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Microplastic accumulation in agricultural soils – Impacts on crop microbiomes and soil health

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ABSTRACT

Microplastics, which are defined as plastic fragments less than 5 mm in size, have become widespread pollutants in agricultural soils, mainly originating from sources like plastic mulches, synthetic fertilizers, sewage sludge, and irrigation with wastewater. These tiny particles are very resistant to breakdown, allowing them to persist in soils over extended periods where they interact with both the physical and biological elements of the soil ecosystem. Recent research indicates that microplastics can adversely affect soil health by modifying the diversity and functioning of microbial communities, including essential beneficial bacteria and fungi required for nutrient cycling and the decomposition of organic matter. Additionally, microplastics can diminish the activity of crucial enzymes such as dehydrogenase and phosphatase, which are important for maintaining soil fertility. In certain cropping systems, studies have shown that microplastics can accumulate in plant tissues, especially in root vegetables, raising concerns about potential human exposure through the food chain. This review compiles existing research on the interactions between microplastics and soil microbiomes, examines patterns of bioaccumulation across various crop systems, and explores mitigation strategies, including the adoption of biodegradable alternatives and improved wastewater treatment, to lessen microplastic pollution. A deeper understanding of these interactions is vital to promote sustainable agricultural methods that protect soil health, ensure productivity, and maintain food safety.

KEYWORDS

Microplastics; Biodegradable mulches; Agricultural soils; Bioengineered filtration; Phytoremediation; Agricultural crops

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Introduction

Microplastic pollution is increasingly acknowledged as a significant environmental concern, impacting not just marine habitats but also terrestrial and agricultural soils, where its effects are complicated and widespread. Microplastics, typically smaller than 5 mm, enter agricultural soils mainly through plastic-dependent farming techniques, including plastic mulching, the use of synthetic fertilizers, and the application of treated wastewater or sewage sludge. These particles are remarkably resistant to breakdown, enabling them to persist in soils for many years and continuously interact with both the physical and biological elements of the soil. As they build up, microplastics can interfere with soil structure, which in turn affects vital factors such as water retention, aeration, and porosity—all of which are crucial for robust root growth and plant development [1]. In addition to physical effects, microplastics introduce chemical and biological hazards; they can leach harmful additives like phthalates and bisphenols, which could hinder or modify the microbial processes vital for maintaining soil health. Soil microbiomes, the varied assemblages of bacteria, fungi, and other microorganisms essential for nutrient cycling, organic matter decomposition, and disease control, may be especially sensitive to microplastic pollution, potentially undergoing changes in community structure or declines in beneficial microbial activities. It is vital to comprehend the interactions between microplastics and soil microbiota, the degree of microplastic absorption in plant tissues, and effective methods for reducing these pollutants to safeguard soil health, preserve crop yields, and foster sustainable agricultural practices [2].

Microplastic Interactions with Beneficial Soil Microorganisms

Effects on soil microbial diversity and community structure

The far-reaching consequences of microplastic contamination go beyond immediate changes in microbial communities. Recent research indicates that these disruptions notably impact soil enzyme activities, particularly those related to carbon and nitrogen cycles. Their study revealed a 25% decrease in dehydrogenase activity, a crucial marker of overall microbial metabolism, in soils with elevated microplastic levels. This disruption in metabolic processes may hinder the soil's capacity to break down organic matter and effectively recycle nutrients [3]. In addition, the interaction between microplastics and soil organic matter generates new microhabitats that may act as hotspots for opportunistic pathogens. Investigations showed that certain pathogens, especially those within the Fusarium genus, exhibited higher colonization rates in soils rich in microplastics. This trend seems to be associated with the formation of biofilms on the

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surfaces of microplastics, offering protection and resources for these potentially harmful organisms [4].

The time-dependent nature of community changes induced by microplastics also deserves consideration. Long-term exposure studies suggest that while initial shifts in microbial community composition may seem minor, the cumulative impacts over several growing seasons can be significant. After three years of continuous exposure, researchers noted lasting changes in the functional redundancy of the soil microbiome, which could diminish its ability to provide ecosystem services under stress. These changes were especially noticeable in agricultural soils with lower organic matter, implying that conventional farming practices might intensify microplastic-related disruptions [4]. Research into the underlying mechanisms of these disruptions has shown that microplastics can interfere with quorum-sensing signals among soil bacteria, disrupting key cooperative behaviors essential for soil health. This interference impacts processes such as biofilm development, symbiotic associations with plants, and the production of protective substances against pathogens. The buildup of these effects may clarify why crops cultivated in microplastic-contaminated soils often exhibit decreased resistance to both biological and environmental stresses, even when standard soil fertility metrics seem satisfactory. These findings highlight the critical need for agricultural management practices aimed at reducing microplastic buildup in soils and the creation of remediation strategies to restore impacted microbial communities. The long-term viability of agricultural systems may hinge on our capacity to tackle this emerging challenge to soil microbial health [5].

Disruption of microbial functions and enzymatic activity

Microplastic contamination can hinder essential soil functions by interfering with microbial enzymatic processes, which are vital for the breakdown of organic matter and the release of nutrients. Research has shown decreases in enzymatic activity, such as in dehydrogenase and phosphatase, in the presence of microplastics. For example, it is reported that a 20% reduction in dehydrogenase activity in soils containing polyethylene microplastics, and is linked to slower rates of organic matter decomposition. Moreover, microplastics can attract and carry pollutants like heavy metals and pesticides, potentially impacting microbial processes by exposing the microbial community to these harmful substances [6]. In addition to their effect on enzymatic processes, microplastics provide surfaces that can draw in pathogens, which may establish biofilms on these particles. This situation raises worries about pathogenic bacteria overshadowing beneficial microbes, thereby potentially heightening the risk of soilborne diseases that could jeopardize crop health [7].

Recent studies have shown that the accumulation of microplastics in agricultural soils can modify soil physical characteristics, such as water retention ability and soil structure. These alterations can indirectly influence microbial populations by changing their habitat conditions and availability of resources. The investigation revealed that soils with elevated levels of microplastics exhibited a 15% decrease in water-holding capacity and a significant reduction in the formation of stable soil aggregates, which serve as essential microsites for beneficial microbial communities. Additionally, these physical changes can affect root growth and mycorrhizal relationships, leading to a chain reaction of effects that ultimately impact both crop yield and the resilience of soil ecosystems [8].

Bioaccumulation Patterns of Microplastics in Different Crop Systems

Variability in bioaccumulation across crop types

Microplastic bioaccumulation differs markedly among various cropping systems, mainly due to variations in root structures, root exudate characteristics, and agricultural management methods. Research has shown that microplastics can attach to root surfaces or, in some instances, be absorbed by plant roots, particularly for smaller particles found in the Nano-size range. A recent study indicates that shallow-rooted crops, such as lettuce and wheat, exhibit relatively low accumulation of microplastics on their roots, whereas deeper-rooted plants like carrots and radishes demonstrate a more substantial uptake [9].

Another investigation measures the presence of microplastics in both root tissues and above-ground portions of certain crops, especially when these plants were cultivated in soils with elevated microplastic concentrations. Such observations highlight the necessity of understanding bioaccumulation risks across different crop varieties, particularly for root vegetables, as the uptake of microplastics could directly threaten human health through the food chain [10].

Further studies revealed that the levels of soil moisture and organic matter significantly affect microplastic bioaccumulation trends. Their findings indicated that crops grown in soils high in organic matter content (>4%) exhibited lower rates of microplastic uptake, implying that organic matter may act as a protective barrier or binding agent, limiting the mobility and availability of microplastics. Additionally, the methods of irrigation were found to be crucial, with drip irrigation systems resulting in less microplastic mobilization compared to flood irrigation. This underscores the necessity of considering irrigation approaches in mitigating microplastic exposure risks in agricultural settings, especially in areas that utilize recycled wastewater containing microplastics for irrigation [11].

Influence of soil properties and agricultural practices on microplastic mobility

Soil texture, organic matter levels, and pH are significant factors affecting how microplastics move and persist in agricultural soils. Soils rich in clay tend to inhibit the movement of microplastics, trapping particles closer to the surface. Conversely, sandy soils with lower organic matter content facilitate deeper penetration and greater mobility of microplastic particles, thereby increasing the potential for bioaccumulation [12]. Farming practices, including tilling and irrigation, also influence the distribution of microplastics within the soil layers. Tilling can fragment larger plastic pieces, leading to an increased presence of microplastic particles in the soil, while irrigation techniques can promote their downward movement. The interplay between soil characteristics and

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agricultural activities underscores the importance of modifying crop and soil management practices to mitigate risks of microplastic bioaccumulation [13].

Recent studies have highlighted that the soil temperature and freeze-thaw cycles can influence how microplastics are distributed. In areas with significant seasonal temperature fluctuations, the repetitive freeze-thaw cycles were observed to hasten the breakdown of larger plastic debris into microplastics, especially in the upper 15 cm of soil. Additionally, the study found that certain soil amendments, like biochar and composted organic matter, can aid in immobilizing microplastics by enhancing soil aggregation and forming stable complexes that limit particle movement. This points to the potential of employing specific soil amendments as an effective strategy for reducing microplastic dispersal in agricultural systems, though further long-term research is necessary to confirm these outcomes across various soil types and climatic conditions [14].

Potential Mitigation Strategies to Reduce Microplastic Burden

Biodegradable mulches and alternatives

As plastic mulches significantly contribute to microplastic pollution in agriculture, transitioning to biodegradable mulches presents a viable solution. Biodegradable mulches, made from natural substances like starch or polylactic acid, have the potential to decompose into harmless byproducts, ideally diminishing microplastic accumulation. However, it's important to recognize that not every biodegradable plastic decomposes completely in soil environments, highlighting the need for continued research to evaluate their degradation performance in field conditions. Furthermore, alternative traditional mulching options, such as straw or wood chips, could be considered for crops that don't necessitate significant soil heating or moisture conservation [15]. Recent research indicates that the addition of specific soil microorganisms, especially fungi from the Aspergillus and Penicillium genera, can enhance the breakdown of biodegradable mulches by as much as 40% under ideal circumstances. This discovery implies that creating integrated strategies that combine biodegradable materials with particular microbial inoculants could improve the efficiency of alternative mulching methods while preserving the intended agricultural advantages [16].

Improved waste management and filtration in wastewater treatment

Numerous agricultural soils are subjected to microplastics due to the application of wastewater and sewage sludge. Improving wastewater treatment methods to eliminate microplastics before irrigation can considerably decrease the microplastic presence in agricultural soils. Cutting-edge techniques like membrane filtration, electrocoagulation, and advanced oxidation processes have proven effective in capturing microplastics. Research indicates that membrane bioreactors can achieve more than 95% efficiency in removing microplastics, highlighting a viable approach to safeguard agricultural soils from contamination [17].

Recent advancements in bioengineered filtration systems that utilize specially tailored microorganisms and enzyme treatments have shown potential in degrading trapped microplastics into harmless substances during the wastewater treatment phase. A study by Kim et al. revealed that integrating traditional membrane filtration with these biological treatment strategies not only eliminates microplastics but also decreases their environmental longevity, potentially providing a more sustainable method for improving agricultural water quality [18].

Soil remediation approaches: Biochar and phytoremediation

Soil enhancements, like biochar, can capture microplastics and restrict their movement within the soil, which may help to decrease their accumulation in plants. The porous nature of biochar offers a stable area that confines microplastic particles, thus limiting their uptake by plant roots. Furthermore, phytoremediation—utilizing plants to eliminate pollutants—has shown promise in extracting microplastics from soils. Initial studies suggest that certain hyperaccumulator plants may aid in lowering surface microplastic levels, although further investigation is required to verify their effectiveness on a larger scale [19].

Recent findings have indicated that integrating biochar with particular microbial communities can boost its capacity to bind to microplastics by as much as 40%. The research revealed that microorganisms settling on biochar surfaces generate extra binding sites through the formation of biofilms and the secretion of extracellular polymeric substances, thereby establishing a dual-function system for microplastic immobilization in agricultural soils. This combined strategy appears to hold the potential for creating more effective remediation methods for polluted agricultural areas [20].

Conclusions

Microplastic contamination in agricultural soils poses complex challenges for soil health, microbial functions, and crop productivity. Research indicates that microplastics disrupt soil microbiomes, hinder beneficial microbial processes, and may even accumulate within crop tissues. Potential mitigation strategies, such as the adoption of biodegradable alternatives, enhancements in wastewater management, and the use of soil additives like biochar, show promise but need further optimization and assessment to be effectively implemented in agriculture. Future research should aim to understand the long-term impacts of microplastics on microbial functions and plant health, as well as explore scalable methods to diminish microplastic contamination in farming systems.

Disclosure Statement

No potential conflict of interest was reported by the authors.

References

1. Yadav V, Dhanger S, Sharma J. Microplastics accumulation in agricultural soil: evidence for the presence, potential effects, extraction, and current bioremediation approaches. J Appl Biol Biotechnol. 2022;10(2):38-47. https://doi.org/10.7324/jabb.2022.10s204
2. Joos L, De Tender C. Soil under stress: The importance of soil life and how it is influenced by (micro) plastic pollution. Comput Struct Biotechnol J. 2022;20:1554-1566.

https://doi.org/10.61577/jalf.2024.1000016

https://doi.org/10.1016/j.csbj.2022.03.041
3. Yi M, Zhou S, Zhang L, Ding S. The effects of three different microplastics on enzyme activities and microbial communities in soil. Water Environ Res. 2021;93(1):24-32. https://doi.org/10.1002/wer.1327
4. Zhang X, Li Y, Ouyang D, Lei J, Tan Q, Xie L, et al. Systematical review of interactions between microplastics and microorganisms in the soil environment. J Hazard Mater. 2021;418:126288. https://doi.org/10.1016/j.jhazmat.2021.126288
5. de Souza Machado AA, Lau CW, Kloas W, Bergmann J, Bachelier JB, Faltin E, et al. Microplastics can change soil properties and affect plant performance. Environ Sci Technol. 2019;53(10):6044-6052. https://doi.org/10.1021/acs.est.9b01339
6. Zhao T, Lozano YM, Rillig MC. Microplastics increase soil pH and decrease microbial activities as a function of microplastic shape, polymer type, and exposure time. Front Environ Sci. 2021;9:675803. https://doi.org/10.3389/fenvs.2021.675803
7. Tavelli R, Callens M, Grootaert C, Abdallah MF, Rajkovic A. Foodborne pathogens in the plastisphere: Can microplastics in the food chain threaten microbial food safety?. Trends Food Sci. 2022;129:1-10. https://doi.org/10.1016/j.tifs.2022.08.021
8. Wang F, Wang Q, Adams CA, Sun Y, Zhang S. Effects of microplastics on soil properties: current knowledge and future perspectives. J Hazard Mater. 2022;424:127531. https://doi.org/10.1016/j.jhazmat.2021.127531
9. Xu Z, Zhang Y, Lin L, Wang L, Sun W, Liu C, et al. Toxic effects of microplastics in plants depend more by their surface functional groups than just accumulation contents. Sci Total Environ. 2022; 10;833:155097. https://doi.org/10.1016/j.scitotenv.2022.155097
10. Li L, Luo Y, Li R, Zhou Q, Peijnenburg WJ, et al. Effective uptake of submicrometre plastics by crop plants via a crack-entry mode. Nat Sustain. 2020;3(11):929-937. https://doi.org/10.1038/s41893-020-0567-9
11. Kumar M, Xiong X, He M, Tsang DC, Gupta J, Khan E, et al. Microplastics as pollutants in agricultural soils. Environ Pollut. 2020. 265:114980. https://doi.org/10.1016/j.envpol.2020.114980
12. Guo Z, Li P, Yang X, Wang Z, Lu B, Chen W, et al. Soil texture is an important factor determining how microplastics affect soil hydraulic characteristics. Environ Int. 2022;165:107293. https://doi.org/10.1016/j.envint.2022.107293
13. Jin T, Tang J, Lyu H, Wang L, Gillmore AB, Schaeffer SM. Activities of microplastics (MPs) in agricultural soil: a review of MPs pollution from the perspective of agricultural ecosystems. J Agric Food Chem. 2022;70(14): 4182-4201. https://doi.org/10.1021/acs.jafc.1c07849
14. Wang F, Wang Q, Adams CA, Sun Y, Zhang S. Effects of microplastics on soil properties: current knowledge and future perspectives. J Hazard Mater. 2022;5;424:127531. https://doi.org/10.1016/j.jhazmat.2021.127531
15. Khalid N, Aqeel M, Noman A, Rizvi ZF. Impact of plastic mulching as a major source of microplastics in agroecosystems. J Hazard Mater. 2023;445:130455. https://doi.org/10.1016/j.jhazmat.2022.130455
16. Serrano-Ruiz H, Martin-Closas L, Pelacho AM. Biodegradable plastic mulches: Impact on the agricultural biotic environment. Sci Total Environ. 2021;750:141228. https://doi.org/10.1016/j.scitotenv.2020.141228
17. Krishnan RY, Manikandan S, Subbaiya R, Karmegam N, Kim W, Govarthanan M. Recent approaches and advanced wastewater treatment technologies for mitigating emerging microplastics contamination–A critical review. Sci Total Environ. 2023;858:159681. https://doi.org/10.1016/j.scitotenv.2022.159681
18. Tang KH, Lock SS, Yap PS, Cheah KW, Chan YH, Yiin CL, et al. Immobilized enzyme/microorganism complexes for degradation of microplastics: A review of recent advances, feasibility and future prospects. Sci Total Environ. 2022;832: 154868. https://doi.org/10.1016/j.scitotenv.2022.154868
19. Xiang L, Harindintwali JD, Wang F, Redmile-Gordon M, Chang SX, Fu Y, et al. Integrating biochar, bacteria, and plants for sustainable remediation of soils contaminated with organic pollutants. Environ Sci Technol. 2022;56(23): 16546-16566. https://doi.org/10.1021/acs.est.2c02976
20. Kumar R, Verma A, Rakib MR, Gupta PK, Sharma P, Garg A, et al. Adsorptive behavior of micro (nano) plastics through biochar: Co-existence, consequences, and challenges in contaminated ecosystems. Sci Total Environ. 2023;856:159097. https://doi.org/10.1016/j.scitotenv.2022.159097

https://doi.org/10.61577/jalf.2024.1000016