Bangladesh J. Nuclear Agric, 38(1): 1-19, 2024 *ISSN 0258-7130*
DOI: https://doi.org/10.3329/bjnag.v38i1.76558

MICRO-PLASTICS IN SOIL ENVIRONMENT: A REVIEW

M.R. Khan[1], M.A. Tarafder[1], M.S. Priti[1]* and M.A. Haque[1]

Abstracts

Environmental scientists and other stakeholders have paid serious attention to soil pollution by microplastics in the last ten years. In soils, the microplastic particles act as a vector for the toxic persistent organic pollutants and potentially toxic metals that are easily sorbed by plants and enter the food chain. Microplastics are emerging as persistent terrestrial pollutants due to mismanagement and indiscriminate use. Microplastic contaminants affect the physicochemical characteristics of the soil as well as the feeding patterns of the soil biota. Sewage sludge, bio waste compost additions, plastic mulching, wastewater irrigation, landfill leachate, and air deposition are the causes of microplastics in soils. The amount of microplastics particles per kilogram of soil ranged from zero to thirteen thousand pieces. There are 523 times as many microplastic particles in the soil as there are in the ocean. Plant growth and seed germination are slowed down by the microplastic in the soil. Microplastics also affect the soil's enzymatic activities. The environmental sources of microplastic include plastic pellets, city dust, abrasion of road markings, tires, synthetic textiles, personal care products, and cosmetics. Human consumption through food can have a variety of harmful effects, including cytotoxicity, immunotoxicity, pulmonary toxicity, and reproductive toxicity. The current study describes the origins, distribution, and effects of microplastics on plants, soil biota, and human health in the soil environment.

Key word: Microplastic, soil, pollution, plant and human

Introduction

Plasticulture, or the use of plastics in agriculture, is a widely used technique that was first developed in the late 1940s to lower the cost of agricultural infrastructure and prolong the time that crops could be produced and food could be available (Le Moine & Ferry, 2019). With the goal of extending the production window and enhancing crop yield and quality, agriplastics offer improved water-use efficiency, temperature control during critical stages of crop development, weed suppression, and disease and pest protection in contemporary agricultural systems (FAO, 2021).

Microplastics are sunk by soil. Numerous researches, like Yu *et al.* (2022) and Horton *et al.*, (2017), have found that the amount of microplastics pollution in soil exceeds that of microplastics pollution in aquatic bodies; in fact, soil contamination by microplastics is 4-23 times greater than that of ocean contamination. Microplastics-induced soil pollution is one of the top ten environmental issues according to the UN Environmental Programme

[1]Soil Science Division, Bangladesh Institute of Nuclear Agriculture, Mymensingh
*Corresponding author's e-mail:pritimahbubau@gmail.com

(UNEP) report. The World Health Organization (WHO) discussed the effects of these pollutants on people and other organisms during the Scientists' Meeting on March 2-3, 2020. The WHO also established guidelines for the proper application of plastic in the agricultural sector to minimize the negative effects of plastic.

Microplastics can infiltrate and accumulate in the soil through a variety of processes, including the use of organic fertilizer and sewage from agricultural practices. They come from a variety of places, including streams, the environment, and tire dust. Microplastics sludge concentrations range from 1,500 to 56,400 particles/kg, and up to 90% of the microplastics found in sewage accumulate in the sludge (Li *et al.*, 2018). Furthermore, according to Weithmann *et al.*, 2018, organic fertilizers can contain up to 895 microplastics particles/kg. This suggests that using sludge and organic fertilizers over an extended period of time may cause soil contamination with microplastics.

The first study to document the effects of microplastics in the soil environment on the physicochemical characteristics of the soil, as well as its functions, such as bulk density, biophysical environment, microbiological activity, and plant growth and maturity was conducted by German scientist Rillig in 2012. According to research conducted by Moller *et al.*, 2020, soils in metropolitan areas and agricultural areas are more susceptible to microplastics pollution due to increased exposure to artificial activities. According to De Souza *et al.* (2019), microplastics particles in soils adsorb potentially hazardous metals, endocrine-disrupting compounds, and persistent organic pollutants (polycyclic aromatic hydrocarbons), which not only harm the health of the soil but also enter the food chain. According to Kong *et al.*, 2018, microplastics in the soil also reduces the diversity of soil microorganisms. The kind and amount of microplastics found in soils, sludge, and food items, as well as the effects they have on human health, are outlined in this review.

2. Categorization of microplastics

The microplastics remain in the natural environment are found two types and can be categorized as first-class microplastics and subsequent microplastics.

First-class microplastics

These are the ones that are first produced as micro particles and are discharged into the environment through spills, sewage discharge, and other sources, as well as industrial and home effluents. Micro beads found in cosmetics, airborne microplastics from the textile and other industrial abrasives, pellets, film, and fragments are a few typical examples (Galloway *et al.*, 2017).

Subsequent Microplastics

This kind makes up a large portion of the microplastics that is found on earth. This category of microplastics is produced by the slow breakdown and/or fragmentation of larger plastic particles found in the environment due to environmental weathering processes (e.g., photo-oxidation, thermal degradation, biodegradation, thermo-oxidation, mechanical transformation, hydrolysis, wind, wave action, and abrasion) (Auta *et al.*, 2017, Sharma and Chatterjee, 2017). These particles include discarded tires, clothing, disposables, and electronic items Townsend *et al*., 2019. Another source of secondary microplastics is the effluent from washing machines that use synthetic fibers.

3. Principal sources of microplastics in the environment

The cause of the microplastics pollution in the environment is human activity, specifically residential, commercial, industrial, and agricultural activities. The principal resources are:

3.1. Plastic pellets

Plastic pellets, which are primarily microplastics with a diameter of 2.5 mm or in powder form, are distributed to various industries for use in the production of plastic products. These pellets spill into the environment during transportation, manufacture, processing, and recycling. Plastic pellets have been found in the environment according to a number of scientific investigations (Essel *et al.*, 2015).

3.2. Cosmetics and personal care products (PCCP)

According to Auta *et al.* (2017), one or more types of microbeads are an ingredient in about 80% of personal care and cosmetic products and items like face wash, facial scrubbers, shower gel, toothpaste, shaving cream, nail polish, sunscreen, deodorant, mascara, hair color, and makeup foundation. In certain PCCP and cosmetic products, the micro bead content could reach 10% of the total weight of the product. Research has indicated that micro beads are included in 67% of face scrubs and 50% of marketed face cleansers. According to reports, cosmetics and PCCP cause 7 kg of microplastics to enter the European environment every minute. The wastewater streams from homes, hotels, hospitals, and sports facilities, including beaches, have been shown to include microplastics caused by PCCP and cosmetics (Leal Filho *et al.*, 2022; Habib *et al.*, 2020; Bansal, 2020, Boucher and Friot, 2017).

3.3. Tire wear and tear

Tire wear and/or road wear particles are produced by the mechanical abrasion of tires, which are made of polystyrene-butadiene rubber, polyisoprene, and other additives that make up the outer layer of the tires. According to Khan *et al.* (2019), 2.7 billion tires are produced annually on average. Globally, about 6 million tonnes of tire-wear particles are produced (Khan *et al.*, 2019), with Europe producing about 1.3 million tonnes of these particles. Particles from tire wear account for 30-50% of the overall microplastic contamination. Researchers have found tire wear particles in soil, water, and the ocean (Xia, 2019).

3.4. Textile synthetics

Global production of synthetic fiber was 68 million tonnes in 2020 (or almost 62% of all fibers), and growth of 7.4% per year is predicted for the years 2021-2025. According to reports, over 35% of the microplastics pollution in the environment comes from synthetic fiber. The main cause of synthetic textiles entering the environment as microplastics is the abrasion and shedding of fibers (polyester, acrylic, polyethene, or elastane) during home and commercial washing. Approximately 640,000 to 1,500,000 microfibres per kg of washed fabric, or 124-308 mg of microfiber per kilogram of fabric, are released into the environment (De Falco *et al.*, 2019). According to a number of studies, including Boucher *et al.* (2016) and Hamid *et al.* (2018), there are fibers in every area of the environment.

3.5. Road marking abrasion

Road markers and other fundamental traffic safety precautions are necessary for both human and robot drivers. The road marking system consists of paints, glass beads, thermoplastic, polymer tape, and epoxy resins, which are the main type of microplastics. The percentage of these materials that are abrazed by weathering and traffic is 5-10%. According to Burghardt *et al.* (2020), road markings account for 2.3-7% of all environmental microplastics pollution. These particles are carried by the wind and rain into the soil and water bodies.

3.6. Dust from the city

Four percent of microplastics are found in the dust generated in urban areas as a result of abrasion of infrastructure (such as artificial grass, building coatings, and home dust), footwear with synthetic soles, and synthetic cooking utensils and detergents (Magnusson *et al.*, 2016). These tiny plastic particles end up in the seas, waterways, and soil.

4. Microplastics exposure pathways

The most widely used artificial plastics include polystyrene, polyvinyl chloride, polypropylene, polyethene terephthalate, and polythene (both low and high density).

4.1. Via the soil

The soil ecosystem's presence of microplastics is caused by: 1) Mulching and Agricultural Films Agricultural mulching technique has become increasingly popular in recent years due to its ability to improve fruit quality, output, and water utilization. Common plastics used for mulching include polyvinyl chloride, polypropylene, polyethene, and copolymers of ethylene and vinyl acetate. By 2030, there will likely be 5.6 million plastic tons used for mulching, up from the approximately 4.5 million tons used in 2019 (Huang *et al.*, 2020). A significant quantity of plastic mulch waste remains on the surface of agricultural fields as a result of low recycling rates. These films eventually become fragile owing to photo degradation by UV light, and when fields are ploughed, they break up and become buried in the soil. According to research conducted by Ren *et al.* (2021), mulching contributes between 10 and 30 percent of soil microplastic.

4.2. Sludge from sewage

For the past 50 years, sewage sludge-which is high in organic matter and vital nutrients-has been used as fertilizer on agricultural fields to increase soil productivity and promote agricultural growth. Roughly half of the sewage sludge generated is thought to be used to agricultural land. The microplastics is found in the sewage sludge that is obtained from either industrial waste, household wastewater (micro beads from PCCP and cosmetics, polymer fibers from washing clothing), or tire abrasion. These contaminants build up in soils after sewage sludge is put to it. According to Van den *et al.* (2020), there are 280-430 items per kg in sewage sludge.

4.3. Water for irrigation

The majority of agricultural fields in industrialized nations are irrigated with water from rivers, lakes, groundwater, and reservoirs; but, in many developing nations, sewage water is also utilized for soil irrigation due to water constraint. According to a review of the literature, all of these water sources have high concentrations of microplastics (Choi *et al.*, 2021; Qi *et al.*, 2020). Irrigation introduces these hidden microplastic particles into soil.

4.4. Compost

Made from organic and biological waste, compost is an environmentally beneficial soil fertilizer that has been utilized since the beginning of agricultural practices worldwide. Microplastic has been found in the organic compost made from biological wastes as a result of inappropriate disposal (Blasing and Amelung, 2018). Microplastics are incorporated into the soil from organic compost, which is utilized extensively throughout the world as an organic fertilizer.

4.5. Deposition in the Atmosphere

Agriculture soils get contaminated by microplastics through atmospheric deposition. According to studies conducted by Dris *et al.*(2016), microplastic particles measuring 29280 pc/m^2 are daily deposited in Paris' atmosphere. One of the main causes of microplastic deposition in agricultural soil is atmospheric deposition.

5. Soil contaminated with microplastics

Because plastic items are produced, consumed, and disposed of so extensively, microplastics are found throughout the environment. They get into the soil as a result of several human activities. The sources of microplastics in the soil were broadly categorized by Corradini *et al.* (2019) as industrial, agricultural, and other (Table 1). According to Magnusson *et al.* (2016), industrial sources include tire dust, asphalt, different types of paint for roads and buildings, traffic safety facilities, artificial grass, and flooring for sports facilities. Large-scale microplastic pollution in agriculture is caused by a variety of factors, including the use of agricultural machinery, plastic mulch, polytunnels, agricultural waste, sewage sludge containing microplastics, soil amendments, organic fertilizers, controlled-release fertilizers, contaminated irrigation water, and flooding (Rodríguez-Seijo *et al.*, 2019; Weithmann *et al.*, 2018). In addition to being produced during waste incineration, microplastics are also found in a variety of living settings, such as in clothing, furniture, and household objects. Landfills and traffic are other sources of microplastics.

Microplastics can take many different forms in soils. Agricultural areas have been found to have elevated levels of microplastics made of PE, PP, PA, and styrene. On the other hand, styrene-butadiene rubber, which is mostly caused by tire wear and tear from cars, is found in soils close to residential areas and roads (Choi *et al.*, 2021). Polyvinyl chloride (PVC) has been found in the soil of Sydney, Australia's industrial regions (Fuller and Gautam, 2016). The sorts of contaminated plastics generally change depending on where they come from; these sources are usually nearby or on-site. Numerous nations have carried out studies on the spread of soil microplastics (Table 2). Zhou *et al.* (2019) found that the Wuhan region has the greatest concentration of microplastics in agricultural soil, ranging from 4.3×10^4 to 6.2×10^5 particles/kg. These studies show that there are geographical variations in China's microplastic distribution in agricultural soil. According to Piehl *et al.*, 2018, the concentration of microplastics in the agricultural soils in Mittelfranken, Germany, was found to be 0.34 ± 0.36 particles/kg. Concentrations varied from 81 to 18,870 particles/ kg in the Yongin region of South Korea (Kim *et al.*, 2021) and 664 particles/kg in the Yeoju region (Choi *et al.*, 2021). In addition to variations in the degree of soil microplastic pollution, sampling, pretreatment, and analytical techniques can also be blamed for the disparity in reported microplastic concentrations throughout nations and areas.

Table 1. Lists the main sources of soil borne microplastics

Major Sources	Major Pollutants	References
Industrial activities	Tire dust, asphalt, paints from roads and buildings, traffic safety facilities, artificial turf, sports facility flooring, household plastic waste, and airborne microplastics.	Dris *et al.*, 2016, Magnusson *et al.*, 2016, Unice *et al.*, 2019, Prata, 2018
Agricultural activities	Use of agricultural machinery, plastic mulch, polytunnels, agricultural waste, sewage sludge, organic fertilizers, controlled-release fertilizers, soil amendments, contaminated irrigation water, and flooding.	Rodriguez-Seijo *et al.*, 2019, Weithmann *et al.*, 2018, Blasing and Amelung, 2018, Ng *et al.*, 2018,
Others	Clothing, home furniture, waste incineration, landfills, and traffic-emitted particles.	Dris *et al.*, 2016

In addition to agricultural areas, residential areas, roadways, and forested areas also contain microplastics. 9.6×10^4 to 6.9×10^5 particles/kg were found in Wuhan, China's forested areas (Zhou *et al.*, 2019). Microplastics have been found in human residential and living situations in Yeoju (South Korea), where 500 microplastic particles/kg were found in residential areas and 1,108 particles/kg in road soils (Choi *et al.*, 2021).

5.1. Microplastics in the surroundings of the soil

Microplastics were first identified as a marine and aquatic contaminant in the 1970s. Research into their effects on aquatic life was conducted, and in the past ten years, Rillig (2012) has begun to examine the effects of these pollutants on the terrestrial ecosystem. According to research by environmental experts, microplastics are a pollutant that moves between ecosystems (Rodrigues *et al.*, 2018), and soil not only acts as a natural sink for microplastics but also transports them to groundwater and the ocean (Qi *et al.*, 2020). Because the soil can absorb, collect, or transfer microplastics through the soil matrix, microplastics that find their way into the soil become permanently incorporated into the environment.

According to a review of the research by Van Schothorst *et al.*, 2021 and Huerta-Lwanga *et al.*, 2022, there are both direct and indirect sources of microplastics in soils. Agricultural mulching films, greenhouses (made of plastic films and/or non-woven textiles based on plastic), shade nets, polytunnels, wind barriers, and sewage sludge are the direct sources; compost and irrigation with tainted water are the indirect sources. In agricultural soils, the amount of microplastics varies from 0 to 165000 particles per kilogram of soil. According to reports, Pakistani agricultural soil has a maximum content of microplastics of 675 mg/kg (Sajjad *et al.*, 2022). According to a review of the literature, there are more microplastics fragments per kilogram of soil in soils that are regularly modified with sewage sludge or irrigated with sewage water.

The agricultural operations of plowing, tillage, burrowing, crop harvesting, water infiltration, and/or soil cracks all contribute to the belowground transfer of microplastics in soils through bioturbation by plant roots and soil fauna (Rillig *et al.*, 2019). Additionally, through their digging and feeding activities, soil biota such as mites, mosquito larvae, and collembolan spread and redistribute the microplastics in the soil (Al-Jaibachi *et al.*, 2019). The United Nations Environment Programme (UNEP) urged for further research studies on the consequences of microplastics pollution on the soil environment in its meeting on June 5, 2018, citing the fact that the concentration of microplastics in the terrestrial environment is many times higher than in the ocean.

5.2. Microplastics' movement and destiny in the soil

According to Kim *et al.*, 2019, there are three main types of microplastics behavior that occur in subsurface soil environments: surface migration, infiltration in unsaturated zones, and transport in saturated media (Table 3). It is thought that microplastics are either stored in soils or sediments or exhibit delayed mobility; however, further research is necessary to determine if minuscule (µm to nm) microplastics particles can move around in the subterranean environment (Alimi *et al.,* 2018). Theories on soil erosion and sediment transport can be used to explain or predict the movement of microplastics that have accumulated in the soil via surface runoff into streams and groundwater after precipitation (Nizzetto *et al*., 2016). In addition, based on studies of colloid or nanoparticle behavior, research on the transport of microplastics in unsaturated and saturated media has advanced significantly in recent decades (Alimi *et al.*, 2018; Hüffer *et al*., 2017). One important route for the spread and build-up of microplastics in soils is, in fact, the application of biosolids in farming areas. Microplastics concentrations have been found to be higher in agricultural settings that employ biosolids more regularly and in greater volumes. This can be explained by the fact that over time, an accumulation of microplastics in certain locations occurred because part of the microplastics found in biosolids were maintained in the soil (Table 3).

Determining the possible effects of microplastics on soil health and the ecosystem requires an understanding of their dispersion in the soil. The authors of one study examined the distribution of plastics at depths of 0-10 cm (surface layer) and 10-30 cm (deeper layers) in three agricultural environments (agricultural land, orchard, and greenhouse) in the Loess Plateau (northern China). They hypothesized that the concentration of microplastics in the deeper layers was higher than in the surface layer (Han *et al.* 2019). On the other hand, the opposite tendency was seen in the soils of the orchard and greenhouse, where the concentrations of microplastics in the surface layer were 320±329 and 100±254 particles/kg, respectively, higher than those in the deeper layers. This suggests that the cultivation method affects the vertical distribution of microplastics. On the other hand, Kim *et al.* (2021) found no significant variations in the horizontal distribution of microplastics between the areas of polytunnel cultivation and those outside of them in Yongin, South Korea.

Numerous scenarios have been established through investigation into the fate of microplastics in soil settings and their interactions with organisms. For example, plants can absorb nanoscale microplastics, while animals and soil creatures can consume or spread microplastics found in the soil (Ng *et al.,* 2018). Microplastics can be broken down into smaller particles by earthworms, moles, soil bacteria, and other subterranean species, which speeds up their movement through the soil (Rillig, 2012). Plant roots disturb the soil, which has an impact on root growth and mobility as well as microplastics behavior. Furthermore, the upward transport of microplastics is encouraged by the creation of large soil pores as a result of crop harvesting or plant root breakdown (Li *et al.,* 2020).

Metals' adsorption and dispersion in the soil are impacted by interactions between microplastics and metals (Yu *et al.,* 2021). Furthermore, according to Ng *et al.* (2021) microplastics compete with soil organic matter for the adsorption of organic molecules and other chemicals. Microplastics-soil interactions can have negative effects on soil microbial activity, nutrient delivery, and the cycling of nitrogen and organic carbon (Dong *et al.,* 2021a; Liu *et al.,* 2018; Qi *et al.*, 2020).

Table 2: The behavior of microplastics in subterranean environments

Behavior type	Features	References
Surface migration	Surface runoff enters the river during precipitation, which can be explained or predicted using theories related to soil erosion and sediment transport	Nizzetto *et al.*, 2022
Infiltration of unsaturated zones transport within the saturated medium	Studies of transport within unsaturated and saturated media based on the behavior of colloids or nanoparticles	Alimi *et al.*, 2018, Hüffer *et al.*, 2017

Table 3. Microplastics' effects on soil characteristics

Category	Microplastics Impact	References
Physical properties	Microplastics alter soil aggregation, bulk density, porosity, and water-holding capacity	Ng *et al.*, 2021, Qi *et al.*, 2020
	Microplastics cause soil bulk density decrease, which is closely related to soil erosion risk	
	Heteroaggregation, where plastic particles attach to the soil particle surface, can cause microplastics retention in porous media; homoaggregation of microplastics can lead to particle size increase, hindering their movement	Li *et al.*, 2018, Lu *et al.*, 2018
	The soil mobility of nanometer-sized microplastics is affected by soil aggregation	
Chemical properties	Microplastics are involved in the absorption of metals and their distribution within the soil	Yu *et al.*, 2021
	Microplastics compete with soil organic matter for the adsorption of organic compounds and other substances in the soil	Ng *et al.*, 2021
	Microplastics can negatively affect nitrogen and organic carbon cycling, nutrient delivery, and soil microbial activity	Dong *et al.*, 2021a, Qi *et al.*, 2020
Biological properties	Microplastics can affect the soil–plant system, bioaccumulate, and concentrate along the food chain	Mbachu *et al.*, 2021a, b
	Microplastics can disrupt nutrient cycling, affecting the activity, composition, and diversity of soil microorganisms	Mbachu *et al.*, 2021a, b

Recent research indicates that microplastics have an impact on soil-plant systems, are consumed by a variety of species at varying trophic levels, and eventually build up in organisms higher up the food chain (Chai *et al.*, 2020). For example, exposed earthworms consume more microplastics when the amount of microplastics in the soil increases (Guo *et al.*, 2020). Pollutants build up in earthworms and can be passed on to other organisms via the food chain, such as the adsorbed high-molecular weight additives (Li *et al.*, 2020). Microplastics from the soil may eventually have an impact on people as they move up the food chain. In addition to impairing soil microbial activity, composition, and species variety, microplastics can also interfere with the cycling of nutrients in the soil, which might have a negative effect on plants and animals as well as jeopardize food security. Notably, persistent disruption of the species diversity of soil microbes may have a negative impact on the microbial communities in forest soil and may be a factor in climate change (Ng *et al*., 2021).

5.3 Microplastics' effects on soil quality

Because of its small particle size and huge surface area, microplastics in soil adsorbs other organic and inorganic contaminants that negatively impact the ecosystem's health. According to De Souza Machado *et al.* (2019), Wan *et al.* (2019), there is a drop in soil bulk density and water-stable aggregates, an increase in soil water availability, and a decrease in water evaporation when microplastics is present. Additionally, microplastics alters the soil's porosity. According to research by Jiang *et al.* (2017) and Boots *et al.* (2019), HDPE lowers soil pH by 0.62 units. When microplastics additions are added to soil, the concentrations of dissolved organic C, ammonium-N, nitrate-N, and total phosphorus rise noticeably. According to study conducted by Liu *et al*. (2017) and Dong *et al.* (2015), plastic mulch residues have a detrimental effect on plant growth and soil fertility. Numerous researchers have revealed that microplastics in soil greatly modifies the enzymatic activities of the soil (Li *et al.,* 2021b; De Souza Machado *et al.*, 2019).

5.4. Microplastics' effects on soil organisms

According to Wang *et al.* (2019), microplastics in soil affect how soil animals eat, leading to a nutritional imbalance that reduces growth and reproduction, damages organs, and interferes with immune response and metabolism. In their research, Cao *et al.* (2017) discovered that microplastics in soil inhibits earthworm growth by causing immunological and histological harm to the worms. Liu *et al.*, 2018 found that microplastics in soils damages worms' intestines and produces oxidative stress, which reduces the nematodes' body length, survival rate, and ability to reproduce. According to Ju *et al.* (2019), microplastics changes the microbial ecology in the gut of collembolan and reduces mesofauna and Folsomia candida proliferation. Microplastics in the soil have a detrimental effect on the health of macrofauna (earthworms, snails), which transform organic matter and nutrients into a form that plants can use Sun *et al.* (2019).

5.5. Microplastics' effects on plants

Plant growth and seed germination are indirectly impacted by microplastics in the soil (Ng *et al*., 2018). The size, shape, and chemical makeup of the microplastics all affect its ability to translocate. Reviews of the published data indicate that the gaps between root cells are where microplastics enters a plant (Meng and associates, 2021). The root biomass and total root length of onions are enhanced by polystyrene (PS), whereas soil microbial activity and tissue elemental composition are greatly impacted by polyamide and polyester fibers (Machado de Souza *et al.*, 2019). De Souza Machado *et al.* (2019) observed that the presence of polyester sulphone increased the amount of total biomass, root biomass, root length, and root-soil microbial activity in onions. PE slows down the intake of nutrients and the growth of the plant, while PS and polylactic acid reduce the biomass of the roots of maize plants. Low-density polyethene (LPDE) reduces leaf count and fruit biomass, altering vegetative growth, polyethene (PE) influences the root antioxidant system, and PS lengthens and increases the biomass of the roots while decreasing the root/shoot ratio in the wheat plant (Liu and associates, 2021). According to Lozano *et al.* (2021), carrot plants' root mass and above-ground biomass are reduced by PP and LDPE. The carrot plant's biomass and shoot height both decline in the presence of high-density polyethene (HDPE), and seed germination is also slowed down.

5.6 Effects on Human

Humans are exposed to microplastics and other additional chemicals through their skin, lungs, and digestive systems, in that order. The two most prevalent pathways by which microplastics particles enter the human body are (i) endocytosis and (ii) persorption. Global human intake of microplastics is estimated by Senathirajah *et al.* (2021) to be between 0.1 and 5 g per week, or an average of 100,000 plastic pieces or 250 g annually. Globally, each person consumes 35kg of microplastics on average. According to Cox *et al.* (2019) estimates, each citizen consumes between 39,000 and 52,000 plastic particles annually, and 25000 particles are breathed. Every year, an additional 9000 particles are consumed by the residents who exclusively drink bottled water. According to Lian *et al.* (2021), microplastics can harm tissue and induce apoptosis, necrosis, and fibrosis in the human body. Immunotoxicity refers to the carcinogenic effects of microplastics particles on people, such as autoimmune diseases and/or immunosuppression. In the presence of microplastics, the immune cell death rate increased two to three times (University Medical Centre (UMC) Utrecht). Men's and women's fertility is decreased by bisphenol. A due to its effects on the endocrine system. Human immunological and reproductive systems are impacted by polychlorinated biphenyls, which are also carcinogenic flaws. Human feces have also been reported to contain microplastics particles. According to Cox *et al*. (2019), citizens who are exposed to more plastic are more likely to be exposed to hazardous building materials or plastic-like air pollution.

6. Methods for soil microplastic analysis

6.1. Soil sample collection

There are currently no internationally recognized testing standards for the investigation and analysis of microplastics in soil media; however, the International Organization for Standardization (ISO) is working on standardizing test methods in this field. Investigating environmental microplastics involves several stages, such as sampling, isolation, separation, identification, and quantification (Jeong *et al.*, 2018).

Despite being a very straight forward procedure, soil sampling can have a significant impact on the analysis's findings. This is due to the fact that measurement mistakes during the analytical procedure are typically smaller than inaccuracies related to soil sampling. Soil sampling techniques need to be well thoughtout and reliable. To design a soil sampling plan, for instance, ISO 18400-104:2018 (International Organization for Standardization, 2018) might be used. A plan for obtaining representative samples from the target site or area is necessary for soil sampling in order to investigate the spread of soil microplastics. A technique like this needs to take into account particular procedures and standards for choosing soil sampling locations, depth of sampling, and quantity of samples taken at the intended location.

The target region is divided into five to ten sub-sites for the agricultural land, and samples are taken at each sub-site before being merged. Five sub-sites, i.e., one in the target area's center, one every five to ten meters from the center, and one in each of the four directions away from the center, must be tested for factory areas, landfill sites, urban areas, and other locations. Appropriate adjustments are performed to this distance when it becomes insufficient due to the existence of facilities in the target region. It is recommended by domestic regulations for soil contamination testing to gather roughly 0.5 kg of soil at each sampling station. Samples of soil are taken at different depths based on the investigation's goal. In an ideal world, the vertical distribution of microplastics in the soil would be taken into account when determining the sampling depth. Periodic plowing, like field and paddy plowing, disturbs the top soil layer on agricultural land. Because the soil is mixed to a depth of about 30 cm during plowing, soil samples taken up to 30 cm below the surface are often homogeneous. Therefore, the topsoil layer depth in agricultural land where periodic plowing is done could be set at a depth of up to 30 cm from the surface for ease of investigation.

6.2. Decomposition of organic materials

Significant amounts of organic matter, such as plant roots and tree branches, are frequently present in soil samples. The analytical separation of plastics from soil is hampered by the presence of organic materials. More specifically, spectrally separating microplastics from organic materials is challenging, which lowers detection accuracy. According to Blasing and Amelung (2018), organic matter has the ability to skew results in infrared spectroscopy by visually interfering with the analysis. Furthermore, there exists a similarity in the densities of some soil constituents (such as soil organic matter and organic fibers) and microplastics, which may influence the precision of density separation (Zhang and Liu, 2018). Therefore, before analysis, organic matter needs to be removed from soil samples. Reagent concentration, reaction duration, temperature, and reaction conditions can all be changed to enhance the removal efficiency of organic materials by decomposition. But there's a chance that this will lead to the disintegration of microplastics. Standardized pretreatment techniques should therefore be applied to reduce plastic damage (Loder *et al.*, 2017). As of right now, there are no standardized techniques for decomposing organic matter, and systematic research evaluating the effectiveness of different approaches or offering defined procedures and standards are hard to come by (Rocha-Santos and Duarte, 2017). While there are a number of techniques for breaking down organic matter, each has its drawbacks, and further study is necessary to enable precise isolation of microplastics from soil samples.

6.3. Separation of density gradients

The density differential between the microplastics in a sample and other materials that aren't eliminated by organic matter oxidation serves as the basis for density gradient separation. During separation, high-density sand particles sink to the bottom, and the low-density microplastics-containing supernatant is kept for further examination. The density difference between the plastic and separation solution determines the separation efficiency; the greater the difference in density, the better the separation.

Conclusion

Finding the existence and concentrations of microplastics in the soil environment has been the primary goal of study on the subject. To enable the management of microplastics in the environment, systematic research is necessary to comprehend the prevalence, distribution, and effects of microplastics specifically in soil. Though, there are still some important questions to be answered, it is imperative to comprehend the behavior and migration features of microplastics in soil environments. Research should be done on the properties of microplastics and surrounding conditions, technology for measuring and identifying microplastics in soil settings should be created. In summary, as global plastic manufacturing rises, so does soil exposure to and accumulation of microplastics, which may have negative effects on human health, food security, and climate change. It is necessary to have a thorough plan for logically defining the behavior of microplastics in soil.

References

Alimi, O.S., Budarz, J.F., Hernandez, L.M. and Tufenkji, N. 2018. Microplastics and nanoplastics in aquatic environments: Aggregation, deposition, and enhanced contaminant transport. Environ. Sci. Technol. 52:1704-1724. https:// doi. org/ 10. 1021/ acs. est. 7b055 59

Al-Jaibachi, R., Cuthbert, R.N. and Callaghan, A. 2019. Examining Effects of Ontogenic Microplastic Transference on Culex Mosquito Mortality and Adult Weight. Science of the Total Environment. 651(1):871-876.

Auta, H.S., Emenike, C.U. and 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. https://doi.org/10.1016/j.envint.2017.02.013.

Bansal, O.P. 2020. Microplastic in the Rivers and Oceans and Their Impact: A Review. International Journal of Recent Scientific Research.11 (2):3729137298. http://dx.doi.org/10.24327/ijrsr.2020.1102.5083.

Blasing, M. and Amelung, W. 2018. Plastics in Soil: Analytical Methods and Possible Sources. Science of the Total Environment. 612:422-435. https://doi.org/10.1016/j.scitotenv. 2017.08.086.

Boucher, J. and Friot, D. 2017. Primary Microplastics in the Oceans: A Global Evaluation of Sources.

Boucher, C., Morin, M. and Bendell, L.I. 2016. The Influence of Cosmetic Microbeads on the Sorptivebehavior of Cadmium and Lead Within Intertidal Sediments: A Laboratory Study. Regional Studies in Marine Science. 3:1-7. https://doi.org/10.1016/j.rsma.2015.11.009.

Burghardt, T.E., Pashkevich, A. and Mosböck, H. 2020. Microplastics Originating from Road Markings: A Significant Overestimate. International Conference "Fate and impacts of Microplastics: Knowledge and Responsibilities". 2327.11.2020. https://doi.org/10.13140/ RG.2.2.10974.36169.

Chai, B., Li, X., Liu, H., Lu, G., Dang, Z. andYin, H. 2020. Bacterial communities on soil microplastic at Guiyu, an E-Waste dismantling zone of China. Ecotoxicol. Environ. Saf. 195:110521. https://doi.org/10.1016/j. ecoenv. 2020. 110521

Cao, D., Xiao, W., Luo, X., Zhang, D., Ma, L. and Zheng, H. 2017. Effects of Polystyrene Microplastics on the Fitness of Earthworms in an Agricultural Soil. IOP Conference Series: Earth and Environmental Science. 61. https://doi.org/10.1088/17551315/61/1/012148.

Choi, Y.R., Kim, Y.N., Yoon, J.H., Dickinson, N., Kim and K.H. 2021. Plastic contamination of forest, urban, and agricultural soils: a case study of Yeoju City in the Republic of Korea. J. Soils Sediment. 21:1962-1973. https:// doi. org/ 10. 1007/ s11368- 020- 02759-0

Corradini, F., Meza, P., Eguiluz, R., Casado, F., Huerta-Lwanga. E. and Geissen, V, 2019. Evidence of microplastic accumulation in agricultural soils from sewage sludge disposal. Sci. Total Environ. 671:411-420. https://doi.org/10.1016/j.scito tenv. 2019. 03.368

Cox, K.D., Covernton, G.A., Davies, H.L., Dower, J.F., Juanes, F. and Dudas, S. E. 2019. Human Consumption of Microplastics. Environmental Science & Technology. 53:7068-7074. https://doi.org/10.1021/acs.est.9b01517.

De Falco, F., Di Pace, E., Cocca, M. and Avella, M. 2019. The Contribution of Washing Processes of Synthetic Clothes to Microplastic Pollution. Scientific Reports. 9:6633. https://doi.org/10.1038/s41598-019-43023-x.

De Souza Machado, A.A., Lau, C.W., Kloas, W., Bergmann, J., Bachelier, J.B., Faltin, E., Becker, R., Görlich, A.S. and Rillig, M.C. 2019. Microplastics Can Change Soil Properties and Affect Plant Performance. Environmental Science & Technology. 53:6044-6052. https://doi.org/10.1021/acs.est.9b01339.

Dong, Y., Gao, M., Qiu, W. and Song, Z. 2021a. Effect of microplastics and arsenic on nutrients and microorganisms in rice rhizosphere soil. Ecotoxicol. Environ. Saf. 211:111899. https:// doi. org/ 10. 1016/j. ecoenv. 2021. 111899

Dong, H.D., Liu, T., Han, Z.Q., Li, W., He, Y.Q. and Zhang, D. M. (2015. Determining Time Limits of Continuous Film Mulching and Examining Residual Effects on Cotton Yield and Soil Properties. Journal of Environmental Biology.36:677-684. http://www.jeb.co.in/.../paper_25.pdf.

Dris, R., Gasperi, J., Saad, M., Mirande, C. and Tassin, B. 2016. Synthetic Fibers in Atmospheric Fallout: A Source of Microplastics in the Environment? Marine\Pollution Bulletin. 5: 104 (1-2): 290-293. https://doi.org/10.1016/ j.marpolbul. 2016.01.006.

FAO. 2021. Assessment of agricultural plastics and their sustainability. A call for action. Rome. Retrieved March 9, 2023. https://doi.org/ 10.4060/cb7856en

Fuller, S. and Gautam, A. 2016. A procedure for measuring microplastics using pressurized fluid extraction. Environ. Sci. Technol. 50:5774-5780. https://doi.org/10.1021/acs. est. 6b008 16

Essel, R., Engel, L., Carus, M. and Ahrens, R.H. 2015. Sources of Microplastics Relevant to Marine Protection in Germany. Texte. 64/2015. German Federal Environment.

Galloway, T.S., Cole, M. and Lewis, C. 2017. Interactions of Microplastics Throughout the Marine Ecosystem. Nature Ecology & Evolution. 1(5):116. https://doi.org/10.1038/ s41559-017-0116.

Gland, Switzerland : IUCN. 2017. 43. https://doi.org/10.2305/IUCN.CH.2017.01.en.

Guo, J.J, Huang, X.P, Xiang, L., Wang, Y.Z, Li, Y.W, Li, H., Cai, Q.Y., Mo, C.H. and Wong, M.H. 2020. Source, migration and toxicology of microplastics in soil. Environ. Int. 137:105263. https:// doi. org/ 10. 1016/j. envint. 2019. 105263

Habib, R., Thiemann, T. and Al Kendi, R. 2020. Microplastics and Wastewater Treatment Plants-A Review. Journal of Water Resource and Protection. 12:1-35. https://doi.org/10.4236/jwarp.2020.121001

Hamid, F.S., Hatti, M.S., Anuar, N., Khoder, G. and Elhag, A.A. 2018. Worldwide Distribution and Abundance of Microplastic: How Dire is the Situation? Waste Management & Research. 36(10): 873-897. https://doi.org/10.1177/0734242X18785730.

Han, X., Lu, X. and Vogt, R.D. 2019. An optimized density-based approach for extracting microplastics from soil and sediment samples. Environ. Pollut. 254:113009. https://doi. org/10. 1016/j. envpol. 2019. 113009

Horton, A.A., Walton, A., Spurgeon, D.J., Lahive, E. and Svendsen, C. 2017. Microplastics in Freshwater and Terrestrial Environments: Evaluating the Current Understanding to Identify the Knowledge Gaps and Future Research Priorities. Science of the Total Environment. 586:127-141. https://doi.org/10.1016/j.scitotenv. 2017.01.190.

Huang, Y., Liu, Q., Jia, W., Xu, X., Zhang, Y. and Li, X.. 2020. Agricultural Plastic Mulching a Source of Microplastics in the Terrestrial Environment. Environmental Pollution. 260. https://doi.org/10.1016/j.envpol.2020.114096.

Huerta -Lwanga, E., Beriot, N., Corradini, F., Silva, V., Yang, X., Baartaman, J., Rezaei, M., Van Schaik, L., Riksen, M. and Geissen, V. 2022) Review of Microplastic Sources, Transport Pathways and Correlations with Other Soil Stressors: A Journey from Agricultural Sites into the Environment. Chemical and Biological Technologies in Agriculture. 9:20. https://doi.org/10.1186/s40538-021-00278-9.

Huffer, T., Praetorius, A., Wagner, S., von der Kammer, F. and Hofmann, T. 2017. Microplastic exposure assessment in aquatic environments: Learning from similarities and differences to engineered nanoparticles. Environ. Sci. Technol. 51:2499-2507. https://doi.org/10.1021/ acs. est. 6b040 54

International Organization for Standardization. 2018. Standard ISO 18400–104:2018-Soil Quality Sampling. https:// www. iso. org/ stand ard/ 65223. html. Accessed Oct 2018

Jeong, D.H., Ju, B., Lee, W., Chung, H., Park, J. and Kim, C. 2018. A mini-review on discharge characteristics and management of microplastics in sewage treatment plants. J. Korean Soc. Water Wastewater. 32:337–348. https:// doi. org/ 10. 11001/ jksww. 2018. 32.4. 337

Jiang, X.J., Liu, W., Wang, E., Zhao, J., Zhang, C. and Zhang, J. 2017. Residual Plastic Mulch Fragments Effects on Soil Physical Properties and Water Flow Behavior in the Minqin Oasis, Northwestern China. Soil and Tillage Research. 166:100-107. https://doi.org/ 10.1016/ j.still.2016.10.011.

Ju, H., Zhu, D. and Qiao, M. 2019. Effects of Polyethylene Microplastics on the Gut Microbial Community, Reproduction and Avoidance Behaviors of the Soil Springtail, Folsomia Candida. Environmental Pollution. 247:890-897. https://doi.org/10.1016/j.envpol. 2019. 01.097.

Khan, F.R., Halle, L.L. and Palmqvist, A. 2019. Acute and Long-Term Toxicity of Micronized Car Tire Wear Particles to Hyalella Azteca. Aquatic Toxicology. 213. https://doi.org/ 10.1016/ j.aquatox.2019.05.018.

Kim, S.K, Kim, J.S, Lee, H and Lee, H.J. 2021. Abundance and characteristics of microplastics in soils with different agricultural practices: Importance of sources with internal origin and environmental fate. J. Hazard Mater. 403:123997. https:// doi. org/ 10. 1016/j. jhazm at. 2020. 123997

Kim, Y., Han, W.S. and Yoon, H. 2019. Mobility of microplastics in subsurface environments: Current knowledge and perspectives. J. Soil Groundw. Environ. 24:1-12. https://doi.org/ 10.7857/JSGE. 2019. 24.3. 001

Kong, X., Jin, D., Jin, S., Wang, C., Li, X. and Zhang, W. 2018. Responses of Bacterial Community to Dibutyl Phthalate Pollution in a Soil-Vegetable Ecosystem. Journal of Hazardous Materials. 353:142-150. https://doi.org/10.1016/j.jhazmat.2018.04.015.

Leal Filho, W., Dedeoglu, C., Dinis, M.A.P, Shiel, C. and Olsson, E.2022. Riverine Plastic Pollution in Asia: Results from a Bibliometric Assessment. Land. 11. https://doi.org/10.3390/land11071117.

Le Moine, B., and Ferry, X. 2019. Plasticulture: Economy of resources. Acta. Horticulturae. 1252: 121–130. https://doi.org/10.17660/actahortic. 2019.1252.17

Li, J., Liu, H., and Paul Chen, J. 2018. Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. Water Res. 137:362–374. https://doi.org/10.1016/j. watres. 2017. 12. 056

Li, J., Song, Y., and Cai, Y. 2020. Focus topics on microplastics in soil: Analytical methods, occurrence, transport, and ecological risks. Environ. Pollut. 257:113570. https://doi.org/ 10.1016/j.envpol. 2019. 113570

Li, H., Lu, X., Wang, S., Liu, L., Zhang, Y., and Zhang, H. 2021b. Vertical Migration of Microplastics Along Soil Profile Under Different Crop Root Systems. Environmental Pollution. 278. https://doi.org/10.1016/j.envpol.2021.116833.

Liu, M., Lu, S., Song, Y., Lei, L., Hu, J., Lv, W., Zhou, W., Cao, C., Shi, H., and Yang, X. 2018. Microplastic and mesoplastic pollution in farmland soils in suburbs of Shanghai, China. Environ. Pollut. 242:855–862. https:// doi. org/ 10. 1016/j. envpol. 2018. 07. 051

Liu, H., Yang, X., Liu, G., Li, X., and Zhang, Y. 2017. Response of Soil Dissolved Organic Matter to Microplastic Addition in Chinese Loess Soil. Chemosphere. 185:907-917. https://doi.org/10.1016/j.chemosphere. 2017.07.064.

Liu, S., Wang, J., Zhu, J., Liu, X., Liu, W., and He, H. 2021. The Joint Toxicity of Polyethylene Microplastic and Phenanthrene to Wheat Seedlings. Chemosphere. 282. https://doi.org/ 10.1016/ j.chemosphere.2021.130967.

Loder, M.G., Imhof, H.K., Ladehoff, M., Löschel, L.A., Lorenz, C., Mintenig, S., Piehl, S., Primpke, S., Schrank, I., Laforsch, C., and Gerdts, G. 2017. Enzymatic purification of microplastics in environmental samples. Environ. Sci. Technol. 51:14283-14292. https:// doi. org/ 10. 1021/ acs. est. 7b03055

Lozano, Y.M., Lehnert, T., Linck, L.T Sampson, M., and Hübner, S. 2021. Microplastic Shape, Polymer Type, and Concentration Affect Soil Properties and Plant Biomass. Front Plant Science. 12. https://doi.org/10.3389/fpls.2021.616645.

Lu, S., Zhu, K., Song, W., Song, G., Chen, D., Hayat, T., Alharbi, N.S., Chen, C., and Sun, Y. 2018. Impact of water chemistry on surface charge and aggregation of polystyrene microspheres suspensions. Sci. Total Environ. 630:951–959. https:// doi. org/ 10. 1016/j. scito tenv. 2018. 02. 296

Magnusson, K., Eliaeson, K., Frane A., Haikonen, K., Olshammar, M., Stadmark, J., and Hultén, J. 2016.Swedish sources and pathways for microplastics to the marine environment. http:// urn. kb. se/ resolve? urn= urn: nbn: se: ivl: diva- 362

Mbachu, O., Jenkins, G., Kaparaju, P., and Pratt, C. 2021a. The rise of artificial soil carbon inputs: Reviewing microplastic pollution effects in the soil environment. Sci. Total Environ. 780:146569. https:// doi. org/ 10. 1016/j. scito tenv. 2021. 146569

Mbachu, O., Jenkins, G., Pratt, C., and Kaparaju, P. 2021b. Enzymatic purification of microplastics in soil. MethodsX. 8:101254. https://doi.org/10.1016/j.mex.2021. 101254

Moller, J., Loder, M.G.J. and Laforsch, C. 2020. Finding Microplastics in Soils - A Review of Analytical Methods. Environmental Science & Technology. 54(4):2078-2090. https://doi.org/10.1021/acs.est.9b04618.

Ng, E.L., Huerta, L.E., Eldridge, S.M., Johnston, P., Hu, H.W., Geissen, V., and Chen, D. 2018. An overview of microplastic and nanoplastic pollution in agroecosystems. Sci. Total Environ. 627:1377–1388. https:// doi. org/ 10. 1016/j. scito tenv. 2018. 01. 341

Ng, E.L., Lin, S.Y., Dungan, A.M., Colwell, J.M., Ede, S., Huerta, L.E., Meng, K., Geissen, V., Blackall, L.L. and Chen, D. 2021. Microplastic pollution alters forest soil microbiome. J. Hazard Mater. 409:124606. https://doi.org/10.1016/j.jhazm at. 2020. 124606

Nizzetto, L., Norling, M. and Kainz, M. 2022. Catchment-scale mechanistic predictions of microplastic transport and distribution across land and water. Research Square.

Prata, J.C. 2018. Airborne microplastics: consequences to human health? Environ. Pollut. 234:115-126.

Qi, R., Jones, D.L., Li, Z., Zhang, L., Wu, X. and Xu, L. 2020. Behavior of Microplastics and Plastic Film Residues in the Soil Environment: A Critical Review. Science of the Total Environment. 703. https://doi.org/10.1016/j.scitotenv.2019.134722.

Ren, S.Y., Kong, S.F. and Ni, H.G. 2021. Contribution of Mulch Film to Microplastics in Agricultural Soil and Surface Water in China. Environmental Pollution. 291. https://doi.org/10.1016/j.envpol.2021.118227.

Rillig, M.C. 2012. Microplastic in terrestrial ecosystems and the soil. *Environmental Science & Technology*. *46*(12):6453-6454. Rillig, M.C., Lehmann, A., de Souza Machado, A.A. and Yang, X. 2019. Microplastic Effects on Plants. New Phytol. 223:1066-1070. https://doi.org/10.1111/nph.15794.

Rodrigues, M.O., Abrantes, N., Gonçalves, F.J.M., Nogueira, H., Marques, J.C. and Gonçalves, A.M.M. 2018. Spatial and Temporal Distribution of Microplastics in Water and Sediments of a Freshwater System (Antuã River, Portugal). Science of the Total Environment. 633:1549-1559. https://doi.org/10.1016/j.scitotenv.2018.03.233.

Rodríguez-Seijo, A., Santos, B., Ferreira da Silva, E., Cachada, A. and Pereira, R. 2019. Low-density polyethylene microplastics as a source and carriers of agrochemicals to soil and earthworms. Environ. Chem. 16:8–17. https:// doi. org/ 10. 1071/ EN181 62

Rocha-Santos, T. and Duarte, A.C. 2017. A critical overview of the analytical approaches to the occurrence, the fate and the behavior of microplastics in the environment. Trends in Analytical Chemistry. 111: 135-146.

Sajjad, M., Huang, Q., Khan, S., Zhang, S., Hussain, R. and Li, W. 2022. Microplastics in the Soil Environment: A Critical Review. Environmental Technology & Innovation. 27. https://doi.org/10.1016/j.eti.2022.102408.

Senathirajah, K., Attwood, S., Bhagwat, G., Carbery, M., Wilson, S. and Palanisami, T. 2021. Estimation of the Mass of Microplastics Ingested- A Pivotal First Step Towards Human Health Risk Assessment. Journal of Hazardous Materials. 404. (Pt B). https://doi.org/10.1016/j.jhazmat.2020.124004.

Sharma, S. and Chatterjee, S. 2017. Microplastic Pollution, A Threat to Marine Ecosystem and Human Health: A Short Review. Environmental Science and Pollution Research. 27:21530-21547. https://doi.org/10.1007/s11356017-9910-8.

Sun, X., Li, Q., Shi, Y., Zhao, Y., Zheng, S., Liang, J., Liu, T. and Tian, Z. 2019. Characteristics and Retention of Microplastics in the Digestive Tracts of Fish from the Yellow Sea. Environmental Pollution. 249:878-885. https://doi.org/10.1016/j.envpol.2019.01.110.

Townsend, K.R., Lu, H.C., Sharley, D.J. and Pettigrove, V. 2019. Associations Between Microplastic Pollution and Land Use in Urban Wetland Sediments. Environmental Science and Pollution Research. 26:22551-22561. https://doi.org/10.1007/s11356-019-04885-w.

Unice, K.M., Weeber, M.P., Abramson, M., Reid, R.C.D., van Gils, J.A.G., Markus, A.A., Vethaak, A.D. and Panko, J.M. 2019. Characterizing export of land-based microplastics to the estuary-Part I: application of integrated geospatial microplastic transport models to assess tire and road wear particles in the Seine watershed. Sci. Total Environ. 646:1639-1649.

Van den Berg, P., Huerta-Lwanga, E., Corradini, F. and Geissen, V. 2020. Sewage Sludge Application as a Vehicle for Microplastics in Eastern Spanish Agricultural Soils. Environmental Pollution. 261. https://doi.org/10.1016/j.envpol.2020.114198.

Van Schothorst, B., Beriot, N., Huerta-Lwanga, E. and Geissen, V. 2022. Sources of Light Density Microplastic Related to two Agricultural Practices: The Use of Compost and Plastic Mulch. Environments. 8:36. https://doi.org/10.3390/environments8040036

Wang, J., Liu, X., Li, Y., Wang, Z. and Zhang, Y. 2019. Microplastics as Contaminants in the Soil Environment: A Mini-Review. Science of The Total Environment. 691:848859. https://doi.org/10.1016/j.scitotenv.2019.07.209.

Weithmann, N., Moller, J.N., Loder, M.G.J., Piehl, S., Laforsch, C. and Freitag, R. 2018. Organic fertilizer as a vehicle for the entry of microplastic into the environment. Sci. Adv. 4:8060. https:// doi. org/ 10.1126/ sciadv. aap80 60

Xia, R. 2019. The biggest likely source of microplastics in California coastal waters? Our car tires, The Loss Angeles Times.

Xu, B., Liu, F., Cryder, Z., Tang, C. and Chen, L. 2020a. Microplastics in the Soil Environment: Occurrence, Risks, Interactions and Fate-A Review. Critical Reviews in Environmental Science and Technology. 50(21):2175-2222. https://doi.org/10.1080/10643389.2019. 1694822.

Yu, H., Zhang, Z., Zhang, Y., Fan, P., Xi, B., Tan, W. 2021. Metal type and aggregate microenvironment govern the response sequence of speciation transformation of different heavy metals to microplastics in soil. Sci. Total Environ. 752:141956. https:// doi. org/ 10. 1016/j. scito tenv. 2020. 141956

Yu, J.R., Adingo, S., Liu, X.L., Wang, J. and Zhang, Y. 2022. Micro-plastics in soil ecosystem - A review of sources, fate, and ecological impact. Plant, Soil and Environment. 68:117. https://doi.org/10.17221/242/2021-PSE.

Zhang, G.S., Liu, Y.F. 2018. The distribution of microplastics in soil aggregate fractions in southwestern China. Sci. Total Environ. 642:12–20. https://doi.org/10.1016/j. scito tenv. 2018. 06. 004

Zhou, Y., Liu, X. and Wang, J. 2019 Characterization of microplastics and the association of heavy metals with microplastics in suburban soil of central China. Sci Total Envirn 694:133798. https://doi. org/10.1016/j. scito tenv. 2019. 133798.