



POPULAR SCIENCE ARTICLE

Microplastics in Soil: An Emerging Threat to Soil Health and Food Safety

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Abstract

Microplastic (MP) pollution is emerging as a serious but often overlooked threat to soil health, agricultural productivity, and environmental sustainability. Although attention to plastic pollution research initially focused on aquatic ecosystems, agricultural soils are increasingly recognized as important reservoirs and sinks for MPs. This article synthesizes current knowledge on the sources, occurrence, ecological effects, analytical detection and remediation of microplastics in soil. Agricultural plastic mulch, wastewater irrigation, sewage sludge, contaminated organic amendments, surface runoff and atmospheric deposition are major pathways of MP entry into soils. Once present, MPs can alter aggregation, bulk density, porosity, water-holding capacity, and infiltration, while also influencing nutrient cycling, enzyme activities, microbial communities and soil fauna. Their surface may adsorb heavy metals and organic contaminants, thereby influencing contaminant mobility, plant uptake and potential transfer through food webs. Accurate assessment remains challenging because of the diversity of polymer types, particle sizes and shapes, and the complexity of soil matrices. Fourier-transform infrared (FTIR) spectroscopy, thermal analytical methods and Raman spectroscopy are among the most widely used techniques for MP characterization. Effective plastic-waste management, preventive agricultural practices, analytical standardization, and environmentally compatible remediation strategies are essential for reducing MP contamination and protecting soil ecosystems and food security.

Keywords: Agricultural soil, Microplastics, Nutrient cycling, Remediation, Soil biota, Soil health

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1. Introduction

Microplastics are tiny plastic particles that are smaller than 5 millimetres in size. They originate from the intentional manufacture of small plastic materials and from the fragmentation of larger plastic products under mechanical, thermal, photochemical, and biological weathering (Tian *et al.*, 2022; Surendran *et al.*, 2023). It has become widespread in terrestrial environments, where soils may act both as receiving compartments and as long-term storage reservoirs for plastic particles (Rillig, 2012). Their persistence, small particle size, and diverse polymer composition allow them to interact with soil minerals, organic matter, microorganisms, plant roots, and soil fauna (Tian *et al.*, 2022; Surendran *et al.*, 2023). MPs can also act as physical particles and carriers of other contaminants, making their environmental behaviour particularly complex (Surendran *et al.*, 2023). This dual role makes

their behaviour in soil complex and difficult to predict (Hechmi *et al.*, 2024). Agricultural soils are particularly vulnerable because they receive plastics through cultivation practices, irrigation, amendments, and waste-derived inputs (Kumar *et al.*, 2020).

2. Sources and pathways of microplastics into the soil

Primary MPs are manufactured at small sizes for products such as cosmetics, industrial abrasives, and polymer carriers, whereas secondary MPs form when larger plastic items fragment through ultraviolet radiation, temperature fluctuations, mechanical abrasion, and biological activity (Tian *et al.*, 2022; Surendran *et al.*, 2023). Agricultural soils receive MPs from plastic mulch films, irrigation pipes, polymer-coated fertilizers, wastewater, sewage sludge, compost, biosolids, surface runoff, and atmospheric deposition (Kumar *et al.*, 2020;

mulching is frequently identified as a dominant source of MPs because polyethylene films are widely used and can fragment into particles that remain in the field after harvest (Lwanga *et al.*, 2022; Surendran *et al.*, 2023).

Wastewater irrigation and sewage-sludge application represent additional important pathways. Although wastewater treatment removes part of the MP load, a substantial fraction may be retained in sludge, which can transfer MPs to agricultural land when applied as an amendment (Hechmi *et al.*, 2024). Organic fertilizers, compost, and biosolids may therefore contribute to frequent MP inputs, particularly in intensive agricultural systems (Kumar *et al.*, 2020; Hoang *et al.*, 2024). Once introduced, MPs may be redistributed by tillage, water movement, wind, and biological activity. Ploughing can move particles through the upper soil profile, while bioturbation by earthworms and plant roots may enhance vertical transport (Huerta Lwanga & Santos-Echeandía, 2021; Liu *et al.*, 2025).



Fig. 1. Major sources and pathways of microplastic contamination in agricultural soils.

3. A. Impact of microplastics on soil properties: Impact on Soil Physical Characteristics

Microplastics can influence different soil properties such as soil texture-related behaviour, aggregate stability, bulk density, porosity, water-holding capacity, and saturated hydraulic conductivity (Shi *et al.*, 2024; Wang *et al.*, 2022). The direction and magnitude of these effects depend on polymer type, particle size, shape, concentration, ageing, and soil texture (Feng *et al.*, 2025; Surendran *et al.*, 2023). Microplastics may also alter evapotranspiration, pore-space distribution, and soil structural stability. Such changes can indirectly affect root growth, aeration, and the availability of water and nutrients to crops (Shi *et al.*, 2024; Wang *et al.*, 2022). Therefore, MP impacts on soil physical properties should be evaluated under realistic particle characteristics, application rates, and soil conditions rather than assuming uniform effects (Tian *et al.*, 2022; Araujo *et al.*, 2018).

B. Impact on Soil Chemical Properties and Nutrient Cycling

Microplastics may influence soil pH, cation-exchange capacity, electrical conductivity, nutrient availability, and biochemical processes involved in carbon, nitrogen, and phosphorus cycling (Tian *et al.*, 2022). The magnitude of these effects depends on polymer composition, additives, particle ageing, organic-matter content, soil pH, and microbial activity. For instance, polyethylene tends to lower pH in acidic soils and raise it in alkaline soils. Their surfaces can provide sites for the adsorption and transport of metals and organic contaminants, potentially modifying their mobility and bioavailability (Violante *et al.*, 2010). Changes in microbial activity and extracellular enzymes may further interfere with nitrogen and phosphorus transformations. These interactions suggest that the effects of MPs should be evaluated not only in terms of their concentration but also in relation to soil type, contaminant load, and nutrient status (Iqbal, 2024).

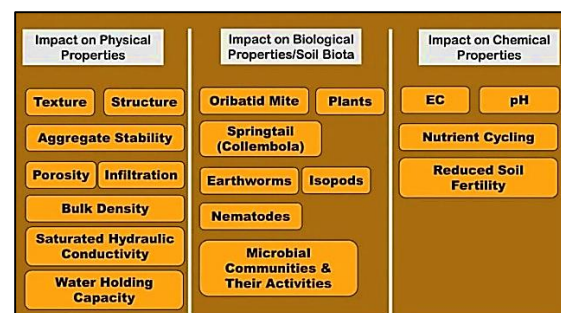


Fig. 2. Impacts of microplastics on soil health, illustrating their effects on soil physical properties, biological properties and soil biota, and chemical properties.

C. Impact on Soil Biological Properties

Microplastics can influence the abundance, diversity, community structure, and activity of soil organisms such as earthworms, springtails, nematodes, and collembolans (Sholokhova *et al.*, 2023). Polymer identity significantly influences the compositional and functional responses of bacterial and fungal communities, with particle size, concentration, and exposure time acting as key modulating parameters (Chen, 2025). The recorded effects include altered movement, reduced growth and reproduction, gut damage, oxidative stress, and changes in microbial associations (Lwanga *et al.*, 2022; Selonon *et al.*, 2023; Wang *et al.*, 2022). In earthworms, toxicity may involve histopathological damage, oxidative stress, and the transport of adsorbed pollutants (Selonon *et al.*, 2023). The use of low-density polyethylene in soil can change the number of microarthropods and nematodes. When earthworms consume microplastics, these materials can move up the food chain.

Earthworms can ingest, break down, and carry microplastics from the top layers of soil down into deeper layers, reaching groundwater and causing contamination (Singh and Bhagwat, 2022; Liu *et al.*, 2025).

D. Effects on Plants and Food Safety

Microplastics may affect plants through changes in soil structure, water availability, nutrient supply, and microbial interactions (Wang *et al.*, 2022). These include altered germination, root growth, photosynthesis, nutrient uptake, biomass accumulation, and yield, although effects differ among species, polymer types, and exposure conditions. MPs may also interact with plant roots and potentially enter plant tissues, although the extent of uptake and translocation remains uncertain and is strongly influenced by particle size and plant species (Kumar *et al.*, 2024). The presence of MPs in edible plant tissues raises concerns about food-chain transfer, but evidence for human-health effects remains limited (Hechmi *et al.*, 2024).

5. Detection and Characterization of MPs

Reliable detection is fundamental for determining MP abundance, polymer composition, particle morphology, and ecological significance. Soil analysis is difficult because MPs occur within heterogeneous matrices containing mineral particles, organic matter, plant residues, and biological materials (Singh *et al.*, 2026; Liu *et al.*, 2025). A typical analytical workflow includes sampling, density separation, digestion of organic matter, filtration, visual sorting, polymer identification, and quality control. Each step can influence particle recovery, contamination risk, and the comparability of results among studies. Spectroscopic techniques are widely used for polymer identification (Tiwari *et al.*, 2020). Raman spectroscopy and Fourier-transform infrared spectroscopy are the most common methods, while near-infrared spectroscopy may be useful for rapid screening under certain conditions (Singh *et al.*, 2026). Thermal analytical methods, including pyrolysis-gas chromatography-mass spectrometry and thermal desorption methods, provide complementary information on polymer composition and mass concentration. Chromatographic and thermal approaches can support polymer identification, particularly when visual identification alone is insufficient. However, method selection should consider the target particle-size range, expected polymer types, soil properties, detection limit, and available instrumentation (Ivleva, 2021). Contamination controls, procedural blanks, recovery tests, and transparent reporting of

particle-size limits are essential for improving reproducibility and enabling meaningful comparisons across studies (Aslam *et al.*, 2026).

5. Mitigation and Remediation Strategies

Microplastic remediation in soil is challenging because MPs are persistent, heterogeneous, and dispersed throughout a complex soil matrix (Abdul Rahman *et al.*, 2026). Complete removal from large agricultural areas is generally impractical; therefore, prevention of further inputs should be the primary management strategy (Huerta Lwanga and Santos-Echeandia 2021; Hechmi *et al.*, 2024).

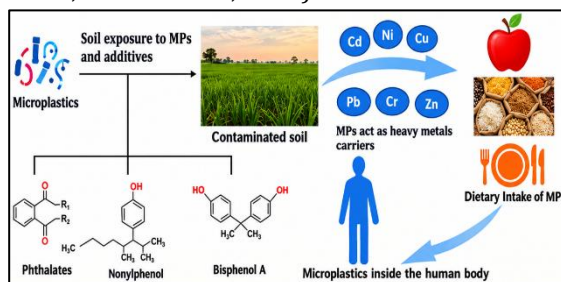


Fig. 3. Pathways of microplastic contamination from agricultural soils to the human body

Filtration, coagulation, sedimentation, activated-carbon adsorption, and membrane-based technologies such as nanofiltration, ultrafiltration, and reverse osmosis are primarily relevant to water and wastewater treatment (Kolya *et al.*, 2023). Their role in agricultural mitigation is to reduce MP inputs before contaminated water or sludge reaches the soil, rather than to remove MPs directly from field soil. Electrochemical treatment has been investigated for MP removal from contaminated semi-urban agricultural soil (Sholokhova *et al.*, 2023). This approach may offer a potential remediation option, but its field-scale feasibility, energy demand, cost, and effects on soil biological and chemical properties require further evaluation (Shivaswamy *et al.*, 2023).

6. Research Gaps and Future Directions

Several research gaps limit current understanding of MP impacts in agricultural soils. First, most studies use short-term experiments, high MP concentrations, or simplified polymer types that may not represent field exposure (Tian *et al.*, 2022; Kumar *et al.*, 2024). Second, the combined effects of MPs with agrochemicals, heavy metals, salinity, drought, and other soil stressors remain insufficiently understood. Third, long-term field studies are needed to determine whether observed changes in soil structure, microbial activity, nutrient cycling, and crop performance persist under realistic agricultural conditions (Kumar *et al.*, 2024; Wang *et al.*, 2022).

7. Conclusion

Microplastic contamination has emerged as a significant environmental concern for agricultural soils because MPs can affect soil structure, water movement, nutrient cycling, microbial communities, soil fauna, and plant performance. Their effects are highly context-dependent and vary with polymer type, particle characteristics, concentration, soil properties, and environmental conditions. Preventing further contamination through improved agricultural plastic management, responsible use of wastewater and amendments, and reduced plastic waste is essential. Biological and physicochemical remediation approaches offer promising research directions, but their effectiveness, scalability, cost, and environmental compatibility must be demonstrated before widespread agricultural application.

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