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Research Article

Effect of Microplastics on Soil and Terrestrial Ecosystem

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Abstract

Plastics are petrochemical derived complex hydrocarbons, essential for modern civilisation. These plastic derived microplastics are released in the soil and terrestrial environment from various sources. Due to their small size, microplastic penetrate and migrate inside the soil easily. They have many fold toxic effects on soil structure, nutrient and mineral content of soil, effect the microbial community as well as on soil flora and fauna.

This review paper aims to discuss the toxic effects of microplastics on soil structure, on various soil parameters like nutrient content, enzyme activity, the complex interaction of microplastics with other soil contaminants such as pesticides, antibiotics. Impact of microplastic pollution in soil microbial community, plants, soil dwelling animals, flow of microplastics through terrestrial food chain are also discussed. Probable future research perspectives are also proposed here.

Keywords: Food Chain; Terrestrial Flora; Soil Animals; Soil Structure; Soil Microbes

Introduction

Globally plastic products become an essential commodity now a days. The annual global plastic production increases from 1.5 metric tons in the year 1950 to 390.7 metric tons in 2021 [31]. The high demand of plastics in every sector is due to its properties like durability, lightweight, hydrophobic and inexpensive. They can easily be moulded, cast, spun, or applied as a coating. The same properties make plastic an environmental hazard [54]. Due to its durability and hydrophobicity, it can persist in the environment for hundred to thousand years. Once the plastic waste gets enter the environment, it is broken down into large plastics (particle size >2.5 cm), medium plastics (particle size = 0.5–2.5 cm), microplastics (MPs) (particle size = 1 μm–5 mm) and nanoplastics (NPs) (particle size <1 μm) by the effect of various physicochemical processes like weathering, ultraviolet (UV) radiation, and human activities [21]. It is estimated that, among all the plastic toxicity, 58% are due to microplastics and 42% are due to macroplastics [4]. Microplastics have been listed among the top environmental concerns by the United Nations Environment Programs (UNEP, 2014) [54].

According to the shape, microplastics can be referred to as granules, fragments, films, pellets, fibres, and foams [36]. According to the source to environment or production procedure, microplastic can be classified into two groups.

Primary-When millimetre sized plastic particles are designed and synthesized in the manufacturing units for commercial purpose, these plastics are called primary microplastic. They are used in the cosmetic industry to produce pharmaceuticals and personal care products (PPCPs), industrial and engineering applications such as air blasting [17,31].

Secondary- These microplastics are derived from large sized plastics. When the large plastic materials get exposed to the environment, they undergo chemical (i.e. UV radiation, sunlight, the freeze–thaw cycle), physical (abrasion, wind flow, wave strike, water disturbance), and biological (degradation) activities involving fragmentation and degradation. These processes give rise to secondary microplastics.

Industry sector and human daily life activities contribute a huge amount of secondary microplastics to the environment. Plastic manufacturing industry, textile and laundry services, agricultural sector, wastewater treatment plants, improper littering and leachate from runoff surface water are reported to contribute to microplastic contamination [57]. These MPs easily gets accumulated in soil, water and through food chain become biomagnified. The plasticizers, colourants added to plastics also contribute to its toxicity. As a result of MPs' detrimental and toxic impacts on the environment, the scientific community has begun to pay more attention to them.

Most of the waste plastics end up in water bodies like pond, river and sea, hence the effects of microplastics on aquatic flora and fauna was studied extensively. The terrestrial environment also gets contaminated with microplastics but there are relatively lesser studies regarding the toxic effects of microplastics on terrestrial environment. Hence, this paper aim to discuss the negative impacts of MPs on various soil parameters, soil microbes, on plants, animals. This paper also emphasises the biomagnification process of microplastics through terrestrial food chain.

Effect of microplastics on terrestrial environment

Microplastics in soil

Microplastics are present in both soil and aquatic ecosystems and proven to have negative impact on the ecosystem. It is reported that the amount of MPs present on land is 4–23 times that of marine MPs, and that the amount of MPs imported into the soil is much larger each year than the amount of MPs imported into the ocean [20,48]. The sources of MPs to terrestrial ecosystem are diverse type like application of biosolids, sewage sludge, organic fertilization, waste water irrigation, plastic film mulching, atmospheric deposition, littering etc [12,49]. After reaching to the soil the vertical and horizontal movement of MPs in soil is important. These movements can be affected by various factors including soil characteristics such as soil macropores (pores > 75 μm), soil aggregation and soil cracking, agronomic practices such as plowing and harvesting, activities of soil biotic community [16].

Effect on soil structure

Microplastic particles can change some soil parameters like soil aggregation, water holding capacity, soil bulk density. MPs can incorporate into soil aggregations and soil clumps to varying degrees [7] and theses can, in turn alter soil porosity, soil aggregation and thus altering the soil-water dynamics [48]. Water holding capacity of soil increases when get contaminated with polyester fibre but exhibit no clear trend with polyacrylic and polyethylene particles [7]. In a PE contaminated clay soil, a significant increase in soil water evaporation was observed because of increased water movement channels. Desiccation cracking was also observed on the soil surface due to the disturbance of soil water holding capacity [47]. This can also lead to the migration of pollutants into deep soil layers along the cracks.

On the contrary to these, addition of microplastics to soil increase the accumulation of high molecular-weight humic-like materials. It indicates that microplastics may play a role in improving the soil quality, since that humic-like materials can improve the soil stability, water holding capacity, and nutrient availability [32].

Effect on soil nutrient and fertility

Microplastics can also alter the soil nutrient and fertility characteristics. Soil enzymes, with high catalytic capacity, play an important role in various soil biochemical reactions and nutrient cycling [16]. Microplastics have significant effect on soil enzymes like urease, catalase activities, fluorescein diacetate hydrolase (FDAse), and phenol oxidase [21]. Being a carbon rich polymer MPs have a considerable effect on soil bulk density. Polymers like polyester fibre, polyacrylic and polyethylene particles considerably decrease soil bulk density [7]. A high level of MP exposure for 30 days period shows decreased accumulation of Dissolve Organic Matter (DOM) and increase the release of soil nutrients, such as dissolved organic carbon (DOC), dissolved organic nitrogen (DON), and dissolved organic phosphorus (DOP) [18]. In contrary whit this another study found that MPs have no significant effects on soil dissolved organic carbon contents and the amounts of available phosphate, nitrate, and ammonium [30].

Effect on soil microbial community

After entering in the soil MPs undergo an ageing process by which, embrittlement, cracking, weakening, and chemical group changes like phenomenon occurs gradually [38,54]. These processes subsequently lead to soil characteristics change and soil microbial habitat and diversity change. Soil aggregations with microplastic fibers are expected to shape the microbial diversity and evolution differently than the non-microplastic structured soil. MP induced changes in soil porosity and soil moisture can alter the oxygen flow in soil and can change the aerobic-anaerobic organism ratio [54]. Along with this, MP induced soil parameter changes may lead to microhabitat loss and the extinction of indigenous microorganisms [25]. High concentrations of PP MPs (28% weight/weight) have reported to increase significantly the enzymatic activity, dissolve organic matter (DOM) and pools of organic C, N, and P [25,32]. The soil enzyme activities can reflect microbial activity and the availability of substrates for microbial uptake; therefore, changes to soil enzymes can indicate potential effects of microplastics on soil microbes. Most microorganisms specially the plastic-degrading bacteria, fungus and algae colonize and assemble on MP surface and form 'plastisphere'. Fei., *et al*. 2020 reported that soil microbial diversity decreases, urease and acid phosphatise enzyme activity increases and the fluorescein diacetate hydrolase activity was inhibited after adding PE and PVC MPs. Polyester microfiber (PES) greatly increases the growth and abundance of hyphae, arbuscules, and coils of arbuscular mycorrhizal fungi (AMF) [7]. On the contrary, PLA microparticles induce adverse effects on AMF diversity and community composition, possibly due to the chemical toxicity after biodegradation [48]. It is observed that different or even same MPs have different effects on microorganisms depending on the soil structure, type and the climatic conditions. The local climates and soil conditions may be more important than the plastic types in causing microbial changes [54]. In a study relating to three different soil types, three MP exposure (PE, PET, PVC) also present no clear trends in microbial communities in the cross-over trial [24]. Therefore, because of the highly diverse microbial community structure, the effects of MPs could also be altered with the environmental parameters [54]. As per Ren., *et al*. 2021; Ya., *et al*. 2021, presence of MPs in soil can reduce the emission of greenhouse gas N2O by changing the microbial association [41,52].

Effect on other soil contaminants and antibiotics

Microplastic in the soil can interact with other soil pollutants and contaminants in various ways and lead to complex changes in soil pollutants [41,52]. The hydrophobic nature and large surface area make the MPs a great agent for adsorbing the other hydrophobic soil pollutants and heavy metals. They can adsorb plastic additives such as diethyl hexyl phthalate (DEHP), Polybrominated diphenyl ether (PBDE), perfluorochemicals (PFOS), organochlorine pesticides, polycyclic aromatic hydrocarbons (PAHs), Polychlorinated Biphenylis (PCBs), heavy metals such as zinc, copper, and lead, and antibiotics [16,19,29]. Previous studies provide an overview that toxic chemicals and additives present in microplastics can slowly migrate in the soil and can cause ecological and health risks [15,25]. MPs can act as a vector for the huge amount of soil pollutants and contaminants and increase the risk of exposure to other organisms [52]. So, it is important to understand the complex interaction between MPs and other pollutants, as well as their combined effects on terrestrial ecosystem. The simultaneous use of pesticides and plastic mulch at agricultural field is a great concern now, because these MPs can act as both source and sink for the toxic chemicals [11]. Some physico-chemical processes like UV radiation, ageing can lead to increasing the adsorption capability of MPs for heavy metals, such as Cu and Zn, organic pollutants, and hydrophilic substances [10,14].

It was reported that, MPs have the ability to adsorb sulfadiazine, amoxicillin, tetracycline, ciprofloxacin, trimethoprim and other antibiotics [14,29]. Hydrogen bonding, hydrophobic interaction, van der Waals forces, and electrostatic interactions are the main binding mechanisms between antibiotics and MPs [14,29,33]. The aged and weathered MPs have higher adsorption capacity then the newly exposed MPs, because they have a larger specific surface area, micropore area and oxidation degree [53]. A study showed that the adsorption capacity of UV-treated PS and PVC MPs to ciprofloxacin increased 123.3% and 20.4% than that of the original MPs [34]. Therefore, the terrestrial organisms become more susceptible to antibiotic-resistant.

Effect on plants

The potential effects of MPs on plants are still not so clear due to limited data availability. Existing researches indicated that the effects depend on various factors, such as the type of MPs, species of plant, soil and environmental conditions [48]. Studies on wheat (*Triticum aestivum*) [24,40], perennial ryegrass (*Lolium perenne*) [2], *Vicia faba* [23], cress (*Lepidium sativum*) [3], spring onion (*Allium fistulosum*) [8] show that MPs inhibit plant growth, seed germination and gene expression. Various types of microplastics can also induce cyto-genotoxicity by aggravating reactive oxygen species generation [38]. HDPE, PVC, PET have no proven significant effects on sidling emergence and biomass [24]. Jiang., *et al*. 2019 observed that 100 nm sized PS-MPs can induce more oxidative damage, genotoxicity to *Vicia faba,* than 5 mm PS-MPs. A laser confocal scanning microscopic study on *V. faba* showed that large amounts of the PS-MPs was accumulated in root tips and inhibit the transport across cell by blocking the cell pores [22]. Another study with three different size of MPs (50, 500, and 4 800 nm) showed that 4.8 µm MP can accumulate in cress (*Lepidium sativum*) seed capsule. A significant decrease of gemination rate and root growth was observed after 8h and 24h of MP exposure respectively [3,38]. Spring onion (*Allium fistulosum*) showed significant changes in biomass, water content, leaf nitrogen content and C–N ratio, root traits (including root length, root average diameter, total root area, and root tissue density), root symbioses in response to various MPs and all these responses were MP type dependent [8,17]. 100 nm sized MPs can induce the morphological and cytogenotoxic effects on *Allium cepa* by affecting the cell cycle [38].

Effects on soil dwelling animals

Microplastics can impart their effects on soil animals by three routes- internally via ingestion, external exposure like dermal contact and by inhalation. Most of the MPs are excreted after ingestion but there is evidence that some of the residues may remain in the gut for a long time [46]. When animal ingest microplastics, it can cause false satiation, which reduces the food intake and finally leading to energy depletion, decreased growth, and even death [6,44]. MPs and the plastic associated toxic chemicals can cause various effects like mechanical damage to the oesophagus, intestinal obstruction, decreased reproduction, decreased immune responses, metabolism disorders, harmful effects on invertebrate sperm [50,26,52]. Earthworms are the most studied soil animal, also they are considered as the model animal for studying the impact of MPs and other pollutants in soil ecosystems. They can ingest small-sized plastics and they have the ability to generate secondary MPs in their body. Cao., *et al*. in 2017 [5], showed that PS-MP at exposure concentrations of 1% and 2% (w/w) had a significant effect on growth inhibition and mortality rate of earthworm (*Enchytraeus fetida*). 1% PES can cause decreased cast production by 1.5 times, decrease in heat shock protein (*hsp 70*) by 9.9 times [39]. *E. fetida* Exposure to 20% PS and PE microplastics for 14 days can increase catalase, peroxidise, lipid peroxidation and suppress the level of superoxide dismutase, glutathione-S-transferase [50].

Polystyrene (PS) have significant effect on body length, survival rate, reproduction rate and oxidative stress genes of *Caenorhabditis elegans* [28]. Exposure to LDPE and a blend of PLA-PBAT significantly reduced body length and reproduction of *C. Elegans* [42]. High concentration of MPs can effect the gut biota of soil organisms like *Enchytraeus crypticus* [55]. 0.1% of PVC and 0.5% of PE microplastics can significantly change the gut biota community of collembolan (*Folsomia candida*). The reproduction rate of *Folsomia candida* reduced by 70.2% in response to 1% PE exposure [55]. Ingestion of PET microfiber by snail *Achatina fulica* can cause lipid peroxidation, villous injury of intestinal wall after 28 days exposure [45]. Microplastic exposure of soil dwelling mice can cause hepatic lipid metabolic disorder, lipogenesis disorder, decrease gut mucin secretion, and triglyceride synthesis in the liver and epididymal fat [35].

In addition to the hazards caused by direct ingestion, the toxic effects of microplastic derived additives and heavy metals can be adsorbed to microplastic and amplify the toxicity to soil animals. MPs can adsorb a high amount of zinc and increase its bioavailability [19]. There are different findings also, like addition of high level of MPs (5% and 10% w/w) can decrease the accumulation of PAHs and PCBs in the earthworm *E. fetida* [50].

Effects on terrestrial food chain

Trophic transfer of microplastics in marine food chain is well recognised. Food chain simulations have proved that MPs can transfer from lower trophic level to higher trophic level of food chain [16]. The predators are become more susceptible to MP consumption when microplastic remain the intestine of prey species for a longer time [51]. Informations, related to trophic transfer of MPs in terrestrial food chain is limited. A study based on home gardens of SE Mexico showed 17 ± 14.6 fold magnification of microplastics in earthworm casts then soil and 149 ± 41.8 fold in chicken faeces [37]. Even when chickens were feed with microplastic free crops, MP particles were found in gizzards and faeces of chickens. This can occur possible due to consumption of earthworm meal, which indicates the transfer of microplastics from earthworm to chicken [37]. Microplastic accumulation in mice tissue such as liver, kidney and gut indicate that MPs can be accumulated in tissue of prey species and get transferred to the predator [9]. These animal model studies suggest that, as top consumer of food chain, humans are also susceptible to MP consumption and accumulation from lower food chain. Therefore, the bioaccumulation and biomagnification of MP can adversely affect the terrestrial food web as well as human health [16].

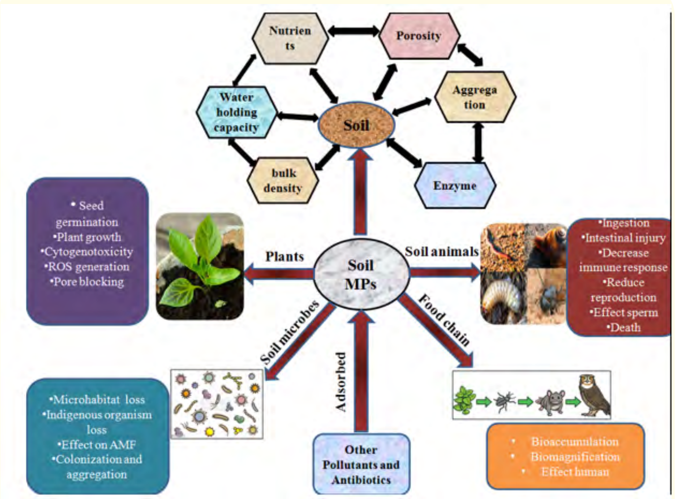

Figure 1: Effects of microplastics on soil properties, plant, soil animals, soil microbes, food chain and microplastics interaction with other soil pollutants and antibiotics.

Discussion

Microplastic is a threat to human health and environmental sustainability due to its small size, hydrophobic, persistence nature. Hence the need of the hour is to mitigate this problem. Until and unless there will be an effective way to degrade or separate microplastics from environment, they will continue to accumulate in soil, water, plants and animals. Soil act as both source and sink of microplastic pollution as most of the single use plastics go to landfills, open dumping areas and generate a huge amount of microplastics. These MPs get accumulated in the soil, further change its structure and nature. Addition of MPs can alter the soil porosity, create extra channels for water movement and increase the risk of pesticide and other contaminant infiltration. This also increase the soil evaporation rate and soil cracking, decrease the accumulation of dissolved organic matter. By altering the nutrient content and oxygen flow MPs also alter the aerobic-anaerobic microorganism ratio. Polyester microfiber (PES) increases the growth of arbuscular mycorrhizal fungi (AMF) but PLA microparticles induce adverse effects on AMF diversity. Microplastic is a good absorbent of antibiotics, heavy metals and pesticides used in agriculture. The synergistic effect of these chemicals makes MPs more harmful to plants. They have the ability to delayed the seed germination, plant growth and fruit formation. In soil dwelling animals, MPs can effect the growth, enzyme activities, reproduction. When ingested it can cause false satiation and lower the energy. Food chain accumulation of MPs are also evident in various studies. Further studies are required to deal with the various adverse effects on terrestrial environment.

Future Prospects

Research related to effects of microplastics on terrestrial ecosystem is much lesser in compare to the studies in marine ecosystems. More and more studies are required to identify the effects of microplastics on soil environment.

Soil type, microplastic type, and the environment are the key factors which interact with each other to determine the degree of effects. The complex interaction between soil flora, fauna and microplastic need more intense study for further comprehension.

Like all other toxicological studies, dose and exposure time are the two important parameters for studying the effects of MPs. Hence, more study designing related to dose and time is needed.

The role of microplastic degrading microbes present in the soil need more attention, as they can shape the microenvironments surrounding the microplastics. They can degrade the microplastics and make the carbon available as energy source to themselves and other microorganisms. Therefore, the existing ecosystem can be replaced by a new microplastic based ecosystem.

The synergistic effect of microplastics and antibiotics as well as other agricultural pesticides need a grater attention as all these are entering to the soil due to anthropogenic activities. Interactions pattern of these factors among themselves and with the flora and fauna is important to understand the in-situ situations of microplastics effects. Flow of MPs through food chain and food webs, their degree of bioaccumulation, biomagnification is not well understood.

As human serves as the top consumer of several food chain, the intake of microplastics in human through food chain and its effects on human body should be the most concerned area of research today. Lase but not the least, microplastic remediation and biodegradation is the prime need of this time.

Conclusion

Microplastics are complex hydrocarbons of various types, shape, size and origin. They enter in the soil through industrial runoff, waste water treatment plant effluent, landfills, agricultural mulching and from household wastes. MPs interact with various soil parameters like soil structure, soil porosity, nutrient cycling, soil fertility. They interact with and adsorb other soil contaminants like pesticides, antibiotics, which increase its toxicity. The adverse toxic effects of MPs on seed germination, plant growth, root structure was documented. They also can harm the soil native fauna by altering the population structure and sometime enhance the growth of several 'plastic eating' microbial population. Their accumulation in food chain is also a matter of concern. As soil microbes like bacteria, fungus and algae play important role in microplastic breakdown, they can also play a role in MPs biodegradation and mitigate the microplastic pollution. This study proposes some future research areas to deal with microplastics in the soil and terrestrial ecosystem.

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