially microplastics) may be introduced with organic amendments such as biosolids and irrigation water. Although the relative significance of each source of plastic pollution to agricultural systems has yet to be established, the latter route is likely the most important, and in particular for microplastics. For example, in a recent study of waste water treatment plants (WWTP), Kelly et al. (2021) found that microplastics were mostly (>99%) retained in the WWTP sludge. The common practice in many countries of applying sludge as a fertilizer has the potential to inadvertently introduce vast quantities of plastics to agricultural soils.

Non-agricultural soils are under-represented in the existing literature (Büks and Kaupenjohann, 2020). These include grassland, forest and wilderness, as well as locations close to industrial sites or significantly impacted by unmanaged litter in low-income countries (Figure 1B). Runoff from roads or urban areas that is not captured by sewer systems can also contaminate surrounding soils (Figure 1E).

In soils, therefore, we face the presence of plastics of all types and sizes, ranging from large macroplastic (>5 mm) residues that have the potential to harm wildlife through ingestion and entanglement, to smaller yet more abundant micro- and nanoplastics (Figure 1F) that have the potential to be transferred through various trophic levels and, ultimately, result in human exposure. In the present collection, both macro- and microplastics have been addressed in the agricultural setting. Thus, McKay et al. found that macrofragments of both polyethylene and polyvinyl chloride constitute a novel plastisphere habitat that supports a distinct microbial habitat hosting a larger, more efficient microbial biomass with greater labile nutrient pools than the surrounding bulk soil. Yu et al. discuss the sources, distribution and migration of microplastics in agricultural soil ecosystems as well as their effects on soil physicochemical properties and nutrient cycling. Möhrke et al. show that almost all experiments involving soil invertebrates are based on short-term, single-species testing that involve only a small number of species and single microplastic types. A standardized approach allowing an ecologically relevant risk assessment of the impacts of microplastic on invertebrates in terrestrial ecosystems is called for.

Irrespective of the environmental compartment considered, the degradation of plastics does not end at the nano- or microplastic size level, and final degradation products can be more mobile and exhibit greater toxicity than the starting material. Lee et al. adopt the colorimetric MTT assay to show that expanded polystyrene exhibits increased toxicity upon its photodegradation. Specifically, the polymer, which is commonly used for packaging across a range of sectors that includes agriculture, breaks down into 68 compounds, with only 13 identified.

Clearly, the impacts arising from waste plastics are extremely complex and diverse, and multidisciplinary approaches are required in order to develop practical solutions.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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