# Effects of Soil Microplastics on Plant Growth and Soil Health

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**Abstract:** *Microplastics (MPs; <5 mm) are emerging contaminants in terrestrial ecosystems, yet their effects on soil health and plant growth remain poorly understood. This study investigates the impact of polyethylene (PE) and polypropylene (PP) microplastics on soil properties, microbial activity, and the growth of Lactuca sativa (lettuce). Soil was artificially contaminated with MPs at concentrations of 0.5%, 1%, and 2% (w/w). After a 60-day greenhouse experiment, MP-treated soils showed reduced water retention (−15–20%) and microbial biomass (−25%). Lettuce grown in MP-contaminated soil exhibited stunted root growth (−30%) and decreased biomass (−22%). These findings highlight the need for sustainable agricultural practices to mitigate microplastic pollution*

***Keywords:*** *Microplastics, soil contamination, plant physiology, soil microbiology, sustainable agriculture*

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## Introduction

Microplastics (MPs), defined as synthetic polymer particles smaller than 5 mm in size, have emerged as pervasive and persistent environmental pollutants with far-reaching ecological consequences. While initial research efforts predominantly focused on marine ecosystems, recent studies reveal that terrestrial environments receive an estimated 4-23 times greater quantities of MPs than aquatic systems (Horton et al., 2017). This disproportionate contamination stems from multiple anthropogenic pathways, with agricultural soils serving as major sinks for plastic particle accumulation.

Agricultural systems are particularly vulnerable to MP pollution due to several key contamination routes. The widespread use of plastic mulch films in modern agriculture represents a primary source, with studies indicating that conventional polyethylene films can degrade into millions of microplastic particles per hectare within a single growing season (Qi et al., 2020). Additionally, the common practice of applying sewage sludge and compost as soil amendments introduces substantial MP loads, as these materials often contain synthetic fibres from laundry wastewater and fragmented plastic debris (Weithmann et al., 2018). Wastewater irrigation further exacerbates the problem, delivering suspended plastic particles directly to crop root zones (Mahon et al., 2017). The presence of MPs in soil ecosystems induces complex physicochemical and biological alterations. Plastic particles physically disrupt soil structure by interfering with aggregate formation and pore connectivity, which consequently affects water infiltration and retention capacities (Zhang et al., 2022). At the microbial level, MPs create distinct ecological niches that favor certain bacterial taxa while suppressing others, leading to fundamental shifts in community composition and diversity (Seeley et al., 2020). These microbial perturbations have cascading effects on critical biogeochemical processes, including nitrogen fixation, organic matter decomposition, and nutrient mineralization (Rillig et al., 2021).

Perhaps most critically, MPs interfere with soil-plant interactions through multiple mechanisms. The altered soil physical properties can mechanically impede root penetration and development, while the modified microbial communities may disrupt beneficial plant-microbe symbioses (de Souza Machado et al., 2019). Furthermore, MPs can adsorb and subsequently release various organic pollutants and heavy metals, potentially creating localized toxicity hotspots in the rhizosphere (Wang et al., 2022). Emerging evidence suggests that certain crop species may even uptake nano plastics through their root systems, raising concerns about trophic transfer and food chain contamination (Li et al., 2021). These multifaceted impacts occur against a backdrop of rapidly increasing global plastic production, which has grown from 2 million metric tons in 1950 to over 400 million metric tons annually in recent years (Plastics Europe, 2022). With plastic waste management systems failing to keep pace with this exponential growth, agricultural soils are becoming long-term reservoirs for MP accumulation, with potentially severe consequences for soil health, crop productivity, and ultimately, global food security.

## Materials and Methods

Loamy agricultural soil (pH 6.8, 2.1% organic matter) was used for the experiment. Polyethylene (PE) and polypropylene (PP) microplastic particles (500–1000 µm) were mixed into the soil at concentrations of 0% (control), 0.5%, 1%, and 2% (w/w). Lettuce (*Lactuca sativa*) was chosen as the test plant due to its sensitivity to soil contaminants. The experiment was conducted in a controlled greenhouse (25°C, 16/8 h light/dark cycle) for 60 days.

Soil physical properties, including water-holding capacity (WHC) and bulk density, were measured. Chemical properties such as pH, organic matter content, and NPK levels were analyzed using spectrophotometry. Microbial activity was assessed via $CO_2$ respiration (MicroResp™) and enzyme assays (β-glucosidase, urease). Plant growth was evaluated based on germination rate, root length (measured using ImageJ), shoot biomass (dry weight), chlorophyll content (SPAD meter), and oxidative stress (malondialdehyde assay). Statistical analysis was performed using one-way ANOVA with Tukey's HSD (*p* < 0.05) in R v4.0.

**Results**

The experimental results demonstrated significant alterations in soil properties and plant growth due to microplastic contamination. Soil water-holding capacity showed a concentration-dependent decrease, with reductions of 12% (0.5% MPs), 17% (1% MPs), and 20% (2% MPs) compared to the control ($p < 0.05$). This aligns with findings by Zhang et al. (2022), who reported similar reductions in water retention capacity in MP-contaminated soils, attributing this to disrupted soil pore structure and hydrophobicity of plastic particles.

Nutrient analysis revealed substantial changes in soil chemistry. Available nitrogen decreased by 10%, 13%, and 15% in 0.5%, 1%, and 2% MP treatments respectively, while phosphorus availability was reduced by 8%, 12%, and 18% in the same treatments. These results corroborate studies by Rillig et al. (2021), who found that MPs can adsorb nutrients and alter their bioavailability through surface interactions. The decrease in nutrient availability was particularly pronounced for phosphorus, possibly due to the high affinity of phosphate ions for plastic surfaces (Wang et al., 2023). Microbial activity exhibited a marked decline, with $CO_2$ respiration rates decreasing by 15%, 20%, and 25% in 0.5%, 1%, and 2% MP treatments respectively ($p < 0.01$). Enzyme activities followed similar trends, with β-glucosidase activity reduced by 22% and urease by 18% in the highest MP treatment. These findings support the hypothesis of Lehmann et al. (2022) that MPs create unfavourable microenvironments for soil microbes, potentially through physical barrier effects or chemical toxicity from plastic additives.

Plant growth parameters showed clear responses to MP contamination. While germination rates remained unaffected ($p > 0.05$), root development was significantly impaired, with root length decreasing by 15%, 22%, and 30% in 0.5%, 1%, and 2% MP treatments respectively ($p < 0.05$). Shoot biomass followed similar patterns, with reductions of 10%, 17%, and 22% in the respective treatments. These growth inhibitions were accompanied by physiological stress indicators, including a 40% increase in leaf malondialdehyde (MDA) content and 25% reduction in chlorophyll content in the 2% MP treatment. Similar observations were made by Li et al. (2023), who reported oxidative stress and growth inhibition in various crops exposed to soil MPs.

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**Table Shows the key findings**

| Parameter Measured | Microplastic Concentration | Observed Effect | Statistical Significance |
|---|---|---|---|
| **Soil Water-Holding Capacity** | 0.5% MPs | 12% reduction | $p < 0.05$ |
| | 1% MPs | 17% reduction | $p < 0.05$ |
| | 2% MPs | 20% reduction | $p < 0.05$ |
| **Available Nitrogen** | 0.5% MPs | 10% reduction | - |
| | 1% MPs | 13% reduction | - |
| | 2% MPs | 15% reduction | - |
| **Available Phosphorus** | 0.5% MPs | 8% reduction | - |
| | 1% MPs | 12% reduction | - |
| | 2% MPs | 18% reduction | - |
| **Microbial $CO_2$ Respiration** | 0.5% MPs | 15% reduction | $p < 0.01$ |
| | 1% MPs | 20% reduction | $p < 0.01$ |
| | 2% MPs | 25% reduction | $p < 0.01$ |
| **β-Glucosidase Activity** | 2% MPs | 22% reduction | - |
| **Urease Activity** | 2% MPs | 18% reduction | - |
| **Root Length** | 0.5% MPs | 15% reduction | $p < 0.05$ |

| Parameter Measured | Microplastic Concentration | Observed Effect | Statistical Significance |
|---|---|---|---|
| | 1% MPs | 22% reduction | $p < 0.05$ |
| | 2% MPs | 30% reduction | $p < 0.05$ |
| **Shoot Biomass** | 0.5% MPs | 10% reduction | - |
| | 1% MPs | 17% reduction | - |
| | 2% MPs | 22% reduction | - |
| **Leaf MDA Content** | 2% MPs | 40% increase (oxidative stress) | - |
| **Chlorophyll Content** | 2% MPs | 25% reduction | - |
| **Seed Germination Rate** | All concentrations | No significant effect | $p > 0.05$ |

**Discussion**

The observed alterations in soil physical properties, particularly water retention, can be explained by the fundamental changes' MPs induce in soil structure. As demonstrated by de Souza Machado et al. (2022), plastic particles disrupt the natural soil matrix, creating discontinuous water pathways and increasing water repellence. Our findings of 20% reduction in water-holding capacity at 2% MP concentration substantiate these mechanisms, highlighting the potential for MPs to exacerbate drought stress in agricultural systems, particularly in arid regions (Kumar et al., 2023). The nutrient depletion observed in MP-contaminated soils presents a multifaceted challenge. While direct adsorption of nutrients onto plastic surfaces contributes to reduced availability (Wang et al., 2023), the disruption of microbial communities likely plays an equally important role. The significant decreases in $CO_2$ respiration (25%) and enzyme activities (18-22%) suggest impaired microbial-mediated nutrient cycling, consistent with the "microbial bottleneck" hypothesis proposed by Zhu et al. (2022). This dual mechanism of nutrient immobilization and impaired mineralization could have cascading effects on soil fertility, particularly in intensively managed agricultural systems (Yang et al., 2023). Plant responses to MP stress appear to follow a dose-dependent pattern, with root systems showing particular vulnerability. The 30% reduction in root length at 2% MP concentration supports the "physical impedance" theory (Gao et al., 2023), where plastic particles mechanically obstruct root elongation. However, the concurrent increase in oxidative stress markers (40% MDA increase) suggests that biochemical mechanisms are equally important. As proposed by Jiang et al. (2023), MPs may induce reactive oxygen species (ROS) production through both direct chemical toxicity and indirect nutrient deficiency effects.

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