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Microplastics in Agriculture: A Silent Threat

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Microplastics have emerged as a significant environmental contaminant, infiltrating agricultural systems through plastic mulching, sewage sludge application, irrigation water, and atmospheric deposition. Due to their small size and persistence, microplastics accumulate in soil, altering its physical and chemical properties and disrupting soil microbial communities. This contamination can affect soil structure, water retention, and nutrient cycling, ultimately reducing crop productivity and soil health. Recent studies also indicate that microplastics can be taken up by plant roots, potentially entering the food chain and posing risks to human and animal health. Moreover, microplastics may act as carriers for toxic chemicals and pathogens, increasing ecological and health hazards. The silent and long-term nature of microplastic pollution in agriculture makes it a growing concern for food security and sustainability. This review highlights the sources, pathways, impacts, and mitigation strategies for microplastics in agroecosystems, emphasizing the urgent need for research and policy intervention.

Introduction

Microplastics are tiny plastic particles less than 5 millimeters in size, originating from the breakdown of larger plastic debris or produced intentionally as microbeads, fibers, and pellets. Initially, microplastics were mainly studied in aquatic environments, where they were found to contaminate oceans, rivers, and marine organisms. However, in recent years, research has revealed that agricultural soils are becoming a major reservoir of microplastics, which poses a serious threat to terrestrial ecosystems and food security. Unlike marine pollution, microplastic contamination in agriculture is often invisible, yet it is continuously increasing due to the widespread use of plastics in farming practices. Agriculture has become heavily dependent on plastic products such as mulching films, greenhouse covers, irrigation pipes, and packaging materials. These plastics provide benefits such as increased soil moisture, higher crop yields, and reduced weed growth. However, when exposed to sunlight, heat, mechanical stress, and microbial activity, plastic materials break down into smaller particles. Over time, these particles accumulate in soil, where they can persist for decades due to their resistance to natural degradation processes. The issue becomes more serious because agricultural soils act as a long-term sink for microplastics. These particles do not remain isolated but interact with soil components, microorganisms, and plants, leading to changes in soil structure, nutrient availability, and microbial activity. Microplastics also have the potential to act as carriers for toxic substances such as pesticides, heavy metals, and pathogens, increasing the risk of contamination of soil and crops. Furthermore, microplastics can be transported into agricultural systems through multiple pathways. Sewage sludge and organic amendments, commonly used as fertilizers, often contain microplastics that accumulate during wastewater treatment. Irrigation with treated wastewater is another major route of microplastic entry, especially in water-scarce regions. Additionally, microplastics can be deposited through wind and atmospheric transport, which means even fields without plastic use can become contaminated over time. Given that agriculture is directly linked to food production, the presence of microplastics in soil is a matter of global concern. The particles can affect crop growth and may enter plant tissues, posing a potential risk to human health through the food chain. As microplastics continue to accumulate, their effects may become more pronounced, potentially leading to reduced crop productivity and soil degradation. Therefore, microplastic contamination in agriculture is not just an environmental issue; it is also a threat to long-term food security and sustainable development.

Sources and Pathways of Microplastics in Agriculture

The main sources of microplastics in agriculture include plastic mulching films, sewage sludge, irrigation water, and atmospheric deposition. Plastic mulching is widely used to improve soil moisture, increase temperature, and boost crop yields. However, after several seasons of use, these films fragment into small pieces that become mixed with soil during tillage. Research has found that agricultural fields using plastic mulch can contain thousands of microplastic particles per kilogram of soil, which is much higher than in natural soils. Sewage sludge, which is used as organic fertilizer, also contains high levels of microplastics because wastewater treatment plants cannot fully remove these particles. Studies show that application of sewage sludge can increase soil microplastic concentrations dramatically, leading to long-term accumulation. Irrigation water, especially treated wastewater, also carries microplastics. This is a major concern in water-scarce regions where treated wastewater is widely used for irrigation. Atmospheric deposition is another important source. Microplastic particles released from road dust, industrial emissions, and degraded plastic products can be transported by wind and deposited on farmland. Once in the soil, these particles can remain for long periods due to their resistance to natural degradation processes.

Microplastics In Crop Fields

1. Wang *et al.* (2022): Wang et al. (2022) reviewed the presence of microplastics in agricultural soils and reported that croplands are major sinks due to plastic mulching, greenhouse films, and irrigation systems. They emphasized that microplastics alter soil physical properties like porosity and water retention, which can negatively impact crop growth. The study also highlighted that microplastics can adsorb pesticides and heavy metals, increasing their mobility in soil. Overall, Wang et al. concluded that microplastics pose a serious threat to soil health and crop productivity in agricultural systems.

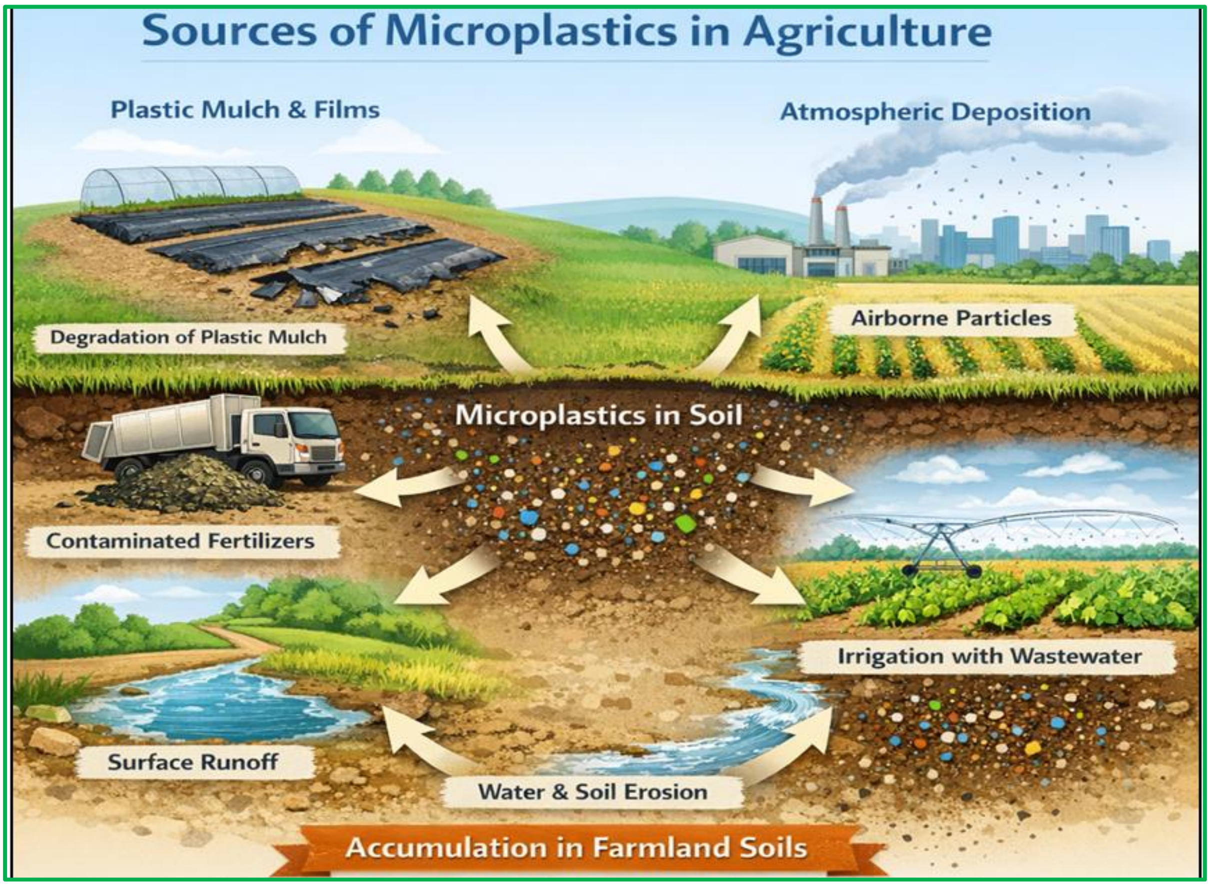
2. Liu *et al.* (2023): Liu et al. (2023) reviewed the pathways of microplastic contamination in croplands and noted that sewage sludge and wastewater irrigation are major contributors. They reported that microplastic particles affect soil microbial communities, reducing beneficial microbes and altering nutrient cycling. The review also discussed that microplastics can influence plant root development and may reduce crop yield under high contamination levels. Liu et al. called for urgent policy measures and better waste management to control microplastic pollution in croplands.

3. Rillig *et al.* (2019): Rillig et al. (2019) reviewed the ecological effects of microplastics in terrestrial ecosystems, including croplands, and pointed out that soil structure and aggregation are significantly affected by microplastic particles. They emphasized that soil organisms such as earthworms and microbes ingest microplastics, which may alter their growth and activity. The review suggested that microplastics can disrupt soil functions essential for crop productivity, including decomposition and nutrient cycling. Rillig et al. highlighted the need for long-term studies to understand the full impact on agricultural soils.

Impact on Soil Health and Function

Microplastics affect soil health by altering soil structure, water dynamics, nutrient cycling, and microbial balance. Soil is a complex living system where tiny organisms like bacteria, fungi, and earthworms interact to maintain fertility. Microplastics disrupt this balance. The physical presence of microplastics changes soil aggregation and porosity. Soil particles bind together to form aggregates, which create spaces for water, air, and root growth.

Microplastics interfere with this process, causing weaker soil structure and reducing the ability of soil to hold water. This can lead to poor soil aeration and reduced water retention, especially in sandy soils. Chemically, microplastics can interact with soil nutrients and pollutants. They may absorb toxic chemicals like pesticides, heavy metals, and organic pollutants, acting as carriers that increase the mobility of these toxic substances. This can lead to increased pollution in soil and plant tissues. Additionally, microplastics may release additives such as plasticizers and stabilizers, which can be harmful to soil organisms and plants.Biologically, microplastics can significantly alter soil microbial communities. Microbes play a key role in decomposing organic matter and releasing nutrients for plant uptake. Studies have shown that microplastics reduce microbial diversity and disrupt the balance of beneficial soil bacteria and fungi. This can negatively affect nutrient cycling and soil fertility over time.



Effects on Plant Growth and Crop Productivity

Microplastics in soil affect plant growth in multiple ways. Microplastic particles can interfere with root growth and function. Roots may become physically blocked or damaged by particles, reducing their ability to absorb water and nutrients. Some research shows reduced root length and weaker root systems in plants grown in microplastic-contaminated soils. There is also evidence that plants can take up microplastics. Tiny particles and nanoplastics may enter root cells through pores or cracks and move into the vascular system. Although this process is still under study, recent research confirms that microplastics can reach plant tissues and may accumulate in leaves, stems, and edible parts. Crop productivity is affected when plants experience stress due to microplastic pollution. Reduced root growth, lower nutrient uptake, and disrupted water balance can lead to decreased biomass, lower yield, and reduced quality of produce. This has major implications for food security, especially in regions where agriculture relies heavily on plastic mulch and wastewater irrigation.

Case Studies on Microplastics in Agriculture

1. Western Greece Fields (Watermelons & Tomatoes): A detailed field investigation in Ilia County (Western Greece) examined microplastic contamination in soils from agricultural lands with long-term cultivation of watermelon and canning tomatoes. Researchers collected soil samples from fields used for more than 10 years and showed that microplastics in soils were directly related to plastic mulch films used in cultivation. The fields growing watermelons, which involved more frequent mulch use, contained about 301 ± 140 microplastic items per kg of soil, more than four times the number found in tomato fields (69 ± 38 items/kg). Uncultivated control sites had no detectable microplastics, clearly showing that agricultural activities contributed to soil contamination.

2. Banana Farmlands in Kerala, India: A study in Kasaragod District, Kerala, India revealed that all sampled banana farmland soils contained microplastics, with concentrations ranging between ≈19 to 319 particles per kg of soil, averaging about 137 particles/kg. Fibres dominated the particle types (72%), followed by fragments and microbeads. Polymer identification showed that polypropylene (70 %) and polyethylene (30 %) were the main materials, suggesting inputs from agricultural plastic use and domestic sources. Ecological risk assessment indicated medium to high risk at the majority of sites, indicating significant contamination from human-related activities.

Mitigation and Future Directions

Controlling microplastic pollution in agriculture requires a combination of technological, policy, and behavioral changes. Reducing the use of single-use plastics and promoting biodegradable alternatives can decrease the primary source of microplastics. Improved recycling and waste management of agricultural plastics are also essential. Upgrading wastewater treatment technology to better remove microplastics can reduce contamination from irrigation water. Farmers should be encouraged to adopt sustainable practices like reduced plastic mulching, better plastic disposal, and use of organic amendments free from microplastic contamination. Research must also focus on understanding microplastic behavior in soil, plant uptake mechanisms, and long-term impacts on crop productivity. Standardized methods for detecting and measuring microplastics in soil and plants are needed to assess the true extent of contamination.

Conclusion

Microplastic pollution in agricultural soils presents a hidden but serious threat to economic sustainability in farming systems. The widespread use of plastic mulching, irrigation pipes, and packaging materials has increased productivity in the short term, but the long-term accumulation of microplastics can reduce soil health, decrease crop yield, and increase the cost of agricultural inputs. Soil contamination disrupts nutrient cycling and microbial balance, leading to lower soil fertility and reduced crop resilience. Additionally, potential microplastic uptake by crops raises food safety concerns, which may impact market demand and consumer trust. As a result, the economic viability of farming could be undermined through reduced productivity, higher remediation costs, and potential loss of market access. Therefore, addressing microplastic contamination through sustainable farming practices, improved waste management, and policy interventions is essential to protect both agricultural productivity and long-term economic stability. Investing in sustainable alternatives now will ensure resilient and profitable farming systems for future generations.

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