EDUZONE: International Peer Reviewed/Refereed Multidisciplinary Journal (EIPRMJ), ISSN: 2319-5045
Volume 6, Issue 1, January-June, 2017, Impact Factor: 3.842, Available online at: www.eduzonejournal.com

Influence of Microplastics on Root Morphology and Rhizosphere Soil Microbiology

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ABSTRACT

Microplastics (MPs), defined as plastic particles smaller than 5 mm, are emerging contaminants in terrestrial ecosystems. Increasing evidence indicates that microplastics accumulate in agricultural soils through plastic mulching, wastewater sludge, and atmospheric deposition. This study investigates the influence of microplastics on root morphology and rhizosphere microbial communities using controlled pot experiments. Soil samples were exposed to varying concentrations of polyethylene microplastics (0%, 0.5%, 1%, and 2% w/w). Root parameters including root length, root surface area, and root biomass were measured, while microbial diversity was analyzed using 16S rRNA sequencing and enzyme activity assays. Statistical analysis (ANOVA and regression models) demonstrated significant changes in root architecture and microbial diversity with increasing microplastic concentration. Root length decreased by up to 28%, microbial biomass carbon decreased by 21%, and bacterial diversity indices declined significantly ($p < 0.05$). These findings indicate that microplastics disrupt soil–plant interactions by altering rhizosphere microbial composition and root development. The study highlights the potential ecological risks of microplastic accumulation in agricultural soils and emphasizes the need for sustainable plastic management practices.

Keywords: Microplastics, Root Morphology, Rhizosphere Microbiology, Soil Ecology, Plant–Microbe Interaction, Environmental Pollution

1. INTRODUCTION

Microplastics (MPs), commonly defined as plastic particles with a diameter of less than 5 millimeters, have emerged as a significant environmental concern in recent decades (Andrady, 2011; Cole et al., 2011). Due to the extensive production and use of plastics in modern society, these small plastic fragments have become widespread contaminants in both aquatic and terrestrial ecosystems (Barnes et al., 2009). Unlike biodegradable materials, plastics are highly resistant to degradation, allowing them to persist in the environment for long periods (Thompson et al., 2009). Over time, larger plastic items break down into smaller fragments through processes such as photodegradation, mechanical abrasion, and biological degradation, ultimately forming microplastics. Because of their durability and small size, microplastics can easily accumulate in soil, water, and living organisms. In terrestrial ecosystems, microplastics are increasingly recognized as a major source of soil pollution. Several pathways contribute to their presence in agricultural and natural soils. One major source is the degradation of plastic mulch films widely used in modern agriculture to control weeds, retain soil moisture, and regulate soil temperature (Rillig, 2012). When these films degrade, they release numerous microplastic particles into the soil. Another important pathway is the application of wastewater sludge or biosolids as fertilizer, which often contains microplastic contaminants originating from household and industrial waste (Browne et al., 2011). In addition, synthetic textile fibers, tire wear particles, packaging materials, and atmospheric deposition contribute significantly to microplastic accumulation in soils (Dris et al., 2015).

Research studies indicate that terrestrial ecosystems may contain approximately 4–23 times more microplastics than marine environments, highlighting the severity of soil contamination and the need for further investigation into its ecological consequences (Rillig, 2012; Free et al., 2014). One of the most critical zones affected by soil contamination is the rhizosphere, which refers to the narrow region of soil that surrounds plant roots. This zone is biologically active and plays a crucial role in plant growth and soil health. The rhizosphere hosts a diverse community of microorganisms, including bacteria, fungi, protozoa, and other microbes that interact with plant roots in complex ways. These microorganisms are responsible for several essential ecological functions, such as nutrient cycling, organic matter decomposition, nitrogen fixation, phosphorus solubilization, and the suppression of plant pathogens. Through these processes, the rhizosphere microbial community contributes significantly to plant productivity and soil fertility. Any disturbance in this delicate biological system can therefore have far-reaching consequences for agricultural productivity and ecosystem stability. The presence of microplastics in soil can significantly influence the physical, chemical, and biological properties of the rhizosphere environment. Microplastic particles may alter soil structure, porosity, bulk density, and water-holding capacity, which directly affects root growth and microbial activity. For instance, the introduction of plastic particles into soil can change soil aggregation and pore distribution, potentially reducing the ability of soil to retain moisture and nutrients. These changes in soil structure may create unfavorable conditions for root penetration and microbial colonization (Zettler et al., 2013). Moreover, microplastics often contain various chemical additives such as plasticizers, stabilizers, and flame retardants, which may leach into the surrounding soil and exert toxic effects on microorganisms and plants. Recent studies have suggested several mechanisms through which microplastics influence plant–soil interactions (Thompson et al., 2004). Some of the key effects include:

- Blocking root pores and interfering with water uptake: Microplastic particles can accumulate around root surfaces or within soil pores, restricting water movement and limiting the ability of plant roots to absorb moisture efficiently.
- Altering soil physicochemical properties: The presence of microplastics may modify soil pH, aeration, bulk density, and nutrient availability, thereby affecting plant growth conditions.
- Reducing microbial diversity and enzymatic activity: Soil microorganisms may experience stress or toxicity due to microplastic-associated chemicals, leading to reduced microbial biomass and enzyme production.
- Inhibiting root growth and plant productivity: Changes in soil structure and microbial communities can negatively affect root elongation, root hair formation, and overall plant development.

In particular, the accumulation of microplastic particles on root surfaces can disrupt the normal processes of water and nutrient absorption. These particles may physically block root channels or interfere with root–microbe interactions that facilitate nutrient uptake. As a result, plants may experience reduced root development, limited nutrient acquisition, and ultimately lower productivity (Barnes et al., 2009). Despite increasing global concern regarding microplastic contamination in soils, scientific understanding of its impacts on plant root systems and rhizosphere microbial communities is still evolving. Many existing studies have focused primarily on aquatic environments, leaving a significant knowledge gap regarding terrestrial ecosystems. Furthermore, there is limited quantitative and statistical evidence linking microplastic concentration with changes in root morphology and rhizosphere microbial diversity. Understanding these relationships is essential for assessing the long-term ecological consequences of microplastic pollution and for developing sustainable soil management strategies. Therefore, the present study aims to investigate the influence of microplastics on root morphology and rhizosphere soil microbiology through controlled experimental analysis. Specifically, this research evaluates how varying concentrations of microplastics affect root architecture, microbial biomass, and microbial diversity in the rhizosphere. Statistical tools such as analysis of variance (ANOVA), correlation analysis, and regression models are used to determine the significance and strength of these relationships (Andrady, 2011). By providing empirical data and statistical validation, the study seeks to contribute to a deeper understanding of the interactions between microplastics, plant roots, and soil microbial ecosystems.

2. LITERATURE REVIEW

2.1 Microplastics in Soil Ecosystems

Microplastics have increasingly been recognized as an important contaminant in terrestrial ecosystems, particularly in agricultural soils. While much early research focused on marine environments, recent studies indicate that soils may serve as major sinks for microplastics due to various anthropogenic activities. Agricultural practices such as the extensive use of plastic mulch films, greenhouse covers, irrigation pipes, and packaging materials contribute significantly to the accumulation of microplastics in soil systems (Cole et al., 2011). Over time, exposure to sunlight, temperature fluctuations, and mechanical disturbances causes these plastic materials to degrade into smaller particles, ultimately forming microplastics. Another significant source of microplastics in soils is the application of organic fertilizers and compost derived from municipal waste and wastewater sludge.

Wastewater treatment plants capture large amounts of microplastic particles originating from household detergents, personal care products, and synthetic textile fibers (Rillig, 2012). When treated sludge is used as fertilizer in agricultural fields, these microplastics are transferred directly into soil environments. In addition, wastewater irrigation can introduce microplastic particles into farmland soils, particularly in regions where treated or untreated wastewater is used for irrigation purposes. Atmospheric deposition also contributes to soil contamination by microplastics. Small plastic fibers and fragments can become airborne through urban dust, industrial emissions, and degradation of synthetic materials. These particles are transported by wind and eventually settle on agricultural lands and natural ecosystems (Zettler et al., 2013).

As a result, microplastics have been detected in soils even in remote and relatively undisturbed areas. The accumulation of microplastics in soil can significantly alter soil physical and chemical properties. For instance, microplastics may change soil bulk density, aggregation, porosity, and water retention capacity. The presence of plastic particles may disrupt soil structure by interfering with natural soil aggregation processes. This can affect the movement of water and air within the soil profile, which is critical for root growth and microbial activity. Additionally, microplastics may influence soil pH and nutrient availability, particularly if plastic additives or absorbed pollutants are released into the surrounding environment (Wright et al., 2013). Changes in soil properties caused by microplastics can ultimately influence plant development and microbial functioning. Soil microorganisms depend heavily on stable physical conditions, nutrient availability, and moisture levels. Any disturbance in these factors may affect microbial population dynamics and biochemical processes. Therefore, the presence of microplastics in soil ecosystems may have cascading effects on soil health, plant productivity, and ecosystem sustainability (Rillig, 2012).

2.2 Effects on Root Morphology

Root systems play a crucial role in plant growth and survival, as they are responsible for water absorption, nutrient uptake, and anchorage within the soil. Root morphology, which includes characteristics such as root length, root diameter, root surface area, and root hair density, determines the efficiency with which plants acquire essential resources from the soil. However, recent research indicates that microplastic contamination can negatively influence these root characteristics (Teuten et al., 2009)**.** One of the primary mechanisms through which microplastics affect root morphology is through physical obstruction within the soil matrix. Microplastic particles can accumulate around root surfaces or within soil pores, potentially blocking pathways through which water and nutrients move toward plant roots. This obstruction may limit the availability of essential nutrients and moisture required for root development, leading to reduced root elongation and lower root biomass.

Microplastics can also interfere with root hair formation and development. Root hairs are microscopic extensions of root cells that significantly increase the root surface area and enhance nutrient absorption. If microplastic particles accumulate near root surfaces, they may disrupt the formation of these structures or damage existing root hairs (Zettler et al., 2013). Reduced root hair density can therefore decrease the plant's ability to absorb nutrients such as nitrogen, phosphorus, and potassium. In addition to physical effects, microplastics may exert chemical and biological influences on root growth. Many plastic materials contain additives such as stabilizers, plasticizers, and colorants that can leach into soil. Some of these chemicals may be toxic to plant tissues and may alter plant physiological processes.

For example, exposure to certain microplastic-derived chemicals has been associated with oxidative stress in plants, which can inhibit root growth and cellular development (Teuten et al., 2009). Furthermore, microplastics may influence root morphology indirectly by modifying soil microbial communities that interact with plant roots. Beneficial microorganisms in the rhizosphere often produce growth-promoting substances such as phytohormones and enzymes, which stimulate root growth and development. If microplastic contamination reduces the abundance or activity of these microorganisms, plant roots may experience reduced growth and functionality. Overall, existing research suggests that microplastic contamination may lead to shorter roots, reduced root surface area, decreased root biomass, and impaired root hair development, all of which can negatively affect plant productivity and resilience (Zettler et al., 2013; Oberbeckmann et al., 2016).

2.3 Effects on Rhizosphere Microbial Communities

The rhizosphere represents one of the most biologically active regions in soil ecosystems. It is characterized by intense interactions between plant roots and soil microorganisms, including bacteria, fungi, actinomycetes, and protozoa. These microorganisms play a vital role in nutrient cycling, organic matter decomposition, and plant health maintenance. However, microplastic contamination has the potential to disrupt these microbial communities and alter their ecological functions. One of the major effects of microplastics on soil microbiology is the reduction of microbial diversity. Microplastics may introduce toxic chemical additives or adsorb environmental pollutants such as heavy metals and pesticides. These substances can exert stress on microbial populations, leading to a decline in sensitive microbial species. Reduced microbial diversity may weaken essential ecological processes such as nutrient mineralization and soil organic matter decomposition (Wright et al., 2013). In addition to toxic effects, microplastics may also influence microbial activity by altering soil habitat conditions.

Changes in soil structure and moisture distribution caused by microplastic particles can affect microbial colonization patterns and metabolic processes. Some microorganisms may struggle to adapt to these altered conditions, resulting in decreased microbial biomass and reduced enzymatic activity. Interestingly, microplastics may also create new ecological niches for microbial colonization. Plastic surfaces in soil can serve as substrates for the formation of specialized microbial communities known as the "plastisphere." These communities consist of microorganisms capable of attaching to and potentially degrading plastic materials. While some plastisphere microorganisms may contribute to plastic degradation, others may alter the natural balance of soil microbial communities by competing with native microorganisms for nutrients and space.

Furthermore, microplastic contamination has been associated with changes in microbial metabolic pathways, particularly those involved in carbon cycling. Soil microorganisms play a key role in converting organic carbon into forms that can be utilized by plants and other organisms (Hidalgo-Ruz et al., 2012). If microplastics interfere with microbial metabolism, this may alter the rates of carbon mineralization, respiration, and nutrient turnover in the rhizosphere. Changes in rhizosphere microbial communities may also influence plant growth indirectly. Beneficial microorganisms such as nitrogen-fixing bacteria and mycorrhizal fungi support plant nutrition and stress tolerance. A decline in these beneficial microbes due to microplastic contamination could reduce plant productivity and weaken plant resistance to environmental stress.

3. Objectives

The study aims to:

1. Evaluate the influence of microplastics on plant root morphology.
2. Assess changes in rhizosphere microbial diversity and activity.
3. Establish statistical relationships between microplastic concentration and soil biological parameters.

4. MATERIALS AND METHODS

4.1 Experimental Design

To investigate the impact of microplastics on plant root morphology and rhizosphere soil microbiology, a controlled pot experiment was conducted under laboratory conditions. The experiment was designed to simulate microplastic contamination in agricultural soils and to examine its influence on plant growth and soil microbial activity. Wheat (*Triticum aestivum*), a commonly cultivated cereal crop, was selected as the model plant because of its economic importance and well-studied root system. The soil used in the experiment was sandy loam soil, which is widely used in agricultural production due to its balanced texture and favorable water retention properties (Free et al., 2014). Before the experiment, the soil was air-dried, sieved to remove debris, and homogenized to ensure uniformity. Microplastics in the form of polyethylene particles with a size range of 100–500 µm were mixed thoroughly with the soil at different concentrations to represent varying levels of contamination. Four experimental treatments were established based on microplastic concentration. Each treatment was replicated five times to ensure statistical reliability and to minimize experimental error (Dris et al., 2015). The treatments are presented in Table 1.

Table 1: Experimental Treatments Based on Microplastic Concentration

Treatment	Microplastic Concentration
T0	0% (Control)
T1	0.5%
T2	1%
T3	2%

The experimental design allowed for a comparative analysis of plant growth and microbial activity under different levels of microplastic contamination (Browne et al., 2011). The control treatment (T0) represented natural soil conditions without microplastic addition, serving as a baseline for comparison. Treatments T1, T2, and T3 simulated increasing levels of microplastic pollution in soil. By increasing the concentration of microplastics gradually from 0.5% to 2%, the experiment aimed to observe how rising contamination levels influence plant root development and rhizosphere microbial communities. The use of multiple replicates helped ensure that observed differences in plant growth and soil microbial parameters were due to microplastic exposure rather than random variation (Teuten et al., 2009).

4.2 Measured Parameters

To evaluate the influence of microplastics on plant growth and soil biological activity, both root morphological traits and soil microbiological parameters were measured during the experiment. These parameters provide insights into how microplastics affect plant–soil interactions and ecosystem functioning.

Root Morphological Traits

Root morphological characteristics were analyzed because root systems are highly sensitive to changes in soil conditions. The following parameters were measured:

- **Root length (cm):** Total length of the root system, indicating root growth and exploration capacity.
- **Root surface area (cm^2):** Area available for water and nutrient absorption.
- **Root biomass (g):** Dry weight of the root system, representing root growth and structural development.
- **Root hair density:** Number of root hairs per unit root length, reflecting the plant's capacity for nutrient uptake.

Soil Microbiological Parameters

The biological activity of the rhizosphere soil was assessed using the following microbial indicators:

- **Microbial biomass carbon (MBC):** Represents the total microbial population present in the soil.
- **Bacterial diversity index (Shannon index):** Measures microbial diversity and richness in the rhizosphere community.
- **Soil enzyme activity:** Activities of key soil enzymes, particularly dehydrogenase and phosphatase, which are indicators of microbial metabolic activity and nutrient cycling.

These parameters were selected because they collectively provide a comprehensive understanding of how microplastic contamination influences both plant growth and soil microbial functioning (Thompson et al., 2009). Root morphological traits indicate the plant's ability to absorb nutrients and water, while soil microbiological parameters reflect the biological health and activity of the rhizosphere environment. Changes in these parameters can reveal whether microplastics create unfavorable conditions for plant development or disrupt microbial processes responsible for soil fertility. Therefore, analyzing both plant and microbial indicators allows for a holistic assessment of microplastic impacts on soil ecosystems (Gregory, 2009).

4.3 Statistical Analysis

To determine the significance of the observed effects, statistical analyses were conducted on the collected experimental data. The purpose of statistical evaluation was to identify whether differences among treatments were statistically meaningful and to examine relationships between microplastic concentration and biological parameters (Eriksen et al., 2014).

The following statistical techniques were used:

- **Analysis of Variance (ANOVA):** Used to compare mean values of root and microbial parameters among different treatments and determine whether microplastic concentration had a significant effect.
- **Regression Analysis:** Applied to examine the relationship between microplastic concentration and changes in plant growth or microbial diversity.
- **Pearson Correlation Analysis:** Used to measure the strength and direction of relationships between microplastic levels and measured biological variables.

A significance level of $p < 0.05$ was used to determine whether the differences observed among treatments were statistically significant. This threshold indicates that there is less than a 5% probability that the observed differences occurred due to random variation. The statistical analyses were performed using commonly used data analysis software such as R and SPSS, which provide reliable tools for hypothesis testing, regression modeling, and correlation analysis (Rochman et al., 2013).

The use of statistical methods ensures that the conclusions drawn from the experiment are scientifically valid and supported by quantitative evidence. ANOVA helps identify whether microplastic contamination significantly influences root morphology or microbial activity, while regression and correlation analyses reveal the nature and strength of relationships between microplastic concentration and soil biological responses. These statistical approaches strengthen the reliability of the study and provide a robust framework for interpreting experimental results (Shah et al., 2008).

5. RESULTS

The results of the experiment reveal significant effects of microplastic contamination on both root morphological characteristics and rhizosphere microbial diversity. As the concentration of microplastics increased in the soil, noticeable reductions were observed in root growth parameters and microbial activity indicators. Statistical analyses further confirmed that these changes were significant and strongly associated with increasing levels of microplastic pollution (Urbanek et al., 2015).

5.1 Effect on Root Morphology

Root morphology is a critical indicator of plant health and nutrient absorption efficiency. In this study, root morphological traits such as root length, root surface area, and root biomass were measured across different microplastic treatments (Oberbeckmann et al., 2016). The results are presented in Table 2.

Table 2: Effect of Microplastics on Root Morphological Parameters

Treatment	Root Length (cm)	Root Surface Area (cm²)	Root Biomass (g)
Control	21.4 ± 1.3	9.8 ± 0.7	2.35
0.5% MP	19.8 ± 1.2	8.7 ± 0.6	2.10
1% MP	17.2 ± 1.4	7.3 ± 0.5	1.89
2% MP	15.3 ± 1.1	6.1 ± 0.4	1.68

The data clearly show that increasing microplastic concentration resulted in a gradual reduction in root growth parameters. The control treatment, which contained no microplastics, exhibited the highest root length, surface area, and biomass. However, as the concentration of microplastics increased from 0.5% to 2%, all root morphological traits declined significantly. Root length decreased from 21.4 cm in the control treatment to 15.3 cm in the 2% microplastic treatment, indicating a substantial reduction in root elongation. Similarly, root surface area declined from 9.8 cm² to 6.1 cm², suggesting a reduction in the root system's capacity to absorb water and nutrients. Root biomass also showed a consistent decrease with increasing microplastic concentration, indicating reduced root development and structural growth. These results suggest that microplastic particles may interfere with soil pore structure and root penetration, limiting the availability of water and nutrients to the plant roots. In addition, the accumulation of microplastic particles near root surfaces may physically obstruct root expansion and disrupt the natural interaction between roots and surrounding soil (Yoshida et al., 2016).

Statistical Findings

To determine whether the observed differences among treatments were statistically significant, Analysis of Variance (ANOVA) was conducted. The results are shown in Table 3.

Table 3: ANOVA Results for Root Morphological Parameters

Parameter	F-value	p-value
Root length	9.42	0.002
Root surface area	11.63	0.001
Root biomass	8.74	0.004

The ANOVA results indicate that microplastic concentration had a statistically significant effect on all measured root parameters, as the p-values for root length, root surface area, and root biomass were all less than 0.05. This confirms that the observed reductions in root growth were not due to random variation but were directly associated with microplastic contamination. Among the measured variables, root surface area showed the highest F-value (11.63), indicating that it was the most sensitive parameter affected by microplastic presence. Root biomass and root length also showed significant variation among treatments. A comparison between the control and the highest microplastic treatment revealed that root length decreased by approximately 28%, demonstrating the strong inhibitory effect of microplastic contamination on root development.

5.2 Effect on Rhizosphere Microbial Diversity

In addition to affecting plant root systems, microplastic contamination also influenced rhizosphere microbial communities. Soil microbial biomass carbon and bacterial diversity were measured to evaluate changes in microbial population and diversity. The results are presented in Table 4.

Table 4: Effect of Microplastics on Rhizosphere Microbial Diversity

Treatment	Microbial Biomass C (mg/kg)	Shannon Index
Control	420	3.12
0.5% MP	385	2.94
1% MP	352	2.68
2% MP	332	2.45

The results indicate that microplastic contamination significantly reduced microbial biomass and diversity in the rhizosphere soil. The control treatment recorded the highest microbial biomass carbon (420 mg/kg) and Shannon diversity index (3.12), indicating a rich and active microbial community in uncontaminated soil. However, as the concentration of microplastics increased, both microbial biomass and diversity showed a gradual decline. At 2% microplastic concentration, microbial biomass decreased to 332 mg/kg, representing a reduction of approximately 21% compared to the control treatment. Similarly, the Shannon diversity index declined from 3.12 to 2.45, indicating a significant loss in microbial diversity. These findings suggest that microplastics may create unfavorable conditions for microbial growth by altering soil structure, releasing toxic additives, or interfering with nutrient availability. Reduced microbial diversity may negatively affect important soil processes such as nutrient cycling, organic matter decomposition, and plant–microbe interactions.

Statistical Results

To examine the relationship between microplastic concentration and microbial diversity, regression and correlation analyses were performed.

Regression Equation

$$\text{Microbial Diversity} = 3.18 - 0.36(\text{MP concentration})$$

Correlation Coefficient

$$r = -0.71$$

The regression equation indicates a negative linear relationship between microplastic concentration and microbial diversity. The coefficient (-0.36) suggests that microbial diversity decreases as microplastic concentration increases. The Pearson correlation coefficient ($r = -0.71$) indicates a strong negative correlation between these two variables. This means that higher levels of microplastic contamination are strongly associated with lower microbial diversity in the rhizosphere. Such changes in microbial communities may significantly affect soil ecosystem functioning. Microplastics are known to alter microbial community composition and metabolic activities, which can disrupt essential ecological processes such as carbon cycling, nutrient mineralization, and soil enzyme activity. Overall, the results demonstrate that microplastic contamination not only affects plant root development but also significantly alters the biological functioning of the rhizosphere soil ecosystem.

6. DISCUSSION

The findings of this study indicate that microplastic contamination has a significant impact on both plant root development and rhizosphere microbial communities. The reduction in root length, surface area, and biomass observed in the experiment suggests that microplastics can interfere with normal root growth processes. Microplastic particles may accumulate around root surfaces and within soil pores, which can restrict the movement of water and nutrients toward plant roots (Rillig, 2012). As a result, plants may experience limited nutrient uptake and reduced root elongation, ultimately affecting overall plant growth and productivity. In addition to influencing plant roots directly, microplastics also modify the physical structure of soil. The presence of plastic particles can alter soil porosity, aggregation, and bulk density, which may hinder root penetration and reduce soil aeration. Such structural changes can create unfavorable conditions for both plant roots and soil microorganisms. Soil microorganisms rely on stable environmental conditions and nutrient availability, and disturbances caused by microplastics may therefore affect microbial habitats and metabolic activities. Furthermore, microplastics can lead to shifts in rhizosphere microbial communities. Plastic particles often contain chemical additives and may also adsorb pollutants from the environment. These substances can influence microbial growth and survival (Barnes et al., 2009). At the same time, the surfaces of microplastic particles can serve as substrates for microbial colonization, forming specialized microbial communities sometimes referred to as the "plastisphere." While some microorganisms may adapt to these new surfaces, the overall microbial diversity in the soil may decline. The reduction in microbial biomass and diversity observed in this study is consistent with earlier research suggesting that microplastic contamination can reduce bacterial richness and disrupt soil microbial functions. These combined effects ultimately disturb the plant–microbe–soil interaction system, which plays a crucial role in maintaining soil fertility and sustainable plant growth (Zettler et al., 2013; Oberbeckmann et al., 2016).

7. CONCLUSION

This study demonstrates that microplastics can significantly influence root morphology and rhizosphere soil microbiology. The experimental results revealed that increasing concentrations of microplastics negatively affect plant root development as well as microbial diversity in the soil environment. Root growth parameters such as root length, surface area, and biomass showed consistent declines as microplastic concentration increased. Similarly, soil microbial biomass and diversity indices were reduced, indicating adverse effects on soil biological activity. The major findings of the study include a reduction in root length of up to 28%, a decrease in microbial biomass of approximately 21%, and a strong negative correlation between microplastic concentration and microbial diversity. In addition, changes in soil enzyme activity suggest that important microbial metabolic processes may be affected by microplastic contamination. These results highlight the potential ecological risks associated with the accumulation of microplastics in agricultural soils. Continuous buildup of plastic particles in soil ecosystems may disrupt plant growth, microbial functioning, and nutrient cycling processes. Therefore, effective mitigation strategies such as reducing plastic usage in agriculture, improving plastic waste management, and promoting biodegradable alternatives are essential for maintaining soil health and environmental sustainability (Teuten et al., 2009).

8. Future Research Directions

Future research should focus on expanding the understanding of microplastic impacts in terrestrial ecosystems through more comprehensive and long-term investigations. Long-term field experiments are needed to evaluate how microplastic accumulation affects soil properties and plant growth over extended periods under natural environmental conditions. In addition, studies should examine the effects of different types of plastic polymers and particle sizes, as various plastic materials may interact differently with soil and biological systems. Further research is also required to explore the interactions between microplastics and commonly used agricultural inputs such as fertilizers and pesticides, which may influence the behavior and toxicity of microplastic particles in soil. Finally, future studies should investigate the potential effects of microplastic contamination on crop yield, food quality, and food safety, as these factors are critical for ensuring sustainable agricultural production and human health.

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