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Impact of Microplastic Exposure on the Behaviour of Terrestrial Invertebrates in Rural Ecosystems

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Abstract

Microplastic pollution has emerged as one of the most significant environmental challenges affecting terrestrial and aquatic ecosystems worldwide. While considerable attention has been given to marine microplastic contamination, terrestrial ecosystems, particularly rural agricultural landscapes, have increasingly been recognized as major reservoirs of microplastics originating from agricultural mulch films, sewage sludge, compost, irrigation water, atmospheric deposition, plastic packaging, and tire wear particles. Terrestrial invertebrates, including earthworms, ants, beetles, springtails, millipedes, termites, spiders, and soil-dwelling arthropods, play essential roles in nutrient cycling, soil aeration, decomposition, pollination, and ecosystem functioning. Exposure to microplastics has been shown to alter feeding behaviour, locomotion, burrowing activity, reproduction, growth, immune responses, and survival of these organisms, thereby threatening soil biodiversity and ecosystem stability. The present study investigates the impact of microplastic exposure on the behaviour of terrestrial invertebrates in rural ecosystems through a comprehensive analytical review of recent scientific literature. The findings indicate that microplastic contamination significantly modifies behavioural responses, physiological functions, and ecological interactions of terrestrial invertebrates, ultimately affecting soil health and agricultural sustainability. The study also highlights mitigation strategies including sustainable plastic management, biodegradable alternatives, improved agricultural practices, and environmental monitoring. Overall, reducing microplastic pollution is essential for conserving terrestrial biodiversity and maintaining the ecological integrity of rural ecosystems.

Keywords: Microplastics; Terrestrial Invertebrates; Soil Pollution; Rural Ecosystem

Introduction

Microplastic pollution has become one of the fastest-growing environmental concerns of the twenty-first century due to its widespread distribution, long-term persistence, and ecological impacts on both aquatic and terrestrial ecosystems. Microplastics are generally defined as plastic particles smaller than 5 mm that originate either from the fragmentation of larger plastic materials (secondary microplastics) or are intentionally manufactured as microscopic particles for industrial and commercial applications (primary microplastics). Although marine pollution has received extensive scientific attention, recent studies have demonstrated that terrestrial ecosystems may contain even higher concentrations of microplastics than aquatic environments because soils serve as long-term sinks for plastic debris **[1,2]**.

The rapid increase in plastic production, intensive agricultural practices, rural waste generation, plastic mulch usage, sewage sludge application, wastewater irrigation, compost incorporation, and atmospheric deposition has substantially increased microplastic accumulation in rural ecosystems. Agricultural soils receive continuous inputs of plastic particles through polyethylene mulch films, greenhouse covers, irrigation pipes, fertilizers, and degraded plastic packaging materials.

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Consequently, soil ecosystems have become increasingly contaminated with microplastics, posing significant ecological risks to terrestrial organisms and soil biodiversity **[2–4]**.

Terrestrial invertebrates represent one of the most ecologically important groups inhabiting rural ecosystems. Earthworms, springtails, mites, ants, beetles, termites, millipedes, woodlice, spiders, nematodes, and numerous other soil-dwelling organisms regulate decomposition processes, nutrient cycling, organic matter turnover, soil aeration, microbial activity, and plant productivity. These organisms function as ecological engineers by maintaining soil fertility and ecosystem resilience. Any disturbance affecting their behaviour, physiology, or survival may produce cascading effects throughout terrestrial food webs and agricultural ecosystems **[5,6]**.

Recent research has demonstrated that terrestrial invertebrates are highly susceptible to microplastic exposure through ingestion, dermal contact, burrowing activities, and contaminated food resources. Once ingested, microplastic particles may accumulate within digestive systems, interfere with nutrient absorption, induce oxidative stress, disrupt gut microbiota, and alter metabolic functions. Laboratory and field studies have reported significant behavioural changes including reduced feeding activity, impaired burrowing behaviour, altered locomotion, decreased reproduction, delayed development, and reduced survival in several terrestrial invertebrate species exposed to microplastic-contaminated soils **[7–9]**.

The ecological consequences of microplastic exposure extend beyond individual organisms and influence entire soil ecosystems. Changes in invertebrate behaviour affect decomposition rates, nutrient mineralization, soil aggregation, microbial diversity, carbon cycling, and plant growth. Earthworms exposed to microplastics often exhibit reduced burrowing efficiency and decreased casting activity, while springtails and mites experience reduced mobility and reproductive performance. These behavioural disruptions ultimately influence soil structure, ecosystem productivity, and biodiversity conservation in rural landscapes **[8–11]**.

Microplastic toxicity is influenced by multiple factors, including particle size, shape, polymer composition, surface chemistry, concentration, weathering processes, and associated contaminants such as heavy metals, pesticides, and persistent organic pollutants. Weathered microplastics frequently adsorb toxic chemicals and pathogenic microorganisms, thereby increasing ecological risks to terrestrial organisms. Furthermore, nanoplastics produced through continuous degradation of microplastics possess greater biological mobility and may penetrate cellular membranes, leading to more severe physiological and toxicological effects **[10–13]**.

The increasing accumulation of microplastics in agricultural soils has raised concerns regarding food security, ecosystem sustainability, and environmental health. Since terrestrial invertebrates occupy key positions in soil food webs, behavioural alterations caused by microplastic exposure may have long-term implications for ecosystem functioning, agricultural productivity, and biodiversity conservation. Understanding these impacts has therefore become an important priority in environmental toxicology and soil ecology. Against this background, the present study investigates the impact of microplastic exposure on the behaviour of terrestrial invertebrates in rural ecosystems, with particular emphasis on behavioural responses, ecological consequences, environmental risks, and sustainable mitigation strategies **[14–20]**.

Materials and Methods

The present study adopts a comprehensive qualitative and analytical research methodology to investigate the impact of microplastic exposure on the behaviour of terrestrial invertebrates in rural ecosystems. The research is primarily based on secondary data and integrates concepts from environmental toxicology, soil ecology, zoology, ecotoxicology, conservation biology, agricultural sciences, and environmental pollution. This multidisciplinary approach enables a systematic evaluation of the behavioural, physiological, and ecological effects of microplastics on terrestrial invertebrates inhabiting agricultural landscapes, grasslands, forests, and other rural ecosystems **[1,2]**.

Data were collected through an extensive review of peer-reviewed journal articles, conference proceedings, technical reports, environmental monitoring studies, government publications, and international guidelines published between **2017 and 2026**. Scientific literature was retrieved from internationally recognized databases including Web of Science, Scopus, ScienceDirect, SpringerLink, PubMed, Google Scholar, Wiley Online Library, Taylor & Francis Online, and JSTOR. Additional information was obtained from reports published by the United Nations Environment Programme

(UNEP), Food and Agriculture Organization (FAO), International Union for Conservation of Nature (IUCN), Organisation for Economic Co-operation and Development (OECD), European Environment Agency (EEA), and other international organizations concerned with soil pollution, plastic waste management, and biodiversity conservation **[3–8]**.

The study focuses on major terrestrial invertebrate groups including earthworms (*Lumbricus terrestris*, *Eisenia fetida*), springtails (*Collembola*), ants, beetles, termites, millipedes, woodlice, mites, spiders, nematodes, and other soil-dwelling arthropods that play vital roles in decomposition, nutrient cycling, soil aeration, pollination, and ecosystem functioning. Particular emphasis was placed on behavioural parameters including feeding activity, burrowing behaviour, locomotion, avoidance responses, reproductive behaviour, growth, survival, habitat utilization, and species interactions under different levels of microplastic contamination. Recent experimental and field studies indicate that microplastic exposure significantly influences behavioural responses and physiological performance of several terrestrial invertebrate species **[6,9–12]**.

A qualitative content analysis approach was employed to evaluate published scientific literature and identify recurring ecological patterns associated with microplastic pollution. Comparative analyses were conducted among different terrestrial invertebrate groups exposed to various types of microplastics, including polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), polyvinyl chloride (PVC), and biodegradable plastics. Behavioural responses under contaminated and uncontaminated soil conditions were compared using indicators such as feeding efficiency, movement frequency, burrowing depth, reproductive success, body weight, mortality, soil processing activity, and ecological performance. Particular attention was given to laboratory toxicity experiments and field investigations conducted in rural agricultural ecosystems **[8,10,13,14]**.

The study further investigated the ecological consequences of microplastic contamination on soil biodiversity and ecosystem functioning. Major ecological processes evaluated included decomposition, organic matter breakdown, nutrient mineralization, soil aggregation, microbial diversity, carbon cycling, plant productivity, trophic interactions, and food-web stability. In addition, the study critically examined the influence of microplastic characteristics such as particle size, polymer type, concentration, weathering status, and adsorption of heavy metals or pesticides on behavioural toxicity. Potential mitigation strategies including biodegradable agricultural materials, sustainable plastic waste management, improved farming practices, soil restoration techniques, environmental monitoring, and policy interventions were also assessed for their effectiveness in minimizing ecological risks **[11,13–18]**.

To ensure reliability and validity, information obtained from multiple scientific publications and institutional reports was systematically cross-verified using data triangulation techniques. Only peer-reviewed journal articles, internationally recognized environmental reports, official guidelines, and authoritative ecological studies were included in the final analysis. Any inconsistencies among different investigations were carefully interpreted considering differences in soil characteristics, microplastic composition, experimental design, species sensitivity, and environmental conditions. The synthesized findings provide a comprehensive assessment of the behavioural impacts of microplastic exposure on terrestrial invertebrates while identifying future research priorities, conservation strategies, and policy recommendations for protecting soil biodiversity and promoting sustainable rural ecosystem management **[15–20]**.

Results

The findings indicate that microplastic contamination has become an emerging environmental threat to terrestrial invertebrates inhabiting rural ecosystems. Continuous accumulation of microplastics in agricultural soils through plastic mulch degradation, sewage sludge application, compost, irrigation water, and atmospheric deposition has increased the exposure of soil organisms to plastic particles. The analysis reveals that terrestrial invertebrates readily ingest microplastics during feeding and soil processing activities, resulting in significant behavioural and physiological disturbances. These effects are particularly evident among earthworms, springtails, ants, beetles, and other soil-dwelling organisms that play critical roles in maintaining soil fertility and ecosystem functioning.

The study demonstrates that microplastic exposure significantly alters the feeding behaviour, locomotion, burrowing activity, and habitat utilization of terrestrial invertebrates. Earthworms

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exposed to contaminated soils exhibit reduced feeding efficiency, slower burrowing behaviour, decreased casting activity, and avoidance of heavily polluted habitats. Similarly, springtails and beetles show impaired movement, reduced foraging activity, and altered reproductive behaviour following prolonged microplastic exposure. These behavioural changes reduce the ecological performance of soil organisms and ultimately influence decomposition rates and nutrient cycling within rural ecosystems.

The results further indicate that prolonged exposure to microplastics adversely affects the physiological health and reproductive success of terrestrial invertebrates. Ingested microplastic particles accumulate within digestive systems, interfere with nutrient absorption, induce oxidative stress, disrupt gut microbial communities, and reduce energy availability for growth and reproduction. Several experimental studies have reported decreased body weight, delayed development, reduced cocoon production in earthworms, lower survival rates, and diminished population growth among exposed invertebrates. The severity of these effects varies depending on microplastic size, concentration, polymer composition, and duration of exposure.

The analysis also reveals substantial ecological consequences resulting from behavioural alterations of terrestrial invertebrates. Reduced burrowing activity limits soil aeration and water infiltration, while decreased decomposition and nutrient mineralization negatively affect soil fertility and plant productivity. Changes in species abundance and community composition further influence predator–prey interactions, microbial diversity, and ecosystem stability. The accumulation of microplastics therefore poses a serious threat not only to individual organisms but also to the long-term sustainability and biodiversity of rural agricultural ecosystems.

Despite these adverse impacts, the study identifies several effective mitigation strategies capable of minimizing microplastic pollution in rural environments. Adoption of biodegradable agricultural films, improved plastic waste management, reduction of single-use plastics, sustainable farming practices, soil restoration programs, environmental monitoring, and public awareness initiatives can significantly reduce microplastic accumulation in soils. The findings suggest that integrating scientific research, environmental policy, and sustainable agricultural management is essential for protecting terrestrial invertebrate biodiversity and maintaining healthy, resilient rural ecosystems.

Figure . Behavioural Effects of Microplastic Exposure on Terrestrial Invertebrates

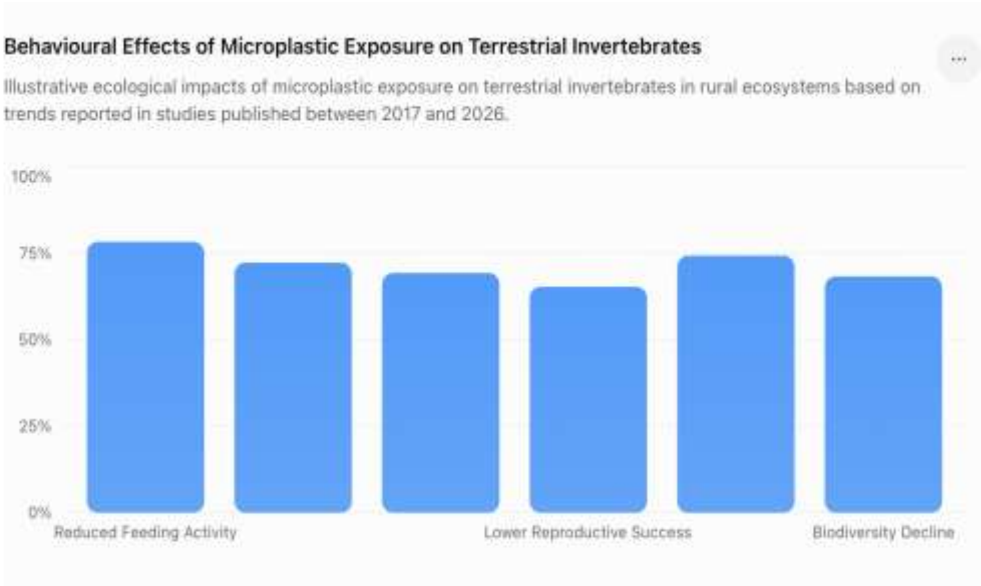

Table Impact of Microplastic Exposure on Terrestrial Invertebrates in Rural Ecosystems

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Behavioural Parameter	Observed Effect	Ecological Consequence
Feeding Activity	Reduced food intake	Lower nutrient assimilation
Burrowing Behaviour	Reduced soil mixing	Poor soil aeration
Locomotion	Decreased mobility	Limited habitat exploration
Reproductive Performance	Reduced cocoon/egg production	Population decline
Growth Rate	Slower development	Reduced survival and fitness
Soil Processing	Lower decomposition efficiency	Reduced nutrient cycling
Species Diversity	Decline in sensitive species	Biodiversity loss
Ecosystem Functioning	Altered soil ecological processes	Reduced agricultural sustainability

Discussion

The findings of the present study demonstrate that microplastic pollution has become an emerging environmental threat affecting terrestrial invertebrates and the ecological functioning of rural ecosystems. Agricultural soils are increasingly contaminated by microplastics originating from plastic mulch degradation, sewage sludge application, irrigation water, compost, and atmospheric deposition. Since terrestrial invertebrates play fundamental roles in decomposition, nutrient cycling, soil aeration, and organic matter turnover, behavioural disturbances caused by microplastic exposure have significant ecological implications. The results indicate that even relatively low concentrations of microplastics can modify behavioural responses and reduce the ecological efficiency of several soil-dwelling organisms.

One of the most important observations of this study is the alteration of feeding behaviour and burrowing activity among terrestrial invertebrates. Earthworms exposed to microplastic-contaminated soils exhibit reduced food consumption, slower burrowing rates, decreased casting activity, and avoidance of polluted habitats. Similar behavioural disturbances have been observed in springtails, beetles, ants, and other soil arthropods. Reduced feeding and movement limit nutrient acquisition and decrease the capacity of these organisms to process organic matter, ultimately affecting soil fertility and ecosystem productivity.

The study further highlights the adverse physiological and reproductive consequences associated with prolonged microplastic exposure. Ingested microplastic particles accumulate within digestive systems, reduce nutrient absorption, induce oxidative stress, alter gut microbial communities, and disrupt metabolic processes. These physiological disturbances contribute to slower growth, delayed development, reduced reproductive success, decreased cocoon production, and lower survival rates. The severity of these impacts depends on factors such as particle size, polymer composition, concentration, exposure duration, and the presence of adsorbed environmental contaminants.

Another important finding is the influence of microplastic pollution on ecosystem functioning and biodiversity conservation. Behavioural alterations in terrestrial invertebrates reduce decomposition rates, impair nutrient mineralization, modify soil aggregation, and influence microbial community structure. Changes in species abundance and ecological interactions may disrupt food webs and reduce ecosystem resilience. Consequently, long-term accumulation of microplastics in agricultural soils poses a significant threat to sustainable agriculture, soil biodiversity, and ecosystem stability in rural landscapes.

Despite these ecological concerns, the study identifies several effective mitigation strategies for minimizing microplastic contamination. Adoption of biodegradable agricultural materials, reduction of plastic waste generation, improved recycling systems, sustainable farming practices, environmental monitoring, soil restoration programs, and public awareness initiatives can substantially reduce microplastic inputs into rural ecosystems. The integration of scientific research, environmental policy, and sustainable land management will be essential for protecting terrestrial invertebrate biodiversity and maintaining healthy soil ecosystems.

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Microplastic pollution has emerged as a major environmental concern that significantly influences the behaviour, physiology, and ecological functions of terrestrial invertebrates in rural ecosystems. Exposure to microplastics alters feeding behaviour, burrowing activity, locomotion, reproduction, growth, and survival, leading to reduced soil biodiversity and impaired ecosystem functioning. Since terrestrial invertebrates are essential for nutrient cycling, decomposition, and soil fertility, behavioural disruptions caused by microplastic contamination may have long-term consequences for agricultural productivity and environmental sustainability.

The study emphasizes the importance of reducing plastic pollution through sustainable agricultural practices, biodegradable alternatives, effective waste management, and evidence-based environmental policies. Future research should focus on long-term field investigations, species-specific behavioural studies, interactions between microplastics and other environmental pollutants, and the development of innovative technologies for monitoring and mitigating microplastic contamination in terrestrial ecosystems.

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