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# Effects of Microplastics on Agriculture: A Mini-review

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### Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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## ABSTRACT

Microplastics have permeated most, if not all, ecosystems including the terrestrial ones. The presence of microplastics in soil poses concerns on plants and agriculture. Microplastics alter soil biophysical properties including bulk density, water holding capacity and soil microbial interactions with water stable aggregates. The effects of microplastics on soil and plants frequently depend on the types and sizes of microplastics. This mini review presents a concise illustration of the impacts of microplastics on plants and crops. From the review, microplastics alter soil biophysical and chemical characteristics either positively or negatively depending on their types, concentrations, sizes and shapes. It reveals the ability of microplastics to affect enzymatic activities of plants which could lead to genotoxicity and oxidative damage. It unveils endocytosis of microplastics by specific plant cells as well as the uptake of microplastics via root and their accumulation and transport in plants facilitated by transpiration. This review also shows microplastics reduce root growth and seed germination at least transiently while do not seem to alter chlorophyll content. Microplastics were found to not interfere with phytoremediation of metals by the common reeds. This review highlights the need of more studies to confirm the effects of microplastics on crops and plants as the existing studies in this area are limited.

**Keywords:** Microplastics; agriculture; soil; plants; crops.

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## 1. INTRODUCTION

Microplastics present a persistent environmental problem due to their presence in the terrestrial and aquatic ecosystems, and the difficulty in detecting them [1]. Microplastics have been detected in atmospheric fallout indicating their dispersion into and transportation via the air [2]. The increasing uses of plastics as packaging, raw materials and in various consumers' products result in increasing microplastics in the environment. Microplastics can be primary, coming directly from the use of materials or products with microplastics as constituents, or secondary, formed during the breakdown and degradation of larger plastics [1].

Permeation of microplastics into multiple ecosystems raises concerns of their potential toxicity. Studies have shown that microplastics affect aquatic fauna physically, causing blockage of digestive tracts and gills, as well as behaviourally and physiologically through disruption of hormones and enzymes [3]. Ecotoxicity of microplastics is complicated by the ability of microplastics to adsorb an array of chemicals such as polyaromatic hydrocarbons, antibiotics and antimicrobials, thus, concentrating harmful chemicals in aquatic ecosystems [3]. Microplastics also contain various additives and leaching of these chemicals into the aquatic environment could lead to toxicity [3]. In addition, numerous studies on the effects of microplastics on terrestrial ecosystems demonstrated the presence of microplastics in livestock [4] and birds [5], and the ingested microplastics could release additives which are potential endocrine disrupters [6]. Similar to those in the aquatic environment, terrestrial microplastics can be transferred and biomagnified along the food chains. Large amount of microplastics in soil is known to adversely affect soil biophysical properties, including soil biota such as earthworms whose growth and reproduction declined as their guts' microbiomes were disrupted by ingested microplastics [2].

While many studies focus on the impacts of microplastics on fauna, few actually probed their impacts on plants and agriculture. It was found that farmlands contain substantial microplastics because sludge from wastewater and sewage treatment plants is often used as soil additives for agriculture [7]. In fact, wastewater and sewage treatment plants are significant contributors of environmental microplastics

through discharge of effluents and sludge containing microplastics. They concentrate microplastics already present in natural waterbodies through treatment processes and eventually return the microplastics into the environment [1]. Application of sludge for agriculture leads to localized microplastics contamination which subsequently spreads through transportation by runoffs, air and soil biota [8]. There are very few studies that examine how the elevated levels of microplastics in agricultural soil affect the growths of crops and threaten food supply. This mini review, therefore, aims to put together a concise review of the implications of micro plastics in soil on crops and agriculture.

## 2. IMPACTS OF MICROPLASTICS ON SOIL HEALTH

Soil health is frequently associated with soil biophysical and chemical properties that determine plant health. The physical properties of soil encompass its texture and surface area, structure, bulk density, porosity, infiltration rate, available water capacity and depth whereas the biological properties concern the soil organic carbon, microbial biomass as well as soil enzymes and biota. Chemical properties of soil comprise pH, electrical conductivity, cation exchange capacity, nutrient reserves, heavy metals, elemental balance and carbonates [9]. Soil health affects agricultural production. Bacterial diversity as an indicator of soil health was linked to net primary productivity of plants. Trivedi et al. reported positive correlation between bacterial diversity and net primary productivity in the arid regions of Australia [10]. In the Australian continental and temperate zones, relative abundance of bacterial phyla was found to positively correlate with net primary productivity and soil properties [10].

In addition to agricultural intensification which strains soil health hence long-term agricultural productivity, microplastics have been reported to alter soil biophysical properties encompassing bulk density, water holding capacity and soil microbial interactions with water stable aggregates. The effects of microplastics on soil are dependent on types and concentrations of microplastics (6). Polyester fibers were observed to increase water holding capacity of soil to a greater extent than polyethylene fibers with increasing concentrations. Polyester fibers at increasing concentrations also led to larger

decline in soil bulk density compared to polyacrylic and polyethylene microparticles [6]. However, the extents of changes in soil properties are often not proportional where larger effects were elicited at low microplastics concentrations and the increase of effects did not appear to correspond uniformly with the increase of microplastics concentrations [6]. This indicates that microplastics could exert substantial alterations in soil biophysical properties even at low concentrations and the interactions of microplastic particles with soil matters are complex.

Microplastics were observed to change microbial activities and the change correlated to the concentrations of microplastics instead of the types [11]. Another study reported the shape of microplastics could play a role in microbial activities with linear microplastics such as polyacrylic and polyester fibers causing lower microbial activities compared to nonlinear microplastics [6]. As the soil microbial communities affect and are affected by soil aggregation, and microplastics could affect microbial activities which reflect the metabolic rates of the communities, the presence of microplastics may modify soil microbial communities, hence soil aggregation and health [12,13].

Microplastics were also observed to change the nutrient profile of soil. Addition of 28% of microplastics by weight to soil was shown to significantly raise the nutrient contents in soil solution through decomposition of dissolved organic matter [11]. Even at a lower concentration of microplastics (7% w/w), nutrient contents in soil solution were reported to be higher than control after 14 days. The nutrient release was linked to the increased enzymatic activity of phenol oxidase which decomposed high-molecular-weight compounds into low-molecular-weight compounds. Microplastics also enhanced the activity of diacetate hydrolase, indicating higher microbial hydrolysis of soil organic matter [11]. Microplastics addition was thought to increase microbial activity, thus improving bioavailability of soil C, N and P [14]. This was in contrary to the decline in soil microbial carbon, nitrogen, as well as activities of fluorescein diacetate and soil dehydrogenase reported earlier [15].

Different studies have demonstrated different effects of microplastics on soil properties, hence

health and the directions of the effects remain inconclusive as either positive or negative effects have been reported. In addition, the effects are dependents of several factors such as the types, concentrations, sizes and shapes of microplastics. In the following section, the direct impacts of microplastics on plants and crops are further probed.

### **3. IMPACTS OF MICROPLASTICS ON CROPS AND PLANTS**

It has been explained in the previous section that sewage and wastewater treatment sludge captures microplastics. It was reported that approximately 50% of sewage sludge in Europe and North America was eventually applied to farmlands as economic fertilizers, resulting in as much as 870 tons of microplastics per million inhabitants to enter the European agricultural soils. The amount could be higher in countries with higher usage of plastics [8]. The use of agricultural plastic films for mulching also introduces microplastics into soil as the films degrade [16]. There are currently very few studies on how microplastics affect crops. A study showed fluorescent polystyrene nanobeads (< 100 nm) made their ways into tobacco cells via endocytosis [17]. Li et al. demonstrated crops' tissue cultures to uptake and accumulate polystyrene microplastics (0.2  $\mu\text{m}$ ) and implied potential transfer of the microplastics to human through food chain [18]. Moving beyond cellular level, Qi et al. reported potential interference of biodegradable and polyethylene microplastics on wheat's growth and biodegradable microplastics seemed to exert larger negative effects [16]. The study also showed biodegradable microplastics reduced fruit biomass and the presence of earthworm partly negated the negative effects [16]. This study highlighted a new concern for biodegradable plastics which have been advocated as a substitute for conventional plastics to reduce environmental microplastics.

Having known that microplastics alter soil biophysical properties, Rillig et al. added that microplastics could improve penetration of plant roots into soil, soil aeration and root growth via lowering soil bulk density [19]. On the other hand, fragments of plastic films added experimentally to soil gave rise to channels which facilitated water movement and evaporation, hence water loss from soil which might affect plant health [20]. Plant health is also

influenced by alteration in soil microbial communities induced by the presence of microplastics, and the influence is likely to be negative if root symbionts such as mycorrhiza and nitrogen fixers were affected. Slow degradation of microplastics has been linked to microbial immobilization though there is currently a lack of empirical evidence for the immobilization [19]. Besides, microplastics may serve as media which introduce phytotoxic substances into soil, thus adversely affecting plant roots and health [21].

Generally, by altering soil structure and microbial diversity, microplastics could alter plant diversity and community composition [22,23]. Nonetheless, while postulates were made by relating changes in soil biophysical properties to the impacts of microplastics on plants, there are few studies to prove the postulates. Boots et al. found addition of synthetic fiber and biodegradable polylactic acid reduced the shoot height of perennial ryegrass (*Lolium perenne*) but increased its chlorophylls a and b levels (7). Synthetic fiber and biodegradable polyacetic acid also retarded seed germination though the former was linked to an increase in root biomass. Kalcikova et al. studied the effects of increasing concentrations of polyethylene microbeads on duckweed (*Lemna minor*) and revealed the root lengths to have decreased as concentrations increased [24]. The leaves demonstrated 10% growth inhibition compared to less than 8% in

control after a 7-day treatment, indicating an insignificant effect. Similarly, the increasing microbeads concentrations did not alter the levels of chlorophylls a and b significantly [24]. Contrarily, Mateos-Cárdenas et al. revealed adding a concentration of 50,000 polyethylene microplastics/mL of water increased root length of duckweed (*Lemna minor*) between 24 hours and 168 hours after addition though the increase was insignificant compared to control [25]. While the effects on root growth are inconclusive at this juncture, microplastics do not seem to significantly affect photosynthetic capacity of duckweed [24,25].

In a study by Manjate et al., microplastics were reported to not interfere with phytoremediation of metals (the use of plant to remove metal contaminants in soil) by common reeds, scientifically known as *Phragmites australis*, which hyperaccumulated at least 70 times more metals in their root tissues with concentrations up to 1 mg/g of Cu and 70 µg/g of Cd in contaminated media [26,27]. Addition of polyethylene microplastics did not affect the metal concentrations in the root tissues of *Phragmites australis* [26]. Bosker et al. found significant reduction in the germination rate of Cress (*Lepidium sativum*) seeds 8 hours after being exposed to plastic particles of 50, 500 and 4800 nm, and the reduction positively correlated to plastic sizes [28].

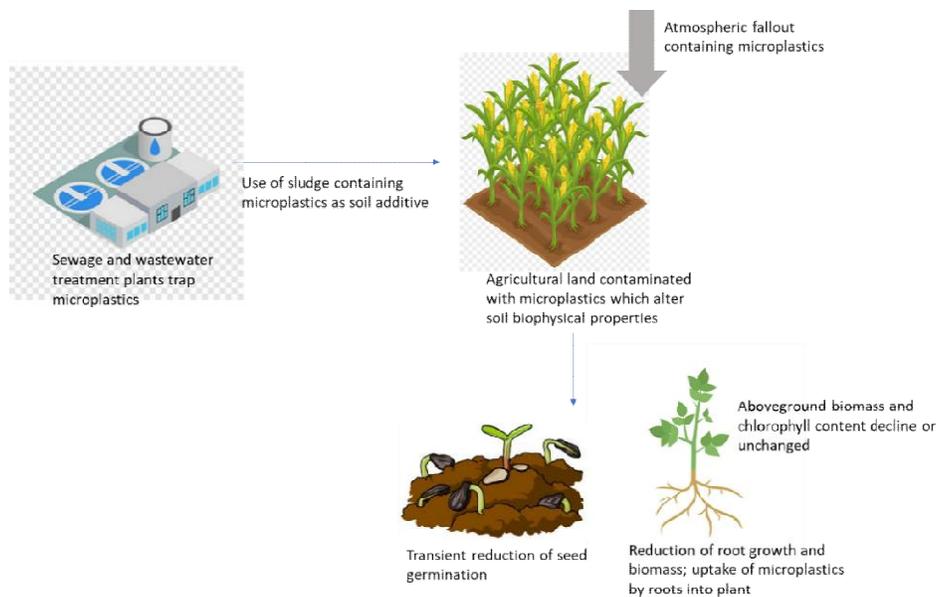


Fig. 1. Sources and impacts of microplastics on soil and plants

**Table 1. Summary of the effects of microplastics on plants**

<b>Plant/ Crop</b>	<b>Types of microplastics</b>	<b>Treatment</b>	<b>Findings</b>	<b>References</b>
<i>Zea mays</i> (maize)	Polyethylene and polylactic acid	Maize grown in soil mixed with 0.1%, 1% and 10% (w/w) microplastics and spiked with 5 mg Cd/kg soil.	Biomass and leaf chlorophyll content of maize decreased after exposure to 10% polylactic acid but phytotoxicity of polyethylene was insignificant. Polyethylene and cadmium interacted significantly with root biomass.	[29]
<i>Lepidium sativum</i> (garden cress)	Green fluorescent plastic particles	72-hour bioassay of cress seeds exposed to 50 nm, 500 nm and 4800 nm plastic particles at concentrations between $10^3$ and $10^7$ particles.	Significantly lower germination rate was observed after exposure to all three plastic particle sizes for 8 hours and increasing plastic sizes caused more decline in the rate. After 24-hour exposure, the germination rate did not differ significantly. Root growth varied after 24-hour exposure but the variation was negligible after 48-hour or 72-hour exposure.	[28]
<i>Vicia faba</i> (broad beans)	Polystyrene fluorescent microplastics	Exposure of root tips of <i>Vicia faba</i> to 10, 50 and 100 mg/L of microplastics of 5 $\mu$ m and 100 nm.	5 $\mu$ m plastics reduced root biomass and catalase activity but increased superoxide dismutase and peroxidase activities. 100 nm plastics reduced root biomass only at 100 mg/L but caused greater genotoxicity and oxidative damage than 5 $\mu$ m plastics	[30]
Plant generally	Type Beads and fragments, Fibers, Films, Biodegradable Nanoplastics	Hypothesis of effects on plants based on how different types of microplastics affect soil biophysical properties, e.g. beads and fragments only produce minor textural changes in soil, fibers cause alteration of soil structure and bulk density, while biodegradable microplastics temporarily immobilize nutrient in soil.	<u>Changes on plant growth</u> Minor Large (+) Intermediate (-) Intermediate (-) Minimal to intermediate (-)	[19]

Plant/ Crop	Types of microplastics	Treatment	Findings	References
Lettuce	Polystyrene microbeads sized 0.2 and 1.0 $\mu\text{m}$	Tracking of uptake and distribution of polystyrene microbeads in lettuce.	Roots of lettuce trapped, absorbed and transported polystyrene microbeads to stems and leaves via transpiration. This indicates that microplastics can be taken up, accumulated and transferred in crops such as lettuce.	[18]
<i>Lolium perenne</i> (perennial ryegrass)	Biodegradable polylactic acid and high-density polyethylene	Exposure of perennial ryegrass to 1 g/kg dry soil of polylactic acid and high-density polyethylene with mean diameters of 65.6 $\mu\text{m}$ and 102.6 $\mu\text{m}$ respectively.	Seeds of perennial ryegrass showed lower germination after exposure to polylactic acid microplastics. Root biomass of perennial ryegrass was lower when exposed to polylactic acid, compared to polyethylene microplastics. No significant variation in chlorophyll content was observed.	[7]
<i>Lemna minor</i> (Duckweed)	Polyethylene microspheres	Bioassay of duckweed exposed to about 50,000 microplastics/mL of bioassay suspension with diameter of 10-45 $\mu\text{m}$ .	Duckweed adsorbed a maximum 7 microplastics per $\text{mm}^2$ 7-day after exposure to the microplastics. Photosynthetic efficiency and growth of duckweed were not significantly affected	[25]
<i>Lemna minor</i> (Duckweed)	Polyethylene microbeads	Exposure of duckweed leaves to microbeads from two commercial exfoliators.	The microbeads did not significantly affect leaf growth as well as chlorophyll content in the leaves but retarded root growth through mechanical blocking.	[24]
Tobacco BY-2 cells	Fluorescent polystyrene nano beads of 20 nm diameter	Exposure of BY-2 cells and protoplasts to nano beads followed by examination with confocal microscope.	Endocytosis of 20 nm-diameter beads by BY-2 cells was observed while larger beads (100 nm) were not internalized. Protoplasts internalized beads as large as 1000 nm diameter.	[17]

However, differences in germination rates were not observed after 24 hours and this implies transient negative effect of micro-/ nano- plastics on seed germination attributed probably to blocking of pores on seed capsules by plastic particles [28].

Wang et al. studied the interactions of microplastics with cadmium in soil and how the interactions affected plant performance [29]. They found polyethylene did not elicit significant phytotoxicity while 10% polylactic acid caused decline in the biomass and leaf chlorophyll level of maize grown in soil contaminated with cadmium. Both microplastics did not yield significance differences in the amount of Cd accumulated in plant tissues [29]. In terms of ecotoxicity, Jiang et al. reported decreased root biomass and root catalase enzyme activity of *Vicia faba* (broad beans) upon exposure to 5 µm polystyrene fluorescent microplastics at concentrations ranging from 10 to 100 mg/L for 48 hours while increase in the activities of superoxide dismutase and peroxidase was observed [30]. The study also revealed that 100 nm polystyrene fluorescent microplastics caused a decline in root growth only at a higher concentration of 100 mg/L but posed greater genotoxicity and oxidative damage on *Vicia faba* [30]. Fig. 1 shows the sources and impacts of microplastics on soil and plants. A summary of the effects of microplastics on plants and crops is presented in Table 1.

#### 4. CONCLUSION

Microplastics have been shown to affect crops and plants in various ways. At cellular level, microplastics alter enzyme activities and have the potential to cause genotoxicity and oxidative damage. Microplastics can also be internalized by certain plant cells and protoplasts. Physiologically, microplastics demonstrate adverse effects on root growth and seed germination but the duration of the effects is inconclusive and the extent of the effects depends on the types and sizes of microplastics. It is possible for microplastics to enter plants via roots, accumulate and move to various parts of the plants due to physiologically processes such as transpiration. Microplastics have also been hypothesized to affect plants by changing biophysical properties of soil. However, the knowledge of the impacts of microplastics on plants and crops, and agriculture as a whole, is constrained by the relatively low number of studies in this area. This review therefore calls

for more studies on how microplastics affect different plants to bridge the gaps of knowledge. As this review also highlights potential uptake and internalization of microplastics by plants, it recommends more studies to examine the risks of human exposure to microplastics due to ingestion of agricultural produces. In addition, agricultural impacts of microplastics can be complicated by their ability to adsorb other chemicals, and the events of climate change due to anthropogenic factors, which future studies could aim to investigate [31].

#### COMPETING INTERESTS

Author has declared that no competing interests exist.

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