AGRICULTURE BULLETIN
ISSN: 3049-2289

Microplastic in Agricultural Soil: Understanding the Entry Pathways

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Introduction

Plastics are widely used in everyday life today due to their affordability and durability. According to the latest data from Plastic Europe, global plastic production reached 413.8 million tonnes in 2023 (**Plastics Europe, 2024**). Unfortunately, only a small fraction of this plastic is recycled. Improper disposal has led to the accumulation of over 4.9 billion tonnes of plastic waste in the environment (**Geyer *et al.,* 2017**). Contamination from plastics, particularly in the microplastic (MPs) size range (1 µm–5 mm), has become a significant environmental issue for the biosphere and a growing global concern. While the presence of MPs in marine environments has received considerable attention, recent studies suggest that terrestrial systems, especially soils, may contain even higher concentrations of MPs (**Rillig *et al.,* 2017**; **Machado *et al.,* 2018**). This pollution in terrestrial environments is particularly alarming due to its direct impacts on food production, soil biodiversity, and the potential for MPs to enter the food web through crops. Smaller MPs particles in soil, especially those with high bioavailability, are more likely to be ingested and absorbed by animals and plants.

This article focuses on the pathways through which MPs, primarily polyethylene (PE), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polypropylene (PP), and polystyrene (PS), enter soil systems. MPs can infiltrate various environmental compartments through multiple pathways, which can be broadly categorized into direct and indirect pathways. Understanding these entry points is essential for assessing the environmental fate of MPs, evaluating their ecological risks, and exploring their implications for soil health and food safety (**Rillig & Lehmann, 2020**). MPs also act as carriers for many hydrophobic organic contaminants and heavy metals. The specific pathway (Figure 1) and ultimate fate of plastic particles in soil systems are influenced by a combination of environmental conditions and human activities.

Figure 1: Pathways of microplastic contamination in agriculture soil

1. Direct pathways

These include the application of plastic mulching films, greenhouse coverings, sewage sludge, compost and organic fertilizers, and irrigation with contaminated water. While these practices are beneficial for crop productivity, they inadvertently increase the risk of MPs accumulation in agricultural soils.

- **Plastic mulching films:** Plastic mulching is widely used in agriculture for moisture retention, weed control, and temperature regulation. However, after use, waste plastic residues from these mulching practices often remain in the soil.

These residues gradually degrade into smaller fragments through various physical, chemical, and biological processes in the soil environment, ultimately forming MPs. This transformation occurs due to factors such as ultraviolet (UV) radiation, water and wind erosion, and biological activity including the action of soil fauna like earthworms **(Steinmetz *et al.,* 2016)**. Additionally, photo-oxidative degradation accelerates the fragmentation of plastics into even finer particles. As a result, agriculture has become one of the most heavily impacted sectors in terms of soil MPs contamination.

- **Greenhouse Cover:** Greenhouse coverings, typically made from plastic materials such as polyethylene (PE), polyvinyl chloride (PVC), or polycarbonate (PC), are essential for protecting crops and regulating environmental conditions. Continuous exposure to sunlight, wind, rain, and temperature fluctuations causes the plastic films to degrade through photodegradation and physical wear **(Qi *et al.,* 2020)**. This degradation results in the release of MPs particles into the surrounding soil and air. Additionally, these plastics often contain chemical additives such as plasticizers, UV stabilizers, and flame retardants, which can leach into the environment and pose risks to soil health, plant growth, and even food safety.

- **Sewage Sludge Application:** Sewage sludge is widely applied to agricultural soils across the globe as a fertilizer due to its high content of organic matter and essential macro- and micronutrients, which enhance soil fertility and overall function **(Ramage *et al.,* 2025)**. However, this practice also contributes to the accumulation of MPs in the receiving soils. As the application of sewage sludge is expected to continue, it may lead to a progressive build-up of MPs over time. Nonetheless, MPs are not currently included among the regulated constituents of sewage sludge.

- **Compost and Organic Fertilizers:** In recent years, the application of compost and organic fertilizers has become as a notable pathway for MPs to enter the soil environment. Organic fertilizers, made from composted organic waste, are becoming an important input that helps promote sustainable farming by reusing waste materials **(Li *et al.,* 2024)**. However, a growing concern is the substantial presence of plastics within this process. Numerous studies have reported the widespread detection of MPs in organic fertilizers, highlighting them as a significant and often overlooked contributor to soil MPs contamination.

- **Treated Wastewater Irrigation:** Agricultural sustainability is facing growing challenges due to climate change, water shortage, shrinking farmland, and poor soil health. With clean water becoming less available, many farmers are using treated or untreated wastewater for irrigation because it contains useful nutrients **(Pérez-Reverón *et al.,* 2020)**. However, this water often carries MPs, which are not fully removed by treatment plants. As a result, MPs enter the soil through irrigation and the use of sewage sludge. Over time, this can cause a buildup of MPs in the soil, harming soil quality, crop growth, and long-term farming sustainability.

2. Indirect Pathways

MPs can enter agricultural soils through various indirect routes, primarily influenced by environmental processes involve atmospheric deposition, surface runoff, flooding and soil erosion.

- **Atmospheric Deposition through rainfall:** Rainfall plays a significant role in the atmospheric deposition of MPs onto soil surfaces. As MPs become suspended in the air through wind, human activities, or industrial emissions, they can be carried over long distances **(Dris *et al.,* 2016)**. When it rains, these airborne MPs are captured by raindrops and deposited onto the

ISSN: 3049-2289

ground, including agricultural fields. This process allows microplastics to enter soil ecosystems even in remote or rural areas, far from the original pollution sources. Over time, repeated rainfall events contribute to the accumulation of MPs in the soil, potentially affecting soil structure, fertility, and plant health.

- **Surface runoff: It** plays a significant role as an indirect pathway for the transport and redistribution of MPs into soil environments **(Zhang *et al.,* 2024)**. When rainfall or snowmelt occurs, water flows over land surfaces, collecting and carrying various pollutants, including MPs particles. These MPs originate from urban areas such as tire wear particles, synthetic fibers from washing clothes, plastic debris on roads and rooftops and from industrial zones where plastic pellets or manufacturing residues may be present. As runoff water moves across these surfaces, it picks up MPs and transports them into surrounding environments, including agricultural fields, drainage systems, and natural water bodies.
- **Flooding and soil erosion:** Floods are increasingly recognized as one of the major driving forces in the environmental cycling of plastics. These events intensify the erosion of riverbeds and riverbanks, significantly influencing the re-mobilisation and subsequent deposition of MPs **(Rolf *et al.*, 2022)**. Many studies on erosion have shown that MPs exhibit greater mobility compared to natural river sediments. More recently, research has focused on the role of floods in transporting MPs into floodplains and their eventual incorporation into floodplain soils and agricultural fields.

Conclusion

Microplastic (MPs) contamination in agricultural soils arises through both direct (plastic mulching, sewage sludge, compost) and indirect (atmospheric deposition, runoff, flooding) pathways. These MPs not only persist in soil but also pose risks to soil health, crop productivity, and food safety due to their potential to carry harmful contaminants. Tackling this issue requires better waste management, stricter agricultural regulations, biodegradable alternatives, and continued research to support effective mitigation and ensure sustainable soil and food systems.

Acknowledgement

The authors gratefully acknowledge the financial support received from the National Mission on Himalayan Studies (NMHS) for carrying out this research work under the sanctioned project "Assessment of Microplastic Pollution in the Agricultural Soils of Eastern Himalayan Region of Sikkim State".

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