Chapter 13
Restoration of Micro-/Nano plastics: Contaminated Soil by Phytoremediation

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Abstract This chapter gives an overview of an environmental remediation technology, including its principles, applicability, utilization, and advantages/disadvantages. This report is reported for information view only. Information used in this was collected from periodicals, through web searches, and in some cases, personal communications with the involved party. Microplastics are small pieces of plastic found in the environment and are harmful to animals. I wondered if microplastics could affect plants as well. The objective of this project was to determine if plants could absorb microplastics through their roots. Phytoremediation uses plants to clean up contaminated soil and underground water, taking advantage of plants' natural ability to take up constituents of their soil and water environments. Major advantages of this as compared to traditional methods of remediation, which has the possibility of generating less secondary wastes, minimal associated environmental disturbances and possibility of contaminant entrance into the food chain through consumption of plants by animals.

Keywords Phytoremediation · Nano-/microplastics · Methods · Applicability

13.1 Introduction

Phytoremediation is a special application of bioremediation. It is *a natural biological process of degradation of xenobiotic and recalcitrant compounds responsible for environmental pollution* (Cunningham et al., 1996). The word phyto stands for "plant" hence the remediation mediated by plant system. Environmental restoration is a phenomenon required to keep the ecosystem intact or enhance the rejuvenation of impaired environmental media; soil, water, and air (Wikipedia). Various methods

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N. R. Maddela et al. (eds.), *Micro and Nanoplastics in Soil*,
https://doi.org/10.1007/978-3-031-21195-9_13

of remediation exist, yet restoring the environment to the proximal or original state appears elusive to most methods. Interestingly, phytoremediation, which is a biological process, does not only restore the environment in a greener way but can also adopt diverse mechanisms such as phytoextraction, phytodegradation, rhizodegradation, phytostabilization, and phytovolatilization to achieve the desired outcome (Tanee & Akonye, 2009; Tessier et al., 1979; Cunningham & Ow, 1996). The chapter also unlined the merits and a few demerits of this principle, while the identification of sustainable plants and the mitigation of time constraints were the future directions mentioned for the projection of phytoremediation as the ideal approach for the restoration of the environment EPA (2000). Phytoremediation is proposed as a cost-effective plant-based approach of environmental remediation that takes advantage of the ability of plants to concentrate elements and compounds from the environment and to detoxify various compounds. The concentrating effect results from the ability of certain plants, called hyperaccumulators, to bioaccumulate chemicals (Raskin & Ensley, 2000). The remediation effect is quite different. Toxic heavy metals cannot be degraded, but organic pollutants can be and are generally the major targets for phytoremediation. Several field trials confirmed the feasibility of using plants for environmental cleanup (Li et al, 2014).

Microplastics: Microplastics are small pieces of plastic, less than 5 mm (0.2 inch) in length, that occur in the environment as a consequence of plastic pollution. Microplastics are present in a variety of products, from *cosmetics to synthetic clothing to plastic bags and bottles* (Wikipedia).

13.2 Methodology

The mechanisms and efficiency of phytoremediation depend on the type of contaminant, bioavailability, and soil properties (UNEP) (Fig. 13.1). There are many ways in which plants clean up or remediate contaminated sites. The uptake of contaminants in plants occurs primarily through the root system, in which the initial mechanisms for preventing toxicity are found. The root system provides a surface area that absorbs and accumulates water and nutrients essential for growth, along with other unwanted contaminants. This has identified mechanisms by which plants can affect contaminant mass in soil, sediments, and water (USEPA, 2000). Although overlap or similarities can be observed between some of these mechanisms, and the nomenclature varies, this report makes reference to phytoremediation methods, of these mechanisms will have an effect on the volume, mobility, or toxicity of contaminants, as the application of phytoremediation is intended to do (Figs. 13.2 and 13.3).

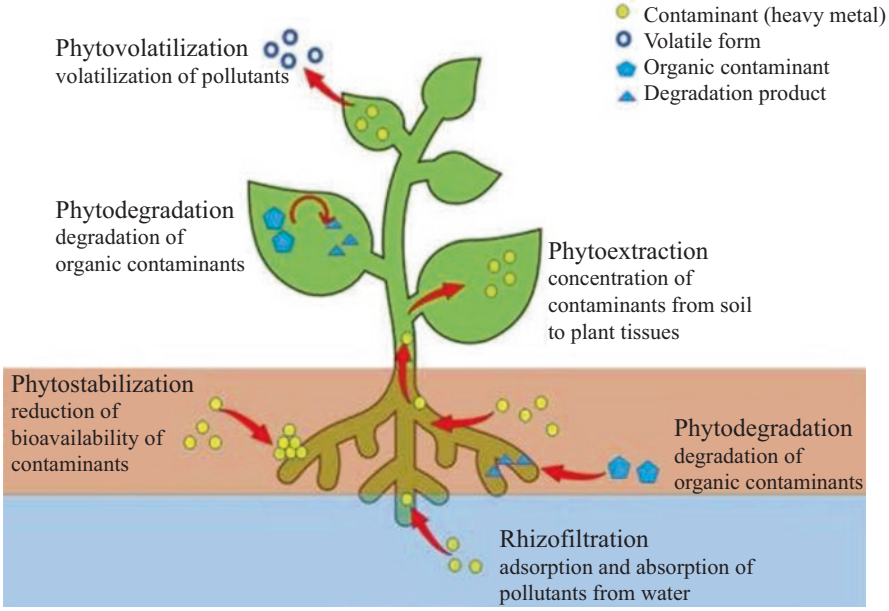

Fig. 13.1 Schematic representation of phytoremediation. (Yadav et al., 2011)

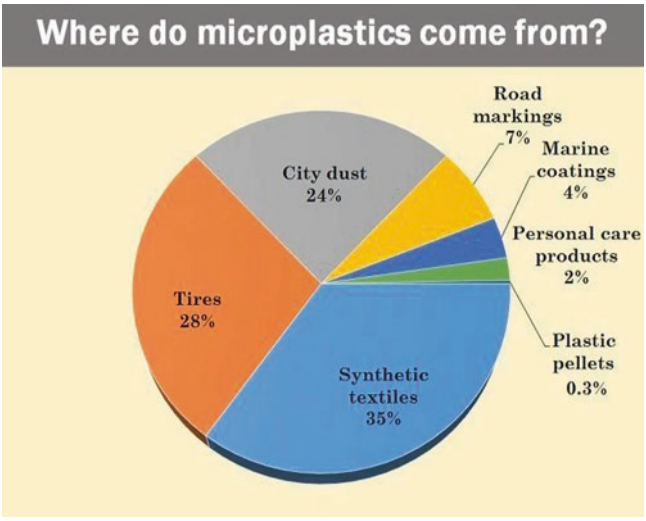

Fig. 13.2 Potential sources of microplastics to contaminate environments. (Source: International Union for Conservation of Nature, 2017)

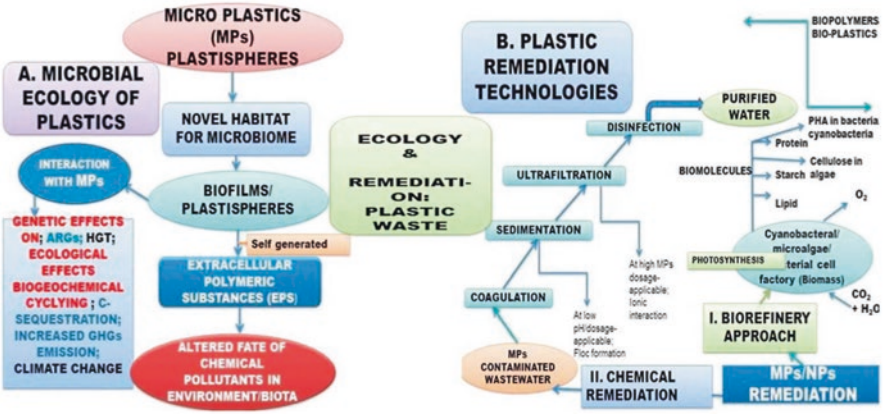

Fig. 13.3 Sources of microplastics in soil. WWTPs indicates wastewater treatment plants. (Andrady, 2011)

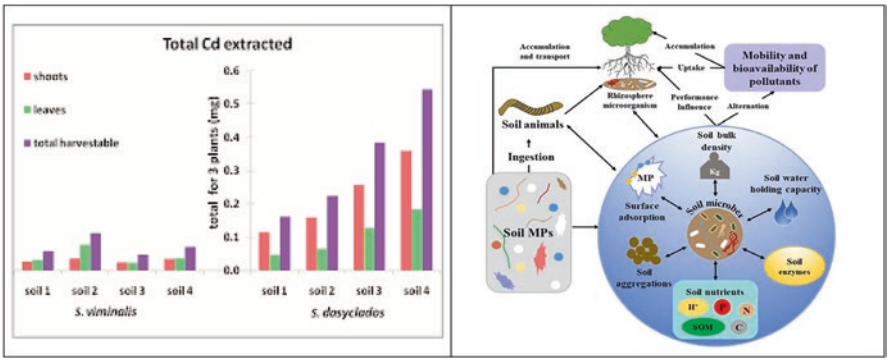

Fig. 13.4 (**a**) Heavy metals: contaminant soils (Wikipedia) (**b**) Microplastics in soil (Gou et al., 2020)

13.3 Types of Phytoremediation

There are many schemes related to this, the most common of them are as follows:

Rhizofiltration: primarily used, absorption, concentration, precipitation of heavy metals and non-metals by roots of plants (Wuana et al., 2010) (Fig. 13.4).

Phytoextraction: contaminants in harvestable plant tissues of roots and surface shoots are extracted and accumulated.

Phytotransformation: The incorporation of simple molecules into plant tissues after degradation of organic compounds..

Phytostimulation: also known as plant-assisted bioremediation. Stimulation of microbial degradation by the release of enzymes into the rhizosphere (Zhuang et al., 2005).

Phytostabilization: by reducing the mobility and preventing their migration to groundwater it involves in absorption, precipitation of contaminants, principally of metals by plants.

13.4 Harvesting/Disposal of Plant Material

Plants shoots are harvested and roots are removed when plants accumulate waste material, and methods used for disposal are based on the toxicity of end products of in-plant organic chemicals and storage locations in plant tissues (Boisson et al., 1999).

If the harmful contaminants are degraded from organic to simpler molecules there is no need for disposal. The significant application takes place only in roots, then those specific things have to be removed. The most common method used is *controlled incineration,* which results in ashes with toxic metals. Other methods of plant tissue treatment currently under investigation include sun, heat, air drying; composting; pressing and compacting; leaching (Li et al, 2014; Miretzky & Fernandez-Cirelli, 2008).

13.5 Soil Remediation Methods

Phytoextraction it involves removal of metals, radionuclides, certain organic compounds like hydrocarbons by direct absorption in plant tissues (Wani et al., 2012). It involves planting of one or more species that are major accumulators of contaminants of concern. Water and fertilizers may be required as primary field testing to ensure successful plant growth. After complete growth and development plant tissue is removed and a new crop is planted Brennan and Shelley (1999).

Characteristics of plants which are able to perform the method are rapid growth rate; high biomass production; ability to tolerate high accumulation of metals in harvestable tissues.

Phytostabilization the use of certain metal-tolerant plant species to absorb and precipitate toxic organic molecules by reducing their bioavailability and reduces the effect on humans. It is used to reestablish a vegetative cover at sites where natural vegetation is lacking due to high metal concentrations in surface soils and materials. Metal-tolerant species can be used to restore vegetation to the sites, thereby decreasing the potential migration of contamination to water bodies (Freitas et al., 2014).

Characteristics of plants suitable for phytostabilization at a particular site: tolerance to high levels of contaminants; high production of root biomass able to immobilize these contaminants through uptake, precipitation, or reduction; retention of

applicable contaminants in roots, as opposed to transfer to shoots, to avoid special handling and disposal of shoots (Tokalıoğlu et al., 2010).

13.6 Applicability

Phytoremediation is a plant-based approach which involves the use of plants to extract and remove elemental pollutants or lower their bioavailability in soil (Tokalıoğlu et al., 1979). Or, in other words, phytoremediation is the direct use of living green plants for in situ removal, degradation, or containment of contaminants in soils, sludges, sediments, surface water, and ground water. By harnessing the natural capabilities of plants, we can remove, degrade, or stabilize contaminants.

There are several ways in which plants are used to clean up or remediate contaminated sites. To remove pollutants from soil, sediment, and water, plants can breakdown or degrade the organic pollutants and stabilize metal contaminants by acting as filters or traps (Kong & Bitton, 2003).

13.7 Conclusion

An abrupt rise in plastic waste has become one of the most serious global environmental problems during the past five decades, and many strategies have been suggested to control the increasing levels of contaminants associated with plastic waste. Although many studies have focused on the fate, toxicity, and health problems of plastic waste contaminants, only a very few have investigated microbial remediation of contaminants using cutting-edge nanoscience. This review focuses on addressing the environmental problems caused by microplastics (MP) and nanoplastics (NP) particles in view of nanoscience. Test microplastics were not absorbed in either soil or tissue culture seedlings, even though plants can absorb small dye molecules. Microplastics breakdown slowly in the soil and it is possible that these breakdown products could be absorbed.

There are several ways in which plants are used to clean up or remediate contaminated sites. To remove pollutants from soil, sediment and/or water, and air, plants can break down or degrade organic pollutants or contain and stabilize inorganic contaminants by acting as filters or traps. The success of phytoremediation at a given site cannot always be attributed to just one of these mechanisms because a combination of mechanisms may be at work. Phytoremediation is a low-cost, solar-energy driven and natural cleanup technique, which are most useful at sites with shallow, low levels of contamination. They are useful for treating a wide variety of environmental contaminants and are effective with or, in some cases, in place of mechanical cleanup methods. Phytoremediation harnesses natural processes to assist in the clean-up of pollutants in the environment (Park et al., 2011). The mechanisms by which plants promote the removal of pollutants are varied, including

uptake and concentration, transformation of pollutants, stabilization, and rhizosphere degradation, in which plants promote the growth of bacteria underground in the root zone that in turn break down pollutants. Phytoremediation is amenable to a variety of organic and inorganic compounds and may be applied either in situ or ex situ. In situ applications decrease soil disturbance and the possibility of contaminants spreading via air and water, reduce the amount of waste to be land filled (up to 95%), and are low-cost compared with other treatment methods. In addition to this, it is easy to implement and maintain, does not require the use of expensive equipment or highly specialized personnel, and is environmentally friendly and aesthetically pleasing to the public.

References

Ahmad, M., Hashimoto, Y., Moon, D. H., Lee, S. S., & Ok, Y. S. (2012). Immobilization of lead in a Korean military shooting range soil using eggshell waste: An integrated mechanistic approach. *Journal of Hazardous Materials, 4*, 392–401.

Allouzi, M. M. A., Tang, D. Y. Y., Chew, K. W., Rinklebe, J., Bolan, N., Allouzi, S. M. A., & Show, P. L. (2021). Micro (nano) plastic pollution: The ecological influence on soil-plant system and human health. *Science of the Total Environment, 20*(788), 147815.

Andrady, A. L. (2011). Microplastics in the marine environment. *Marine Pollution Bulletin, 62*(2011), 1596–1605. https://doi.org/10.1016/j.marpolbul.2011.05.030

Boisson, J., Ruttens, A., Mench, M., & Vangronsveld, J. (1999). Evaluation of hydroxyapatite as a metal immobilizing soil additive for the remediation of polluted soils. Part 1. Influence of hydroxyapatite on metal exchangeability in soil, plant growth and plant metal accumulation. *Environmental Pollution, 104*, 225–233.

Brennan, M. A., & Shelley, M. L. (1999). A model of the uptake, translocation, and accumulation of lead (Pb) by maize for the purpose of phytoextraction. *Ecological Engineering, 12*, 271–297.

Cunningham, S. D., & Ow, D. W. (1996). Promises and prospect of phytoremediation. *Plant Physiology, 110*, 715–719.

Cunningham, S. D., Anderson, T. A., Schwab, P. A., & Hsu, F. C. (1996). Phytoremediation of soils contaminated with organic pollutants. *Advances in Agronomy, 56*, 55–114.

EPA. (2000). *A citizen's guide to phytoremediation*. EPA 542-F-98-011. United States Environmental Protection Agency, p. 6. Available at: http://www.bugsatwork.com/XYCLONYX/EPA_GUIDES /PHYTO.PDF

Freitas, E. V., Nascimento, C. W., & Silva, W. M. (2014). Citric acid-assisted phytoextraction of lead in the field: The use of soil amendments. *Water, Air, and Soil Pollution, 225*, 1–9.

Guo, J. J., Huang, X. P., Xiang, L., Wang, Y. Z., Li, Y. W., Li, H., & Wong, M. H. (2020). Source, migration and toxicology of microplastics in soil. *Environment International, 137*, 105263.

International Union for Conservation of Nature annual report. (2017). International Union for Conservation of Nature annual report 2017, https://portals.iucn.org/library/node/47536, 1, IUCN-2018-007, (2017).

Kong, I. C., & Bitton, G. (2003). Correlation between heavy metal toxicity and metal fractions of contaminated soils in Korea. *Bulletin of Environmental Contamination and Toxicology, 70*, 557–565.

Li, Z., Zhou, M., & Lin, W. (2014). The research of nanoparticle and microparticle hydroxyapatite amendment in multiple heavy metals contaminated soil remediation. *Journal of Nanomaterials, 17*, 1–8. [Google Scholar] [CrossRef].

Miretzky, P., & Fernandez-Cirelli, A. (2008). Phosphates for Pb immobilization in soils: A review. *Environmental Chemistry Letters, 6*, 121–133.

Park, J. H., Lamb, D., Paneerselvam, P., Choppala, G., Bolan, N., & Chung, J. W. (2011). Role of organic amendments on enhanced bioremediation of heavy metal(loid) contaminated soils. *Journal of Hazardous Materials, 85*, 549–574.

Raskin, I., & Ensley, B. D. (2000). Recent developments for in situ treatment of metal contaminated soils. In *Phytoremediation of toxic metals: Using plants to clean up the environment*. John Wiley & Sons. Available at: http://clu-n.org/techfocus

Tanee, F. B. G., & Akonye, L. A. (2009). Effectiveness of Vigna unguiculata as a phytoremediation plant in the remediation of crude oil polluted soil for cassava (Manihot esculenta Crantz) cultivation. *Journal of Applied Sciences and Environmental Management, 13*, 43–47.

Tessier, A., Campbell, P. G. C., & Bisson, M. (1979). Sequential extraction procedure for the speciation of particulate trace metals. *Analytical Chemistry, 51*, 844–851.

Tokalıoğlu, Ş., Yılmaz, V., & Kartal, Ş. (2010). An assessment on metal sources by multivariate analysis and speciation of metals in soil samples using the BCR sequential extraction procedure. *Clean-Soil Air Water, 38*, 713–718.

United Nations Environment Programme Division of Technology, Industry, and Economics. United States Environmental Protection Agency (USEPA). (2000). *Introduction to phytoremediation*. EPA 600/R-99/107. U.S. Environmental Protection Agency, Office of Research and Development.

Wani, S. H., Sanghera, G. S., & Athokpam, H. (2012). Phytoremediation: Curing soil problems with crops. *African Journal of Agricultural Research, 7*, 3991–4002.

Wuana, R. A., Okieimen, F. E., & Imborvungu, J. A. (2010). Removal of heavy metals from contaminated soil using chelating organic acids. *International Journal of Environmental Science & Technology, 7*, 485–496.

Yadav, B. K., Siebel, M. A., & van Bruggen, J. J. A. (2011). Rhizofiltration of a Heavy Metal (Lead) Containing Wastewater Using the Wetland Plant Carex pendula. *Clean-Soil Air Water, 39*, 467–474. [Google Scholar] [CrossRef].

Zhuang, P., Ye, Z. H., Lan, C. Y., Xie, Z. W., & Hsu, W. S. (2005). Chemically assisted phytoextraction of heavy metal contaminated soils using three plant species. *Plant Soil, 276*, 153–162.