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Accumulation of plastics in terrestrial crop plants and its impact on the plant growth

Bhavika Garua, Jai Gopal Sharma*
Department of Biotechnology, Delhi Technological University, Delhi, India.

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ABSTRACT

Small plastic particles are persistent in soil and will remain in the agricultural ecosystem for a long period, so there is an urgent need to uncover their potential impacts on the agricultural ecosystem. Plastics in the agricultural ecosystem are alarming as they can accumulate in crop plants and affect consumers by directly entering through the food web. Through disintegration of plastic, microplastics and nanoplastics (NPs) are generated and accumulated in significant quantities in soil. Incidentally, plastics have been shown to alter biophysical and geochemical properties of soil. The dispersion and transport of plastics in soil could directly impact crop plants and reduce crop yield. There are limited studies on uptake and accumulation of MPs and NPs in terrestrial plants but studies reported so far have shown phytoremediation as a potential remediation technique to extract and degrade plastic particles from agricultural soils. This review discusses the impacts of MPs and NPs on terrestrial plants growth and accumulation in different plant tissues based on recent literature.

1. INTRODUCTION

The properties which make plastic suitable for packing and production of goods—durable and resistant to environmental factors—also makes it almost impossible to eradicate from the environment completely. Various reports have claimed that most plastic materials disintegrate rather than degrade in the environment [1]. The global production of plastics increases every year. In 2019, world plastic production increased to 368 million metric as shown in Figure 1 [2].

These large plastics disintegrate into smaller fragments of size less than 5 mm, referred as microplastics (MPs) [3]. Further deterioration of these microplastic fragments results in emergence of even smaller particles of size less than 0.1 µm, commonly called nanoplastics (NPs) [4]. The distinct sizes of plastics, MPs and NPs, are still unknown. Different authors define MPs and NPs differently. MPs are generally defined as particles in the size range of nanometer (100 nm–5 mm), along with sub-micrometer (100 nm–1 µm) and micrometer (1 µm–5 mm) plastics, and NPs in the range of 1 nm–100 nm.

Plastics in the ocean have drawn considerable attention in the last decade. Marine pollution has shown its effects in aquatic ecosystem and is evident to public. Extensive research have been done on assimilation of MPs and NPs by marine organisms [5,6]. Study on transport of small plastic particles beyond the gut of the organisms, entering the food web and transfer between trophic levels is still in its initial stage. While the fate of plastics in marine ecosystem is being progressively well studied, behavior of MPs and NPs in terrestrial environment is somewhat obscure, especially in agricultural ecosystem [7]. Critical limits for plastic contamination in soil are rarely defined so far which makes it harder to evaluate the bearing capacity of agricultural ecosystems [8]. Whether terrestrial plants can accumulate MPs and NPs and if so then how these can affect their growth and consequently enter the food chain, are two crucial problems of paramount importance to study the effects of plastics on terrestrial crop plants [9].

Recent studies have observed the origin and fate of these plastic fragments in terrestrial ecosystem especially in terrestrial crop plants (Table 1) [10,11]. The occurrence of different plastic materials has clinched much attention in marine environments, and its related shoreline. However, the terrestrial ecosystems are not much reviewed and studied for occurrence of plastics and their detrimental effects. Therefore, we present here a review on the

*Corresponding Author
Jai Gopal Sharma, Department of Biotechnology, Delhi Technological University, Delhi, India. E-mail: sharmajaigopal @ dce.ac.in

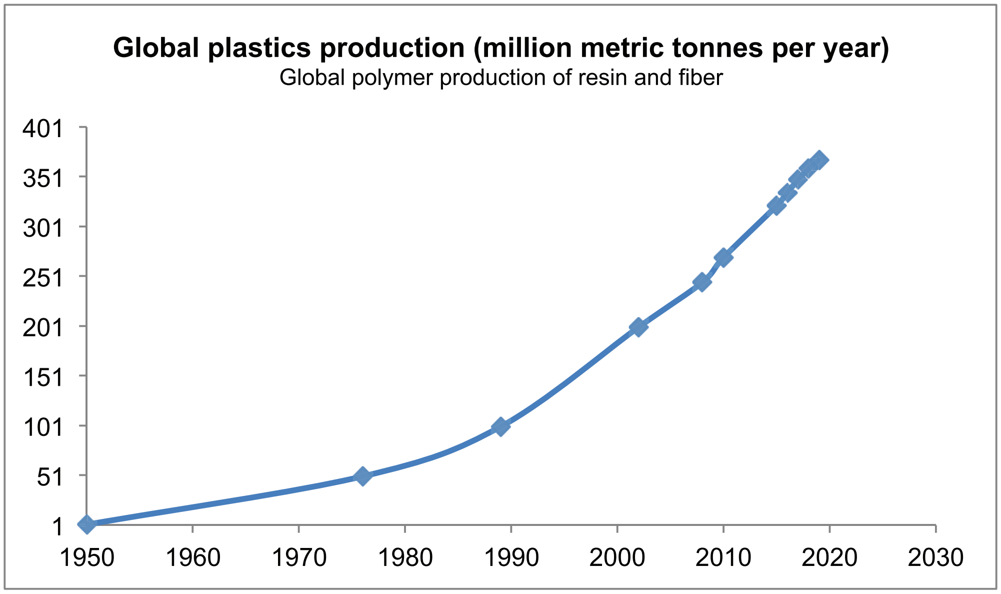

Figure 1. Plastic production from 1950 in million tons.

uptake and accumulation of plastic particles in terrestrial plants, along with its detrimental effects on their growth and yield in agricultural ecosystems.

2. OCCURRENCE AND EFFECT OF PLASTIC PARTICLES ON SOIL QUALITY AND SURROUNDINGS

Terrestrial ecosystem gets all sizes of plastic wastes from plastic mulch film, municipal solid waste bio solids, and plastic-coated fertilizers in soil and atmospheric deposition. Agricultural plastics such as plastic mulch films have advantages and disadvantages. Plastic mulch films used in agriculture are mostly preferred for cultivating specific crops as they help in modifying soil temperatures, maintaining soil moistures, and improving crop productivity within the soil [12]. The most commonly used plastic mulch is low-density polyethylene (LDPE) as it is inexpensive, easy processed, durable, and flexible [13]. The widespread application of these plastic mulches has contaminated soils because they are not entirely removed from the field and remains in the soil in the form of small chunks for decades. The plastic mulch films retained within the soil gradually breakdown into smaller particles [14], resulting in pollution of MPs and NPs. Use of non-degradable LDPE mulches in agriculture is observed extensively for its high stability, but these mulches increase accumulation of plastic wastes in agricultural ecosystem. Mulch fragments can negatively affect soil density.

The sludge is being used directly as a common source of fertilizer in agricultural soils which are concentrated with contaminants like plastic materials [15]. Plastic fibers are found in wastewater from washing clothes as well as microplastic beads from cosmetic and skin care products [16]. The sewage sludge contains around 80%–90% of plastic particles and even after treatment, some amount of plastic still persists in sewage [17]. Studies have reported that plastic fragments retain in agricultural fields up to 15 years [15]. A notable contributor for plastic pollution in soils can be landfills, urban and industrial centers that directly input plastic fragments on land through improper waste disposal, accidental loss, and contamination by soils and aerosols [18]. The contamination by various other soils, like paddy soils and coastal soils [19], plays a crucial role because of the atmospheric particles which can be quickly transported across various distances and contaminates the environment by disintegration of various large plastic fragments into smaller chunks of microplastic and NPs. A significant source of plastic contamination in soil can also be attributed to atmospheric deposition. Moreover, plastic use in irrigation and distribution systems is very common in agricultural fields. As other plastic tends to degrade into smaller particles by environmental factors and application of chemicals in agriculture, these plastic pipes are also subjected to breakdown in a much similar way.

Degradation and fragmentation of plastic occur on soil surface and get transported to other ecosystems like fresh water. Once fragmentation of plastic starts in the upper layer of soil, it sinks to deeper layers, where physical factors like low temperature and less oxygen availability causes decrease in biodegradation rates. As plastic mulches are used repetitively, the amount of fragments increases crop by crop in fields which consequently decreases crop yield [20]. The constituents of plastics, mainly additives like plasticizers, are harmful for agricultural ecosystems. When plastic mulch comes in contact with water, fertilizers and pesticides, its compounds leach into the soil underneath. Phthalate esters (PAEs) leach out from films into the soil and further are absorbed by plants. So with plastic fragments, these chemical compounds also accumulate in soil [20]. The continuous use of plastic films has left residual plastic film particles in farm soil affecting infiltration of water and nutrients into the soil [21]. Soil structure is lost when larger quantities of plastic particles remain in it for a longer time as shown in Figure 2. These plastic particles can obstruct the water infiltration and affect the water holding capacity of soil by blocking soil pores. This can further lead to lesser amount of oxygen in soil

Table 1. Recent studies reported on impacts of MPs and NPs on terrestrial plants.

Plastic	Size	Concentration	Model organism	Reference
PS microbeads	0.2 and 2.0 µm	0.5, 5, 50 mg l^{-1}	Wheat (*Triticumaestivum L.*)	[26]
Micro PS	100 nm	25, 50, 100, 200, and 400 mg/l	Onion (*Allium cepa L.*)	[34]
PS nanoplastic	PS-SO_3H (55 ± 7 nm), PS-NH_2 (71 ± 6 nm), PS-Pd (162 ± 6 nm)	0.0, 0.3 and 1.0 g kg^{-1} of soil	*Arabidopsis thaliana*	[35]
PS and polymethylmethacrylatemicroplastic	0.2 µm and 2.0 µm	0.5, 5, 50 mg l^{-1} of Hoagland solution 150 mg kg^{-1} of sand or 500 mg kg^{-1} of soil	Wheat (*Triticumaestivum L.*) and lettuce (*Lactucasativa*)	[27]
High-density polyethylene (HDPE) and PS	100–154 µm	0%, 0.1%, 1%, and 10% (*w/w*) of soil	Maize (*Zea mays L.*)	[36]
di-n-butyl phthalate (DBP) Polyethylene	~23 µm	10, 20, and 40 mg/kg dry weight of soil	Lettuce (*Lactucasativa L.*)	[37]
PS NPs	100 nm	0.0012, 0.012, 0.12, 1.2 mg/l	Wheat (*Triticumaestivum L.*)	[28]
LDPE and starch-based biodegradable plastic	1 mm, 500, 250 and 50 µm	1% (*w/w*) in soil	Wheat (*Triticumaestivum L.*)	[38]
Polymer microspheres	50, 500, and 4,800 nm	10^3, 10^4, 10^5, 10^6, and 10^7 particles ml^{-1}	Cress (*Lepidium sativum L.*)	[29]
Biodegradable polylactic acid (PLA), HDPE, and microplastic clothing fibers	HDPE—102.6 µm (range = 0.48µ–316 µm) PLA—65.6 µm (range = 0.6µ–363 µm)	HDPE—1 g kg^{-1} dry soil PLA (0.1% *w/w*) Synthetic clothing fibers—10 mg kg^{-1} of dry soil (0.001% *w/w*)	*Loliumperenne* (perennial ryegrass)	[39]
PES	1.28 ± 0.03 mm and a diameter of ~ 30 µm	12 g of microfibers in 3 kg of soil for each pot	Grasses (Festuca brevipila, Calamagrostis epigejos, and Holcuslanatus) and herbs (Achilleamillefolium, Plantagolanceolata, Hieraciumpilosella, and Potentillaargentea)	[24]
Primary polyamide (PA), PES, polyethylene high density (PEHD), polypropylene (PP), PS, polyethylene terephthalate (PET)	PA—15–20µm PES—length 5,000 µm and diameter of 8 µm PEHD—643 µm PP—624 µm PS—492 µm PET—187 µm	PES—0.2% of soil fresh weight. Other MPs—2.0% of soil fresh weight	Spring onion (Allium fistulosum)	[25]

and ultimately leading to anoxia [8] and can affect nitrogen cycling and soil organic carbon [22]. Plastics affect crucial soil parameters such as soil bulk density, water holding capacity and soil structure [23,24]. De Souza MacHado *et al.* [10]showed that plastic fibers of polyester, polyacrylic, and polyethylene decreased the soil bulk density and microbial activity of the soil. They explained the alteration in soil density as a consequence of plastics being less dense than minerals naturally present in soils. The water holding capacity was also majorly affected by polyester fibers (PES) in a concentration dependent manner as compared to other plastic fibers. The effects of plastic fibers on soil structure and properties depend on the nature of plastics, shape and size of the particles. For example more flexible PES blend more homogeneously and entangle effectively with surrounding soil particles and these fibers can incorporate in soil clumps at finer scales affecting soil biophysical properties more than other plastic fibers [23].

Soil structure is lost when larger quantities of plastic particles remain in it for a longer time. These particles obstruct the water infiltration and affect the water holding capacity of soil. This can also further lead to a lesser amount of oxygen in soil ultimately leading to anoxia [8]. Addition of plastics in soil can affect nitrogen cycling and soil organic carbon. This increases nitrogen content in the soil, and further increases leaf nitrogen content [25]. Plastics can contribute to soil carbon content. Plastics are mostly carbon for example polystyrene (PS) and polyethylene are 90% carbon. When these plastics are introduced in agricultural soil, it breaks down into smaller particles and contributes to soil carbon storage [22].

3. TRANSPORT OF MPs IN PLANT TISSUES

Studies have shown translocation of plastics in plant tissues [26–29]. Probable ways of transport of nanoparticles of smaller

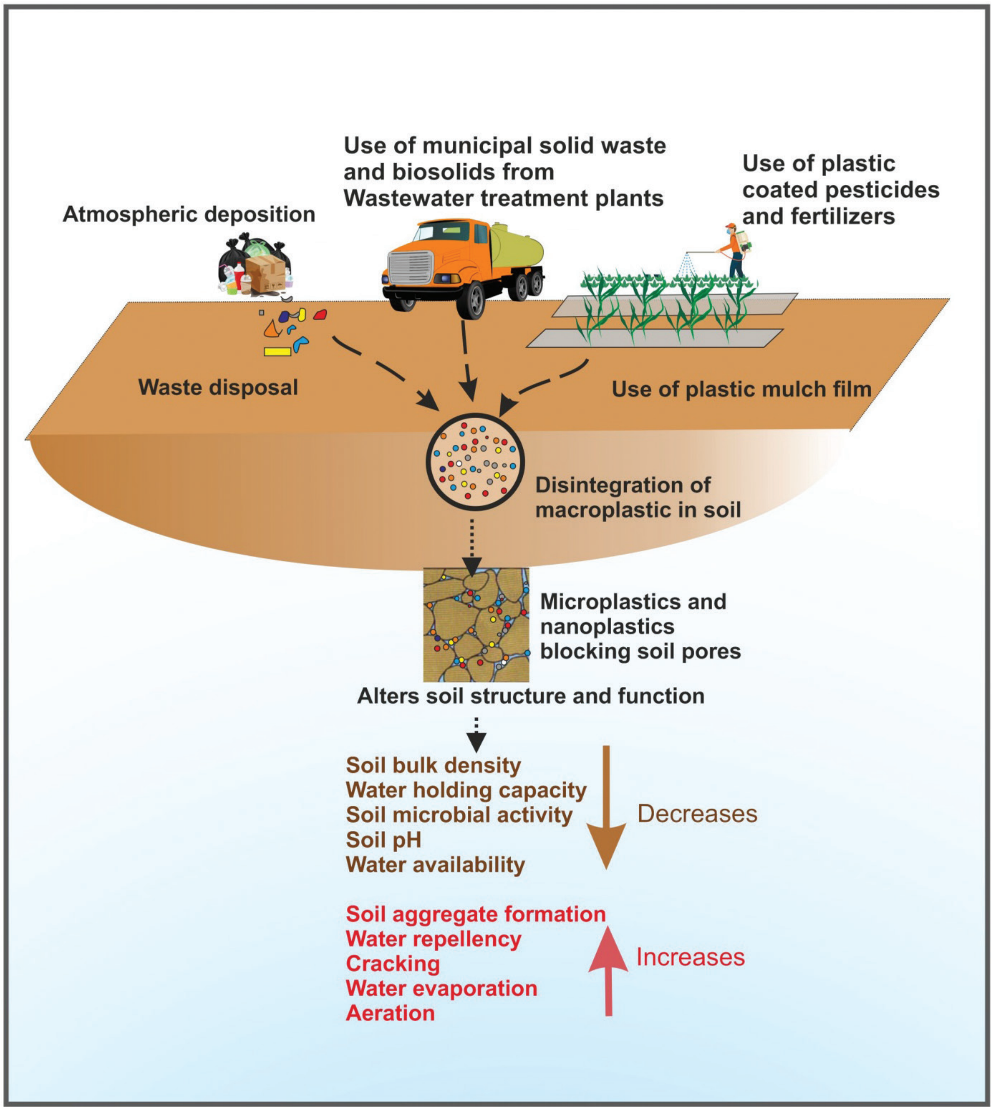

Figure 2. Impact of plastic contamination on soil properties.

sizes into plant cells are endocytosis, passive diffusion, facilitated diffusion, and translocation via plasmodesmata [30]. NPs gets transported into endodermis by capillary action and osmotic pressure [31]. Other nanoparticles can also transport with the help of membrane proteins through symplastic pathway and are taken up by cells directly through plasma membrane or via endocytosis [32]. On the other hand, intercellular transport of such particles is mediated by plasmodesmata connecting cells together [26,27]. The stomatal openings can also be a possible route for assimilation of nanoparticles which then get translocated through the xylem tissue [33].

3.1. Effects of Plastic Particles on Seed Germination

Presence of plastics in soil can cause reduction of seeds that germinate or can reduce the rate of germination (Fig. 3). The probable effects on seed germination can be due to leachates of plastics mixing with water which seeds imbibe during germination or due to change in soil structure (Fig. 2) by smaller plastic particles especially micro and NPs [40]. The angiosperm seeds have testa, seed capsule, which controls germination and protects it from extreme surrounding environmental conditions [41]. The seed coat act as a barrier between surrounding environment and embryo, protecting it from contamination till radical starts developing. During germination, when seeds imbibe water from surrounding, they are prone to toxicants to enter through pores in seed capsule [42].

Boots *et al*. [39] studied effects of different MPs (biodegradable PLA, HDPE, and microplastic clothing fibers) on perennial ryegrass. They reported that plastics reduced the number of ryegrass seeds that germinated. They hypothesized that this reduction can be blockage of seed capsule by plastic particles. Another study conducted by Pflugmacher *et al.* [40] reported that the germination speed and as a consequence germination rate index of seeds of garden cress, *L. sativum,* got reduced when treated with polycarbonate granules and its leachates. Germination rate of seeds is measured by germination rate index which gives

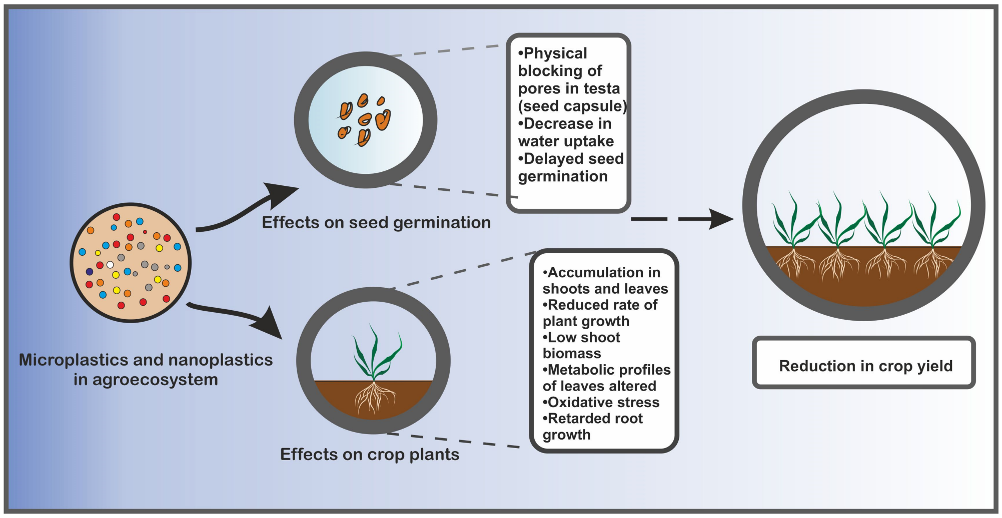

Figure 3. Effects of MPs and NPs on seed germination and plant growth.

the percentage of germination on each day of germination period [28]. The implication of this study can be that if too many plastic particles and their leachates gets mixed with agricultural soil then it can result in delayed growth and lesser germination rate index which can further affect crop yield [40].

Similar to the effects of NPs, MPs can also block pores in the seed capsules affecting water uptake and rate of germination**.** Later these microparticles can block root hairs affecting uptake of nutrients. Bosker *et al.* [29] also observed presence of fluorescent MPs on the surfaces during all the growth stages of *L. sativum* [29]. Therefore, plastic particles small enough to block pores on seed capsule can affect rate of seed germination resulting in lesser germinating seeds.

3.2. Effects of Plastics on Vascular System

No study as such has reported presence of MPs or NPs in vascular system of plants. No accumulation is observed in xylem or phloem [26]. Although the presence of aggregates of PS beads of size 0.2 mm in xylem and on cell wall of cortex tissue was observed in wheat root [27], the observation suggests that beads got transported through intercellular space through apoplastic pathway which is discussed in following section. Once the particles come inside the central cylinder, they move toward aerial parts of the plant through vascular system of xylem tissue in transpiration stream [28]. This transport resulted in plastic particles being transported from roots to stem and leaf vein vasculature. Although, with an increase in microbead size (2.0, 5, 7, and 10 µm), the transport of beads to peripheral parts of plants decreases [26].

3.3. Effects of Plastics on Roots and Shoots

In spite of the various studies on the uptake of nanomaterials by apoplastic transport, researchers have assumed that NPs cannot pass through the cell wall as physical barriers of plant tissue as these particles are too large to internalize into plant cells. Uptake of nanomaterials is possible by plant cells resulting in transport to different parts and accumulation in roots and shoots indicating same for plastics of nano size as shown in Figure 3 [35,43]. For example, confocal images of study conducted by Li *et al.* [26] substantiates increased accumulation of 0.2 µm PS microbeads in roots, shoots, and leaves of wheat in concentration dependent manner. Moreover, studies have shown that MPs can affect root growth negatively and resulting in either reduction of root growth rate or reduction of root biomass. Exposure to smaller sized microplastic can also result in decrease of shoot height [39]. A similar observation was reported by Bosker *et al.* [29], that 50 nm polymer microspheres decreased root growth in *L. sativum* seedlings after 24 hour of exposure. The study also showed accumulation of MPs on root hair. A reduction in root growth was also observed by Kalčíková *et al.* [44], that polyethylene microbeads inhibited root growth for the aquatic duckweed species Lemna minor by mechanically blocking it and further reducing the root length. Exposure of micro PS to *A. cepa* also resulted in reduction of root growth in both dose and time dependent manner [34]. Reduction in root growth due to exposure to toxicant is directly correlated with the inhibition of apical meristem of root tips [45]. Reduction in root length in onion functions as a bioindicator of phytotoxicity of environmental pollutant. Similarly polyamide MPs can decrease root to leaf dry biomass ratio while increasing root length and decreasing root average diameter [25].

Li *et al.* [27] hypothesized transport of plastic particles into the plant roots via crack entry mode; entire lateral root cap and the root apical meristem of wheat and lettuce, further to shoots through apoplastic transport. The apoplast comprises all beyond the plasmalemma including intermicellar and interfibrillar space and xylem stretches to the rhizoplane and cuticle [46]. The Casparian band in root endodermis does not allow transport of water and chemicals into root stele and act as physical barrier. However, in areas where endodermal cells are not mature and at the secondary root initiation sites, this Casparian band is found discontinuous. Discontinuous areas where active cell division is observed in apical meristem can allow transport of plastics unhindered as these areas are entry points for plant pathogens known as crack entry mode [26].

4. TOXIC EFFECTS OF PLASTICS ON SOIL HEALTH AND PLANT GROWTH

Plant communities get affected rapidly to environmental toxicants in terms of evenness than richness on the basis of biomass and species abundance [24]. It can affect ecosystem by promoting growth of some plant species and decreasing others. As discussed above, plastics can change soil structure and properties as well as biophysical and geochemical environment affecting terrestrial plant growth in many ways [47]. The soil microbiota also gets altered in soil where toxicants are observed. All the above characteristics make up the soil ecosystem thus; the effects can be extrapolated to plant growth as well in agricultural ecosystem. Plastics in micro or nano size can enter in plant tissues and accumulate in cells through xylem affecting overall growth of the plant significantly.

A study showed effects of different plastics on soil properties and consequently the plant grown in it. The study by Anderson Abel de Souza Machado showed the effects of six different MPs (PES, polyamide beads, and four fragment types: polyethylene, polyester terephthalate, PP, and PS) on soil health and performance of spring onion (*A. fistulosum*). Soil structure was affected by all the type of plastics. Significant decrease in soil bulk density was observed in soils treated with all types of plastics. Water stable aggregate of soil decreased, whereas rhizosphere showed higher water stable aggregate. The property of water stable aggregate of soil is the ability to resist the change in properties by external forces like soil erosion and it depends on organic matter present in the soil [48]. The plants in soil decreased the water availability which in turn decreased microbial metabolic activity. The exposure to MPs of all type had nearly similar effects on plant roots. The root biomass increased with decrease in root diameter. The ratio of root to leaf dry biomass was increased. Nitrogen in leaf was increased. Polyamide microplastic beads are formed by polymerization of amines and carboxylic acids this can help to elucidate the increase in nitrogen content in plant tissues. Thus, remaining monomers interact loosely with the matrix and get released easily from it into the soil and act as fertilizer. This increases the nitrogen content in soil, and further in leaf nitrogen content, total biomass of plant and decrease in root to leaf dry biomass ratio. Similar pattern can be observed in other plastics which can also contribute to nitrogen content of soil like polyacrylonitrile and polyaramide while polytetrafluoroethylene can contribute fluor in soil [25]. In similar pattern, some of the plastics can also act as carbon storage in soil which can affect soil microbiome [22].

Studies have revealed that even the chemicals used in plastics are harmful for ecosystem if released in soil. Di(2-ethylhexyl) phthalate (DEHP) and DBP are phthalic acid esters which are artificially-synthesized industrial chemical, widely used for plastic production as plasticizer [49]. These chemicals can be released into the soil by weathering and disintegration of plastics. Gao *et al.* [37], reported that DBP and DEHP in soil can cause oxidative stress in wheat grain increasing reactive oxygen species. The DBP, DEHP, and their metabolites were found higher in grains than in stem, leaves and root of wheat crop.

Soils with sludge containing MPs fostered the growth of tomato plants, while delaying and diminished fruit production

5. IMPLICATION OF PLANT-MPS INTERACTION

Small plastic particles can enter marine and terrestrial environments in more than one way thus; consumption of plastics by humans is unavoidable. Plastic particles have low impact on growth of terrestrial plants but high absorption and accumulation in plant tissues can cause negative impact on ecosystem. A similar effect is possible in aquatic ecosystem, where accumulation of plastics in aquatic vascular plants could have implications on herbivore consumers but fewer detrimental effects on plant growth [50,51]. Thus, plastics can enter in food web through plants and get transferred to other trophic levels through consumers.

As discussed earlier, toxic compounds like additives from plastics used in agriculture runoff in soil due to pesticide exposure and breakdown. These compounds then absorb agrochemicals in soil affecting soil quality and microbiota. Plastics have harmful chemicals like bisphenol A, thalates, and poly- fluorinated chemicals etc can affect human and environment. The toxic compounds in plastics cause problems like vision failure, eye irritation, difficulty in breathing, respiratory problems, liver and lung problems, cancers, skin diseases, dizziness and headache, birth defects, reproductive, gastrointestinal, cardiovascular, genotoxic problems, etc [52].

Plastic mulching film used in agriculture increases PAEs in soil [53]. These PAEs are taken up by the food crops and there it gets accumulated posing great risk on consumers. PAEs have been reported to be present in vegetables, fruits, and grains [54,55]. One such crop which can take up such compounds is wheat crop. A study reported that PAE treated soil had DEHP as the dominant PAE compound in soil and wheat grain samples. Major risk group was found to be children in the community [53]. MPs and NPs are reported to be found in fruits and vegetables also. The data for the same is not available for the public. One such study showed that plastic particles are more concentrated in fruits than in vegetables [56]. The most concentrated fruit with plastic was found to be apples due to immense vascularization of the fruit pulp besides their greater size than vegetables. The complexity of their root system and age of the tree, which is about several years, as compared to the vegetable bearing plants also affected plastic concentration in fruits [56]. Thus, assimilation of plastics by crop plants is a gateway for plastic particles leading into the food web from where it gets transferred to other trophic levels.

6. PLASTIC IMAGING: FACTOR LIMITING UNDERSTANDING OF PHYTOTOXICITY

Some factors that limit the understanding of phytotoxicity of such smaller plastic particles can be lack of standardized detection methods that would help in tracking such smaller particles in the environment and in plant tissues as well. Traditional methods for detection of NPs are transmission electron microscopy (TEM) and scanning electron microscopy (SEM). TEM and SEM require extensive sample preparation which requires sample fixation. This limits the field of view for intracellular presence of MPs or NPs in real time. However, for intracellular imaging, SEM and TEM are suitable when plastics are fluorescently tagged. Imaging of fluorescently tagged micro and NPs provides high resolution and rapid results with plant tissues [26]. Another approach for imaging plant tissues can be confocal laser scanning microscopy (CLSM). CLSM does not require extensive sample preparation as required for SEM and TEM. The sample preparation for CLSM is simple and it allows viewing 3-D structures of the sample. Thus, CLSM is a powerful tool for imaging fluorescent specimens. The Widefield fluorescent microscope shows specimen blurry and collects fluorescence signals from areas above and below the area of focus lacking contrast [57].

There is a knowledge gap in understanding the pathways that MPs and NPs go through in nature and enter in cells. The pathway that allows particles like plastic to enter in plant cells where the cell wall is a major barrier is still unknown. Small sized particles can easily enter the cell wall due to their size being in nano and micro meters [30]. The study of such minute particles can be helpful for agriculture in formulating ecologically sound chemicals or nanoformulations. Moreover, development of nanosensor instruments can be helpful for detecting abiotic stress preparatory to affecting the crop yield. Nanotechnology can help build well equipped and high-tech agricultural fields with well developed nanotools [43].

7. PHYTOEXTRACTION OF PLASTICS IN AGRICULTURAL SOILS

Phytoremediation is a green technology where plants in association with microbiota help in remediating contaminants through degradation, stabilization (phytostabilization) or accumulation. One of such techniques which are phytoextraction can be used to remove micro and NPs from agricultural soils where plastic particles are absorbed from root system and transported to other plant parts. Several studies have shown uptake of MPs through root system, this can be advantageous for phytoextraction process in fields. One of the studies has also shown that microspheres of PS broke in aggregates due to transportation decreasing in cohesion which lead to PS degradation in cucumber leaves [58]. Similar aggregates have been seen in plants in vascular system which shows uptake and degradation in terrestrial plants. This process can curb the transport of plastics into lower soil layers and groundwater and also decreases the bioavailability of the plastics in fields. Another way of remediation can be phytofiltration, where contaminants are filtered out from water by adhering to plant roots. Some reports where the study is conducted in Hoagland solution have shown that plastic particles adhered to root hair if not taken up by plants [29]. This process can help in removal of plastics by filtration, decreasing the plastic pollution. Furthermore, studies are needed for better and efficient extraction of plastics through plants from soil.

8. CONCLUSION AND FUTURE PROSPECTS

Interestingly, the low impact of micro and NPs on terrestrial plants and its assimilation and accumulation may have a wide range of ecological repercussions. On the other hand, this interaction has potential phytoremediation benefits. MPs and NPs can be removed through remediation techniques like phytoextraction, phytostabilization, and phytofiltration. Similar viewpoint has been hypothesized for aquatic vascular plants [50,59,60] and microbial remediation of plastics present in soil [61,62,63]. With continuous use of plastics in different fields, many new technologies have been introduced making plastics more durable which will further increase plastics in the ecosystem and ecological risks from its pollution. The research of presence of plastics in the agricultural ecosystem and underlying mechanism of uptake by crop plants is still in its infancy. This information can help in understanding of the extent of long-term exposure and future studies on other crop plants. There are few research articles on the effects of MPs on crop plants grown in plastic contaminated soil. Thus, the amount of plastic that was exposed in such studies is based on a few papers. Future studies should address the accumulation and other effects on different food crops and their edible parts due to various plastic particles. On a wider scale, the number of plastics in the agricultural ecosystem is still under study. Establishing better analytical methods of monitoring and toxicity assessments of soil and terrestrial plants can enhance present understanding. For example, different methods for analyzing sizes of plastic present in soil and their effects on soil properties and thereafter plant growth. Considering plastics as a diverse group of contaminants will help in developing sampling, quantification and characterization techniques in higher plants. This understanding can help in development of management strategies for plastic pollution and emission curb to agricultural ecosystems and further to humans as consumers.

9. AUTHOR CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the international committee of medical journal editors (ICMJE) requirements/guidelines.

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11. CONFLICTS OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

12. ETHICAL APPROVALS

Not applicable.

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