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Uptake of Microplastics by Plant: a Reason to Worry or to be Happy?

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ABSTRACT

Microplastic (MP, 1 μm − 5 mm) pollution has become a global environmental concern with potential risk to ecosystem and human health. Information on the accumulation of MPs in aquatic species has been well documented, while information on the uptake and accumulation of MPs by higher plants is still very scarce. Terrestrial edible plants are directly exposed to MPs when soil was applied with sludge, organic fertilizer, plastic mulching, waste water irrigation, plastic littering, surface runoff or from atmospheric deposition of airborne MP. One study using fluorescent marker recently showed that plant can accumulate MP through uptake from MP polluted soil. Thus, potentially contaminating the base of the food-web and also indicating new exposure route to MP ingestion. This review present a discuss of the implication of these findings to human, who may be ingesting an estimated 80 g of MP through eating of plant daily as global consumption rate of plant continually increase. Also, benefit for the terrestrial ecosystem is discussed, by which plant acts as a potential remediator of MP polluted soil either by phytoextraction, phytostabilization and phytofilteration. We conclude by pointing knowledge gap and suggesting key future areas of research for scientists and policymakers.

***Keyword*:** Agricultural soil, Food, Human health, Phytoremediation, Plant, Toxicity, Microplastic

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1. INTRODUCTION

Microplastics are plastic particles of size range 1μm - 5 mm. They are of current concern globally because they are ubiquitous in nature and thus persistent in the environment (Verla et. al., 2019a,b). Over the last decade and half, extensive studies have been conducted by scientists as well as governmental and non-governmental organizations, on their occurrence and impacts in aquatic environments. Conclusion from those studies has generally shown that aquatic animals can interact with microplastics by entanglement or ingestion/accumulation and cause detrimental effects on their survival and health (Auta et al. 2017; Frydkjær et al. 2017; de Souza Machado et. al., 2018; Li et. al., 2018).

Reports have suggested that soils are probably receiving much more plastic wastes than the oceans (Horton et al. 2017) of which approximately 34.8 million metric tons was in landfills in 2017 (Verla et. al., 2019a) and 80 % of them pollutes the marine environment (Browne et. al., 2008). Given the importance of soil in global ecosystem, studies on terrestrial ecosystem although still very new (mostly published in 2016–2019), have started gaining attention recently. These studies focused on level of contamination and possible sources of microplastics in soil, as well as their effects on survival, growth, reproduction, feeding and immune system of soil organisms (Huerta et al. 2016; Rodriguez-Seijo et al. 2017; Zhang and Liu 2018; Zhu et al. 2018; Huang et. al., 2019) while research regarding soil flora is still very limited and poorly documented perhaps due to complexities. The aim of this review is to provide an overview of current knowledge on the occurrence and likely ecological impacts of microplastics in soil focusing on soil-plant system.

2. OCCURRENCE OF MICROPLASTICS IN PLANT

Microplastics can enter soil environments via multiple routes, which have recently been reviewed by Bläsing and Amelung (2018) and more concisely by incorporating new studies as well as their distribution in soil by Zhu et. al., (2019). In this paper, we will give a quick summary of the routes by which microplastics reach the soil environment, which include (1) land application of sludge and organic fertilizer, (2) agricultural plastic film from plastic mulching, (3) atmospheric deposition of airborne microplastics (Enyoh and Verla, 2019; Enyoh et. al., 2019) and (4) waste water irrigation, littering and surface runoff. The first two routes are common with agricultural lands/soils, while (3) and (4) might be an important source for forest, urban and industrial soils (Zhu et. al., 2019).

The presence of MPs in soil could change soil properties which could be beneficial or detrimental for plants (Figure 1, showing flourishing and stunted plants) and food quality. Furthermore, plants have the ability to grow in an area polluted by plastics; so long they are not shielded from light (Figure 1). This increases their tendency of accumulating microplastics (MPs), since by natural weathering assisted by sunlight large plastic debris are broken into MPs. Studies have shown the possibility of plant accumulating very small size (nano and micro) plastics from plastics polluted soil (Bandmann et al. 2012; Li et al. 2019) and being affected either positively or negatively depending on plant type (Tao et. al., 2012; Zhang et. al., 2015; Qi et. al., 2018). The effects are based on the idea of plants accumulating MPs from soil through uptake. Zhu et. al., (2019) explained that the hypothesis for the uptake is that plant cell wall and membrane barriers can be by-passed by small-sized microplastics, which can be studied/ monitored using fluorescent microbeads.

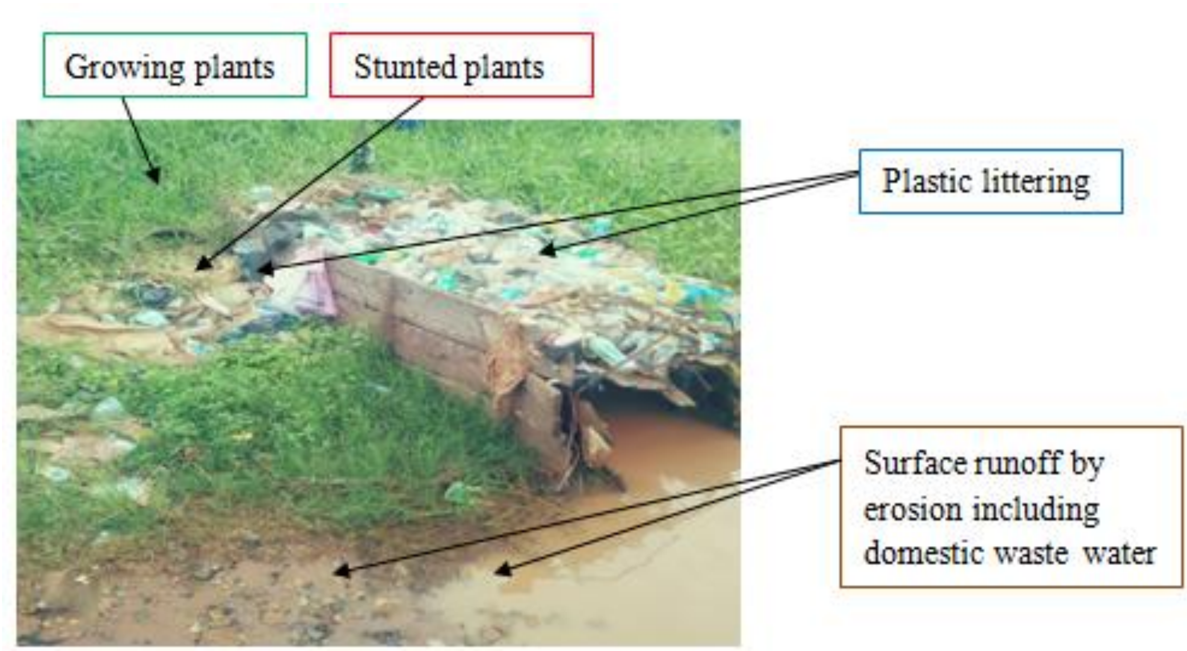

Figure 1. Urban soil plastic pollution, showing growing plants and stunted ones in the polluted site. Plants may be affected either positively or negatively by the presence of plastics in growing soil (Image credit: The authors).

Regarding the possibility of accumulation of MP by plant, Li et. al., (2019) using fluorescent markers studied the uptake, distribution and migration of two sizes of polystyrene (PS) microbeads (0.2 and 1.0 µm) in an edible plant lettuce. The authors observed that 0.2 µm fluorescent microbeads were extracellularly trapped in the root cap mucilage visible to the naked eye and confocal images revealed that the PS luminescence signals were mainly located in the vascular system and on the cell walls of the cortex tissue of the roots,suggesting that the beads passed through the intercellular space via the apoplastic transport system (Figure 2). Once inside the central cylinder, the 0.2 µm PS beads were transferred from the roots to the stems and leaves via the vascular system following the transpiration stream. Furthermore, the PS beads adhered to one another and self-assembled systematically into “grape-like” and “(chain) string-like” clusters in the intercellular space of the root and stem vascular tissue of lettuce plant. In contrast to the root and stem, PS beads were dispersed in the leaf tissue (Li et. al., 2019). This study provided evidence of the adherence, uptake, accumulation, and translocation of submicrometer MPs within an edible plant. Thereby, confirming plant ability to accumulate microplastics from soil through uptake and potentially contaminating the base of the food-web. Regarding the effects of MPs in plant system, Qi et. al., (2018) conducted a pot experiment to investigate different types (low-density polyethylene (LDPE) and starch-based biodegradable plastic) and sizes (1 mm, 500 µm, 250 µm and 50 µm) of plastic mulch film residues present in sandy soil on wheat plant (*Triticum aestivum*) in a climate chamber.

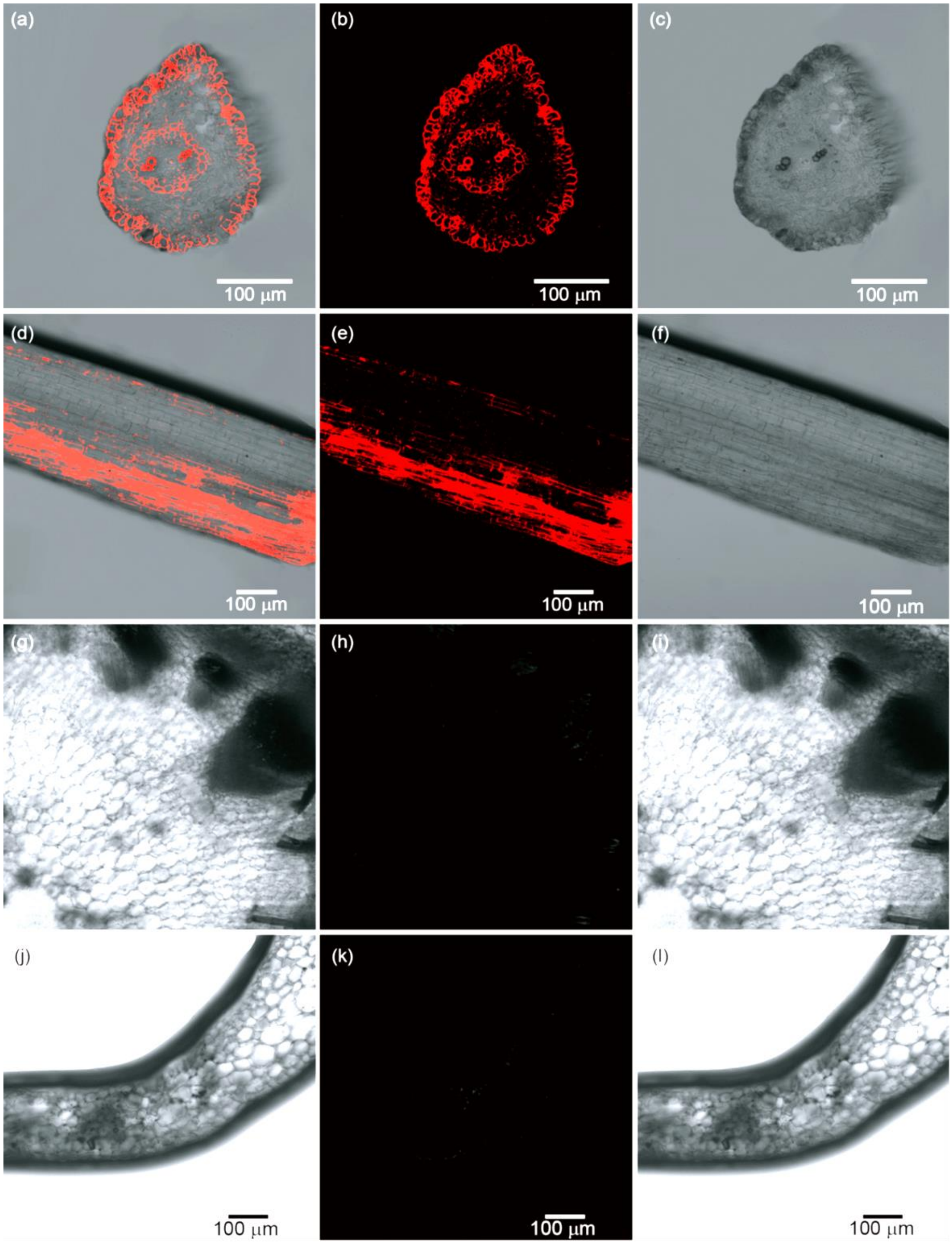

Figure 2. Confocal images of cross ((a)−(c)) and longitudinal ((d)−(f)) section of lettuce root, stem ((g)−(i)) and leaf ((j)−(l)) treated for 14 d with a 50 mg/L solution of 0.2 µm fluorescently labelled polystyrene (PS) microbeads. (a), (d), (g), and (j) are the corresponding merged images of (b) and (c), (e) and (f), (h) and (i), (k) and (l) (Reprinted from Li et. al., 2019)

The wheat was harvested at two time points (after 2 and 4 months) in order to examine the effects on both vegetative and reproductive growth. Overall, the study revealed that MP residues of LDPE and biodegradable mulch films have negative effects on both above-ground and below-ground parts of wheat and affect both vegetative and reproductive growth. Zhang et al. (2015) from a field experiment using corn plant, found that large amounts of accumulated LDPE residues (with the maximum content of 0.35%) may improve soil fertility (Zhang et al., 2015) and also improve corn growth.

3. IMPLICATION OF PLANT-MICROPLASTICS INTERACTION

The global consumption of plant continues to grow annually due to increasing global population and economic growth. From 1995 to 2005, human consumption of land plants (including for food, paper, clothing, livestock feed, firewood, biofuels, building and packaging materials, among other uses) rose from 20 percent to 25 percent of the total plant production of each year (Lynch, 2010). According to estimates, there are over 400,000 species of plant on Earth, of which over 200,000 is edible (Warren, 2016) and all of these species are grown on soil, which may be polluted by MP.

Following the findings of Qi et. al., (2018), Li et. al., (2019) and Bandmann et al. (2012), it is safe to say that humans may be ingesting microplastics and nanoplastics through eating of plants. World Health Organization recommended consumption of at least 400 g of fruit and vegetables per day, excluding potatoes, sweet potatoes, cassava and other starchy roots (WHO, 2003). Inline, one-fifth of this estimate may be consumed as MP i.e about 80 g may be consumed per day considering factors such as the ability of MP to biopersist and translocate in plant. In the European Union (EU), 65.5 % of the population (≥ 15 years old) eats fruits and vegetable daily (Eurostat, 2018), so 5240 g of MP may be consumed daily from fruits and vegetable consumption in the EU. This can be a call for concern. However, this prediction is speculative since there is no study to have quantified MP in plants. In addition the rate of uptake might vary by MP type (size, shape and stage of degradation), MP concentration in soil and plant type. Ingested MP may pose problems to human as MP has the tendency to adsorp toxic chemicals such as heavy metals and persistent organic pollutants from soil (Verla et. al., 2019b) and potentially leaching endocrine disrupting chemicals (EDCs) (Chen et. al., 2019) while preparing the plant containing MP for eating. Also plants have the tendency of also accumulating these toxic chemicals from soil (Uwah et. al., 2011; Ibe et, al., 2017). The potential risks of ingesting MP have been discussed extensively in many studies (GESAMP, 2015; Wright and Kelly, 2017; Smith et. al., 2018), which could be particle and chemical toxicity, relying on individual susceptibility. However, studies are needed to ascertain the effects of MP ingested from plant, since some biochemical reaction may have taken place while the MP was in the plant. Also, research is required to find out if plant accumulates MP with adhered toxic chemicals from soil.

4. PLANT AS POTENTIAL PHYTOREMEDIATOR FOR MPS IN SOIL

The overall objective of any soil remediation approach is to create a final solution that is protective of human health and the environment. Remediation is generally subject to an array of regulatory requirements and can also be based on assessments of human health and ecological risks where no legislated standards exist or where standards are advisory (USEPA, 2007). For MP contaminated soils, the properties of the MP contaminant in soil may strongly influences the selection of the appropriate remediation treatment approach. Information about the physical characteristics of the site and the type and level of contamination at the site must be obtained to enable accurate assessment of site contamination and remedial alternatives.

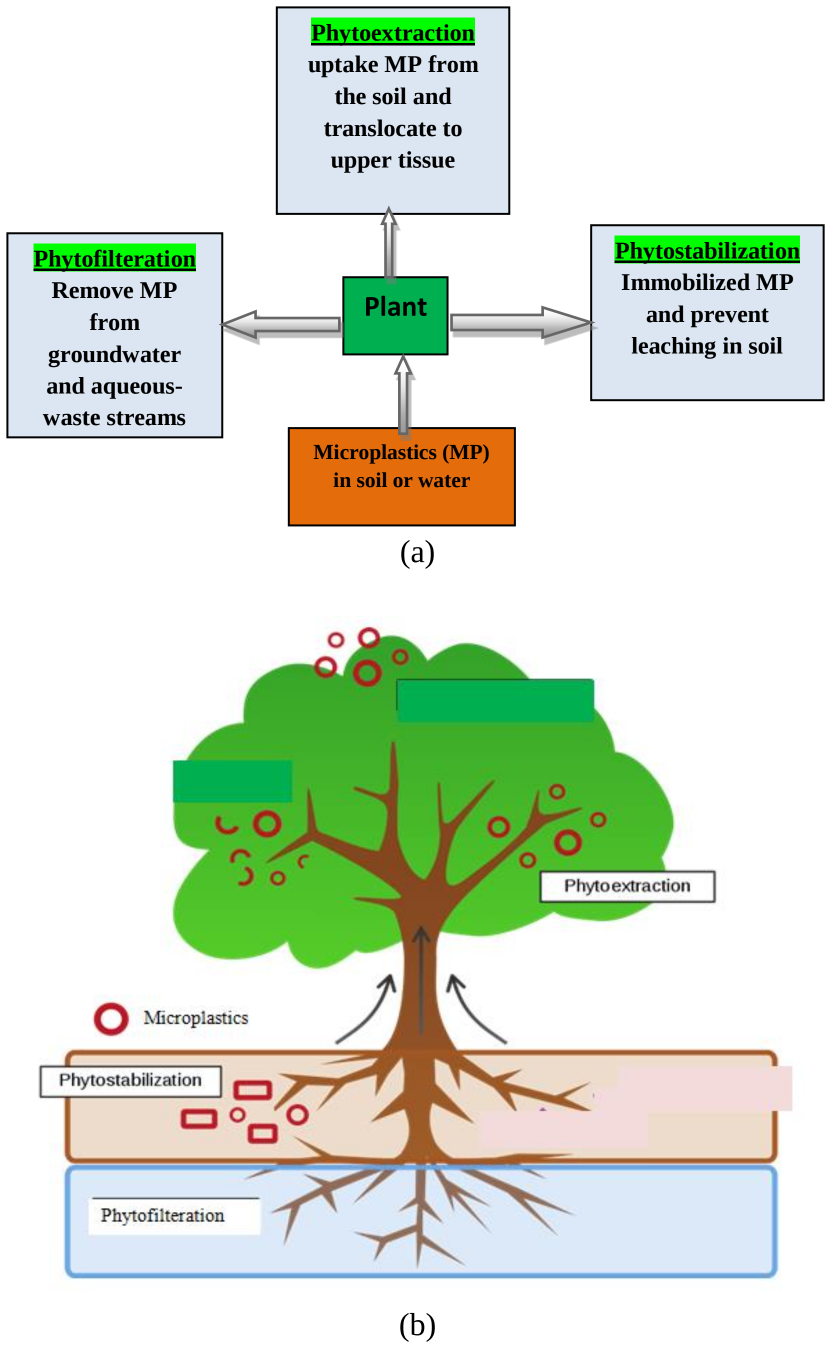

Figure 3. Potential phytoremediation techniques for remediation of MP

Phytoremediation, also called green remediation, botanoremediation, agroremediation, or vegetative remediation, can be defined as an in situ remediation strategy that uses vegetation and associated microbiota, soil amendments, and agronomic techniques to remove, contain, or render environmental contaminants harmless (Gupta et. al., 2000). For heavy metals, the idea of using metal-accumulating plants to remove heavy metals and other compounds was first introduced in 1983, but the concept has actually been implemented for the past 300 years on wastewater discharges (USEPA, 1997). Plants may break down or degrade organic pollutants or remove and stabilize metal contaminants (USEPA, 1997). Similarly, due to recent findings (Bandmann et al., 2012; Qi et. al., 2018; Li et. al., 2019), plant can also accumulate MP contaminant from soil, thus serving as a potential phytoremediator for MP in terrestrial ecosystem. However, potentially useful phytoremediation techniques for remediation of MP contaminated soils or water include phytoextraction (phytoaccumulation), phytostabilization, and phytofiltration (Figure 3a,b). The basis for plant use and examples of potential plants are summarized in Table 1.

Table 1. Phytoremediation techniques, basis for plant use and potential plants for MP remediation.

Techniques	**Basis for plant use**	**Potential plants**	**Merit and Demerit (USEPA, 2007)**
Phytoextraction/ phytoaccumulation	(1) MP tolerant (2) have high MP accumulating ability in the foliar parts (3) have high biomass yield per hectare and rapid growth, (4) have a profuse root system, and a high bioaccumulation factor.	Many plants species including fruits, vegetable and root crops.	**Merits** are (i) more economically viable (ii) less disruptive to the environment and does not involve waiting for new plant communities to recolonize the site, (iii) disposal sites are not needed, (iv) it is more likely to be accepted by the public as it is more aesthetically pleasing, (v) reduce the risk of spreading the contamination, and (vi) it has the potential to treat sites polluted with more than one type of pollutant (MP and heavy metals) **Demerit** are as follow (i) dependant on the growing conditions required by the plant (i.e., climate, geology, altitude, and temperature), (ii) large-scale operations require access to agricultural equipment and knowledge, (iii) success is dependant on the tolerance of the plant to the pollutant, (iv) contaminants collected in senescing tissues may be
Phytostabilization	(1) decrease the amount of water percolating through the soil matrix (2) act as barrier to prevent direct contact with the contaminated soil, and (3) prevent soil erosion or reduce wind erosion and the distribution of the MP to other areas	Ornamental plants, Yard long bean, peanut etc.	
Phytofilteration	MP tolerant (2) have high MP accumulating ability in the foliar parts (3) have a profuse root system, and a high bioaccumulation factor.	Sunflower, Indian Mustard, Tobacco, Rye, Spinach, Corn, Parrot's Feather, Iris-leaved Rush, Cattail,	

		Saltmarsh bulrush, Scirpus, Robustus	released back into the environment in autumn, (v) contaminants may be collected in woody tissues used as fuel, (vi) longer-time is required to remediate sites (vii) contaminant solubility may be increased leading to greater environmental damage and the possibility of leaching.

Plants firstly accumulate MP on their root as first point of contact as shown in the study of Li et. al., (2019), who observed that 0.2 μm microbeads of polystyrene (PS) were extracellularly trapped in the root cap of edible lettuce plant. So, all potential phytoremediation techniques are based on first root contact. Phytoextraction or phytoaccumulation is a publicly appealing (green) remediation technology, where plant roots uptake MP contaminants from the soil and translocate them to their above soil tissues. Phytostabilization is primarily based on the use of certain plants to immobilize MPs in soil. Phytostabilization can occur through the process of sorption and precipitation. MP has the tendency of leaching in deeper zone in soil (Fisner et al., 2013), with potential contamination of ground water.

So by phytostabilization, MP are absorbed and accumulated onto roots or precipitated in the rhizosphere of plant. This reduces or even prevents the mobility of MP, thus preventing migration into the groundwater or air and also reduces the bioavailability of the MP, which in turn prevent spreading of MP through the food chain. Phytofiltration is the use of plant roots (rhizofiltration) or seedlings (blastofiltration), similar in concept to phytoextraction, but is used to absorb or adsorb MP, from groundwater and aqueous-waste streams rather than soil. Rhizosphere is the soil area immediately surrounding the plant root surface, typically up to a few millimetres from the root surface (Figure 3b).

The contaminants are either adsorbed onto the root surface or are absorbed by the plant roots (Gardea-Torresdey et. al., 2004; Fawzy, 2008). Once the roots are saturated, they are harvested and disposed of safely. Repeated treatments of the site can reduce pollution to suitable (Gardea-Torresdey et. al., 2004).

5. CONCLUSION, KNOWLEDGE GAP AND FUTURE AREA OF RESEARCH

Microplastics can be accumulated from MP polluted soil. The pollution of MP in soil can either improve or decrease soil quality, which in-turn may affect either positively or negatively the growing plant. Accumulation can be studied using fluorescent microbeads.

The effect of plants accumulating MP in plant-soil system is Janus-faced. It could be detrimental for human as well as animals health, as the interaction is contaminating the base of the food-web and conferring new exposure route. The interaction could also be good for the environment by acting as a potential phytoremediator of MP through phytoextraction, phytostabilization and phytofilteration.

Knowledge gap and future area of research

- Information regarding the accumulation of MP by plants from soil is still very sketchy and currently not clear. Therefore, more studies are required for better understanding of Plant-MP-Soil interaction
- Edible lettuce plants have only been studied for uptake. Meanwhile, there are more that 200,000 edible plant species, so it is clear there is need for more studies quantifying MP (also in terms of type and shape) in more different plant species to better understand its distribution in plant.
- The effects of MP pollution in soil on plants are not clear. Qi et. al., (2018) observed poor growth of wheat plants while Zhang et. al., (2015) observed improved soil quality for corn plants. Could the effects be based on plant type or MP concentrations and type? There is need for more study regarding the effects of MP pollution in soil on plants.
- Could plant accumulate toxic metals along with MP during uptake from soil, since MPs are known to adsorb toxic chemicals from ambient environment? This is a basis for precise risk assessment.
- There are needs for studies on the potentiality of using plants are phytoremediator of MP pollution from the environment.

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