Journal of Experimental Biology and Agricultural Sciences, April - 2024; Volume – 12(2) page 163 – 174

Journal of Experimental Biology and Agricultural Sciences

http://www.jebas.org

ISSN No. 2320 – 8694

Exploring the Impact of Micro-plastics on Soil Health and Ecosystem Dynamics: A Comprehensive Review

Pratikshya Paudel[1], Rajneesh Kumar[1,2], Manoj Kumar Pandey[1*],
Prateek Paudel[3], Mamata Subedi[1]

[1]Department of Genetics and Plant Breeding, School of Agriculture, Lovely Professional University, Phagwara 144411, Punjab, India
[2]Division of Genetics and Plant Breeding, Faculty of Agriculture (FoA), Sher-e-Kashmir University of Agricultural Sciences and Technology (SKUAST–K), Wadura- 193201, J & K, India
[3]Forest Research Institute (Dimmed to be University), POIPE, Dehradun- 248195, India

Received – February 08, 2024; Revision – April 07, 2024; Accepted – April 09, 2024
Available Online – May 15, 2024

DOI: http://dx.doi.org/10.18006/2024.12(2).163.174

KEYWORDS

Microplastic

Bulk Density

Soil Biota

Intricate

Holistic

Multifaceted

ABSTRACT

Microplastics, defined as particles measuring less than 5 mm, have emerged as widespread environmental pollutants, prompting concerns regarding their impact on soil ecosystems. This review investigates microplastics' presence, movement, and effects on soil health and ecosystem dynamics while highlighting their diverse sources, including industrial production and the breakdown of larger plastic materials. Despite their ubiquity, a significant gap exists in our understanding of the consequences of microplastics in terrestrial ecosystems, particularly within soils. The findings of this review article revealed that microplastics exert notable influences on soil properties, altering bulk density, aggregation, and water-holding capacity, which may have significant implications for soil biota and plant vitality. Furthermore, microplastics also carry toxic substances, complicating their environmental impact. The effects on soil microorganisms and soil-dwelling fauna, such as earthworms, underscore the intricate relationships within soil ecosystems. Additionally, microplastics can interact with other soil pollutants, potentially amplifying their adverse effects. The long-term impacts of microplastics on soil health remain uncertain, underscoring the imperative for sustained research endeavours. Challenges persist, including the absence of standardized methodologies for microplastic extraction and identification in soils, which hampers our ability to understand their presence and effects comprehensively. Furthermore, the lack of regulatory frameworks complicates managing and mitigating microplastic pollution. Future research should adopt a holistic approach, considering diverse microplastic types and applications. Both field and laboratory experiments

* Corresponding author
E-mail: manoj.22848@lpu.co.in (Manoj Kumar Pandey)

Peer review under responsibility of Journal of Experimental Biology and Agricultural Sciences.

Production and Hosting by Horizon Publisher India [HPI] (http://www.horizonpublisherindia.in/).

are essential for accurately capturing the varied influences of microplastics. Efforts should concentrate on understanding the occurrence of microplastics, developing reliable detection methods, and exploring their interactions with other pollutants, especially in terrestrial ecosystems. In conclusion, mitigating microplastic pollution requires multifaceted strategies informed by ongoing research efforts and public awareness campaigns. We can effectively address the challenges posed by microplastic contamination in soil ecosystems through concerted action and comprehensive understanding.

1 Introduction

Each year, millions of tons of plastic are produced by humans, serving various purposes in our daily lives. Microplastics, a type of plastic with a thickness of less than 5 mm, are composed of a heterogeneous mixture of plastic fibers, granules, and pieces (Lusher et al. 2020). These microplastics are gaining attention as potential pollutants of concern (UNEP 2011; Sendra et al. 2021). Plastic waste in the environment can be categorized based on particle size into large plastic (Particle size higher than 5 mm), microplastic (0.1 µm to 5mm) (Barnes et al. 2009), and nano plastic (less than 0.1 µm) (Alimi et al. 2018). Owing to their greater prevalence, smaller particle size, and capacity for long-distance transmission, microplastics may be more harmful than bigger trash (Law and Thompson 2014; Gong and Xie 2020). Along with the terrestrial environment, microplastics have been reported from aquatic environments during the past few decades (Thompson et al. 2004; Thompson 2015). Previous studies suggested that microplastics may pose a hazard to various ecosystems (Andrady 2011; Peng et al. 2017).

Soil is an essential component of the land-based ecosystem. It is under significant pollution stress due to these microplastics, which affect the soil in various ways, such as the storage of carbon, the cycling of biogeochemical processes, and the support of biodiversity, which is severely affected. The term "Soil MP" describes microscopic plastic pieces that come to the soil from a variety of sources, such as processed organic waste from wastewater treatment facilities and the decomposition of used or abandoned plastic products (like plastic mulch) (Weithmann et al. 2018). The entire soil biosphere may be impacted by their ability to change the chemical and physical characteristics of soils. Li et al. (2016) suggest that microplastics may coexist with additional chemical additives during production. These additives may then leak into the environment when the plastics break down, endangering ecosystems and public health. These microplastics have been reported worldwide, including in polar zones, deep oceans, open oceans, and coastlines (Browne et al. 2011). Studies on microplastics in soil and terrestrial ecosystems are very rare, even though microplastics highly contaminate terrestrial ecosystems than aquatic ecosystems (Van Cauwenberghe et al. 2015; De Souza Machado et al. 2018a; Dissanayake et al. 2022). Because of their diminutive stature and possible hazard to aquatic and terrestrial ecosystems, these microplastics are emerging and persistent organic contaminants and have drawn attention worldwide (Huffer et al. 2019). This review delves into the broader context of soil science and how MP influences soil parameters. It is anticipated that this review will elevate the understanding of the impacts of microplastics, or MPs, on soil environments and result in more potent approaches to managing plastic pollution. It will underscore the existing gaps in our understanding, recommend areas for future investigation, and put forth effective strategies for managing and remedial measures for reducing the impact of microplastic pollution in soils.

2 Sources of Microplastic

Microplastics come from various sources and eventually find their way into soil (Figure 1). Cole et al. (2011) state that microplastics can be broadly divided into primary and secondary plastic categories. According to Castañeda et al. (2014), primary microplastics are difficult to remove from wastewater treatment systems and eventually accumulate in the environment (Liu et al. 2021). Secondary microplastics enter the soil in various ways, including soil additions from landfills, sewage sludge applied to land, irrigation using composted wastewater and organic fertilizer, tyre wear and tear, and atmospheric deposition (Liu et al. 2019).

Microplastics in these places are also made worse by sewage, sludge, mulching film, garbage disposal, etc. (Grbić et al. 2020). Sun et al. (2019) suggested that sewage treatment plants can successfully remove 99% of the microplastics from wastewater. However, these removed microplastics might accumulate in the activated sludge, and when farmers put such sludge on the farms, it can add a significant amount of microplastic pollutants to the agricultural soil (Edo et al. 2020). According to Guo et al. (2020), artificial playground turf is an indirect source causing the addition of microplastic in the soil since it can release an average of 2630 tons per year. Utilizing surface water bodies such as lakes or rivers for irrigation purposes can also introduce microplastics into soils because they are frequently contaminated by them (Wang et al., 2017). Furthermore, research indicates that airborne ultrafine plastic fibers result from home washing dryers (O'Brien et al. 2020).

In addition, through biological processes like feeding, digesting, and excretion, soil-dwelling organisms can convert plastic trash into microplastics. These microplastics substantially deteriorate the soil's quality (De Souza Machado et al. 2018b). The transportation

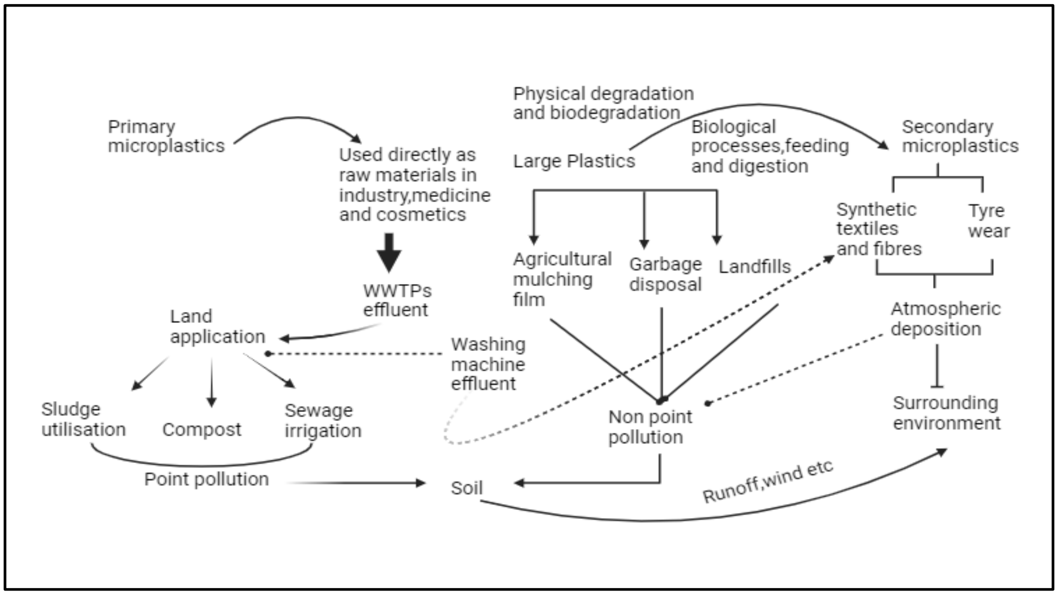

Figure 1 Varied sources of microplastics (WWTP: signifies Wastewater Treatment Plants)

Table 1 Classification of microplastics based on their density in soil

Polymer type/microplastics	Density (g/cm^3)
Poly Propylene (PP)	0.85- 0.95
PolyStyrene (PS)	1.04-1.11
Polyethylene (PE)	0.91- 0.93 (low density PE) 0.93- 0.97 (high density PE)
Poly Vinyl Chloride (PVC)	1.16-1.58
Nylon	1.08 (Nylon6) 1.31 (Nylon66)
Polyester	1.37-1.45

and transfer of microplastics seriously threaten ecosystems across food chains in severely degraded soils, particularly those irrigated with wastewater and wrapped with plastic film (Guo et al. 2020). Types of microplastic/polymer found in terrestrial and marine environments and their density are summarized in Table 1 (Andrady 2011; Hidalgo-Ruz et al. 2012; Scheurer and Bigalke 2018). Furthermore, microplastics also appear in different forms called microplastic morph types, such as fiber, fragment, foam, microbead, and granules (Tanaka and Takada 2016).

3 Impact of Microplastic On Soil

Microplastics could change the biophysical properties of soil, including its structure, porosity, moisture content, and aeration; these microplastics also have a big impact on land plants, soil animals, and soil microbes. These physical and biological impacts are also linked to the soil's chemical characteristics. These effects can be detrimental, neutral, or even beneficial (Wang et al. 2022). However, our understanding of the chain of impacts at the fundamental levels of land-based ecosystems is limited. These impacts included modifications in the non-living elements of soil and other facets of plant-soil interactions, such as soil microbial populations and traits of plants (De Souza Machado et al. 2018b).

4 Effects on Physical Properties of Soil

The physical properties of soil are a critical factor in assessing the microplastic risks posed to terrestrial ecosystems, as reported by Lehmann et al. (2019). These changes can affect the soil's bulk density, capacity to hold water, the stability of its aggregates, and its ability to repel water.

4.1 Bulk Density

The bulk density of soil, a significant determinant of estimating carbon storage in the soil, is also influenced by microplastics. This might be because plastic materials typically have a lower density than soil particles. A study by De Souza Machado et al. (2018b) revealed that the bulk density of soil was reduced more by polyester fibers than by fragments and beads. Similarly, De Souza

Machado et al. (2018b) and De Souza Machado et al. (2019) reported that PE, PS, and PP reduced the soil bulk density (Figure 2). Changes in bulk density could be partly attributed to the fact that plastics are typically less dense than numerous natural minerals prevalent in soils. Moreover, the specific type of microplastics also plays an additional role in influencing the pore space and particle interaction within the soil. Interestingly, while polyacrylic fibers and polyethylene fragments exhibit densities of approximately 86% and 71% of polyester, they did not induce as significant decreases in bulk density as polyester fibers. A reduction in the stability of soil aggregates can generally have adverse effects on the soil's biological activities and overall function, particularly on the exchange of air, water, and nutrients. This soil feature can be altered by the ongoing entry of microplastics into the soil environment.

4.2 Soil Aggregation

Various researchers have deeply investigated the effect of microplastics on soil aggregation (Boots et al. 2019; De Souza Machado et al. 2019; Lehmann et al. 2019; Zhang et al.2019) and reported that the form of the polymer affects soil aggregates when it comes from microplastics. In comparison to non-linear plastic particles, it was found that linear plastic particles altered higher soil aggregate stability. Furthermore, Zhang et al. (2019) observed that the inclusion of polyester microfibers resulted in a decrease in the number of pores smaller than 30 µm and an increase in the number of pores larger than 30 µm. This can be explained by the microfibers' capacity to enter and occupy microspores (Figure 2). The linear nature of the polyester microfibers facilitates their ability to entangle with soil particles and create clods. Consequently, increased clods from polyester microfibers might also contribute to proliferating the soil's larger pores or macropores (Jiang et al. 2019).

4.3 Water Holding Capacity

The maximum quantity of water a specific soil can restore against the force of gravity is known as the water holding capacity of a particular soil, also known as field capacity. Microplastics may alter the soil pore sizes, affecting the soil's water-holding capacity or its ability to hold onto water. A study by De Souza Machado et al. (2019) revealed that applying various polymers in different concentrations increased the WHC (water-holding capacity) of loamy soils. Moreover, research by Zhang et al. (2019) indicated that the soil's hydraulic conductivity (HC), which is its ability to transmit water, is enhanced when organic matter and microfibers are present together in the soil (Figure 2)

4.4 Soil water evaporation, evapotranspiration and desiccation

Depending on their size, microplastic particles can interact with the soil differently. Particles about the same size as soil aggregates (around 2 mm) could blend into the soil profile, creating pathways for water to move through. On the other hand, medium-sized particles (5–10 mm) can act as a soil cover, initially preventing water from evaporating. However, larger particles (10–15 mm) can cause the surface to crack, leading to increased evaporation and soil drying (Wan et al. 2022). In agriculture, plastic mulch is often used to conserve water. However, environmental factors like rain

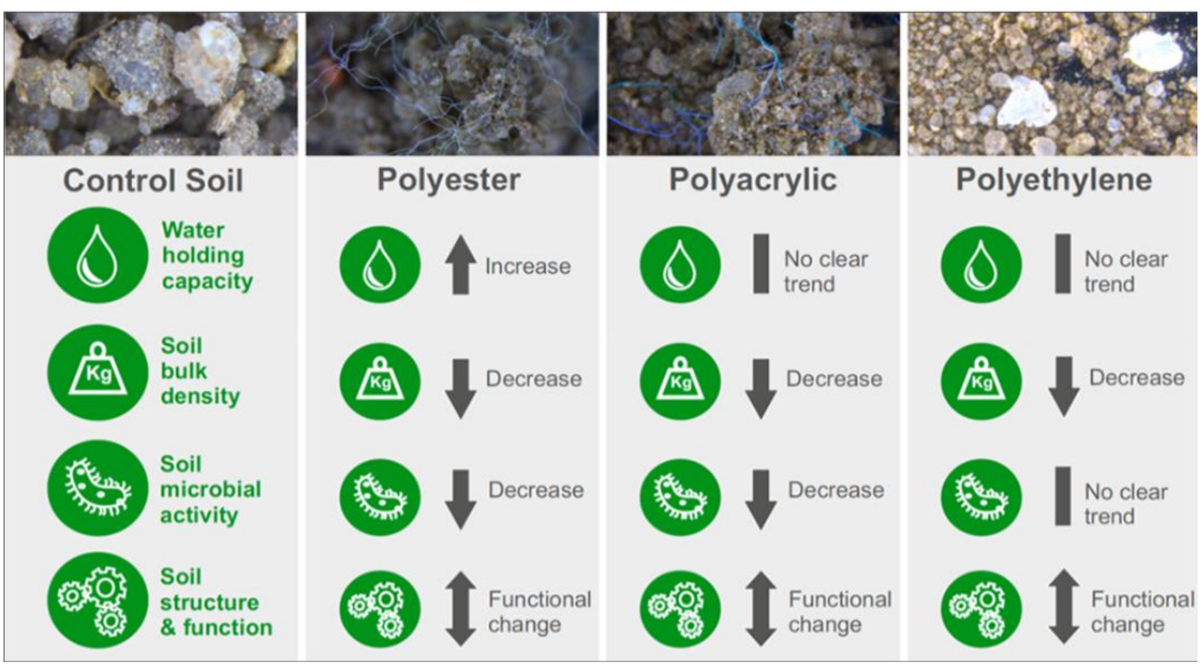

Figure 2 Impacts of Microplastics (MPs) on the Soil Biophysical Properties (Source: De Souza Machado et al. 2018b).

and sunlight can cause these materials to break down into smaller pieces. This can lead to unintended consequences such as increased evaporation, reduced soil moisture, and increased reliance on irrigation. Additionally, as the soil dries, tiny plastic particles may find their way into groundwater through fissures, which might exacerbate the issue of microplastic contamination in aquatic ecosystems (Mbachu et al. 2021). Although there isn't much research on the subject, plastic pollution in soil ecosystems can worsen water scarcity, particularly in dry regions. This emphasizes how crucial it is to carry out additional studies and create plans to control the effect of microplastics on our water and soil systems.

5 Effects on Soil Chemical Properties

Plastic materials, rich in carbon and slow to decompose, can potentially serve as a carbon source for soil microbiota as they break down over time (Rillig et al. 2019). De Souza Machado et al. (2019) claimed that certain plastic polymers, such as polyacrylonitrile and polyamide, contain nitrogen (N), and polytetrafluoroethylene contains fluorine (F) have nutritional components that could affect the biogeochemical properties of soil. However, the role of microplastics as a nutrient source in soils needs to be further confirmed because it's plausible that certain microplastics can modify the soil biogeochemical cycle by leaching. Moreover, because of their hydrophobic nature and expanded surface area, microplastics can adsorb various toxic substances, including heavy metals, hydrophobic organic compounds, and antibiotics (Sun et al. 2018). If microplastics carrying these contaminants are exposed to the environment through leaching, they could negatively impact the soil ecosystem (Kim et al. 2021).

Palansooriya et al. (2022) found variances in soil enzyme activities across all treatments. In particular, soils treated with a high temperature of 700 degrees Celsius biochar showed increased fluorescein diacetate activity during dry circumstances. Applying softwood pellet biochar heated at 700-degree Celsius increased urease activity by 146 percent in well-watered MP-contaminated soil. Biochars from OSR significantly decreased soil acid phosphatase activity in both water conditions (Palansooriya et al. 2022).

6 Effects on Biological Properties

6.1 Effects on Soil microorganisms

Microorganisms in the soil ecosystem constitute a substantial part of all land-based life forms. However, our understanding of how microplastics (MPs) affect these species is incomplete. It is conceivable that MPs could alter the soil's physical properties, such as its moisture content and porosity. These modifications may impact the soil's oxygen flow, altering the ratio of aerobic to anaerobic microbes. Furthermore, alterations brought by MPs to the pore spaces in the soil may cause the extinction of endemic microorganisms and the loss of microhabitats (Veresoglou et al. 2015). Studies have demonstrated that specific MPs, notably membrane-like polyethylene and fibrous polypropylene, can drastically shift soil microbial communities' population and alpha diversity (Figure 2). According to Yi et al. (2021) there has been a rise in soil Acidobacteria and Bacteroidetes populations, while Deinococcus-Thermus and Chloroflexi have decreased when MPs are applied to the soil. Similarly, Judy et al. (2019) suggested that the incorporation of MPs considerably changed the microbial community's structure and resulted in a considerable drop in substrate-induced respiration (SIR) rates, indicating that MPs may affect the functioning of soil microbes. Furthermore, de Souza Machado et al. (2019) suggested that MPs had variable effects on the root colonization of soil fungi *Arbuscular mycorrhiza*. In general, MPs can modify soil characteristics and impose selective pressures on soil microorganisms, which might impact the diversity and structure of communities and possible evolutionary outcomes. Further, it was reported that MPs can be more quickly biodegraded by certain bacteria like *Pseudomonas aeruginosa, Bacillus megaterium, Rhodococcus ruber, Cupriavidus necator, Pseudomonas chlororaphis* (Stawiński and Wal 2021; Kalia et al., 2021) and fungi like *Aspergillus terreus, Engyodontium album, Cochliobolus sp., A. sydowii, A. flavus, Fusarium lini, Pycnoporus cinnabarinus, Mucor rouxiiacidobacteria* that live in soil environment (Shah et al. 2008; Ali et al. 2021; Miri et al. 2022).

6.2 Effects on Soil Animal

As representative species in the soil ecosystem, Earthworms have been the focus of many studies regarding their interaction with microplastics. The influence of microplastics on earthworms is contingent upon the concentration and variety of the microplastics, which can cause a decrease in growth rate and harm to the immune system. As per the research by Cao et al. (2017), earthworms' adaptability was not significantly affected by exposure to 0.25–0.5% microplastics, and growth was only seen to drop at exposure concentrations greater than 1%. The mortality of earthworms increased by 8 and 25 percent when exposed to microplastic concentrations, which were as high as 28% and 60%, respectively (Lwanga et al. 2016). First-time negative effects of microplastic exposure on invertebrate sperm were observed in a recent study by Kwak and An (2021); these researchers suggested that these effects were independent of the size of the plastic particles. Additionally, microplastics can alter the gut microbiome of animals that live in soil, which may impact how organic materials are used and how necessary elements are cycled. While most plastics are eliminated from the body after consumption, research by Browne et al. (2011) indicated that microplastics could remain in the gut for extended periods and may have various harmful consequences. Furthermore, according to Selonen et al. (2020) microplastics can change the ecosystem which surrounds soil animals, having an indirect effect on them.

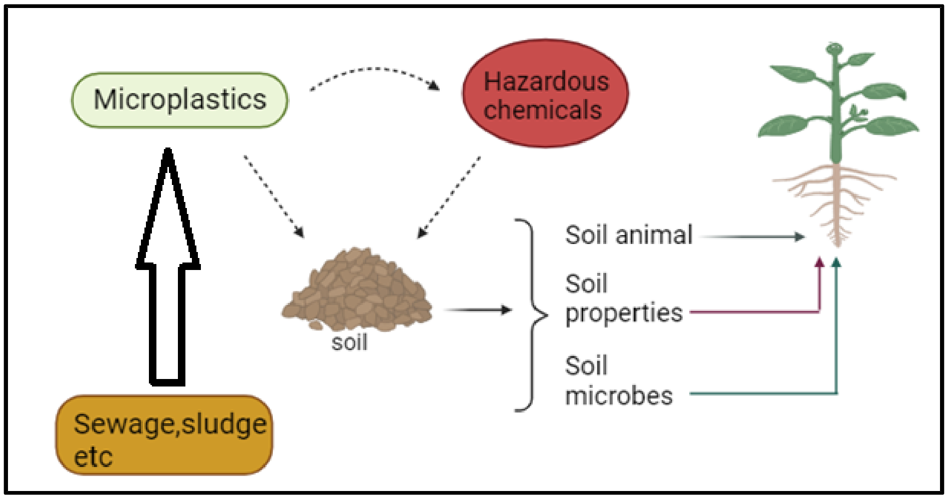

Figure 3 Picturesque representation of the impact of microplastic on various factors

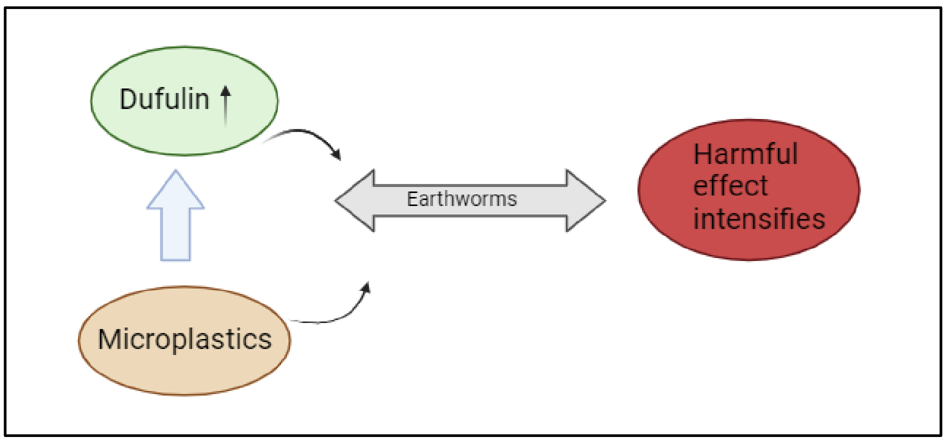

Figure 4 Impact of microplastics on earthworms

To deduce, microplastics resulting from different sources like sewage, sludges, etc., have detrimental effects on soil-dwelling organisms and other physical and chemical properties of soil. These variations in traits hamper the normal growth and development of plants if they survive under pollutant conditions; it has remnants of these compounds (dangerous substances found in microplastic), which could be lethal to living things if swallowed. Hence, microplastic sources should be considered to limit their negative impact on the health of soil, plants, microorganisms, and living beings. This pattern/ chain of microplastic to the health of the soil and the living beings is portrayed in Figure 3.

7 Microplastic and other pollutants on soil

Toxic chemicals like plasticizers, retardants, and antioxidants can leak into the soil due to microplastics. Furthermore, weathered regions of microplastics can draw other toxic pollutants from the soil, like heavy metals and organic pollutants, converting the microplastics into chemical reservoirs (Wang et al. 2020). The interaction between arsenic and polystyrene microplastics reduced the amount of bioavailable arsenic in the soil, hence mitigating the effect of arsenic on soil microorganisms in the rice rhizosphere. Microplastics may also affect plants' capacity to absorb heavy metals. Dong et al. (2021) conducted a study to evaluate the effects of polystyrene microplastics and arsenic on carrot growth and reported that 0.2 µm polystyrene microplastics may reach the leaves and roots of carrots when As (III) is present. According to Gaussian analysis, arsenic promoted cell wall deformation and elevated the negatively charged area of polystyrene microplastics, making it easier for the microplastics to enter carrots (Dong et al. 2021). It is ambiguous how other contaminants and microplastics affect soil fauna together. However, it has been noted that exposure to both microplastics and cadmium together accelerates the cadmium buildup in earthworms, increasing oxidative damage and death (Zhou et al. 2020). According to another study, microplastics greatly accelerated dufulin's bioaccumulation in earthworms and increased its harmful effects, as presented in Figure 4 (Sun et al. 2022).

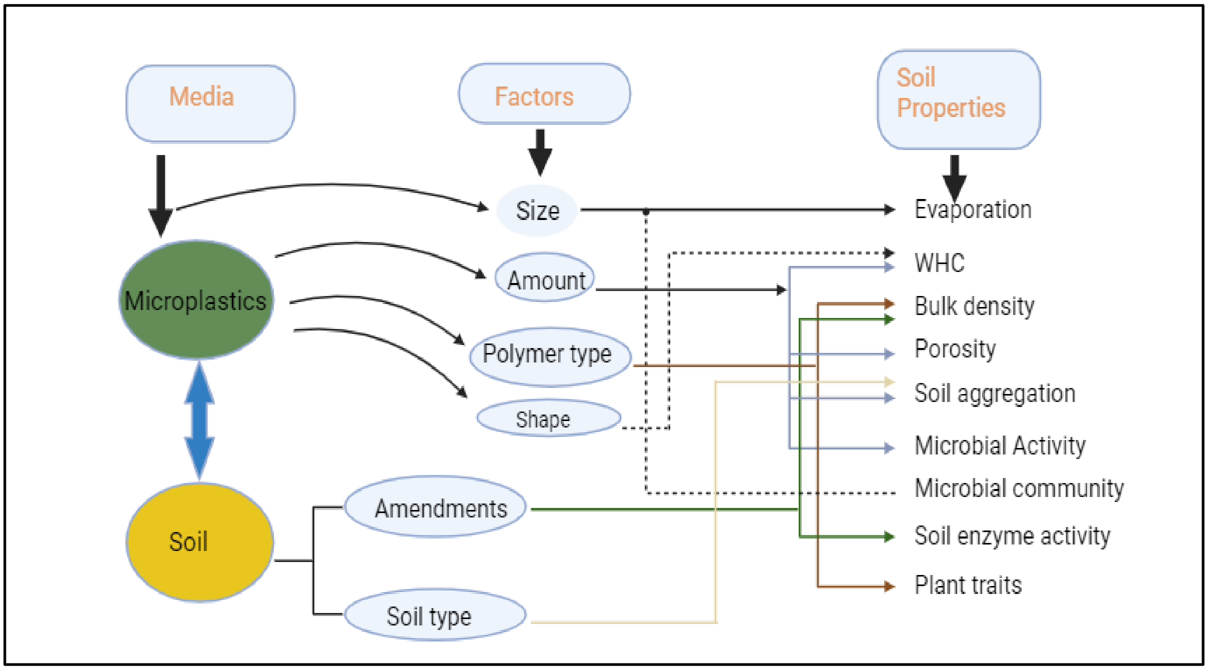

Figure 5 Demonstrating the major relationship between physical properties of soil and rhizosphere function and microplastic input components

8 Key relationship between microplastic and soil responses

This review revealed that microplastics in the soil environment can impact a wide variety of vital characteristics. This review article consolidated the relationships between input variable (such as size and shape of plastic and soil type) and their responses on soil features viz, porosity, water holding capacity (WHC), as well as microbial activity (Figure 5). These relationships demonstrate how each factor can impact a key soil parameter, providing a roadmap for future research to focus on pertinent relationships. Research has indicated that MPs' long-term build-up and concentration can modify soil's chemical, biological, and physical characteristics. The size of the microplastic and soil type can have diverse effects on the soil environment, whether positive, negative, or neutral. It's crucial to acknowledge that the abovementioned relationship is based on our present knowledge of the relationship between soil and MPs, which is still in its nascent stages. As more research is conducted and new studies are published, these relationships can be further refined, enabling ongoing research efforts to be more precisely directed.

9 Status of microplastic pollution in soil

The distribution of microplastics in marine settings has been the subject of numerous research studies (Auta et al. 2017), but minimal information is known about the status of microplastic pollution in soil/terrestrial environments. Here, this review article offers an overview of pertinent studies in Table 2 that have been published. The data highlighted below provides deeper insights into how microplastic jeopardizes the soil ecosystem, thereby influencing crop production and productivity and threatening the health of living beings.

Based on the above data, microplastics have significantly contaminated industrial regions soil, especially soils near industrial areas of Australia (Fuller and Gautam 2016), containing a range of 0.03-6.7% microplastic (mostly PVC). In Switzerland, microplastic pollution was widespread but not as severe (≤0.00555%, mostly PE) (Scheurer and Bigalke 2018). According to Gourmelon (2015), China produces, consumes, and discards a large amount of plastic annually, causing soil microplastic pollution and seeking particular attention. It is crucial to conduct extensive and ongoing microplastic surveys to prevent soil degradation, as high microplastic content has been found in certain industrial, agricultural, and even forest soils (Table 2). Information on hotspot zones, main microplastics, and related sources is essential for hazard evaluation and pollution control.

10 Prevention/Countermeasure

The influx of microplastics into soil ecosystems is expected to rise continually due to increasing production, widespread use in line with population growth, their resistance to degradation, and the significant quantities currently in existence (Eerkes-Medrano et al. 2015). Hence, there is an urgent need for potential remediation measures to reduce microplastic hazards and lessen their contamination. Implementing required policies and institutional governance initiatives could prevent microplastics and associated

Table 2 Various published sources show the proportion of microplastic pollution in soil

Source of soil	Country	Processes for quantification extraction and identification	Microplastics				References
			Size (mm)	Morphotype	Concentration (%)	Major type	
Agriculture fields	China (Northwest area)	Microplastics were treated at 130°C for 3-5 seconds, and their identification was confirmed using a microscope before and after the heat treatment.	>0.1	-	≤0.000054	PE, PP	Zhang and Liu (2018)
mix-culture ecosystem (rice-fish)	China (Shanghai)	The organic matter was identified under a microscope through density separation using a saturated NaCl solution and 30% H2O2 treatment.	<1	Mainly fibers	-	PE, PP	Lv et al. 2019
Forest buffer zone Greenhouse vegetable soils	China (Southwest area)	The process involves separating organic matter by treating organic matter with a saturated NaI solution.	<1	mainly fibers	-	-	Zhang and Liu (2018)
Vegetable fields	China (Shanghai)	separation of organic matter using a saturated NaCl solution and 30% H2O2 treatment, and its identification through a µFT-IR assay.	<1	fibers and fragments	-	PE, PP	Liu et al. 2018
Floodplain soils	Switzerland	The organic matter was treated with 27%NaCl solution and 65%HNO3 to achieve density separation, which was then identified using an FT-IR microscope.	-	-	0.03-6.7	PVC	Scheurer and Bigalke (2018)
Near industrial area	Australia	The extraction process involved pressurized fluid extraction, which was then identified using GC-MS and FT-IR spectrophotometer.	<0.5	-	≤0.0055	PE	Fuller and Gautam (2016)

Here, FT-IR denotes Fourier transform-infrared spectroscopy while GC-MS represents Gas chromatography-mass spectrometer

Potentially Toxic Elements (PTEs) from entering the human food chain. Moreover, integrating the 3R (Reduce, Reuse, Recycle) approach and circular economy principles, thereby reducing the amount of microplastics and PTEs released into the environment as well as their recontamination and spread, could aid in the mitigation process (Igalavithana et al. 2022). Research on microplastic pollution in soil must be prioritized to lessen environmental and food chain hazards. This entails investigating the origin, build-up, deterioration, movement, and possible hazards within the food chain and eco-environment (Yongming et al. 2018). Methods must be developed to eliminate microplastics. For example, reducing the quantity of microplastics entering soil ecosystems through sewage irrigation might be achieved by implementing microplastic removal techniques during wastewater treatment (Guo et al. 2020). To preserve soil quality, targeted mitigation and management plans must be created for impacted areas (Kublik et al. 2022). Some bacterial species, like *Rhodococcus ruber* and *Pseudomonas putida*, have been shown to break down plastics and may be useful for bioremediation of soil contaminated with microplastics. Nonetheless, it is important to consider the possible risk of eliminating microplastics using bioremediation (Caruso 2015).

11 Microorganisms for Plastic Management

The ability of soil microorganisms to break down natural and artificial materials in the environment is essential for the ecosystem's nutrient cycling. Therefore, they have a big natural impact on the breakdown of synthetic polymers. Utilizing an array of enzymes, these microbes may break down polymers into intermediate chemicals that can be taken up by the body and processed to meet their energy requirements. Degradation of plastic polymers by various actinomycetes, bacteria, and fungi has been reported. The rhizosphere of soil, plastic-contaminated areas, animal intestines, and landfills are the usual locations for these microbes. The inherent ability of bacteria to break down long-chain fatty acids makes them capable of degrading polymers. The breakdown of polyethylene (PE) films is largely attributed to

Arthrobacter sp. and *Streptomyces* sp., as demonstrated by the rise in the carbonyl index and CO2 evolution (Han et al. 2020).

12 Prospects and Challenges

Microplastic contamination in soil poses serious environmental issues that could jeopardize the health of the soil ecosystem and humans. Microplastics can interact with other contaminants found in soil, including organic and heavy metal pollutants. However, our understanding of these interactions is still limited, making it hard to predict the environmental hazards associated with microplastic pollution. The intricate and variable characteristic of the soil matrix makes it difficult to separate and identify microplastics. As there are no standard methods for removing, identifying, and measuring microplastics from soil samples, it is difficult to compare the outcomes of various studies, which ultimately hinders the development of a comprehensive understanding of microplastic pollution. The long-lasting impacts of microplastics on the health of soil and ecosystem functionality are largely unknown, underscoring the need for more long-lasting studies to evaluate the potential risks and effects of microplastic pollution on soil ecosystems. Currently, there are no regulatory frameworks for microplastics in soil, which complicates the management and mitigation practices of the impact of pollution generated by microplastics. Typically, the degree of microplastics in soil is lower than those used in experimental settings. Therefore, future studies should aim to use microplastics at concentrations that more closely mirror those found in the environment to reflect their ecological impacts more accurately. Additional research in this area is advised, mainly for soil types apart from light-textured soils, such as heavy-textured and carbon-rich soils, where it is unclear how adding microplastics to soil may affect its hydraulic conductivity. Research on microplastics in agricultural environments looks towards future directions and focus, offering reasonable suggestions for current issues to provide a theoretical foundation for future related research.

13 Future Research Priority Recommendation

Due to their fundamental structure and qualities, microplastics, with their different forms, shapes, sizes, and uses, have unique reactions on soil. Therefore, studies investigating the environmental impacts of microplastics must include a diverse spectrum of microplastics with varying functions and origins. Studies that consider the quantitative or qualitative features of soil microplastics might not adequately account for the impact these particles have on the soil and living things. Experiments in the field and the lab are required to determine the lowest concentration and length of exposure that result in negative consequences. Consequently, more field research is needed to confirm microplastics' effects on soil's physical properties.

Using population models, Browne (2015) established a system to examine and direct the management of ecological consequences and to establish ecological links between anthropogenic garbage and the environment. This suggests that rather than focusing solely on the existence of microplastics and their sublethal consequences, further analysis of the effects on ecological relationships is needed, and to help minimize the risks that microplastics pose, research on various microplastics is required. Microplastic has an adsorption capacity that is often comparable to other environmental contaminants; nevertheless, the ability of different microplastic materials to adsorb various antibiotics under different ecological conditions varies significantly (Guo et al. 2020).

Conclusion

Soil contaminated by microplastics is an emerging environmental concern with potential repercussions for soil health and ecosystem integrity. Exploring the Impact of Microplastics on Soil Health and Ecosystem Dynamics comes with challenges, such as a lack of standardized methodologies and regulatory frameworks, emphasizing the need for concerted research efforts. Mitigating microplastic pollution in soils requires a multi-faceted approach, including developing effective removal technologies, policy interventions, and public awareness campaigns. Recognizing the potential synergies or antagonisms between microplastics and other pollutants is crucial for informed environmental management. As microplastics continue to proliferate, especially in agricultural and forestry sectors, it is imperative to prioritize research that informs sustainable practices, minimizes ecological footprints, and safeguards soil ecosystems for future generations.

References

Ali, S.S., Elsamahy, T., Koutra, E., Kornaros, M., El-Sheekh, M., et al. (2021). Degradation of conventional plastic wastes in the environment: A review on current status of knowledge and future perspectives of disposal. *Science of the Total Environment*, *771*, 144719.

Alimi, O.S., Farner Budarz, J., Hernandez, L.M., & Tufenkji, N. (2018). Microplastics and nanoplastics in aquatic environments: aggregation, deposition, and enhanced contaminant transport. *Environmental Science & Technology*, *52*(4),1704-1724.

Andrady, A.L. (2011). Microplastics in the marine environment. *Marine pollution bulletin*, *62*(8),1596-1605.

Auta, H. S., Emenike, C. U., & Fauziah, S. H. (2017). Distribution and importance of microplastics in the marine environment: a review of the sources, fate, effects, and potential solutions. *Environment International*, *102*, 165-176.

Barnes, D.K., Galgani, F., Thompson, R.C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical transactions of theroyal society B: biological sciences*, *364*(1526), 1985-1998.

Boots, B., Russell, C.W., & Green, D.S. (2019). Effects of microplastics in soil ecosystems: above and below ground. *Environmental Science & Technology*, *53*(19), 11496-11506.

Browne, M.A. (2015). Sources and pathways of microplastics to habitats. In M. Bergmann, L. Gutow, M. Klages, (Eds.) *Marine Anthropogenic Litter* (pp. 229-244). Springer, Cham. https://doi.org/10.1007/978-3-319-16510-3_9.

Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., & Thompson, R. (2011). Accumulation of microplastic on shorelines woldwide: sources and sinks. *Environmental Science & Technology*, *45*(21), 9175-9179.

Cao, D., Wang, X., Luo, X., Liu, G., & Zheng, H. (2017). Effects of polystyrene microplastics on the fitness of earthworms in an agricultural soil. *IOP conference series: Earth and Environmental Science*, *61* (1), 012148.

Caruso, G. (2015). Plastic degrading microorganisms as a tool for bioremediation of plastic contamination in aquatic environments. *Pollution Effects & Control*, *3*, e112.

Castañeda, R.A., Avlijas, S., Simard, M.A., & Ricciardi, A. (2014). Microplastic pollution in St. Lawrence River sediments. *Canadian Journal of Fisheries and Aquatic Sciences*, *71*(12), 1767-1771.

Cole, M., Lindeque, P., Halsband, C., & Galloway, T.S. (2011). Microplastics as contaminants in the marine environment: a review. *Marine pollution bulletin*, *62*(12), 2588-2597.

De Souza Machado, A.A., Kloas, W., Zarfl, C., Hempel, S., & Rillig, M.C. (2018a). Microplastics as an emerging threat to terrestrial ecosystems. *Global change biology*, *24*(4), 1405-1416.

De Souza Machado, A.A., Lau, C.W., Kloas, W., Bergmann, J., Bachelier, J.B., et al. (2019). Microplastics can change soil properties and affect plant performance. *Environmental Science & Technology*, *53*(10),6044-6052.

De Souza Machado, A.A., Lau, C.W., Till, J., Kloas, W., Lehmann, A., Becker, R., & Rillig, M.C. (2018b). Impacts of microplastics on the soil biophysical environment. *Environmental Science & Technology*, *52*(17), 9656-9665.

Dissanayake, P.D., Kim, S., Sarkar, B., Oleszczuk, P., Sang, M.K., et al. (2022). Effects of microplastics on the terrestrial environment: a critical review. *Environmental Research*, *209*, 112734.

Dong, Y., Gao, M., Qiu, W., & Song, Z. (2021). Effect of Microplastics and Arsenic on Nutrients and Microorganisms in Rice Rhizosphere Soil. *Ecotoxicology and Environmental Safety*, *211*,111899.

Edo, C., González-Pleiter, M., Leganés, F., Fernández-Piñas, F., & Rosal, R. (2020). Fate of microplastics in wastewater treatment plants and their environmental dispersion with effluent and sludge. *Environmental Pollution*, *259*,113837.

Eerkes-Medrano, D., Thompson, R.C., & Aldridge, D.C. (2015). Microplastics in freshwater systems: a review of the emerging threats, identification of knowledge gaps and prioritization of research needs. *Water research*, *75*, 63-82.

Fuller, S., & Gautam, A. (2016). A procedure for measuring microplastics using pressurized fluid extraction. *Environmental science & technology*, *50*(11), 5774-5780.

Gong, J., & Xie, P. (2020). Research progress in sources, analytical methods, eco-environmental effects, and control measures of microplastics. *Chemosphere*, *254*, 126790.

Gourmelon, G. (2015). Global plastic production rises, recycling lags. *Vital Signs*, *22*, 91-95.

Grbić, J., Helm, P., Athey, S., & Rochman, C.M. (2020). Microplastics entering northwestern Lake Ontario are diverse and linked to urban sources. *Water Research*, *174*, 115623.

Guo, J.J., Huang, X.P., Xiang, L., Wang, Y.Z., Li, YW, et al. (2020). Source, migration and toxicology of microplastics in soil. *Environment international*, *137*,105263.

Han, Y.N., Wei, M., Han, F., Fang, C., Wang, D., et al. (2020). Greater biofilm formation and increased biodegradation of polyethylene film by a microbial consortium of Arthrobacter sp. and Streptomyces sp. *Microorganisms*, *8*(12), 1979.

Hidalgo-Ruz, V., Gutow, L., Thompson, R.C., & Thiel, M. (2012). Microplastics in the marine environment: a review of the methods used for identification and quantification. *Environmental Science & Technology*, *46*(6), 3060-3075.

Hüffer, T., Metzelder, F., Sigmund, G., Slawek, S., Schmidt, T.C., & Hofmann, T. (2019). Polyethylene microplastics influence the transport of organic contaminants in soil. *Science of the Total Environment*, *657*, 242-247.

Igalavithana, A.D., Mahagamage, M.G.Y., Gajanayake, P., Abeynayaka, A., Gamaralalage, P.J.D., et al. (2022). Microplastics and potentially toxic elements: potential human exposure pathways through agricultural lands and policy-based countermeasures. *Microplastics*, *1*(1),102-120.

Jiang, C., Yin, L., Li, Z., Wen, X., Luo, X., et al. (2019). Microplastic pollution in the rivers of the Tibet Plateau. *Environmental Pollution*, *249*,91-98.

Judy, J.D., Williams, M., Gregg, A., Oliver, D., Kumar, A., Kookana, R. & Kirby, J.K. (2019). Microplastics in municipal mixed-waste organic outputs induce minimal short to long-term toxicity in key terrestrial biota. *Environmental Pollution*, *252*, 522-531.

Kalia, V.C., Patel, S.K.S., Shanmugam, R., & Lee, J.K. (2021). Polyhydroxyalkanoates: Trends and advances toward biotechnological applications. *Bioresource Technology*, *326*, 124737.

Kim, Y.N., Yoon, J.H., & Kim, K.H.J. (2021). Microplastic contamination in soil environment–a review. *Soil Science Annual*, *71*(4),300-308.

Kublik, S., Gschwendtner, S., Magritsch, T., Radl, V., Rillig, M.C., & Schloter, M. (2022). Microplastics in soil induce a new microbial habitat, with consequences for bulk soil microbiomes. *Frontiers in Environmental Science*, *10,* 989267.

Kwak, J.I., & An, Y.J. (2021). Microplastic digestion generates fragmented nanoplastics in soils and damages earthworm spermatogenesis and coelomocyte viability. *Journal of Hazardous Materials*, *402*,124034.

Law, K.L., & Thompson, R.C. (2014). Microplastics in the seas. *Science*, *345*(6193),144-145.

Lehmann, A., Fitschen, K., & Rillig, M.C. (2019). Abiotic and biotic factors influencing the effect of microplastic on soil aggregation. *Soil Systems*, *3*(1), 21.

Li, C., Chen, J., Wang, J., Han, P., Luan, Y., Ma, X., & Lu, A. (2016). Phthalate esters in soil, plastic film, and vegetable from greenhouse vegetable production bases in Beijing, China: concentrations, sources, and risk assessment. *Science of the Total Environment*, *568*, 1037-1043.

Liu, K., Wang, X., Wei, N., Song, Z., & Li, D. (2019). Accurate quantification and transport estimation of suspended atmospheric microplastics in megacities: Implications for human health. *Environment international*, *132*,105127.

Liu, M., Lu, S., Song, Y., Lei, L., Hu, J., et al. (2018). Microplastic and mesoplastic pollution in farmland soils in suburbs of Shanghai, China. *Environmental pollution*, *242*, 855-862.

Liu, W., Zhang, J., Liu, H., Guo, X., Zhang, X., et al. (2021). A review of the removal of microplastics in global wastewater treatment plants: Characteristics and mechanisms. *Environment international*, *146*, 106277.

Lusher, A.L., Bråte, I.L.N., Munno, K., Hurley, R.R., & Welden, N.A. (2020). Is it or isn't it: the importance of visual classification in microplastic characterization. *Applied spectroscopy*, *74*(9), 1139-1153.

Lv, W., Zhou, W., Lu, S., Huang, W., Yuan, Q., et al. (2019). Microplastic pollution in rice-fish co-culture system: A report of three farmland stations in Shanghai, China. *Science of the Total Environment*, *652*, 1209-1218.

Lwanga, H. E., Gertsen, H., Gooren, H., Peters, P., Salánki, T., et al. (2016). Microplastics in the terrestrial ecosystem: implications for *Lumbricus terrestris* (Oligochaeta, Lumbricidae). *Environmental Science & Technology*, *50*(5),2685-2691.

Mbachu, O., Jenkins, G., Kaparaju, P., & Pratt, C. (2021). The rise of artificial soil carbon inputs: Reviewing microplastic pollution effects in the soil environment. *Science of the Total Environment*, *780*,146569.

Miri, S., Saini, R., Davoodi, S.M., Pulicharla, R., Brar, S.K., & Magdouli, S. (2022). Biodegradation of microplastics: Better late than never. *Chemosphere*, *286*, 131670.

O'Brien, S., Okoffo, E.D., O'Brien, J.W., Ribeiro, F., Wang, X., et al. (2020). Airborne emissions of microplastic fibres from domestic laundry dryers. *Science of the Total Environment*, *747*, 141175.

Palansooriya, K.N., Sang, M.K., Igalavithana, A.D., Zhang, M., Hou, D., Oleszczuk, P., Sung, J. & Ok, Y.S. (2022). Biochar alters chemical and microbial properties of microplastic-contaminated soil. *Environmental Research*, *209*,112807.

Peng, G., Zhu, B., Yang, D., Su, L., Shi, H., & Li, D. (2017). Microplastics in sediments of the Changjiang Estuary, China. *Environmental Pollution*, *225*, 283-290.

Rillig, M.C., Lehmann, A., de Souza Machado, AA, & Yang, G. (2019). Microplastic effects on plants. *New Phytologist*, *223*(3),1066-1070.

Scheurer, M., & Bigalke, M. (2018). Microplastics in Swiss floodplain soils. *Environmental science & technology*, *52*(6), 3591-3598.

Selonen, S., Dolar, A., Kokalj, A.J., Skalar, T., Dolcet, L.P., Hurley, R. & van Gestel, C.A. (2020). Exploring the impacts of plastics in soil–The effects of polyester textile fibers on soil invertebrates. *Science of the Total Environment*, *700*,134451.

Sendra, M., Sparaventi, E., Novoa, B., & Figueras, A. (2021). An overview of the internalization and effects of microplastics and nanoplastics as pollutants of emerging concern in bivalves. *Science of the Total Environment*, *753*, 142024.

Shah, A.A., Hasan, F., Akhter, J.I., Hameed, A. & Ahmed, S. (2008). Degradation of polyurethane by novel bacterial consortium isolated from soil. *Annals of microbiology*, *58*, 381-386.

Stawiński, W., & Wal, K. (2021). Microbial degradation of polymers. *Recent Advances in Microbial Degradation*, 19-46. DOI:10.1007/978-981-16-0518-5_2.

Sun, J., Dai, X., Wang, Q., Van Loosdrecht, M.C., & Ni, B.J. (2019). Microplastics in wastewater treatment plants: Detection, occurrence and removal. *Water research*, *152*, 21-37.

Sun, J., Peng, Z., Zhu, Z.R., Fu, W., Dai, X. & Ni, BJ (2022). The atmospheric microplastics deposition contributes to microplastic pollution in urban waters. *Water Research*, *225*,119116.

Sun, M., Ye, M., Jiao, W., Feng, Y., Yu, P., et al. (2018). Changes in tetracycline partitioning and bacteria/phage-comediated ARGs in microplastic-contaminated greenhouse soil facilitated by sophorolipid. *Journal of Hazardous Materials*, 345,131-139.

Tanaka, K., & Takada, H. (2016). Microplastic fragments and microbeads in digestive tracts of planktivorous fish from urban coastal waters. *Scientific reports*, *6*(1), 34351.

Thompson, R.C. (2015). Microplastics in the marine environment: sources, consequences and solutions. In: M. Bergmann, L. Gutow, & M. Klages (Eds.), *Marine Anthropogenic Litter* (pp. 185–200). Springer, Cham. https://doi.org/10.1007/978-3-319-16510-3_7.

Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W., McGonigle, D. & Russell, A.E. (2004). Lost at sea: where is all the plastic?. *Science*, 304(5672), 838- 838.

United Nations Environment Programme. Division of Early Warning. (2011). UNEP year book 2011: *emerging issues in our global environment*. UNEP/Earthprint.

Van Cauwenberghe, L., Devriese, L., Galgani, F., Robbens, J., & Janssen, C.R. (2015). Microplastics in sediments: a review of techniques, occurrence and effects. *Marine Environmental Research*, *111*, 5-17.

Veresoglou, S.D., Halley, J.M., & Rillig, M.C. (2015). Extinction risk of soil biota. *Nature communications*, *6*(1), 8862.

Wan, Y., Chen, X., Liu, Q., Hu, H., Wu, C., & Xue, Q. (2022). Informal landfill contributes to the pollution of microplastics in the surrounding environment. *Environmental Pollution*, *293*, 118586.

Wang, F., Wang, Q., Adams, C.A., Sun, Y., & Zhang, S. (2022). Effects of microplastics on soil properties: current knowledge and future perspectives. *Journal of Hazardous Materials*, *424*, 127531.

Wang, S., Chen, H., Zhou, X., Tian, Y., Lin, C., Wang, W., Zhou, K., Zhang, Y., & Lin, H. (2020). Microplastic abundance, distribution and composition in the mid-west Pacific Ocean. *Environmental pollution*, *264*,114125.

Wang, W., Ndungu, A.W., Li, Z., & Wang, J. (2017). Microplastics pollution in inland freshwaters of China: A case study in urban surface waters of Wuhan, China. *Science of the Total Environment*, *575*,1369-1374.

Weithmann, N., Möller, J.N., Löder, M.G., Piehl, S., Laforsch, C., & Freitag, R. (2018). Organic fertilizer as a vehicle for the entry of microplastic into the environment. *Science Advances*, 4(4), eaap8060.

Yi, M., Zhou, S., Zhang, L. & Ding, S. (2021). The effects of three different microplastics on enzyme activities and microbial communities in soil. *Water Environment Research*, *93*(1), 24-32.

Yongming, L., Qian, Z., Haibo, Z., Xiangliang, P., Chen, T., Lianzhen, L. & Jie, Y. (2018). Pay Attention to Research on Microplastic Pollution in Soil for Prevention of Ecological and Food Chain Risks. *Bulletin of Chinese Academy of Sciences (Chinese Version)*, *33*(10), 1021-1030.

Zhang, G., Zhang, F., & Li, X. (2019). Effects of polyester microfibers on soil physical properties: perception from a field and a pot experiment. *Science of The Total Environment*, *670*, 1- 7.

Zhang, G.S., & Liu, Y.F. (2018). The distribution of microplastics in soil aggregate fractions in southwestern China. *Science of the Total Environment*, *642*, 12-20.

Zhou, Y., Liu, X., & Wang, J. (2020). Ecotoxicological effects of microplastics and cadmium on the earthworm *Eisenia foetida*. *Journal of Hazardous Materials*, *392*, 122273.