Micro and Nanoplastics in Soil: Pollution and Remedial Measures

Megha Sharma[1]*, RP Sharma[2] and Dhanbir Singh[3]

[1]M.Sc. Scholar, Department of Soil Science, CSKHPKV, Palampur, HP (India) 176062
[2]Head, Department of Soil Science, CSKHPKV, Palampur, HP (India) 176062
[3]Assistant Soil Chemist, Department of Soil Science, CSKHPKV, Palampur, HP (India) 176062

Corresponding Author
Megha Sharma
Email: meghasharma2501@gmail.com

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ABSTRACT

Micro and nanoplastics have emerged as pervasive pollutants in soil ecosystems posing significant risks to plant, animal and human health. Several studies highlight that agricultural and industrial sources are the largest contributors towards micro and nanoplastics. Their interactions with soil components alter physical, chemical and biological properties ultimately reducing soil fertility and productivity. Additionally, these particles negatively affect plant growth and can enter the food chain raising serious health concerns. The adoption of various remediation strategies such as bioremediation, flocculation and membrane technologies can reduce the presence of these plastics in the environment. A comprehensive approach involving sustainable practices, improved waste management and multidisciplinary approaches are essential for the effective mitigation of micro and nanoplastics.

INTRODUCTION

Soil is a vital natural resource that sustains terrestrial life by supporting plant growth, regulating water flow, and maintaining ecological balance. It plays a crucial role in nutrient cycling, organic matter decomposition, carbon sequestration and providing habitat for diverse microorganisms. However, rapid industrialization, urbanization and intensive agricultural practices have led to the accumulation of various contaminants in soil ecosystems. Among these emerging pollutants, microplastics and nanoplastics have gained significant attention due to their persistence, ubiquity and resistance to natural degradation processes. Microplastics (<5 mm) and nanoplastics (<100 nm) originate from both primary sources (intentionally produced small particles) and secondary sources formed through fragmentation of larger plastic materials under environmental stress such as UV radiation and mechanical abrasion.

Sources and occurrence in soil

Micro and nanoplastics enter soil systems through agricultural practices, including plastic mulching and polymer-coated fertilizers as well as through sewage sludge, compost application, irrigation with contaminated water and atmospheric deposition. Their continuous addition and slow degradation lead to accumulation in agricultural soils. Recent studies have confirmed their presence even in relatively less industrialized regions such as Himachal Pradesh, highlighting their widespread distribution and persistence in diverse environmental conditions (Dhiman *et al*. 2024).

Fate and transport

Once introduced into the soil, micro and nanoplastics undergo complex interactions with soil components such as minerals, organic matter and soil water. Their movement depends on soil texture and porosity allowing them to migrate within the soil profile and sometimes reach deeper layers. Moreover, microplastics act as carriers or “vectors” for other contaminants. They have a high surface area and strong adsorption capacity, allowing them to bind heavy metals, pesticides and organic pollutants. This interaction can alter the mobility, bioavailability, and toxicity of these contaminants, thereby amplifying environmental risks (Ren *et al*. 2026).

Effects on soil properties

The presence of microplastics significantly alters the physical, chemical and biological properties of soil. Physically, they alter soil structure, aggregation and bulk density which can influence aeration, water infiltration and water-holding capacity (Maji and Mistri 2021). Chemically, microplastics may influence soil pH and nutrient dynamics, thereby affecting the availability of essential nutrients such as nitrogen, phosphorus, and potassium. Biologically, their impact is particularly concerning as they disturb soil microbial communities. They can alter microbial diversity, abundance, and activity, thereby affecting key processes such as organic matter decomposition and nutrient mineralization (Ko *et al*. 2023). These changes ultimately reduce soil fertility and overall productivity.

Impact on plant growth

The presence of micro and nanoplastics negatively affects plant growth and development. Studies have shown delayed seed germination, reduced root and shoot growth and lower crop yields. Microplastics can also induce oxidative stress in plants by generating reactive oxygen species, leading to cellular damage. They may reduce chlorophyll content, ultimately affecting photosynthesis and plant productivity. Studies have reported reduced growth and biomass in crops such as cowpea exposed to microplastics (Radharamanan *et al*. 2025).

Furthermore, nanoplastics can accumulate in plant tissues, raising concerns about food safety and the transfer of these particles into the food chain (Lakshmikanthan and Chandrasekaran 2022).

Implications for human health

Micro and nanoplastics present in soil can enter the food chain through plant uptake and contaminated agricultural produce. Due to their extremely small size, nanoplastics can penetrate biological membranes and interact with cellular systems. Research indicates that nanoplastics may cross physiological barriers and undergo transformation within the human body, potentially posing health risks (Monikh *et al*. 2024). Their ability to carry toxic substances such as heavy metals and organic pollutants further increases their potential hazard. Although research is still ongoing, the possible long-term effects on human health still remain a subject of major concern.

Remedial and mitigation measures

According to Roy *et al*. (2022), micro and nanoplastic pollution can be managed through advanced approaches such as bioremediation, where microorganisms degrade plastic particles. Techniques like flocculation help in aggregating microplastics for easier removal, while membrane technology effectively filters them from contaminated systems. Additionally, advanced photo-oxidation processes use light-induced reactions to degrade plastics into less persistent forms. These approaches can help reduce microplastic accumulation in soil systems.

In addition to technological solutions, reducing plastic use, promoting biodegradable alternatives, and improving waste management practices are essential. Sustainable agricultural practices should also be encouraged to minimize plastic inputs into soil.

CONCLUSION

Micro and nanoplastics are ubiquitous pollutants that pose a serious threat to soil health, agricultural productivity, and environmental sustainability. Their persistence and widespread occurrence make them difficult to manage.

Future research should focus on developing standardized detection methods, understanding long-term ecological impacts and studying their interactions with other soil contaminants. A multidisciplinary approach involving scientific research, policy measures and public awareness is essential for addressing this issue. Effective management strategies and sustainable practices will play a crucial role in mitigating microplastic pollution and ensuring long-term soil health and environmental sustainability.

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