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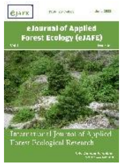

Toxicity of the Nano Plastic Pollution and Phytoremediation with Tree Plants

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Abstract

The new growing pollution is nanoparticles of microplastics that are indigestible but can enter the biotic system and thereby interrupt their development, or facilitate or to be the reason for appearance of new type of diseases that are not known up to now. Nanoparticles have the potential to be harmful to living organisms due to their small size and unique properties. When nanoparticles are released into the environment, they can interact with and potentially enter the bodies of organisms. This can lead to various adverse effects, such as cellular damage, inflammation, and even genetic mutations.

The review article aims to lighten the question about nanoparticles, their spread in the ecological systems, and how they are dangerous for life and different populations of organisms. Also, it presents some data about different plants that are able to mitigate nanoplastics pollution and to be used for phytoremediation. By highlighting the effectiveness of these tree plants, the article aims to provide potential solutions to the problem of plastic pollution.

Keywords: Microplastic, nanoplastics, air, water and soil contamination, phytoremediation.

Introduction

Plastic pollution is a significant environmental issue, with plastic waste accumulating in various ecosystems, including oceans, rivers, and forests (Weinstein et al., 2023; Senarathand Kaushalya, 2023).Plastic particles can be released into the environment through various sources such as the breakdown of larger plastic items, the release of microplastics from synthetic fibers, or the use of personal care products containing microbeads.Nanoplastics (< 100 nm), are all-around found in the environment including water, atmosphere, and soil (Liu et al., 2022), as well as in food (Mikulec et al., 2023; Vitali et al., 2023).Nanoplastics (NPs) and microplastics (MPs) as an environmental pollution are harmful for animals, plants and human (Azeem et al., 2021).Due to thepotential toxicity to humans, NPs are of particular concern (Alqahtaniet al.,2023). The toxic impacts of MPs/NPs in plants and their accumulation in the food chain become a top priority for investigation recently (Roy et al., 2023).

Plastic waste is the primary sources of MPs and NPs (Alqahtani et al., 2023). Major raw polymers of microplastics include polyethylene terephthalate (PET), polyurethane (PU), polystyrene (PS), polyvinylchloride (PVC), polypropylene (PP), polyesters, polyethylene (PE), and polyamide (PA, nylon) (Mohsen et al., 2020). Only 9% of plastic waste is recycled in developed countries, and the remaining 91% stays in the environment for centuries (Brooks et al., 2018) and generates MPs (1 µm–5 mm). MPs have been detected in most biomes, which has emerged to be a critical global challenge (Barnes 2019; Iñiguez et al., 2018; Zettler et al., 2013). Now environmental pollution and recession in the entire globe are already rather severe. Even in 2009 (UNEP Yearbook 2009), there are 25 countries where the entire forest ecosystem has disappeared and another 29 countries with a 90 % decrease.

In the water biomes, since the 1960s, the biomass of major economic marine fishes has been reduced by 90 % (Jianping et al., 2013). Now the ecological situation may be worse.

Nanoplastics are drawing a significant attention as a result of their propensity to spread across the environment and pose a threat to all organisms (Imran et al. 2021; Keerthana et al. 2022; Gomes et al., 2022). Organic pollutants could be adsorbed onto MPs/NPs and there is evidence that this could potentially enhance their effective uptake and toxicity (Velzeboer et al., 2014; Hüffer and Hofmann 2016; Hüffer et al., 2018; Fang et al., 2019; Maocai et al., 2019; Tourinho et al., 2019). The evidence for the health impacts of MPs and NPs is still limited, and more examinations are needed to fully understand the risks associated with exposure to these pollutants.

The review article aims to shed light on these potential dangers and provide a better understanding of the risks associated with nanoparticles, also proposes information about tree plants that have been proven to mitigate plastic pollution. By highlighting the effectiveness of these tree plants, the article aims to provide potential solutions to the problem of plastic pollution.

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Micro- and nanoplastics in different environments

NPs/MPs contamination is a rapidly growing worry throughout the world and has been listed as the second most concerning environmental problem (Horton et al., 2017; He et al., 2018a; Mai, 2018) after global warming (Jianping et al., 2013).

Geyer et al., (2017) estimate that 8.3 billion tons (Bt) of plastics were produced from 1950 to 2015, and 5.7 Bt of them became waste, 4.9 Bt were discarded into landfills, or in natural environments, such as oceans and waterways (Barnes et al., 2009). Production forecast of plastics worldwide from 1950 to 2050 in millions of metric tons are given in fig.1 (Coyle et al., 2020 and Mikulec et al., 2023).

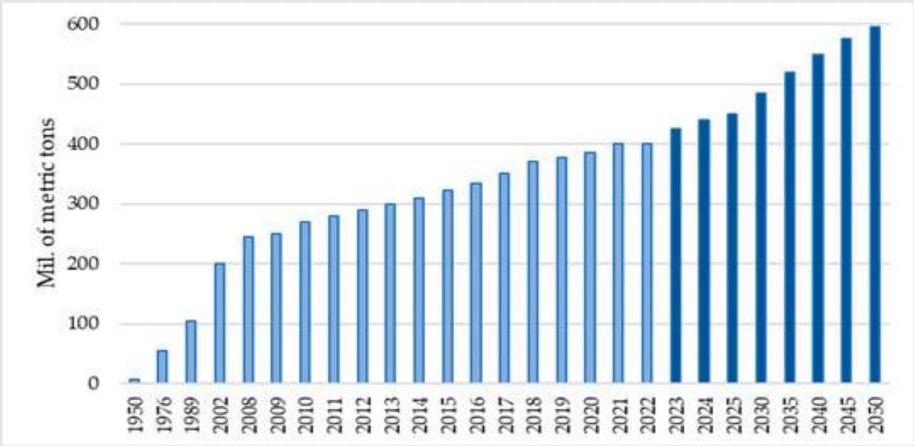

Figure 1. Production forecast of plastics worldwide from 1950 to 2050 in millions of metric tons (Coyle et al., 2020 and Mikulec et al., 2023).

Plastic pollution at high levels is derived from wastewater treatment plants (WTPs) established on agricultural land, approximately 7.76 million tons per year (Peccia and Westerhoff, 2015). The breakdown of microplastics is extremely slow in the soil and aquatic environment and in addition to that it is possible that these breakdown products could be easily absorbed by the organisms and enter in food chain.

MPs and NPs in the air

Urban areas in Western Europe as Frankfurt, industrial Ruhr area in Germany, Netherlands, Paris, and even London are important sources of nanoplastics. Nanoplastics are detected in remote areas in the snow, with average concentration 46 ng/mL of melted surface snow at the high-altitude Sonnblick Observatory in the Alps, with a correlation between nanoplastics concentrations and winds coming from the major European cities. The calculated deposition rate at the snow surface was 42 kg km^{-2} year^{-1}(Materić et al., 2021).

Thermal Desorption-Proton Transfer Reaction-Mass Spectroscopy (TD-PTR-MS) wereuse to measure the mass-concentrations of nanoplastics in the surface waters from two contrasting sites; a remote tundra landscape in the far east Siberian Arctic, and a forested area close to population centres in Sweden. All examined Swedish lakes (n = 7) and streams (n = 4) had a mean concentration 563 µg l^{-1} of NPs from four polymer types polyethylene, polyvinyl chloride (PVC), polypropylene, polyethylene terephthalate. In Siberia nanoplastics were detected in 7/12 sampled lakes, ponds and surface flooding, and two polymer types PVC and polystyrene, with lower concentrations mean of 51 µg 1^{-1} (Dušan et al., 2022).

Thereis a lack of information on atmospheric microplastic deposition or transport, analyzing samples, over five months, atmospheric wet and dry deposition, were identified fibres up to~ 750 µm long and fragments≤ 300 µm as microplastics. Approximately 249 fragments, 73 films, and 44 fibers per square meter deposited on the catchment were detected daily. The air trajectory analysis displays microplastic transport through the atmosphere over a 95 km distance. The suggestion is that microplastics can reach and affect remote, sparsely inhabited areas through atmospheric transport (Allen et al., 2019).

Both MPs and NPs can be inhaled and reach the alveolar surface. However, NPs can overcome the pulmonary epithelium, which acts as a barrier to prevent foreign particles from entering the bloodstream, while MPs may not be able to do so (Facciolà et al., 2021).

MPs and NPs in the aquatic environment

NPs negatively impacts both aquatic and terrestrial ecosystems. Nanoplastics are found all over the Earth, including in the oceans, on coasts, and inland. They can easily travel through the soil, ending up in aquifers and contaminating drinking water. The harmful effects of nanoplastics are found in all three components of the environment. Aquatic systems, in particular, are greatly affected by nanoplastics (Joksimović et al., 2022). The presence of nanoplastics in water is given attention nowadays as the transit of nanoplastics occurs through the aquatic ecosphere besides terrestrial mobility. The principal removal procedures for macro-and micro-plastic particles are effective, but nanoparticles escape from the treatment, increasing in the water and significantly influencing the society (Keerthana et al., 2022).

The main aquatic contaminants comprise PET (Polyethylene Terephthalate), PVC (Polyvinyl Chloride), and PS (Polystyrene) nano plastics (Keerthana et al., 2022).Heavy metals and microplastic pollutants can interact with each other, for example Pb (II) can be absorbed by surface carboxyl functional groups of aged nylon microplastics and that process is spontaneous and endothermic (Gao et al., 2019;Tang et al., 2020; Chen et al., 2023).MPs and NPs can bioaccumulate in the environment and pose acute and chronic toxicity in various animals and marine species (Imran et al., 2021).The amounts of microplastics (MPs) present in marine ecosystems are with potential impacts on human health, because they are associated with an increase in the ecotoxicity of certain foods, such as fish (Mikulec et al. 2023). The ingestion of seafood and utilization of untreated drinking water can lead to the bioaccumulation of MPs and NPs, eventually harming human health (Imran et al., 2021).

MPs and NPs in the soil environment

Soil, especially arable soil, is a major and permanent sink for plastic, coming from anthropogenic activities such as manufacturing (Geyer et al., 2017;de Souza Machado et al., 2018; He et al., 2018b;ChaeandAn 2018). Most of the world's productive and valuable soil resources are exposed to plastic residue (Azeem et al., 2021). Plastics enter through mulching in the soil (SintimandFlury 2017; Luo et al., 2018), through landfills sites (Gasperi et al., 2018; Wright et al., 2020), and through watering with wastewater agricultural lands (Peccia and Westerhoff 2015).

MPs and NPs contain harmful substances including pesticides, polybrominated diphenyl ethers (PBDEs), endocrine-disrupting chemicals (EDCs), polycyclic aromatic hydrocarbons (PAHs), phthalates, and bisphenol-A that are transported to soil systems and leach down to subsoil based on temperature, ultraviolet radiation, soil pH, oxygen content, and dissolved organic matter content (Teuten et al., 2009; Rochman et al., 2013; Adeel 2021; Adeel et al.,2021).

Various MP and NP polymers with different properties may form a diverse range of ecocorona in the soil, and make the situation worse (Roy et al., 2023).

Effects of MPs and NPs on living organisms

Adverse effects on plants

Micro- and nanoplastics are contaminants of alarm and at present nothing is known about the global effects on plants (Rillig et al., 2019). Plants are basic living components of the environment; and producers of organic matter, so a risk assessment of MPs/NPs adverse effects is a crucial (Li et al., 2020). Plants do not absorb microplastics between 1-150 microns (Evans, 2019).Figure 2 shows the absorption mechanism and transport pathways from root to stem and the transport to leaf and fruits of microplastic (Azeem et al., 2021).

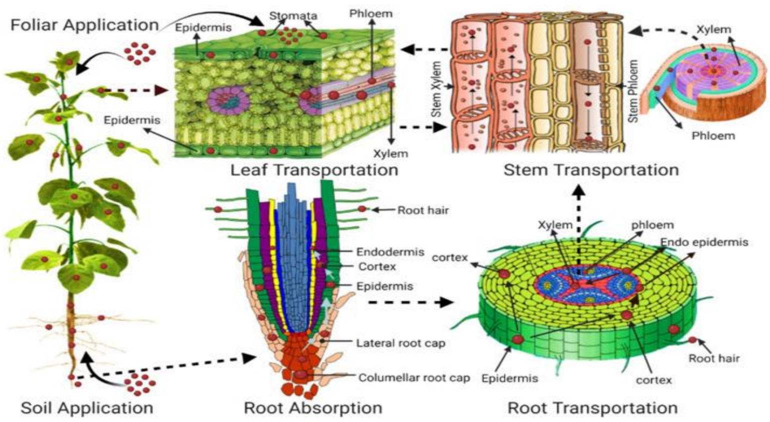

Figure 2. Mechanism of microplastic uptake by plant roots from the soil via absorption mechanism and the transport pathways from root to stem and stem transport to leaf and fruits. Cure arrow indicates the availability of plastic to plant and the dashed arrow indicates transportation within the plant (Azeem et al., 2021).

MPs have insignificant negative effects on plant physiological and biochemical indicators (Azeem et al., 2021).MPs/NPs inhibit seed germination and crop growth in addition to transporting a variety of toxic substances, heavy metals, and pathogens into agroecosystems(Roy et al., 2023). Rice plants are more susceptible to MPs/NPs toxicity than wheat (Roy et al., 2023).

Environmental conditions such as temperature and humidity have an impact on the transpiration pull within the plant that ultimately influences the uptake of MPs or NPs in plants. Crops grown hydroponically are more susceptible to MPs/NPs toxicity (Roy et al., 2023).

Table 1. Adverse effects of micro- and nanoplastics on plant species.

Plant species	Adverse effects	References
Scenedesmus obliquus (green microalgae, a common component of freshwater plankton)	Nanoplastics can inhibit the growth and development of algae species. It also had an impact on increased mortality.	Besseling et al., 2014 Joksimović et al., 2022
Arabidopsis thaliana (L.) Heynh.	Negativephysiological effects.	Sun et al., 2020
Allium cepa	Nano PS reduced root elongation in onion seedlings during germination andinduced cyto/genotoxicity on root meristem. The highest applied concentrations of nano PS triggered oxidative stress.	Giorgetti et al., 2020
Lepidium sativum (Garden cress)	Accumulated on the root hairs. Exposure to plastics caused significant impacts on germination and root growth. Late germination is likely related to accumulation of microplastics on seed case. Physicalblockage of the pores in the seed capsule.	Bosker et al. ,2019
Lactuca sativa (Lettuce)	Reduction ofplant shoot length, photosynthesis and chlorophyll content, plant biomass, and the content of amino acids.	Lian et al., 2021a Lian et al., 2021b Wang et al., 2021a
Vallisneria natans (Lour.) Hara(eelgrass)	Inhibitthe growth.	Wang et al., 2021b
Glycine max (Soybean)	Higher genotoxic and oxidative damage to soybean roots. Germination viability of soybean seeds.	Xu et al., 2021 Li et al., 2021a
Hordeum vulgare (Barley)	Polystyrene microplastics disturb the redox homeostasis, carbohydrate metabolism and phytohormone regulatory network.	Li et al., 2021b
Zea mays (Maize)	Photosynthesis and antioxidant systems. Biochemical imbalance, cell membrane, photosynthetic pigments, photosynthetic capacity, and xenobiotic stress.	Fu et al., 2022 Pehlivanand Gedik 2021; Sun et al., 2021
Avena sativa (Oat)	Reduce length of roots.	Rychter et al., 2019

Phaseolus vulgaris L (common bean)	Significanteffects on shoot, root and fruit biomass reduction and lower leaf relative chlorophyll content.	Janice et al., 2021

Polyethylene microplastics increase cadmium uptake in lettuce (*Lactuca sativa* L.) by altering the soil microenvironment (Wang et al., 2021a). The same effect was discovered for *Zea mays* (Maize), polyethylene (*PE)* and polylactic acid (PLA) microplastics, reduces plant growth and increases Cd accumulation in plant tissues (Wang et al.,2021a).

Effects of micro- and nanoplastics on animals

The surface chemical properties and particle size of nanoplastics play a significant role in their toxic effects. Positively charged nanoplastics have more significant effects on the normal physiological activity of cells than negatively charged nanoplastics. Smaller particle-sized nanoplastics can more easily penetrate cell membranes and accumulate in tissues and cells (Maocai et al., 2019). MPs affect physicochemical processes of the surrounding environment with adverse effects on marine biota (Khalid et al., 2020).

The release of additives and contaminants adsorbed on nanoplastics in the organism body poses more significant threats to organisms than nanoplastics themselves (Maocai et al. 2019). For example, microplastics (MPs) can act as carriers and transport phthalate esters (PAEs) into the gut, leading to their accumulation in the intestines. Transcriptomic analysis revealed that exposure to DEHP-contaminated MPs led to differential regulation of 703 genes involved in oxidative stress, immune response, lipid metabolism, and hormone metabolism (Deng et al. 2020).

Table 2. Adverse effects of nanoplastics on animal species.

Animal species	**Adverse effects**	**References**
Caenorhabditis elegans	Growth reduced, reproductive failure	Kruszewski et al., 2010
Daphnia magna (Water flea)	Nanoplastic affects reproduction. Altersthe immune system.	Besseling et al., 2014 Abel et al., 2023 Sadler et al., 2019
Enchytraeus crypticus (Grindal worm)	Decreasedsurvival and reproduction.	Barreto et al., 2019
Mus musculus (mouse)	Alterations in gut microbiota composition, PAEs accumulation in the gut, body weight significantly decreased, inflammatory cell infiltration was observed, oxidative stress, altered immune responses, and endocrine disrupting effects.	Deng et al., 2020
Mytilus spp	Causes DNA damage.	Revel et al., 2019;

Health effects on human of MPs/NPs

Humans ingest tens of thousands to millions of MP particles annually, or several milligrams daily (Kannan and Vimal kumar, 2021). There is an extensive knowledge gap between microplastic contamination and its effects on human health (Qun et al., 2020; Blackburn et al., 2021; Kennedy, 2022; Ahmed et al., 2023; Weinstein et al., 2023). Current studies confirmed MP contamination in food items, including seafood, table salt, drinking water, etc. (Jin et al.,2021; Muthumali et al., 2023). For instance, a single plastic teabag at brewing temperature could release approximately 11.6 billion MPs and 3.1 billion nanoplastics (NPs) into a single cup of beverage (Hernandez et al., 2019). Nanoplastics exert adverse effects on living organisms, on their growth, development, reproduction, and normal metabolism. Nevertheless, the transportation of nanoplastics along food chains is not well understood (Maocai et al., 2019).

Micro- and nanoplastics can enter the human and mammalian body through inhalation - airborne plastic particles; ingestion - through contaminated food and water supplies, the primary way through which humans uptake plastic particles (Lehner et al., 2019); and skin penetrating - plastic particles passing through the skin barrier (Guerranti et al. 2019; Shan et al., 2022; Khan and Jia 2023).

According to Kennedy (2022), over 900 NP pieces, enter the human body a day and what health problem they can cause is not fully known yet. Up to now is clear that nano- and microplastics are ubiquitous, these particles enter peoples' bodies regularly during inhalation or through consumption of food or drinks (Bush 2022), especially drinking water, seafood, sea salt, sugar, honey and beer (Karbalaei et al., 2018; Mikulec et al., 2023; Jayasinghe et al.,2023). MPs and NPs travel into the body, lodge in organs, but the impacts on health are unknown (Yong et al., 2019; Trainic et al.,2020; Das et al., 2021; Xie et al., 2022; Alqahtaniet al., 2023; fig. 3). Every 10 g of human feces contains at least 20 particles of MP or NP (Schwabl et al., 2019)

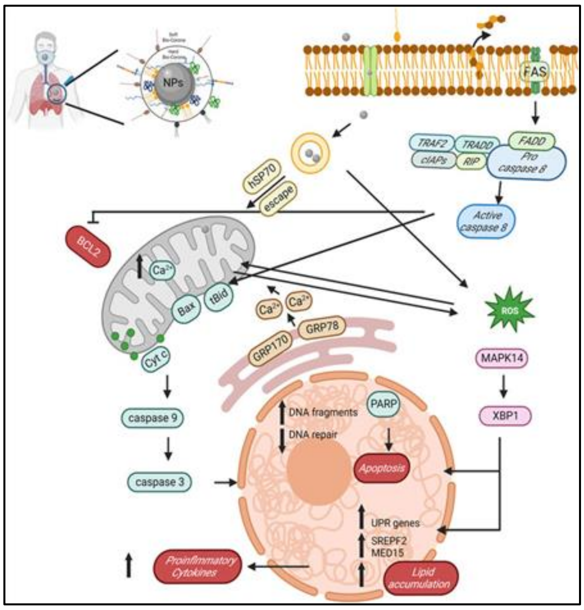

Figure 3. The toxicity of NPs is associated with inducing changes in the mitochondria, endoplasmic reticulum, and lysosomes in cells (Alqahtani et al., 2023).

People are exposed to microplastics through ingestion, inhalation, and dermal exposure, and frequent exposure can cause respiratory diseases, lung cancer, and many more complications (Senarathand Kaushalya2023).Researchersare concerned that perhaps microplastics cause damage to human cells as it was found in the laboratory, and air pollution particles are already known that enter into the human body and cause millions of early deaths a year(Muanya, 2022).

Humanbreastmilk samples analysed by Raman Microspectroscopy, for the first time, discovered MPs contamination found in 26 out of 34 samples, composed of polyethylene, polyvinyl chloride, and polypropylene, with sizes ranging from 2 to 12 μm (Ragusa et al., 2022). Microplastic particlesare detected in human blood in almost 80% of the testedpeople (Muanya, 2022).

MPs and NPs are consumed indirectly via personal care products such as tooth paste, lip balm, or other cosmetics (Karbalaei et al. 2018). Human exposure to MPs/NPs could lead to oxidative stress, inflammation, apoptosis, dysregulation of the endocrine system, genetic material damage, amid other health problems (Urli et al., 2022). Chronicexposure to MPs/NPs has adverse effects on human health (Sandra et al., 2021). Particularly, when inflammation becomes chronic, this can raise serious health problems (Muanya, 2022).

Phytoremediation of micro- and nano plastic pollution using tree plants

Plastic pollution is a significant concern for human society, and its mitigation is a challenge for future research and policy-making (Murazzi et al., 2022). Nanoplastics are a ubiquitous pollutant that seriously threatens the environment and living ecosystems. MPs and NPs can cause inhibition of growth, reproduction disability, blockage of the digestive tract, and death in organisms. Nanoplastics can change entire ecosystems' population structure and dynamics (Joksimović et al., 2022).

Tree plants have the ability to absorb and break down certain types of plastic, reducing their impact on the environment. To assess the uptake of nanoplastics by trees, roots of seedlings from three different tree species(*Q. petraea*, *P. abies*, and *B. pendula*.) were immersed in a 13C-labelled nano-sized polystyrene particle suspension, and the transport of nanoplastics to aboveground tissues was investigated. The results confirm that tree species can take up nanopolystyrene through their roots and incorporate it in their tissues (Murazzi et al., 2022).

Pilot study suggests birch has real potential for long-term soil remediation solutions – including reducing the amount of microplastics in soil and possibly water (Austen et al., 2022).Recently, some studies confirmed that nanomaterial can beaccumulating in woody plants mainly through the leaf uptake and be transported to the stem, but the uptake and presence of NPs in trees are still largely unexplored (Ballikaya et al., 2021).Table 3 lists some tree species which are investigated as promising for improvement of eco conditions in urban areas and areas with higher pollution.

Table 3. Trees with potential to remove nanoplastics particles from the environment.

Tree species	**Geographic region of distribution**	**References**
Betula pendula Roth. (Silver birch)	Common across temperate Eurasian and North American landscapes	Austen et al., 2022
Quercus petraea Matt. [Liebl.](sessile oak)	The native range of this species is Europe to N. Iran. It is a tree and grows primarily in the temperate biome.	Murazzi et al., 2022
Picea abies [L.] Karst. (Norway spruce)	Dominatesthe Boreal forests in Northern Europe.	Murazzi et al., 2022
Salix sps (Willow)	Widespreadglobal distribution and species indigenous to all continents except Antarctica.	Gordon et al., 1998
Rubus fruticosus (European blackberry)	Nativeto much of Europe, genus Rubus is distributed in all continents except in Antarctica.	Alagić et al., 2016
Fraxinus excelsior L. (common ash), and	Nativeand widely distributed in Europe	Bibi et al.,2023
Quercus robur L. (European oak)	Nativeand widely distributed in Europe	Bibi et al., 2023
Acer platanoides L. (Norway maple)	Nativeand widely distributed in Europe	Bibi et al., 2023

Birch trees have been found to have the ability to remove or reduce the levels of various pollutants present in the soil. The researchers suggest that birch trees could potentially be used to remediate soil contaminated with microplastics, in addition to sites with chemical contamination (Austen et al., 2022).

Tree plants, specifically, are used in phytoremediation due to their ability to absorb and accumulate pollutants from the soil and water. Phytoremediation with tree plants can be an effective and sustainable approach to mitigate the environmental impact of nano plastic particles. By using tree plants, the accumulation of nano plastic particles in the environment can be reduced, leading to a cleaner and healthier ecosystem.

Conclusions

Trees mitigate pollution and improve ecological conditions; many results showed that they are useful tools to combat climate change, and soil erosion and to make urban areas healthy and esthetic. The results of numerous investigations, undoubtedly underline that serious environmental and health problems in front of humanity caused by plastic pollution. The methods for detecting NPs are developed fast, but the way to resolve the problems and their consequences are still limited, even don't exist. Despite the progress in detecting NPs, there are still limitations in terms of finding effective solutions to address the problems and consequences associated with NPs.The impacts of NPs on human health and the environment are not yet fully understood, and there is a lack of comprehensive strategies to mitigate their potential risks. Further research and development are needed to explore the potential adverse effects of NPs and to devise appropriate measures to minimize their negative impacts.

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