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Microplastics in Soil: Assessing Environmental Risks and Remediation Strategies

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SUMMARY

Plastic has become essential in modern society but has led to a concerning rise in waste, with over 350 million tonnes produced yearly. Much of this waste ends up in oceans, comprising 85% of marine debris and posing threats to terrestrial environments as well. Plastic pollution on land not only harms soil quality but also impacts ecosystems and air quality when burned. Without intervention, projections indicate a staggering 12 billion tonnes of plastic waste in landfills by 2050. Microplastics, particles smaller than 5mm, represent a significant portion of this pollution, with estimates suggesting trillions of pieces in oceans. Despite attention on marine contamination, microplastics infiltrating soil, especially in agriculture, pose significant concerns. They enter soil through various sources, including fertilizers, mulches, and wastewater. Efforts to address this issue, such as regulating plastic use and improving waste management, are crucial to prevent further damage to soil health and ecosystems. Failure to act swiftly may have severe consequences for the environment and human well-being.

INTRODUCTION

Plastic, hailed for its versatility and utility, has become an indispensable material in modern society. However, its widespread usage has led to an alarming surge in plastic waste accumulation, with over 350 million tonnes generated annually. A significant portion of this waste finds its way into our oceans, constituting approximately 85% of marine debris, totalling millions of tonnes per year. Yet, the adverse impact of plastic extends beyond marine ecosystems; it poses a grave threat to terrestrial environments as well. On land, plastic waste not only jeopardizes soil quality but also endangers surrounding ecosystems. The burning of plastic waste exacerbates the issue, releasing toxic particles that degrade air quality and pose health risks to organisms. Projections paint a grim picture of the future, with estimates suggesting that over 12 billion tonnes of plastic waste will inundate landfills by 2050 if current consumption patterns persist. Mitigating this impending environmental catastrophe necessitates the implementation of robust waste management systems to curtail plastic leakage into the environment.

Microplastics (MPs), defined as plastic particles smaller than 5mm, represent a significant fraction of this pollution. Coined by Thompson in 2004, the term "microplastics" gained prominence as scientists began to uncover their ubiquitous presence in marine environments. Recent estimates indicate a staggering 15 to 51 trillion individual pieces of MPs in the world's oceans, weighing between 93,000 to 236,000 metric tons. While marine contamination has garnered considerable attention, the infiltration of microplastics into soil ecosystems, particularly agricultural land, remains a pressing concern. Microplastics infiltrate soil through various primary and secondary sources. Primary sources include the application of organic fertilizers, composts, sewage sludge, and the use of plastic mulches in agriculture. Moreover, flooding and irrigation with microplastic-contaminated wastewater further exacerbate soil pollution. Secondary sources stem from the degradation of macroplastics in the environment and leachate from landfills. Packaging, plastic mulches, and sewage sludge emerge as major contributors to microplastic contamination in soil. Studies have revealed that up to 40% of microplastics persist in the effluent discharge of wastewater treatment plants, with a portion infiltrating agricultural soils through irrigation practices. Addressing the menace of microplastics in soil demands concerted efforts from policymakers, industries, and communities. Implementing stringent regulations on plastic usage, enhancing waste management infrastructure, and promoting sustainable agricultural practices are imperative steps toward mitigating this burgeoning environmental crisis. Failure to act swiftly may have far-reaching consequences for soil health, ecosystem integrity, and human well-being.

The sources of microplastics in soil are diverse and can be categorized into primary and secondary sources:

Primary Sources:

- **Application of Organic Fertilizers and Composts**: Organic fertilizers and composts derived from various sources, including agricultural and municipal waste, can contain microplastics. These microplastics may originate from plastic contamination in the waste streams used to produce these fertilizers and composts.
- **Use of Plastic Mulches in Agriculture**: Plastic mulches are commonly used in agriculture to suppress weeds, conserve moisture, and regulate soil temperature. Over time, these plastic mulches can degrade, releasing microplastic particles into the soil.
- **Flooding and Irrigation with Microplastic-Contaminated Wastewater:** Wastewater, particularly from urban areas and industrial processes, can contain microplastics. When this wastewater is used for flooding or irrigation in agricultural practices, it can introduce microplastics into the soil.
- **Atmospheric Deposition:** Microplastics present in the atmosphere can settle onto soil surfaces through deposition. These microplastics may originate from various sources, including airborne plastic particles from industrial processes, vehicle tire wear, and atmospheric transport of microplastics from distant sources.

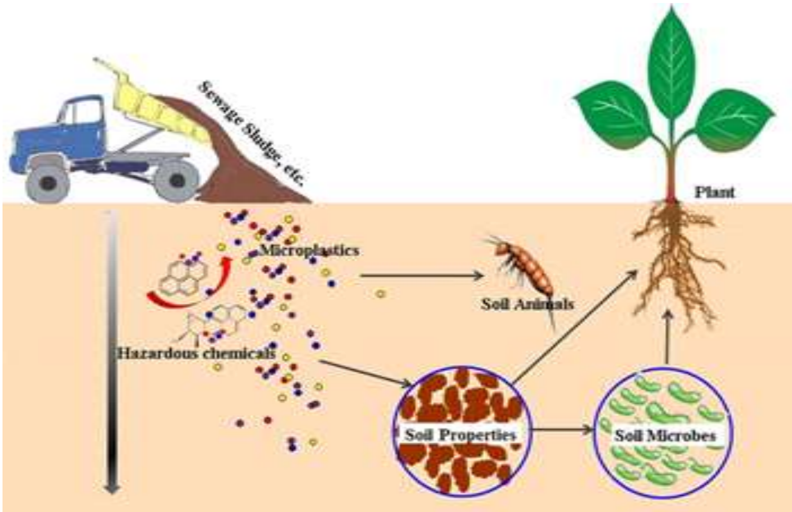
Secondary Sources:

- **Degradation of Macroplastics (Large Plastic Items) in the Environment:** Macroplastics, such as plastic bags, bottles, and packaging materials, can degrade over time due to environmental factors such as UV radiation, temperature fluctuations, and mechanical weathering. This degradation process can result in the fragmentation of macroplastics into smaller microplastic particles that subsequently enter the soil.
- **Leachate from Landfills:** Landfills serve as repositories for large quantities of plastic waste. As plastic waste undergoes decomposition and degradation within landfills, microplastics can leach out into the surrounding soil and groundwater through leachate—a liquid that forms as rainwater percolates through the landfill layers, carrying dissolved and suspended contaminants, including microplastics.

Impacts of microplastics on soil:

- **Physical Properties of Soil:** Microplastics can alter the physical properties of soil by affecting its texture, structure, and water retention capacity. The presence of microplastics can modify soil porosity, potentially impacting root growth, soil aeration, and drainage.
- **Soil Biota and Microbial Communities:** Microplastics can interact with soil organisms, including bacteria, fungi, microarthropods, earthworms, and other invertebrates.
- **Toxicity and Bioaccumulation:** Microplastics can adsorb and accumulate various pollutants, including heavy metals, pesticides, and organic contaminants, from the surrounding environment. These contaminants can leach out from microplastics into the soil, potentially increasing soil toxicity and posing risks to soil organisms. Additionally, microplastics themselves may release additives and plasticizers, which could have toxic effects on soil biota.
- **Plant Uptake and Crop Contamination:** There is emerging evidence suggesting that microplastics can be taken up by plants and translocated to different plant tissues, including roots, stems, leaves, and fruits. This uptake of microplastics by plants raises concerns about potential contamination of agricultural crops and food safety.
- **Soil Erosion and Transport:** Microplastics in soil can be transported through various processes, including erosion by wind and water, runoff, and sediment transport. These microplastics can be transported over long distances, potentially leading to contamination of remote terrestrial and aquatic ecosystems.
- **Human Health Risks**: There is growing concern about the potential human health risks associated with exposure to microplastics in soil. Contaminated soil particles can adhere to crops during cultivation, potentially

leading to human exposure through the consumption of contaminated food. Additionally, airborne microplastics from soil erosion and dust resuspension may be inhaled, raising concerns about respiratory health effects.



Mitigation–remediation measures of microplastic

- Implement measures to reduce the production and consumption of plastic products, including single-use plastics.
- Enhance waste management infrastructure to improve the collection, sorting, recycling, and disposal of plastic waste.
- Enforce regulations and policies aimed at controlling the production, use, and disposal of plastic products.
- Encourage sustainable agricultural practices that minimize the use of plastic mulches, films, and other plastic inputs. Promote alternatives such as biodegradable mulches, organic farming techniques, and precision agriculture methods to reduce microplastic contamination in agricultural soils.
- Soil Remediation Techniques:
- Phytoremediation: Utilize plants to uptake and sequester microplastics from soil. Certain plant species have the ability to absorb and accumulate microplastics in their tissues, which can then be harvested and removed from the soil.
- Biochar Amendment: Apply biochar, a carbon-rich material produced from organic waste through pyrolysis, to soil contaminated with microplastics. Biochar has been shown to adsorb and immobilize microplastics, reducing their bioavailability and potential impacts on soil organisms.
- Soil Washing: Employ soil washing techniques to remove microplastics from contaminated soil. This involves washing the soil with water or environmentally friendly solvents to separate and recover microplastic particles from soil aggregates.
- Bioremediation: Harness microbial degradation processes to break down microplastics in soil. Research is ongoing to develop microbial-based remediation strategies that utilize specialized microorganisms capable of degrading or mineralizing plastic polymers.

CONCLUSION

In conclusion, the pervasive use of plastic in modern society has led to a staggering accumulation of plastic waste, with severe consequences for both marine and terrestrial ecosystems. While plastic pollution is often associated with marine environments, its detrimental impacts extend to soils, posing significant threats to soil health, biodiversity, and human well-being. Microplastics, defined as plastic particles smaller than 5mm, have emerged as a particularly concerning pollutant in soil ecosystems, infiltrating through various primary and secondary sources. Primary sources of microplastics in soil include the application of organic fertilizers, composts, sewage sludge, and the use of plastic mulches in agriculture. Secondary sources include the degradation of macroplastics in the environment and leachate from landfills. Once introduced into soil environments, microplastics can alter soil properties, interact with soil organisms, accumulate toxic pollutants, contaminate crops, and pose risks to human health through exposure pathways. Addressing the menace of microplastics in soil requires coordinated efforts from policymakers, industries, and communities. Therefore, it is imperative to prioritize the implementation of robust control and management strategies to mitigate the burgeoning environmental crisis posed by microplastic pollution in soil environments. By taking proactive measures and fostering collaboration across sectors, we can work towards a more sustainable and resilient future for our planet.

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