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http://currentagriculturetrends.vitalbiotech.org/

ISSN (E): 2583 – 1933

Curr. Agri.Tren.:e- Newsletter, (2026) *5*(6), 51-55

Current Agriculture Trends: *e-Newsletter*

Article ID: 654

Microplastics in Agricultural soils: an emerging threat to soil health, crop productivity and food security

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Article History
Received: 09.06.2026
Revised: 14.06.2026
Accepted: 19.06.2026

INTRODUCTION

The global production of plastics has increased dramatically over the last several decades owing to their durability, lightweight nature, versatility and low production cost. Plastic materials are extensively used in agriculture for mulching, greenhouse coverings, irrigation systems, seed coatings and packaging materials (Chia *et al*., 2021). While these applications have significantly improved agricultural productivity, they have contributed to widespread plastic pollution in terrestrial ecosystems.

Microplastics, defined as plastic particles less than 5 mm in diameter, are classified into primary microplastics, which are manufactured at microscopic sizes or secondary microplastics, which are generated through the fragmentation of larger plastic debris (Chia *et al*., 2022). Due to their persistence and resistance to degradation, microplastics have become ubiquitous pollutants detected in oceans, rivers, atmosphere, soils, food products and even human tissues.

Agricultural soils have emerged as major sinks for microplastic contamination due to various agricultural activities, including the use of plastic mulch, biosolids, treated wastewater and polymer-coated agrochemicals, which introduce plastic particles into the soil environment. After entering the soil environment, microplastics can interfere soil properties by altering its physical and biological properties, affecting soil microbial communities, impairing plant growth and potentially enter the food chain through accumulating in crop (Chaudhary *et al*., 2025). The growing concern regarding microplastic pollution has stimulated extensive research into their occurrence, transport, ecological effects and potential risks to human health.

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Sources and occurrence of microplastics in agricultural soils

Agricultural soils receive microplastics from numerous sources, both directly and indirectly. Among these, plastic mulch films represent a major source of microplastics contamination in agricultural soils. Continuous exposure to UV radiation, mechanical abrasion and environmental weathering causes polyethylene mulch films to break down into smaller particles, leading to persistent accumulation of microplastic particles in soils (Qi Y et al., 2018). Sewage sludge applied as organic fertilizer represents another major source of microplastic contamination. Wastewater treatment plants effectively remove a significant proportion of microplastics from wastewater; however these particles become concentrated in sewage sludge, which is often applied to agricultural fields. Consequently, microplastics are continuously introduced into soils through biosolid applications (Dogra et al., 2024).

Wastewater irrigation contributes to soil contamination. Irrigation water derived from rivers lakes or treated wastewater may contain microplastics originating from urban runoff, industrial discharges, textile fibres and household waste. Atmospheric deposition further transports microplastic particles to agricultural lands through wind and precipitation. Additional sources include tire wear particles, compost derived from municipal solid waste, plastic-coated fertilizers, greenhouse films and agricultural packaging materials. Polyethylene, polypropylene, polystyrene, polyethylene terephthalate and polyvinyl chloride are among the most frequently detected polymers in agricultural soils.

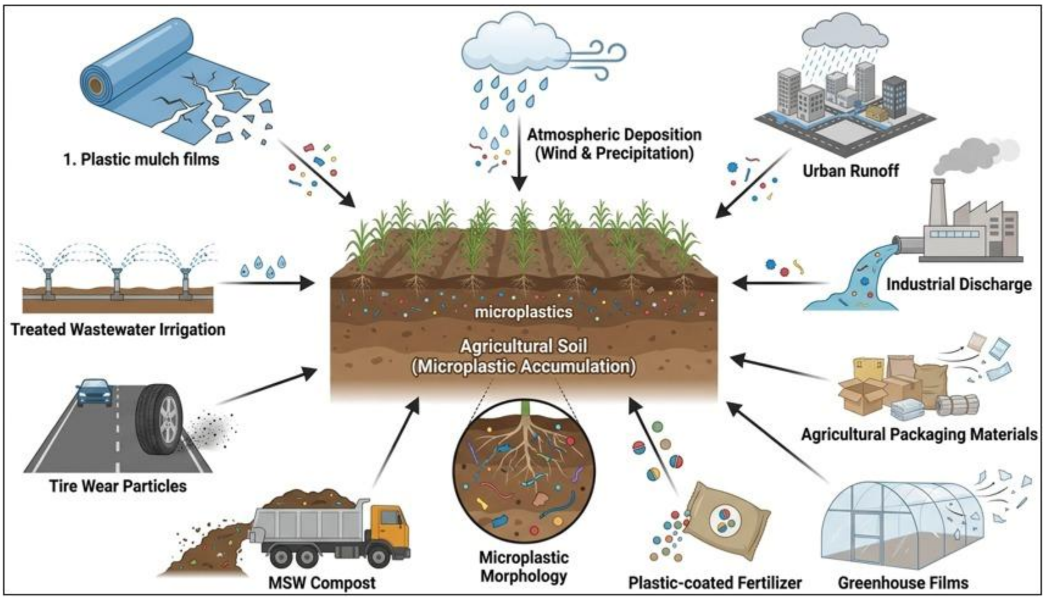

Fig 2: Sources of microplastic pollution in agricultural soils

Effects of microplastics on soil properties and soil biota

Microplastics can substantially alter the physical characteristics of soil. Their accumulation affects important properties such as soil aggregation, porosity, bulk density and water-holding capacity, which are essential for maintaining soil health and productivity. The influence of microplastics on soil physical properties is largely determined by their polymer type, particle size and concentration, their presence may enhance soil porosity and lower bulk density leading to changes in water infiltration and aeration dynamics, which can ultimately affect root architecture and nutrient acquisition by plants (Ihenetu *et al*., 2024). Microplastics may significantly influence soil chemical processes by disrupting nutrient

ISSN (E): 2583 – 1933

cycling and organic matter decomposition. Owing to their large surface area and adsorption capacity, they can bind with heavy metals, pesticides and persistent organic pollutants, facilitating their movement and accumulation in soil.

Microplastics can exert substantial biological impacts on soil ecosystems. Since soil microorganisms play key roles in nutrient cycling, decomposition and the maintenance of soil fertility, any disruption to their communities may adversely affect soil functioning. Exposure to microplastics has been shown to alter microbial diversity, abundance and enzymatic activity. Changes in microbial community composition can disrupt nutrient transformation processes and reduce soil ecosystem functioning. Soil fauna such as earthworms, nematodes, collembolans and arthropods is also adversely affected by microplastics contamination (Hoang *et al*., 2024). Ingestion of microplastics can cause physical damage, reduced feeding activity, impaired reproduction and altered behavior. Earthworms may transfer microplastics vertically through soil profiles, facilitating their retribution within the soil environment. Collectively, these effects compromise soil health, reduce ecosystem resilience and negatively impact agricultural productivity.

Impact of microplastics on plant growth and productivity

Several studies show that that plant roots can absorb microplastic particles and transport them to stems, leaves, fruits and other tissues. Exposure to microplastics negatively impacts seed germination, root growth, root growth, biomass accumulation, and overall plant development. Microplastics can physically block root pores, hindering water and nutrient uptake, which leads to nutrient deficiencies and reduced plant growth. (Jiang *et al*., 2019).

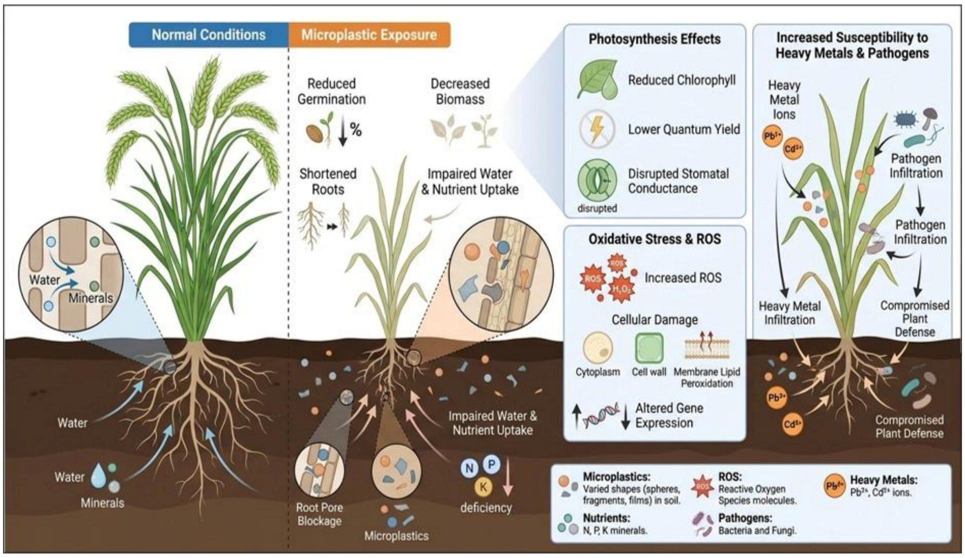

Fig 2: Impact of microplastics on plant growth and productivity

Microplastic pollution also has a detrimental effect on photosynthesis. Photosynthetic pigments are negatively impacted by microplastics by impeding plant's ability to photosynthesize by decreasing the quantum yield. Low chlorophyll content and disruption of stomatal conductance have also been observed in several plant species. Microplastics also induces oxidative stress by stimulating large amount of reactive oxygen species (ROS), leading to cellular damage and membrane lipid peroxidation (Chen *et al*., 2020).

Implication for food safety and human health

One of the most concerning aspects of microplastic contamination is its potential transfer into the food chain. Microplastics can accumulate in edible plant tissues including roots, stems, fruits and leaves. Consumption of contaminated crops may therefore serve as a direct route of human exposure. They also act as carriers for toxic substances, including pesticides, antibiotics and microbial pathogens. Once ingested, these contaminants possess serious health risks. Microplastics exposure to human has been associated with inflammation, oxidative stress, immune dysfunction, endocrine disruption and potential reproductive issues (Atem *et al*., 2024).

Mitigation strategies

Several approaches have been proposed to reduce microplastic contamination in agricultural systems. Improved plastic waste management and recycling programs represents fundamental strategies for minimizing environmental plastic inputs. The development and adoption of biodegradable mulch films offer a promising alternative to conventional plastic mulches. These materials can degrade naturally under environmental conditions, reducing the accumulation of plastic residues in soils. Advanced wastewater treatment technologies capable of removing microplastics can significantly reduce contamination associated with irrigation. Sustainable agricultural practices such as conservation agriculture, organic farming and integrated waste management can contribute to reducing microplastic pollution. Public awareness campaign and policy interventions are also essential for promoting responsible plastic use and disposal.

Future prospects:

Future research goal is to focus on creating standardized methods for the detection, quantification and classification of microplastics in soils and plants. Harmonized protocols will facilitate comparison and improve risk assessment accuracy. Long-term field trials are required to understand the consistency, degradation and ecological impacts of microplastics under realistic agricultural conditions. Research should also investigate the key process of microplastic uptake, translocation and accumulation in various crop species. The development of biodegradable plastics should be prioritized especially bioremediation using microorganisms capable of degrading plastic polymers presents a promising avenue for future research. Additionally, interdisciplinary studies integrating soil science, plant physiology, environmental toxicology and health of the public are critical for comprehensively evaluating the hazards associated with microplastic contamination.

CONCLUSION

Microplastic contamination has emerged as a major threat to agricultural sustainability, soil health, crop productivity and food security. Agricultural soils receive microplastics from more than one sources which includes plastic mulches, sewage sludge and wastewater irrigation. Once present in soil, microplastics change physical, chemical and biological characteristics, adversely affecting soil flora and fauna as well as ecosystem functioning. Microplastics impair plant growth, reduce crop productivity and, thereby creating potential risks to human health through food chain transfer. While mitigation strategies such as biodegradable plastics, improved waste management and advanced wastewater treatment hold promise, substantial research gaps still remain. Addressing microplastic pollution requires coordinated efforts among researchers, policymakers, agricultural stakeholders and industries. Sustainable management strategies and continued scientific investigation are essential to protect agricultural ecosystems and ensure future food security.

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