Chapter 1
Soil Pollution by Micro- and Nanoplastics: An Overview

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Abstract Annual releases of plastic to the terrestrial environment are 4 to 23 times as high as releases to the marine environment. Microplastics can enter the soil by many routes, for example, compost and sewage sludge as fertilizer, plastic mulching, irrigation and flooding, and atmospheric deposition. The process of top-down irrigation into the soil causes microplastics/nanoplastics (MPs/NPs) to be transported downwards along with soil cavities and eventually possibly into groundwater. Contact of toxic and harmful metal pollutants with MPs/NPs will inevitably occur during the migration process in the environment. Various factors are considered in their transportation such as microplastic properties, pore water forms, and properties of packing materials to influence microplastic transport that can indicate the environmental chance of MPs in soil conditions. Among the important roles in the environmental behavior of MPs/NPs are absorption and migration. Microplastic or nanoplastic particles as a carrier adsorb contaminants and increase or decrease their transportation. The transfer of MPs in the soil environment occurs in the form of vertical and horizontal migration and nonliving transport. MPs are known to adsorb toxic chemicals such as PCBs, PAHs, DDTs, PFASs, PPCPs, and heavy metals. Overall, this chapter provides introductory information about the terrestrial pollution of MPs and the structure of this edited volume.

Keywords Microplastic · Nanoplastic · Soil pollutants · Transportation · Carriers

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1.1 Historical Background

Plastic, a synthetic material, is an aggregate of polymers. They are classified into microplastics which are >25 mm, mesoplatic with 5–25 mm, microplastics with 0.1–5 mm, and nanoplastics having <100 mm (Azeem et al., 2021).

After World War II, Age of Plastics began, and tons of plastic production happened worldwide. Since 1950, nearly 200 million tons of plastic material have been dumped into marine accidentally or intentionally (Brack, 2015). In the early 1960s, the awareness raised regarding the plastic waste contamination of the environment when seabirds perished having their gut piled up with plastic debris (Buks & Kaupenjohann, 2020). In 1968, the term microplastic was mentioned by the US Air Force Materials Laboratory in a publication. Microplastic was then described as the deformed plastic on a scale of microinches per inch. These terms were no longer in use as the scientists opted for a new denotation that generally describes the size of plastic piece. This was since the 1970s due to the discovery of minute plastic pieces in the aquatic ecosystems. The awareness of microplastic across the aquatic ecosystem was first identified by the world in 1972 due to the report provided on plasticles, the term given for small plastic particles that are floating on the Sargasso Sea surface (Crawford & Quinn, 2017). Early research related to MPs and NPs focused only on marine ecosystem but ignored soils (Buks & Kaupenjohann, 2020).

From the last decade, study on microplastics has increased exponentially. Though plants are the base of food web, they have been hugely overlooked in examining and studying ecotoxicology of microplastics (MPs) and nanoplastics (NPs). Recently, the knowledge base of MPs and NPs interaction with plants is rapidly mounting though few crucial gaps persist. The data observed from few decades regarding internalization and external adsorption in plants poses an alarming perspective that MPs and NPs may enter the food web which disrupts a broad range of species including humans (Mateos-Cárdenas et al., 2021).

1.2 Scope and Importance

Need for plastic has increased rapidly due to urbanization (Crawford & Quinn, 2017). Modern-day agricultural methods use plastic polymers such as polypropylene, polyolefin, polyvinyl chloride, polythene, acetate copolymer, and ethylene-vinyl for different applications like plastic reservoirs, boxes, mulching films, packaging materials, silage films, harvesting nets, tunnel green house, and irrigation system. These plastic materials are regularly used in agriculture to provide peculiar microclimate conditions that are required for plant growth (Campanale et al., 2022). Besides the abovementioned plastic polymers, the huge widespread usage of plastic materials like plastic resins, packaging material, is on the rise, and this phenomenon is referred to as "white pollution" which turns out to be a serious environmental issue (Azeem et al., 2021). What happens to all the nondegradable plastic products having a long-term lifetime? European nations lead the world in safe disposal and recycling plastics (Brack, 2015). For a certain period of time, MPs on land and on ocean suffer the exposure of high ultraviolet radiation due to the direct exposure of sunlight and ultimately undergo photooxidative degradation (Crawford & Quinn, 2017). Besides being recycled, the remaining plastic is still being dumped as municipal waste. Including New York, most mega cities are not up to the point in achieving plastic degradation. Even though plastic to some extent is being combusted and recycled then, where the remaining plastic goes is a big query. General household waste is a whole world problem, particularly in third world countries that lack landfills for municipal waste. Having industrial revolution and development, huge plastic is generated. What about the plastic waste developed from industrial society and urbanization? Quantum dots, carbon nanotubes, fullerenes, nano squares, nano boxes, nano crystals, and nanowires are intentionally produced nanoplastics. Nanotechnology uses different nano tools in revolutionizing field such as personal care products, medicines, and packaging. What about all these plastic nanoparticle disappearance (Brack, 2015)? Because of weathering, biodegradation or chemical degradation, and abrasion, plastic polymers further transform to microplastics and nanoplastics (Campanale et al., 2022).

Any piece of plastic having size 5 mm to 1 μm which is considered as microplastic and plastic having size less than 1 μm is termed as nanoplastic. MPs and NPs in terrestrial zone have diverse toxic effects based on the exposure medium and interaction with varied contaminants. The interplay with such pollutants can cause major modifications in the surface properties of plastic, due to which agroecosystem can incorporate these MPs and NPs which results in synergistic, antagonistic, or additive effects. In spite of their potential entry into agroecosystems, the data availability on MP and NP is scarce. The soil presence of plastic pollutes plant and soil organisms. Accumulation of plastic in soil occurs in different ways such as atmospheric deposition, through plastic packing, by wastewater treatment plants, daily use of plastic products, and mulching. In several countries, plastic mulching has been widely implemented in agriculture to enhance vegetable and fruit production leading to instant economic profits. Specifically for mulching, low-density polythene (LDPE) is used. Though mulching gives short-term profits to farmers, soil resources are hugely being exposed to plastic. Once plastic aggregates in soil, it's difficult to remove or recycle due its small size and surface-area-to-volume ratio (Azeem et al., 2021). The degraded plastic persists in the surface of soil and incorporated deeply through soil horizons or drive by water erosion or by wind and transfers into different ecosystems (Campanale et al., 2022). But how these MP and NP are being settled in deep sub soils. Agricultural methods like fertilization, moldboard, deep ploughing, and deep tillage methods disrupt soil layers and stimulate deep dispersion of MP and NP in layers of soil as mentioned in Fig. 1.1. Organisms in soil including mites, collembolans, and earthworms facilitate transportation through ingestion, casting, egestion, and adhesion to their peripheral skin. In addition to these methods, rhizomes pruning can also promote migration of MPs and NPs downwards. Besides that, wet-dry circle procedure also supports their movement downward (Azeem et al., 2021).

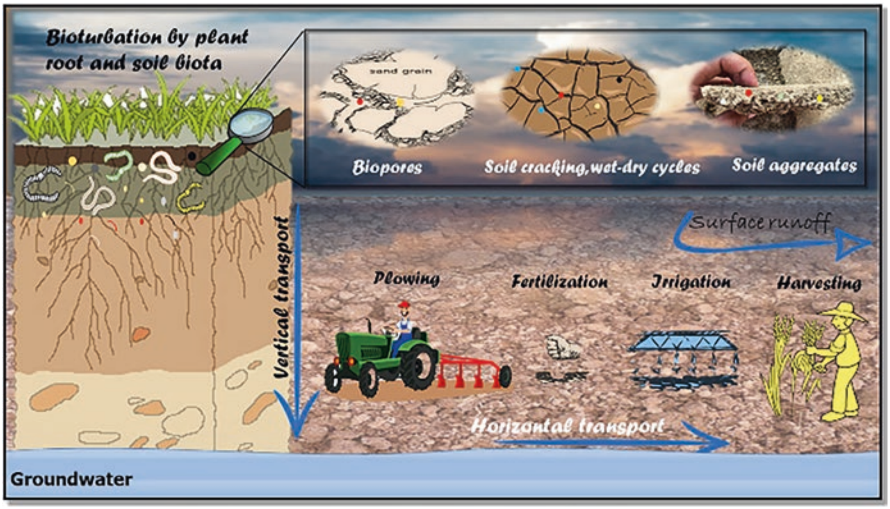

Fig. 1.1 MP and NP transfer in subsoils. (Adapted from Campanale et al., 2022)

The impact of plastics on plants can be internal or external. There is a strong requirement to monitor and study plant as a capable microplastic vector in the environment. Three types of plastic polymers – polypropylene (PP), polyethylene (PE), and polystyrene (PS) – are mostly observed to adsorb on plant surfaces. Numerous mechanisms have been stated to elucidate the spotted adherence of MPs & NPs on plants as mentioned in Fig. 1.2. These mechanisms mainly categorized into entrapment on surface structures and adsorption to surfaces. These mechanisms differs from species to species. Adsorption and internalization of these degraded plastics have a huge impact on the environment. On incorporation they delay germination by adsorption resulting in blockage of pores on surface of spores or in capsules of seeds. Chemical leaching caused from these plastics or by physical presence of MPs and NPs affects germination process. These plastics also have an impact on growth elongation in plants effecting growth between shoot and root, root thickness, and root elongation. These mixed effects of macro- and nanoplastics share similar effects of stressors like "stress-induced morphogenic responses" (SIMR) which cause reactive oxygen species production that results in plant hormone level difference which ultimately terminates growth of few tissues and accelerates other tissues growth. Algae and plants can be utilized as plastic bioindicators that help to recognize plastic hotspots (Mateos-Cárdenas et al., 2021).

Plant roots takes the first contact point with MPs and NPs, and root hairs of plant are majorly observed to be involved. These are absorbed by the plant root system by either symplastic transport through crossing the Casparian strip or apoplastic way which follows cell walls and extracellular spaces (Campanale et al., 2022). This uptake and translocation of these plastics happen in plants majorly by transpiration pull. These particles inside the central cylinder can travel to the plant aerial parts through the xylem. Another pathway for these particles to enter the leaf is possibly

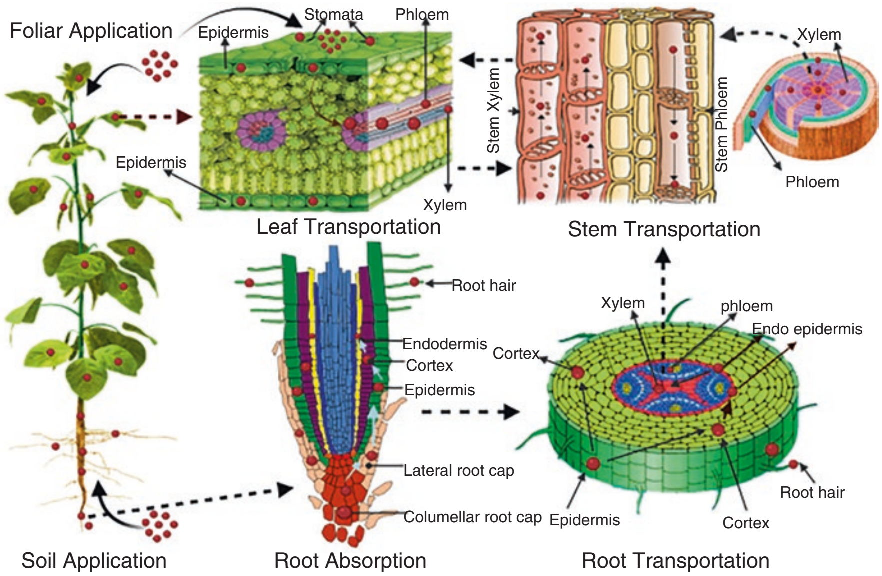

Fig. 1.2 Mechanism indicating plastic uptake by plant. (Adapted from Azeem et al., 2021)

through the stomata by foliar application (Azeem et al., 2021). Plant responses in the presence of NPs include alteration of performance of photosynthesis, pigment reduction, and biochemical changes. NPs induce oxidative stress and rises in reactive oxygen species. Data on accumulation of macro- and nanoplastics in plants, particularly in edible crops demonstrates how we are consuming plastics through food. Compared to vegetables, fruits have been mentioned to have high plastic content due to their greater size, high pulp vascularity, tree age, and complex root system. Few research data demonstrates that when NPs come into contact with heavy metals, they might affect the plant mineral absorption which reduces the plant nutritive value (Campanale et al., 2022). MP and NP abundance in soil also alters microbial population and raises the MP- and NP-favored microbes (Azeem et al., 2021).

So what type of solution has to be expected to prevent the abovementioned issues? To relieve from these problems, biodegradable plastics are the right option. Nowadays mulches are designed in such a way that at the end of harvest season, after being tilled into soil, they are biodegraded and the marked period of time to complete mineralization by microbes is less than 2 years (Douglas Hayes, 2019). Bioplastics are partially or completely biodegradable and are classified into totally biological, partially biological, and synthetic. Polycaprolactone (PCL) and polybutylene adipate-co-terephthalate (PBAT) are the major biodegradable fossil-based synthetic plastics. Besides that, biobased plastics like polylactic acid (PLA) and polyhydroxyalkanoic acids are also produced. All these plastics can replace conventional plastics in packaging and agricultural field. Another promising solution to lower the white pollution in soil is to enhance the in situ degradation by mounting the population of bacteria, fungi, and other organisms in soil. Organic compounds also help in degradation of plastic. Knowing the ecological connection of MP and NP fate and their interactions in soil will provide a better picture of threat to human food chain and health (Pathan et al., 2020).

1.3 Outlines of Volume: Sections, Chapters, and Parts

The main purpose of this book is to give a brief introduction on the terrestrial MPs and NPs and its effects mainly on the terrestrial plants which indirectly affect the human population through trophic transfer and how bioremediation can be used to avoid soil contamination due to MPs and NPs.

This book has four sections in total not only pointing out the problems/concerns of MPs and NPs mainly on plants and humans but also providing the solutions on how to clean the already contaminated soil. Part I comprises one to seven chapters. Chapter 1 has two parts. The first part provides an overview of the soil pollution by micro- and nanoplastics and its impact on ecosystem including human health risk. The second part describes the purpose and sections and the contents of this volume. Chapter 2 focuses on the distribution and occurrence of micro- and nanoplastics in different soil systems (urban, industrial, domestic, and agricultural soils) across the world. Likewise, this chapter will provide the latest insights over the global soil burden by micro- and nanoplastics. Chapter 3 provides latest insights over the soil burden of microplastics and nanoplastics in different regions across the world. A special importance will be given to agricultural ecosystems, because these ecosystems are especially likely to be contaminated with microplastics by multiple sources of plastics used in agricultural practice. Chapter 4 provides that microplastic contamination of the terrestrial ecosystem is a priority research area; however, there is no availability of standard methodologies for the quantification of microplastics and nanoplastics separately. This causes misinterpretations in the analysis of soil burden of MPs and NPs. Therefore, this chapter has been designed exclusively to review the literature in the area of emerging methodologies that are useful for the quantification of MPs and NPs in soil. Chapter 5 has been devoted to providing new insights over the persistence of micro- and nanoparticles in the soil system. This includes interactions between soil particles and micro-/nanoplastics and the impact of micro- and nanoplastics on soil properties. Chapter 6 addresses the following line: interaction of micro- and nanoplastics with different emerging contaminants (e.g., heavy metals, flame retardants, nanoparticles, PFOS, PFOAs, etc.) in the soil system. Thus, this chapter explains how micro- and nanoplastics act as carriers of other pollutants in the soil system and subsequent impact of immobilization of pollutants by micro- and nanoplastics. Chapter 7 is an emerging topic. This chapter provides relevant insights in understanding how micro- and nanoplastics are responsible in making the soil system as a significant reservoir of antibiotic resistance genes. Also, this chapter emphasizes on the spreading of antibiotic resistance genes between different ecosystems and acquisition by pathogens threating human as well as animal health.

Part II comprises one chapter discuss about the trophic transfer of MPs and NPs from root uptake. Chapter 8 describes about the phyto-availability of the micro- and nanoplastics, and factors (both biotic and abiotic) enhance the root uptake of micro- and nanoplastics.

The Part III focuses on all the threats posed to plants and humans in detail. It comprises 9–12 chapters. Chapter 9 provides the details on toxicological effects of different types (qualitatively) of micro- and nanoplastics on microorganisms and flora and fauna in the soil system. Chapter 10 describes toxic effects of MPs and NPs on the environment. Chapter 11 provides information about the effects of micro- and nanoplastics on the stress tolerance in plants and plant growth responses. Chapter 12 aims to provide the deeper insights over the toxic effects of micro- and nanoplastics. In vitro and in vivo experiments using cell cultures and whole animals will be discussed. We are in the opinion that such information aid in the better understanding of micro- and nanoplastics for their cytotoxicity, endocrine disruption propensity, genotoxicity, and carcinogenicity.

The Part IV gives a brief introduction to bioremediation techniques that can be employed in order to bioremediate the soil polluted with MPs and NPs. It comprises 13–17 chapters. Chapter 13 describes different types of plants that exhibit hyperaccumulation of micro- and nanoplastics will be reviewed. Factors that favor the hyperaccumulation will also be covered. This sheds lights on the designing of optimum conditions for the phytoremediation. Chapter 14 which describes potentialities of different bacterial species in the remediation of soils and water contaminated by micro- and nanoplastics will be discussed. Special importance will be given to the diversity in the microbial enzymes that attack these pollutants. Chapter 15 Soil which explains potentialities of different fungal species in the remediation of soils contaminated by micro- and nanoplastics will be discussed. Special importance will be given to the diversity in the microbial enzymes that attack these pollutants. In Chap. 16, a special attention will be paid to recent advances in the remediation of micro- and nanoplastic-polluted sites. Also, some of the recent case studies will be discussed in order to have an idea over the cost analysis for the remediation. Chapter 17 is the concluding chapter of this volume. In this chapter, importance will be given to the main challenges that we are facing in the control or mitigation of micro- and nanoplastics in agricultural soils. Towards the end of the chapter, future guidelines will be suggested.

This book is intended for researchers, scientists, NGOs, authorities, policymakers, and industry professionals in the fields of environmental science, pedology, health science, polymer science, material science, nanotechnology, and hazardous waste management. It will also provide insight into dynamic fields of polymer and health sciences for graduate and postgraduate students.

1.4 Contributors

This volume has been designed with 14 sections having 17 chapters. Overall, the contributors of all 17 chapters are subject experts in their concerned chapters. Professionally contributors are academicians, researchers, and scientists and are geographically belonging to different regions. Overall 54 contributors of 12 countries (Argentina, Algeria, Bangladesh, Canada, Chile, Ecuador, Ethiopia, India, Iran, Nigeria, South Africa, and the USA) have been involved in this volume. We strongly believe that this volume could be a single source of information that provides the latest information regarding micro- and nanoplastics and trophic transfer and remediate the micro- and nanoplastics in soil samples.

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