Sources of Microplastic Pollution in Soil

Subjects: Soil Science

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Microplastics (MPs) are the most versatile, inexpensive, and non-biodegradable materials widely used in daily life. Regardless of their enormous applications, MPs have developed into a critical ecological issue. Major sources of MPs in soil ecosystems are sewage sludge, mulching plastic films, inappropriate dumping of plastic waste, agricultural amendments, etc. which pose a severe environmental threat to the different ecosystems of the earth. Soil has become the reservoir of various micropollutants released from several potential sources over decades of applications, harming the soil and the environment.

microplastics | soil sustainability | land pollution | physiochemical properties of soil | soil microbial community | existing soil pollutants

1. Introduction

Soil is an essential component of the planet Earth, as it provides a plethora of services for the functioning of the ecosystem. However, it has been reported that approximately 25% and 44% of the world's soils are greatly and mildly affected, respectively, mostly due to pesticides, persistent organic pollutants, metals, and metalloids. Additionally, the new emerging pollutants that cause severe environmental threats to the soil system, caused by the mass manufacture of synthetic organic polymers and plastics, have shown prominent growth over the last decade [1][2]. Therefore, there is a need to study the interactions of pollutants with each other to mitigate pollution and maintain soil sustainability [1][2]. The pollutants impact soil homeostasis by altering the soil's properties, such as moisture content, water holding capacity, soil texture, pH, and porosity, thereby affecting everything dependent on them [3]. The predominant conventional types of plastics present in the terrestrial ecosystem include Polypropylene, Polyethylene, Polystyrene, Polyvinylchloride, and Polyethylene terephthalate [4][5].

2. Potential Sources of Microplastic Pollution in Soil

Microplastics are the most versatile, inexpensive, and non-biodegradable materials widely used in daily life. Regardless of their enormous applications, MPs have developed into a critical ecological issue. According to a study, MPs are broadly categorized into primary and secondary MPs [6]. The primary MPs are deliberately produced for certain utilization such as plastic mulch, drug vectors, cosmetics, industrial (textiles, wastewater treatment), and engineering products manufacturing (**Figure 1**) [7]. These types of MPs are generally challenging to mitigate through sewage disposal technologies, and after invading sewage water they ultimately bioaccumulate in the environment [6]. Furthermore, secondary MPs are generated from the fragmentation of larger plastic debris in complex environmental conditions, such as temperature, wind, waves, and exposure to UV light [8]. The plastic debris in soils can also be fragmentized into MPs by biological processes through soil fauna, including feeding habits as well as digestion and excretion processes [9]. Its sources are relatively associated with anthropoid utilization, such as mulching, cosmetics, washing and care, textile industries (microfiber) [10], car manufacturing (tire abrasions/tire wear particles) [11], and plastic commodities, containing all attributes of agriculture, industry, and manufacturing (**Figure 1**) [12]. Therefore, the inevitable occurrence of MPs in the biome and everyday products make the exposure of mankind to MPs certain [13]. It has been reported that major sources of MPs in soil ecosystems are sewage sludge, mulching plastic films, inappropriate dumping of plastic waste, agricultural amendments, etc. which pose a severe environmental threat to the different ecosystems of the earth [6][12]. Soil has become the reservoir of various micropollutants released from several potential sources (**Figure 1**) over decades of applications, harming the soil and the environment [8].

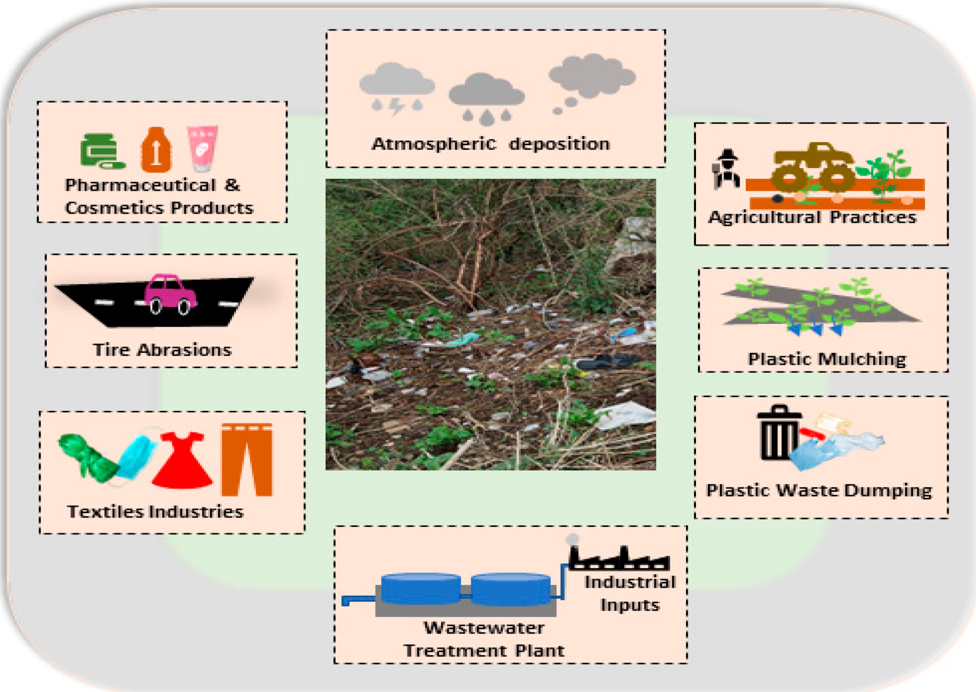

Figure 1. Potential sources of microplastics in soil: agricultural practices, plastic dumping, mulching plastic films, sludge waste, pharmaceuticals, cosmetic products, textile industries (microfiber), tire abrasions (tire wear particles), etc.

2.1. Microplastics as a Driver of Land Pollution

Unauthorized dumping of plastic waste and inefficient waste management are critical reasons for land pollution [14]. The existing literature shows that soil is a bigger reservoir of MPs (plastics) than oceanic basins since most plastic debris is generated and dumped on land [15]. Thus, it is estimated that MP contamination could be 4–23 times more on land than in the oceans [16]. Austen et al. [17] reported that the concentration of MPs reached the maximum in soil near agricultural environments and roads. The estimated concentration of MPs may vary; up to 7% of plastic particles by mass are reported to be present in the topsoil of industries, though levels are often much lower in non-industrialized areas [17]. Microplastics act as a vector for land pollution due to their inevitable and ubiquitous occurrence in the environment. There, sources are reported to be sludge application, plastic mulch, tire abrasions [11], litter run-off from roads and textiles industries [10], and atmospheric depositions [17]. The dispersion of MPs in the environment might influence their interaction with several plant, animal, and microbial species, and alter the behavior of MPs in soil [18]. Microplastics integrate into the soil aggregates through soil cracking, agronomic practices, plant root elongations, and soil burrowing animals, providing transportation of MPs vertically in the soil [9][15]. For instance, a study reported that some soil fauna, such as *Lumbricus terrestis* L. (earthworm), are likely to produce biopores through which MPs can easily leach deep into the soil and serve as the medium for passage of various organic contaminants that are adsorbed on the MPs surface [9]. The intrusion of MPs onto soil intended for deposition, translocation, erosion, deterioration, and percolation to groundwater subsequently threatens micro-organisms and eventually affects all living organisms through indirect utilization [19]. Recent studies have also suggested that tire wear particles (tire abrasions) and microfiber (textiles) are the major emerging microplastic pollution on land, and these MPs gradually runoff from land into the oceans [10][11]. Overall, a thorough study is required to understand the impacts of various MPs on land degradation, though they have the potential to contribute to soil deterioration and impact flora and fauna diversity [6][20]. Therefore, the over-utilization of MPs is considered a prolonged anthropogenic strain and a driver of the global shift in the terrestrial ecosystem [21].

2.2. Impacts of Microplastics on Physiochemical Properties of Soil

There is a wide occurrence of MP pollution in global soil resources [22]. The abundance, composition, shape, and size of MPs may vary significantly in soil, and their different potential sources are one plausible explanation for this [22]. For example, Qi et al. [23] reported that 5 mm low-density polyethylene (plastic mulch film) noticeably affected the physiochemical and hydrological parameters of tested soil. Further, Machado et al. [24] investigated the impact of polyester fibers (5000 μm, 8 μm) on soil parameters such as water holding capacity and showed that MPs decreased bulk density and affected the soil structure. Microplastics adversely impact the soil's biophysical environment through changes in soil pH, bulk density, water holding capacity, porosity, soil aggregations, and hydraulic conductivity [23][24]. Additionally, the change in soil porosity due to MPs can impact the dissipation of volatile soil pollutants and the agglomeration property of MPs can also impact the vertical distribution of pollutants in the soil column [6]. Consequently, soil fertility and health are gradually affected, disturbing the ecological activities associated with them. Eventually, all these changes impact soil sustainability and the environment [23]. The data from previous literature reported that MPs can alter the chemical and physical properties of soil in most cases, but their impacts vary from positive to negative, and depend on the type, shape, dose, and size of the MPs [23].

2.3. Microplastic Effects on Soil Microbial Community

Soil microbes comprise a significant reservoir of living biomass in soil, where they modulate biogeochemical cycles and organic matter decomposition and sustain the earth's ecological balance [25][26]. Preliminary studies have revealed that the presence of MPs in the soil affects bacterial and fungal diversity, besides the reduction of soil enzymatic activities involved in nutrient cycling [6][20][21]. Changes in nutrient cycling-associated microbial enzymes, including β-glucosidase, phosphatase, and urease, can subsequently distress the uptake of substances by plant roots [27][28]. For example, the significant impacts of MPs have been reported on studied soil flora and fauna, including *Eisenia fetida*, *Folsomia candida*, *Lumbricus terrestris*, *Triticum aestivum*, and *Allium fistulosum*, thereby altering the soil diversity (**Table 1**). Microplastics can also directly impact the physiology and metabolism of soil microorganisms by causing oxidative stress and DNA damage in bacteria, which results in cell death and influences microbial activity [21][27]. These alterations also deliver feedback to the microbial environment and affect rhizospheres such as rhizobia and mycorrhiza fungi [20][21][29][30]. For example, Machado et al. [21] reported that the presence of polyamide microplastic beads affected the length and biomass of the plant root, plausibly due to the nitrogen addition and alterations in morpho-physiological traits of roots, and these changes could affect the soil microbial activity related to rhizodeposition. Consequently, soil microbes may directly retort to shifts in soil compositions and structures through inconsistent utilization of nitrogen or organic substrates as an ultimate e-acceptor (organic substrates) [21]. Eventually, changes in microbial activity probably result in a shifting of microorganism composition, which may influence the subset of soil microbes that precisely interact with plant roots [21].

Additionally, Machado et al. [21] reported that the alteration in soil aggregates by MPs can impact pore size and connectivity, thus simultaneously affecting the water holding capacity and permeability of the soil, which can cause a cascade of occurrences that change the biophysical and chemical environment of the soil. In the aging process MPs could absorb, transfer, and desorb other contaminants (ex. pesticides, herbicides, polychlorinated biphenyl, and heavy metals), and all indirectly impact the chemical environment of the soil [6][31]. The exchange of ions in the aging process causes a potential impact on variations in soil pH, water, and nutrient retention [20][21][31][32]. Consequently, the soil microbial community is threatened by changes in soil nutrients, toxins release, and soil pH alteration after interruption by MPs [32]. Rillig et al. [9] reported that soil fauna (earthworms) gulp MPs and co-pollutants sorbed onto the MPs surface and change the microbial gut and associated soil microbial communities in the soil biota [9][28]. In general, MPs have been shown to impact the biophysical and chemical properties of soil, microbial and enzymatic activities, and plant growth, and also cause unfavorable ecotoxicological impacts on soil plant species [10][33]. For instance, a study conducted on wheat (*Triticum aestivum*) (**Table 1**) reported that MPs enter via roots and can move into the trophic food chain, eventually affecting the growth efficacy of wheat in the reproductive as well as in the vegetative stage [34]. On the contrary, pervasive research on *Allium fistulosum* (spring onion) by Machado et al. [21] reported that the types and size of MPs can also positively affect the plants' performance by increasing roots biomass. The impact of different types of MPs on several organisms and flora present in soil ecosystems that have already been tested in earlier studies showed potential impacts (**Table 1**). However, a further detailed investigation is required to perceive the fluctuating contamination of MPs on soil microbes and several plant species, which can increase people's understanding of the ecotoxicity of this emerging threat.

Table 1. Microplastic effect on the soil ecosystem.

Microplastic Type	Size	Species	Effects	Country of Study	References
LDPE	<150 µm, <50 µm,	*Lumbricus terrestris*	*L. terrestris* propagates microplastics from the soil surface into their burrows.	Netherlands	[35]
LDPE	<5 mm, 5–150 mm	Earthworm, chicken (Manure)	Conc. of plastic increases from soil to *L. terrestris* casts and then Chicken feces.	Netherlands	[36]
PE	<50–100 µm, >100 µm	*Lumbricus terrestris*	Higher conc. of MPs may influence the rate of growth in *L. terrestris*.	Netherlands	[36]
PVC	250–80 µm	*Hypoaspis aculeifer*, *Folsomia candida*,	Trophic predator-prey relationships promote the passage of MPs by 40%.	China	[37]
PE, PS	<250 µm–<300 µm,	*Eisenia fetida*	Conc. of HOC (hydrophobic organic compound) in *E. fetida* was minimized in the presence of MPs by above 1%.	China	[31]
PE	2800–710 µm	*Lumbricus terrestris*	The presence of earthworms greatly maximizes the existence of microplastic particles at the bottom of the soil.	Berlin	[9]
PE	<500 µm	*Folsomia candida*	Inhibited breeding and lower bacterial diversity in the springtail gut.	China	[38]
PE	250–1000 µm	*Lumbricus terrestris*	No substantial conclusions were documented on the survival, number, and *L. terrestris* weight.	Spain	[39]
LDPE	0.25 µm, 1–5 mm	*Lumbricus terrestris*	Microplastics cannot be the carriers of organic pollutants to earthworms.	Spain	[39]
Urea-formaldehyde	200–400 µm	*Folsomia candida*, *Proisotoma minuta*	Movement and distribution of MPs by microarthropods.	Berlin	[40]
Polystyrene	0.1–0.05 µm	*Enchytraeus crypticus*	Reduction of biomass in the animals fed 10% PS and an	China	[37]

Microplastic Type	Size	Species	Effects	Country of Study	References
			increase in the breeding of those fed 0.025%.		
PVC	80–250 µm	*Folsomia candida*	Alteration and inhibition of the microbiota in the gut of the collembolan.	China	[37]
LDPE	<150 µm	*Lumbricus terrestris*	Earthworm weight was adversely affected by the amalgamation of glyphosate and MPs	China	[41]
PA, PET, PEHD, PES, PS, PP	20–15 µm	Spring onions (*Allium istulosum*)	MPs can affect leaf attributes, roots of plants, and entire biomass.	Berlin	[21]
LDPE	1 mm–50 µm	*Wheat* (*Triticum aestivum*)	Remains of plastics affected the upper/lower parts of the wheat plant.	Netherlands	[34]

PEHD: Polyethylene High Density, PES: Polyether sulfone, PS: Polystyrene, PA: Polyamide, PET: Polyethylene terephthalate, LDPE: Low-density polyethylene, PVC: Polyvinylchloride, PP: Polypropylene.

ne in the [42][43] tics might have potential health consequences due to their larger surface area, which helps them to adsorb various metals such as Zinc (Zn), Aluminum (Al), Silver (Ag), Lead (Pb), and Copper (Cu), and hazardous pollutants such as Polychlorinated biphenyls (PCBs), Dichlorodiphenyltrichloroethane (DDT), Polycyclic aromatic hydrocarbons (PAHs), other organochlorines and insecticides etc. onto their surfaces [43]. Fu et al. [42] reported that organic pollutants (OPs) can be assimilated onto the surface of MPs through electrostatic, hydrophobic, non-covalent, partition effects, and multiple interactions. Perhaps the molecule size, polarity, ageing, functional group, crystallinity, and surface area of MPs impacts their potential to adsorb OPs. Different types of contaminants might exert antagonistic or synergistic influence on another present in the natural ecosystem. The association of MPs with contaminants develops in an extremely multifaceted way with persistent changes in the environment [42]. Microplastics are highly hydrophobic (water resistant), therefore chemical contaminants can easily be adsorbed onto the surface of plastics, making them a reservoir of hazardous contaminants in the ecosystem [14][44].

MPs are hydrophobic polymers possessing a greater surface area, which makes them competent carriers. Pesticides significantly adsorb pesticides onto the surface of MPs and ultimately reach each trophic food chain of the ecosystem [31][43][44]. Previous studies comprehensively provide significant inferences that the lethal chemicals present in the MPs can persistently migrate within the MPs surface and have the potential to disseminate in the soil [6]. Microplastics can serve as drivers of chemical pollutants, either used as additives during polymer manufacturing or directly assimilated from the environment [43]. Wang et al. [45] investigated the adsorption behavior of diflubenzuron, carbendazim, malathion, diptrex, and difenoconazole pesticides with polyethylene MPs, and showed that all pesticides adsorbed onto the MPs surfaces posed a potential risk to the ecosystem. This is due to the exclusive surface adsorption mechanism between pesticides and MPs, entirely regulated by intermolecular van der Waals forces and microporous filling mechanisms [46]. According to Mohana et al. [47], the adsorption and interaction mechanisms of MPs with various other existing pollutants are mostly unknown since the prevailing literature has focused on the existence of the MPs in the ecosystem [47]. However, it is crucial to study the fate and interactions of MPs with existing co-contaminants to ameliorate the impact on soil biodiversity [31]. Therefore, an imperative study is required to assess the combined interaction and impact of MPs with other pollutants present in the environment [45]. While recent studies have reported that MPs can affect the degradation process of pesticides in the aquatic ecosystem, there is still little relevant research on MPs in soil [43].

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