Chapter 11

FATE OF MICROPLASTICS IN SOIL

Mrs. Suhada K M

Assistant Professor, PG Department of Chemistry, KAHM Unity Women's College, Manjeri, Kerala-676122, India
E-mail: kmsuhada591989@gmail.com

INTRODUCTION

Microplastics (MP) are emerging pollutants, and since they pose a great danger to whole habitats, their existence in water and soil ecosystems has recently attracted significant attention. Recent research has focused on the identification, occurrence, characterization and toxicology of microplastics in marine and freshwater environments, but our understanding of the ecological impact of microplastics in soil ecosystems is still limited compared with that in aquatic ecosystems. In order to resolve the possible ecological and human health risks posed by microplastics in soil, we have compiled literature, analysis of sources, migration of microplastics in soil, negative impacts on soil health and function, trophic transition in food chains and the related adverse effects on soil species.This Chapter aims to address gaps in knowledge, shed light on the fate of microplastics in soil, and propose future studies on microplastic pollution. Furthermore, this chapter is focused on what happens to microplastic when once it entered into soil environment.

TROPHIC LEVEL TRANSFER OF MP

Microplastic particles will be transferred to higher organisms through the food chain. *Lwanga et al*. performed one study on the trophic transfer of MPs in the terrestrial food chain, in which the concentrations of MPs in gardening soil, earthworm casts, and chicken (*Gallus gallusdomesticus*) faeces were analyzed. The concentrations increased along the trophic levels, and the highest concentration of MP was confirmed in chicken faeces. In particular, chicken gizzards also contained MPs, and this indicated that the evidence of transfer of MPs to humans is through food because gizzards are used for human consumption.

TRANSLOCATION AND ACCUMULATION OF MPs IN ORGANISMS

Maab *et al.* used two collembolan species, *Folsomia candida* and *Proisotomaminuta*, and observed the transport of urea-formaldehyde particles. The transport of particles was strongly dependent on the type of particle, size of particles, and size of organisms. Nevertheless, the authors confirmed the horizontal transport of plastic particles by soil microarthropods. Rillig et al. also studied the transport of PE-MP by soil organisms *L. terrestris*, which were cultured in 2.5 kg of soils covered with 750 mg of various sizes of PE-MPs particles. After 21 days of exposure, MPs were detected in the middle and bottom layers of soils, and the smallest particles (710–850 µm) reached the deepest layers of the soil. The mechanisms of plastic transport in soil were not demonstrated, but they suggested that MPs might be transported through the activities of earthworms such as ingestion/egestion, burrowing, adherence, and casts making. So far, despite their ecological importance, the exposure of soil filter feeders such as nematodes, rotifers, and ciliates to MPs and nanoplastics has not yet been determined. Filter feeders in marine ecosystems have been shown to ingest microparticles, while filter feeders in freshwater ecosystems, *Daphnia* *magma* and *Thamnocephalus platyurus* has been shown to be sensitive to nanoplastics. Organisms with other feeding modes are also susceptible to microplastic ingestion. *Taylor et al*. found synthetic microfibers on and inside six out of nine deep-sea organisms that belong to the phyla Cnidaria, Echinodermata and Arthropoda with predatory and feeding mechanisms. As such, woodlice, snails, caecilians, and other soil organisms with similar feeding mechanisms would be subjects of interest in agroecosystems. Information about the bioavailability and bioaccumulation of MPs in soil organisms is generally lacking. We know that nanoplastics can enter cells, as fluorescent nanoplastic polymers have been used as molecular probes for a wide range of biological studies with mammalian cells, for example, to measure blood flow in tissue and as tracers for phagocytic processes. The translocation of a range of microparticles by mammalian gut into the lymphatic system has been demonstrated in rabbits, dogs, and rodents. There is no experimental evidence of nanoplastics being transferred from invertebrates to vertebrates. However, there is evidence of the transfer of MPs from contaminated land to vertebrates and potentially from earthworm to chicken.

DISTRIBUTION OF TOXIC CHEMICALS BETWEEN MPs AND SOIL

Many types of toxic chemicals, such as polychlorinated biphenyls, polycyclic aromatic hydrocarbons, dichlorodiphenyltrichloroethane, perfluoroalkyl substances, pharmaceuticals and personal care products, and heavy metals, can be absorbed by microplastics and also may serve as a sink for certain toxic chemicals in sea water[1]. The concentration of PCBs and dichloro diphenyl dichloroethylene collected in PP pellets can be up to 105-106 times greater than concentrations in ambient seawater because of the hydrophobic nature of plastic surfaces[2]. Unlike water, however, SOM will dominate the sorption of hydrophobic organic compounds(HOCs) when the content of organic carbon is greater than 0.1 percent[3]. Microplastics are likely to compete with SOM for the absorption of chemicals, especially HOCs, once they reach the soil environment[4]. Many kinds of organic compounds have been reported to be sorbed by microplastics, showing a distinct sorption affinity pattern [5&6]. The partition coefficients (Log K_{MP}) of HOCs (e.g., polycyclic aromatic hydrocarbons and hexachlorocyclohexanes) on PE, PP, and PS microplastics showed strong linear correlations with their LogK_{ow} values, with R2 values of 0.92, 0.94, and 0.84 respectively, as reported by Lee et al. (2014)[7].

STORAGE OF MPs IN SOILS

Incorporation of plastics into soil aggregates may promote long term storage. Aggregation may limit exposure to soil fauna and hinder the transport of plastic particles. Nanoparticles aggregate rapidly in aquatic environments and heteroaggregation has been noted as an important control on nanoplastic fate. Aggregate stability is associated with soil system health, so the role of aggregates as micro (nano) plastic stores is likely to be dynamic and environment-dependent. Accumulation may also occur through burial where successive flood events bury contaminated layers in alluvial soils. A theoretical assessment of microplastic transport and erosion, based on the frame of a hydrological/sediment transport catchment model, suggested the potential for soils to effectively retain, and therefore store, micro(-nano)plastics. However, experimental data to confirm these findings are not yet available. Microplastics are preserved in marine and lacustrine sediment profiles. Particle burial limits degradative forces and thus increases preservation potential. It is probable that a similar effect will occur in soil systems, establishing soils as a sink for contamination. The role of soil characteristics, such as pH, and soil microbial communities in maintaining degradation must be assessed. Furthermore, disturbance of buried layers may remobilize stored micro(nano)plastics. For example, alluvial soils may be reworked and agricultural practices such as tilling can bring buried particles back to the surface. The accumulation of plastics in soils must also be examined in the context of ecological risk through long term exposure. While the discussion of the state of ecotoxicological research for microplastics in soils is not the primary focus of this paper, the increasing number of publications in this area demonstrates international interest.

TRANSLOCATION AND EROSION

Erosion by water and wind will transport particles across soil systems and eventually towards streams and rivers. The dynamics of these processes have not yet been investigated; however, inferences can be drawn from the wider domain of microplastics research. Recent work examining the sinking velocities of microplastics in the marine realm has established particle shape as a dominant control. It is likely that shape is also relevant for the erosion of micro(nano)plastics by water in soils. While the effect of erosion and entrainment of microplastics mediated by size and density has been assessed through a theoretical model, the influence of shape on translocation over soils or sediments as well as on their hetero-aggregation has not yet investigated. However, these processes will lead to a winnowing effect based on particle morphology and properties, such as that seen for natural soil particles. The irregular shape and low mass of particles such as fibres lead to a preferential entrainment by wind erosion. Hence, the scale of wind and water erosion is significant in determining enrichment or depletion of specific particle types. Furthermore, micro(nano)plastics do not necessarily represent inert polymers upon entry to soil systems. Particles that have been through wastewater treatment or have been exposed to the environment may have become significantly biofouled or gained a surface charge. This can alter the nature of particle mobilisation and erosion. Soil fauna also contribute to the transport of microplastics within soil systems. Plastic particles may adhere to an organism's exterior or be transported internally through intake and subsequent egestion. These mechanisms have been shown to contribute towards the dispersal of plastic particles from a point source. Bioturbation also results in vertical transport. This occurs through the process of burrowing, which establishes biopores in the soil matrix and incorporates microplastics into burrow walls and casts. This process significantly increases the downward translocation of plastic. Micro(nano)plastic ingestion may represent a removal from soils when this results in systemic translocation or trophic transfer. The uptake of microplastics by plants is unlikely but may occur for nano-sized particles. However, data are insufficient to establish the significance of this process for the overall budget of particles in a soil. Degradation Environmental degradation has been discussed for aquatic and sedimentary environments and many of these processes also occur in soils. The topsoil likely represents a key degradative environment, due to the direct exposure to UV radiation, increased oxygen availability, and higher temperatures. Soil microbial communities and terrestrial organisms may accelerate biodegradation of brittle plastics. Furthermore, agricultural processes such as tilling may fragment plastic debris. All these processes contribute to the progressive fragmentation of plastic from macro-to nanoscale.

LEACHING TO GROUND WATER

Leaching is an important process driving contaminants with certain properties to groundwater. Micro (nano) plastics have not yet been analysed in groundwater samples but transport through biopores has been identified as a possible mechanism for groundwater contamination. Theoretically, assuming plastics as mainly inert materials, the potential for leaching will be modulated by soil texture properties and particle size, density, and shape. Additional soil properties such as zeta potential and ionic strength may, in principle, influence transport of non-inert particles. Fundamental speculative reasoning suggests that nanoscale inert plastics with a density higher than water may be effectively leached to groundwater. This can represent a potential pathway to human exposure. Future research This paper summarises existing studies on soil microplastics and outlines the potential mechanisms for soil micro(nano)plastic dynamics. Further work is crucial to elucidate sources, behaviour, and fate. The following steps in soil micro (nano) plastics research should be prioritized: - Filling the methodological/technological gaps hindering an accurate assessment of micro(nano)plastics in soil samples, including methods for car tire debris and nano-scale materials. - Delivering baseline studies on soil exposure along a gradient of land uses and soil management. This will establish the scale of contamination and can point towards potential source apportionment: for example, fibres and microbeads as indicators of sludge application or tire dust as an indicator for road runoff. - Unravelling the processes controlling budgets of microplastics in soil environments, including the assessment of microplastic transfer from soil to humans through the uptake in foodwebs and through leaching to the groundwater. - Developing a solid experimental and conceptual framework to characterize risk and impacts from soil micro (nano) plastics for humans and the environment. Timely translating of findings to stakeholders (i.e. industry, wastewater utilities, and farmers) and governance endorsing knowledge-based decision making.[8]

MP concentration differed at different soil depths, indicating that the MPs moved downward through unknown mechanisms. The migration behaviour of MPs in soil is complex, and their vertical and horizontal distributions may be affected by many factors. Bioturbation enables the migration of MPs in soil, namely, MPs are transferred and transported by soil fauna (e.g., larvae, earthworms, vertebrates) and poultry, either by attachment to the outside of animals or by ingestion and excretion. Mites (i.e., *Hypoaspisaculeifer*) and collembola (i.e., *Folsomia candida* and *Proisotomaminuta*) were recently reported to promote the migration and distribution of MPs in soil by scraping or chewing on them. Digging mammals (e.g., ground squirrels and moles) exhibit similar behaviour. Behaviour associated with earthworms, including external attachment, ingestion and excretion, promotes the lateral and vertical distribution of MPs in the soil. In addition, larval feeding behaviour was reported to cause MPs carried by adult mosquitoes to spread out into the environment. Earthworm waste (vermicast) contains concentrated MPs that can be eaten by soil microarthropods. Therefore, we speculate that when there exists a predator-prey relationship among soil microarthropods, the complex food web in the soil ecosystem composed of diverse species relationships will definitely promote the migration of MPs. Similarly, the transport of MPs is affected by root disturbances (such as root movement, expansion, and absorption) and rhizosphere hyphae. However, this is only a corollary, and future perspectives should reveal the influential mechanism of plant roots on MP migration. Tillage activities, such as tilling and ridging, make it easy for MPs to be carried into deep soil. In addition, the harvest of tubers (e.g., potatoes and yams) may facilitate the vertical migration of MPs. A recent study demonstrated that the wetting-drying cycle can accelerate the downward migration of MPs. Apparently, these driving factors facilitate the movement of microplastic granules. Nevertheless, the extrinsic forces have little effect on the downward motion of MPs. For example, traditional farming practices affect only the topsoil. Defined as the loss of mineral and organic solutes due to percolation in soil, leaching has a strong role in facilitating the vertical movement of MPs. Soil is a porous medium with μm-sized pores, thus allowing the transport of soluble materials and granules. Therefore, soil texture determines the pore size, which directly affects the migration of MPs. The retention of MPs in quartz sand media can be significantly improved by increasing the ionic strength. This may be due to the high strength of ions pressing against dual thickness, resulting in deceasing energy barriers and deepening depths in elementary and subprime polar regions. The ion strength of soil pore water may be similarly affected, although there is no experimental evidence to prove this. In addition, several studies show that surface roughness, biofiltration, organics, saturation and hydrodynamic conditions of the medium affect the migration and fixation of MPs in quartz sand. Studies of colloidal migration in quartz sand indicate that strain and physico-chemical sedimentation control the critical interactions of colloidal migration and fixation. The results revealed that membrane strain, solid-liquid interface adhesion, air-water interface capture and pore repulsion are the main mechanisms. Keller et al. (2020) synthesized a mixture of passive inorganic tracer and MP fiber, and used inductively coupled plasma mass spectrometry (ICP-MS) to rapidly and quantitatively analyzed the MP transport behavior in simulated soil columns (glass beads). The mobility and transport of MPs into the soil may depend on their size and aggregation state (e.g., organic solids). Transport may also be related to shape or polymers, and to this end, heterogeneous aggregates and/or adhesion to organic matter should be further investigated. Another factor is the presence of highly variable conditions in the soil, such as soil type, temperature, and water status which affect the fate and behavior of MP particles. The above research provides information to explore the migration mechanism of MPs in soil. However, soil as a heterogeneous medium is far more complex than quartz sand. Recently, two simulation studies showed that soil organic carbon (SOC), clay, Fe_2O_3, pH, and CEC play important roles in the adsorption and migration of polystyrene MPs (PSMPs). More research is recommended to reveal the contribution of inherent properties (such as external texture and granule size) and external factors (such as porosity, saturation and ion strength) to the migration of MPs in soils. Soil MPs may migrate through dynamic driving forces such as dustfall, wind and water or soil erosion. MPs, especially microfibers, on the surface of the soil can be suspended in the atmosphere by upper air wind for a period of time before deposition through rain or dust. MPs also enter coastal waters through surface runoff. These migration risks are believed to be relatively high, especially in cultivated soils with extensive irrigation canals, ditches and overland runoff. At present, there is low pollution (12 items/L) in groundwaters, but this does suggest the transfer of MPs. The properties of MPs themselves are also important factors affecting their migration in soils.

CONCLUSIONS AND PERSPECTIVES FOR FUTURE RESEARCH

The current ecological risks from plastic pollution are expected to continue into the future due to expected increases in plastic production, significant durability of plastic particles, degradation of existing plastic pollution and increase in MPs and NPs worldwide. The research of MPs in the environment is still in its infancy. At present, plastic debris are relatively well defined as a group of mixed substances composed of synthetic or heavily modified natural polymers, and they are solid and insoluble at 20°C. Persistent water-soluble polymers like polyacrylamides (PAM) and polycarboxylates would not be considered microplastics and therefore will not gain as much attention as they should. Because of annual production volumes well into the millions of tonnes, especially considering that PAM releases its monomer acrylamide (a powerful neurotoxin) under anaerobic conditions, its harmful environmental effects should not be overlooked. Obviously, we know that microplastics come from a multitude of sources, including products used for a variety of applications (e.g., tires, textiles, packaging), comprise different sizes, shapes, colours, and types of material (molecular composition and structure), and include mixtures of diverse chemicals. They migrate through nature via diverse pathways and affect biota and ecosystems in different ways. Like pesticides with diverse molecules, structures and applications, microplastics should be reconsidered as a diverse suite of contaminants rather than a contaminant. Current research on plastic pollution is limited by the conceptual plastic fate and transport models from land to ocean. Thus far, this holistic and integrated approach has not been widely used and adapted, although some models to follow their fate and transport through the various ecosystem processes it undergoes, as well as potential exposures to human. The introduction of this concept may have important implications for policy and management of this issue. It is therefore suggested to consider the plastic pollution problem as a concept of an environmental or biogeochemical cycle, that is, identify the continuous and complex movement of plastic materials (a diverse contaminant suite of large, medium, micro- and nanoplastic) between different abiotic and biotic ecosystem compartments (including humans), based on atmospheric sciences and biogeochemistry, trophic transfer, and human health and exposure. Moreover, this cycling approach will also aid in identifying and understanding the relationships between plastic manufacturing and pollution to other serious environmental problems such as climate change, species loss, coral disease, pathogens and parasites, and antibiotic resistance.[9]

REFERENCES

1. Engler, R. E. The complex interaction between marine debris and toxic chemicals in the ocean. *Environ. Sci. Technol.***46**, 12302–12315 (2012).
2. Mato, Y. *et al.* Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. *Environ. Sci. Technol.***35**, 318–324 (2001).
3. Xu, B. *et al.* Sorption of pentachlorophenol and phenanthrene by humic acid-coated hematite nanoparticles. *Environ. Pollut.***248**, 929–937 (2019).
4. Andrady, A. L. & Neal, M. A. Applications and societal benefits of plastics. *Philos. Trans. R. Soc. B Biol. Sci.***364**, 1977–1984 (2009).
5. Wang, F. *et al.* Interaction of toxic chemicals with microplastics: A critical review. *Water Res.***139**, 208–219 (2018).
6. Ziccardi, L. M., Edgington, A., Hentz, K., Kulacki, K. J. & Kane Driscoll, S. Microplastics as vectors for bioaccumulation of hydrophobic organic chemicals in the marine environment: A state-of-the-science review. *Environ. Toxicol. Chem.***35**, 1667–1676 (2016).
7. Lee, H., Shim, W. J. & Kwon, J. H. Sorption capacity of plastic debris for hydrophobic organic chemicals. *Sci. Total Environ.***470–471**, 1545–1552 (2014).
8. Hurley, R. R. & Nizzetto, L. Fate and occurrence of micro(nano)plastics in soils: Knowledge gaps and possible risks. *Curr. Opin. Environ. Sci. Heal.***1**, 6–11 (2018).
9. Zhou, Y. *et al.* Microplastics in soils: A review of methods, occurrence, fate, transport, ecological and environmental risks. *Sci. Total Environ.***748**, 141368 (2020).