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Effect of Microplastics on Crop Plants

Prabha Singh

Research Scholar in Botany, Jayoti Vidyapeeth Women's University, Jaipur

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ABSTRACT

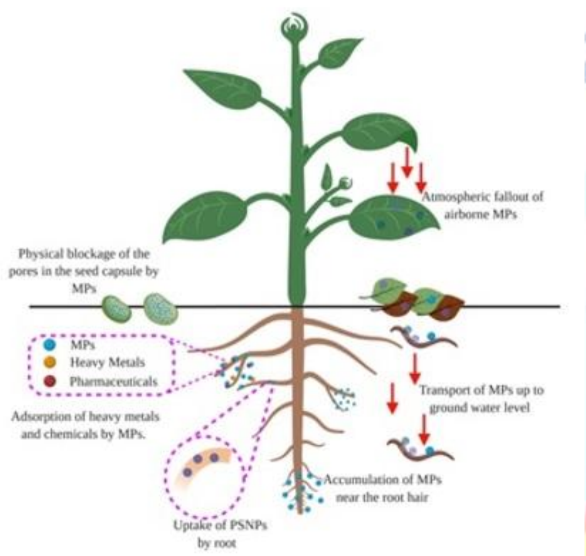
Microplastics can be viewed conceptually as a soil physical contaminant and initial data suggest that, indeed, microfibers have led to lowered soil bulk density . This could translate directly to reduced penetration resistance for plant roots, and better soil aeration, and thus increased root growth . However, other effects are also possible: plastic films (2, 5, and 10 mm size fragments, added at 0.5% and 1.0%) have been shown to create channels for water movement, leading to increased water evaporation .This could lead to soil drying, with potentially negative consequences for plant performance. Phytotoxic substances already present in microplastics before they arrive in the soil (e.g. when added during manufacture), could be transported into soil with these microplastic particles. Toxic substances, either adsorbed onto surfaces (and within the particle 'ecocorona'; microplastic particles in the soil, or already contained in the particles could negatively affect plant roots or their symbionts, potentially translating to negative plant growth effects. Alternatively, the adsorption of contaminants to microplastic surfaces could make other pollutants less available to soil biota and crop plants, thus exerting a protective effect. The latter has been observed in aquatic environments and such effects may be transferable also to soils. Thus, there currently is considerable uncertainty whether pollutant effects will be enhanced or decreased by microplastic.

The rhizodermis of roots would likely be the primary place of interaction and a barrier for microplastic uptake. Although the mechanisms underlying nanoparticle uptake in crop plants are poorly described .it is accepted that nano-sized particles could enter into plant roots, and potentially cause damage (e.g. alteration of cell membrane, intracellular molecules, and generation of oxidative stress) . Plastic films, which increased soil water evaporation may lead to more pronounced drought and subsequently promote the growth of drought-resistant plant species in a community. Moreover, the soil microbial community strongly influences plant community composition, productivity and diversity .

Keywords :microplastic, crop plants, soil, effect, crops, pollutant

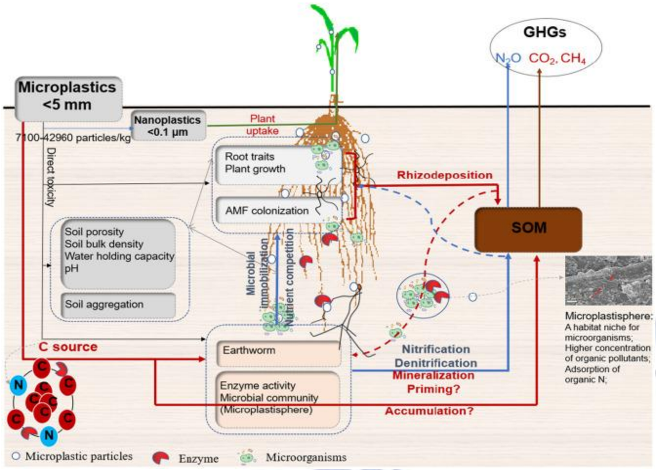
INTRODUCTION

Microplastics have permeated most, if not all, ecosystems including the terrestrial ones. The presence of microplastics in soil poses concerns on crop 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 crop plants frequently depend on the types and sizes of microplastics. This study presents a concise illustration of the impacts of microplastics on crop plants and crops. From the study, 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 crop 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 crop plants facilitated by transpiration. This study 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. [1]



Absorption of microplastics

Recently published advances on different edible species are presented below. One of the first studies was performed using *Lemna minor* L., an aquatic and wild species of the Araceae family used in the pet food industry . This plant was exposed to polyethylene microbeads of two types of exfoliants marketed in the cosmetic industry. The effect of microplastics was evaluated and isolated, finding that the presence of these microparticles caused stress in the plant by decreasing root growth due to mechanical blockage. Vegetative growth was not affected. In 2018, wheat research (*Triticum* spp.) grown in pots in a controlled environment under abiotic stress conditions. The crop plants were subjected to a nutrient solution that, apart from essential elements, contained microplastics. In this solution, low-density polyethylene and also starch-based biodegradable plastic was applied at a concentration of 1%. The results indicated that the residues of macro and microplastics stressed the vegetative and reproductive growth of the crop. The biodegradable film caused the most significant adverse effect compared to low-density polyethylene in the nutrient solution.[2] This could be explained, considering that this biodegradable plastic film is composed of polybutylene terephthalate (PBT) and PET; however, it is not conclusive to indicate that all biodegradable coatings behave in this way. An information was provided on the toxicological effect of microplastics on the plant for the same species. For this purpose, they applied two types of PVC microplastics with different concentrations (0.5%, 1%, and 2%). They evaluated their stressing effect on some physiological characteristics of the plant in both roots and leaves. The results showed that there were differences in root activity but not in leaves. There were variations in total length, surface area, root volume, and root diameter in the root system when the microplastic content varied from 0.5% to 1%. The authors indicated an effect on leaves due to the type of PVC applied in the growing medium and that 1% PVC content in the plant could reduce the ability of the plant to absorb, dissipate, capture, and transfer light energy electrons. The study of microplastics in other species such as garden cress (*Lepidium sativum*) showed that nano and microplastics accumulated in the pores of the seed coat of this species would affect water uptake, with the consequent effect of delaying germination, producing a decrease in root growth when exposed to plastic particles with a size of 50 nm. Different types of microplastics in a chive (*Allium fistulosum*) crop. The microplastics used were polyester fibers, polyamide beads, and four types of fragments: polyethylene, polyester terephthalate, polypropylene, and polystyrene. An Italian research evidenced and quantified the content of microplastics and microplastics in some fruits and vegetables collected from retail. This study showed that crop plants can absorb these small particles of different types of plastic. The analyzed species were apple fruits (*Malus domestica)*, pear (*Pyrus communis*), broccoli inflorescence (*Brassica oleracea* var. italica), lettuce leaves (*Lactuca sativa*), and carrot roots (*Daucus carota*) . [3,4]



Microplastics as an emerging threat to plant soil health

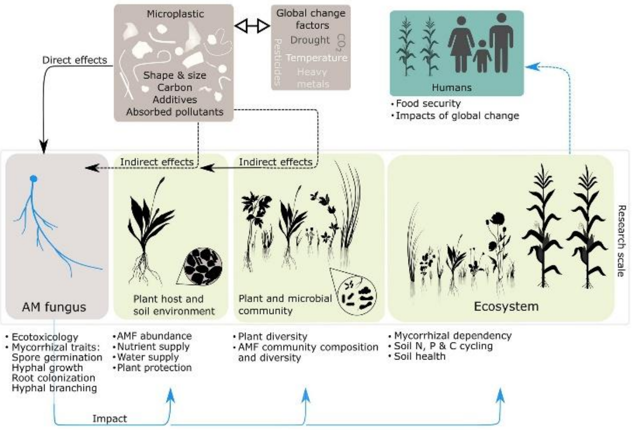
OBSERVATIONS

The researchers added different types of microplastics into the soil: polyamide beads (a primary microplastic), polyester fibers (the most common type of secondary microplastic) and four different plastics in the form of fragmenta (another type of secondary microplastic). They added microplastics at a similar concentration to that of soils exposed to high levels of human activity. Then, they grew spring onions in soil with and without the different microplastic types. The plastic fibers are by far the most common type of microplastic in soils. Both the polyamide beads and polyester fibers increased general microbial metabolic activity. Polyester fibers enhanced the colonization of the spring onions by beneficial fungi, called arbuscular mycorrhizal fungi. These fungi exchange nutrients with their host plant in return for sugars and other carbon compounds the fungi need to grow. When plastic fibers were in the soil, there were more of these structures used to exchange compounds between the fungi and plant. The polyester fibers and other types of microplastics, increased the bulb and root growth of the onions. Moreover, water availability in the soil was higher when it was treated with microplastics, though this effect was reduced by the presence of crop plants.[5,6]

Plant growth, as well as microbial activity, can be enhanced by the presence of microplastics, particularly polyester fibers.

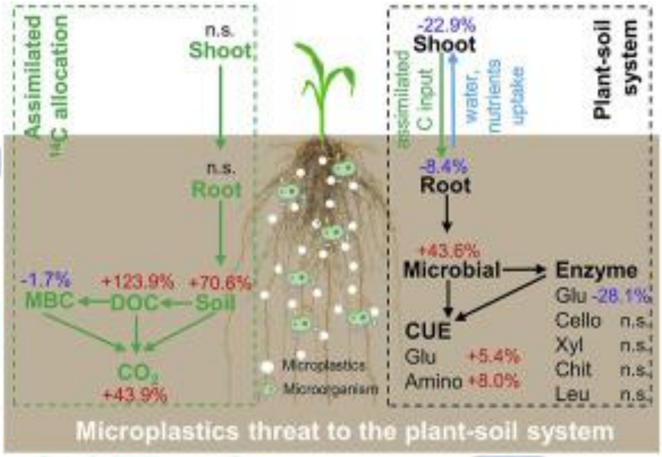
It has been explained in the previous section that sewage and wastewater treatment sludge captures microplastics. It was reported that approximately 50% of sewage sludge in Europe and North America was eventually applied to farmlands as economic fertilizers, resulting in as much as 870 tons of microplastics per million inhabitants to enter the European agricultural soils. The amount could be higher in countries with higher usage of plastics . The use of agricultural plastic films for mulching also introduces microplastics into soil as the films degrade . 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 . Crops' tissue cultures were used to uptake and accumulate polystyrene microplastics (0.2 µm) and implied potential transfer of the microplastics to human through food chain . Moving beyond cellular level, potential interference of biodegradable and polyethylene microplastics on wheat's growth and biodegradable microplastics seemed to exert larger negative effects . The study also showed biodegradable microplastics reduced fruit biomass and the presence of earthworm partly negated the negative effects . 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, microplastics could improve penetration of plant roots into soil, soil aeration and root growth via lowering soil bulk density . 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

.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. [7,8]



Potential effects of microplastics on arbuscular mycorrhizal fungi

Slow degradation of microplastics has been linked to microbial immobilization though there is currently a lack of empirical evidence for the immobilization . Besides, microplastics may serve as media which introduce phytotoxic substances into soil, thus adversely affecting plant roots and health . Generally, by altering soil structure and microbial diversity, microplastics could alter plant diversity and community composition Nonetheless, while postulates were made by relating changes in soil biophysical properties to the impacts of microplastics on crop plants, there are few studies to prove the postulates. 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 Synthetic fiber and biodegradable polyacetic acid also retarded seed germination though the former was linked to an increase in root .Tthe effects of increasing concentrations of polyethylene microbeads on duckweed (*Lemna minor*) and revealed the root lengths to have decreased as concentrations increased . The leaves demonstrated 10% growth inhibition compared to less than 8% 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 trogen fixers were affected. Slow degradation of microplastics has been linked to microbial immobilization though there is currently a lack of empirical evidence. Besides, microplastics may serve as media which introduce phytotoxic substances into soil, thus adversely affecting Generally, by altering soil structure and microbial diversity, microplastics could alter plant diversity and community composition .[9,10]

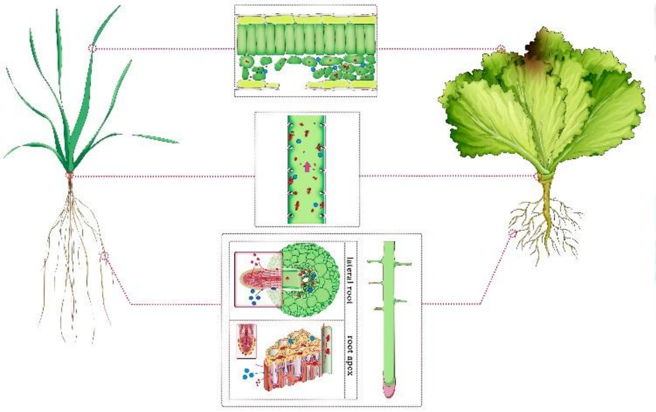


Microplastics in agroecosystems

Nonetheless, while postulates were made by relating changes in soil biophysical properties to the impacts of microplastics on crop plants, there are few studies to prove the postulates. Studies of fiber and biodegradable polylactic acid reduced the shoot *Lolium perenne*) but increased its chlorophylls a and b levels . Synthetic fiber and biodegradable polyacetic acid also retarded seed germination though the former was linked to an increase in root biomass. The effects of increasing concentrations of polyethylene microbeads on) and revealed the root lengths to have decreased as concentrations . 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. It was revealed that adding a concentration of 50,000 polyethylene microplastics/mL of water increased root length of duckweed (*Lemma minor*) between 24 hours and 168 hours after addition though the increase was insignificant compared to control the effects on root growth are inconclusive at this juncture, microplastics do not seem to significantly affect photosynthetic capacity of duckweed .[11,12]

DISCUSSION

In our recent study, first of all we assessed and validated the effective uptake of submicrometer- (0.2 μm) polystyrene (PS) beads in a controlled nutrient solution culture. In addition to the well-known mode of apoplastic uptake of nanometer-sized materials at root apex, our results revealed evidence in support of microplastic penetrating the stele via cracks in the epidermis that initiate lateral root formation . Our study also showed exciting evidences even the micrometer-sized (2.0 μm) PS beads can enter the xylem vessels at the lateral root emergence sites.[13]



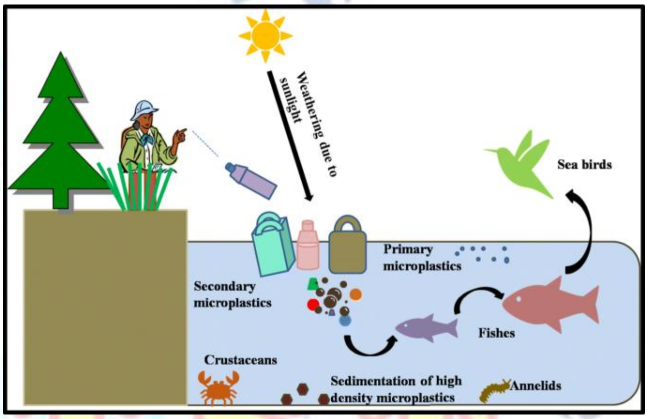
Schematic illustration of adherence, uptake, transport, and penetration of two sizes (0.2 μm and 2.0 μm) of polystyrene beads by two edible crop plants wheat and lettuce.

The use of treated wastewater for agricultural irrigation is increasing worldwide and is not limited to arid zones. Considering the ubiquity of microplastics in treated wastewater, it is very important to evaluate their uptake by crop plants under conditions that are as similar as possible to those of agricultural farming. Polymethylmethacrylate (PMMA) is among the most commonly used plastic type as microbeads in cosmetics in Europe and in other countries. PMMA beads are likely to be transported to wastewater treatment crop plants, and it is anticipated that a substantial proportion will pass through filtration systems due to their small size. Consequently, they will enter the environment. Further studies using spiked wastewater confirmed that both PS and PMMA particles are also taken up by the crop plants from real wastewater.

It was found that both submicrometer- (0.2 μm) and micrometer-sized (2.0 μm) PS beads enter the xylem vessels at the lateral root emergence sites in sand culture and these particles were also present in the xylem sap of wheat and lettuce. Accumulation of 0.2 μm fluorescently labeled PS beads was observed in roots of wheat grown for 20 days in a sandy soil. We think that this is proof of principle that will most likely yield the same results in natural field soils. This finally shed a new light on the possibility of food chain transfer of microplastics and have important implications for crops grown on fields contaminated with either wastewater treatment discharge or sewage sludge.[14]

RESULTS

Growth of crop plants, apart from being complex and highly dynamic, is directly dependent on the environmental conditions, particularly the quality of soil for terrestrial crop plants and the water quality for aquatic crop plants.

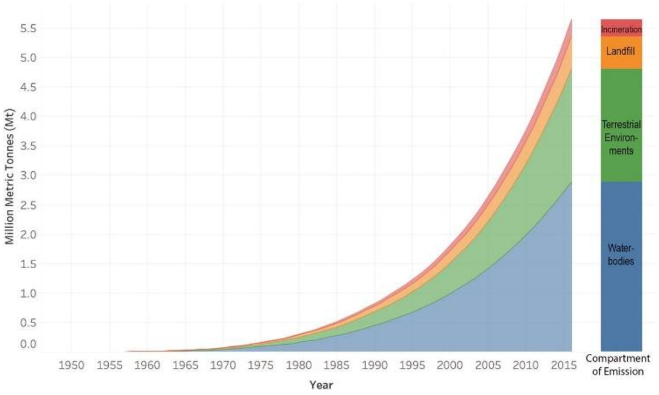


Effect of microplastics in aquatic ecosystem

Presence of microplastics in the environment may affect the plant growth in numerous ways depending on the contents of the growing medium. However, increasing presence of microplastics at an alarming rate due to its pervasive usage and mismanagement of plastics have led to significant environmental problems. Several research studies have been conducted as well as reviewed to investigate the toxic effects of microplastics on aquatic systems, but studies that investigate the toxic effect of microplastics on the terrestrial systems are limited. The individual and the combined effects of microplastics on the growth of crop plants and seed germination in both aquatic and terrestrial ecosystems are concisely toxic.[15] At the beginning accumulation of microplastics on aquatic and terrestrial ecosystem is toxic and the reasonable solutions are highlighted that can mitigate the effects from the widespread increase of the plastic debris. Thereafter, the individual and combined effect of microplastics on seed germination and plant growth is studied separately while studying the important aspects and future perspectives. Thus an insight into the effect of microplastics on plant growth and seed germination in aquatic and terrestrial ecosystem was found to be hazardous for life cycle of herbivores and carnivores.

CONCLUSION

As concern grows among environmentalists and consumers about microplastics in the oceans and in seafood, they are increasingly studied in marine environments, also, "little is known about the behavior of microplastics in terrestrial environments, especially agricultural soils" .



Microplastic pollution on farm fields

"Our findings provide direct evidence that microplastics can accumulate in crop plants, depending on their surface charge. Plant accumulation of microplastics can have both direct ecological effects and implications for agricultural sustainability and food safety." Both positively and negatively charged microplastics accumulate in the commonly used laboratory model plant, *Arabidopsis thaliana*.

Microplastic particles can be as small as a protein or a virus. Weathering and degradation change plastic's physical and chemical properties and imparts surface charges, so environmental particles are different from the pristine polystyrene microplastics often used in the lab. "This is why we synthesized polystyrene microplastics with either positive or negative surface charges for use in our experiments."[16]

We grew *Arabidopsis* crop plants in soil mixed with differently charged, fluorescently labeled microplastics to assess plant weights, height, chlorophyll content and root growth. After seven weeks, they observed that plant biomass and height were lower in crop plants exposed to microplastics than in controls, for example."Microplastics reduced the total biomass of model crop plants," "They were smaller and the roots were much shorter. If you reduce the biomass, it's not good for the plant, yield is down and the nutritional value of crops may be compromised."

"We found that the positively charged particles were not taken up so much, but they are more harmful to the plant. We don't know exactly why, but it's likely that the positively charged microplastics interact more with water, nutrients and roots, and triggered different sets of gene expressions. That needs to be explored further in crop plants in the environment. Until then, we don't know how it may affect crop yield and food crop safety." Our investigation team also analyzed seedlings to investigate sensitivity of the roots to charged microplastics. Exposed for 10 days, seedling growth was inhibited compared with that of control seedlings. To identify molecular mechanisms responsible, the researchers used RNA-Seq transcriptomic analyses of roots and shoots, then verified results with a quantitative PCR assay on three root genes and four shoot genes.[16]

"Regardless of the surface charge, *Arabidopsis* can take up and transport microplastics with sizes of less than 200 nm." We mainly demonstrate that "the pathway of uptake and transport of microplastics in root tissues differed between differentially charged microplastics."

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