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Impact of Pollution by Microplastic on Soil, Soil Microbes and Plants and Its Remediation by The Biochar: A review

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Microplastic pollution is one of the major environmental problems that have recently increased. Some researchers consider it the second largest global environmental problem, and some describe it as we live in a world full of plastic. Microplastic pollution has many negative effects on terrestrial and marine organisms and various environmental elements, and the problem gets worse when microplastics and its degradation derivativesare transferred to food chains and then to humans, which negatively affects their health. This problem has been widely addressed in aquatic and marine ecosystems, but there is still a gap of knowledge in studying the impact of microplastic on soil, soil microbes(largely responsible for its fertility), and plants). Therefore, this review aims to highlight this. Also, it aims to focus on the treatment methods and the potential effect of biochar (because of its unique properties) on the treatment of microplastic pollution. Hence, this review could contribute to reducing the scientific gap on the effects of microplastics on terrestrial ecosystems.

Keywords: Microplastic soilpollutionin soil, microplastic remediation, biochar,for; microplastic remediation

1. Introduction

One of the main problems nowadays that threaten the sustainable development and human health is environmental degradation. Microplastics (MPs) contamination is widespread and has become a significant global environmental concern because of rising usage. There are still many questions about MPs in terrestrial ecosystems, as recent research on MPs contamination has mainly focused on aquatic habitats. The population of the world increased at an average annual rate of 1.68 % between 1955 and 2015.The amount of waste generated by people has increased as a result of this dramatic increase in the world population (Elbasiouny et al., 2021). Recent decades have seen a significant increase in global awareness of the impact that MP soil contamination has on both terrestrial and aquatic ecosystems. Recently, the COVID-19 pandemic outbreak has exacerbated plastic pollution (for instance, by boosting the use of single-use plastics like personal protection equipment) while also having an increasingly detrimental effect on the environment and human health (Palansooiya et al., 2022). Thus, it is difficult to view a world without plastic because we currently live in "a plastic world" where it is used to make almost everything around us. Over the past 60 years, plastic production has grown significantly and is continuously growing, with annual production currently hovering around 300 million tons (Yang et al., 2021, Zhang et al., 2022). By 2050, it is predicted that total plastic manufacturing would amount to 34,000 million metric tonnes (Mt). However, only 9% of the substantial amount of plastic garbage is recycled, 12% is burned, and the rest 79 % is landfilled in the

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soil (Zhang et al., 2022). Therefore, plastic waste accumulation puts pressure on the environment. Due to the overuse of plastic products and careless disposal of plastic trash, MPs pollution has become a global problem (Sridharan et al., 2021).

Plastic is a high molecular weight polymer, a long-chain molecule comprised of repeating structural monomers. Long-chain molecules exhibit powerful van der Waals forces, and as a result of prolonged exposure to the elements, MPsdevelop unique surface properties (such as a high specific surface area, porosity, and amorphous structure), which make them easily absorbed pollutants (Dong et al., 2020). There are many different types of discarded plastic in the environment, ranging in size from nanometers to centimeters, including macro-plastics, meso-plastics, microplastics, and nano-plastics (Fig. 1). Any plastic component with a diameter between 1 µmand 5 mm is considered a MP (Zhang et al., 2020). Microplastics can be secondary, created during the breakdown and degradation of bigger plastics, or main, resulting directly from the usage of products and materials that contain MPs (Yang et al., 2021). Microplastics have been discovered in a wide range of media, including soils, aquatic systems (such as seas, rivers, coastlines, and wetlands), and both vertebrate digestive tracts (Zhang et al., 2020). Even water bottles and varied habitats contain MP (Elbasiouny et al., 2021). Thus, MPs are described as the small particles that result from the fragmentation of plastics and are less than 5 mm in size (Helmberger et al 2020, Elbasiouny et al., 2021). Due to human activity, it enters the environment through many different channels. It accumulates in the food chain and gathers pollution (organic or inorganic) from the environment, among other detrimental effects on habitats and organisms. There is a knowledge gap in this hot topic, particularly concerning how MPs affect the terrestrial ecology (Elbasiouny et al., 2021). Therefore, if released into the environment, they have the ability to disperse widely. They can be carried by the wind after being released into the environment, washed off the soil by rain or storm water run-off, and then they can enter the aquatic environment. Through ingestion, inhalation, and translocation, MPs canbiomagnify and enter the food chain as well as the human body (Anik et al., 2021). Recent research on aquatic species has demonstrated that aquatic animals may consume or collect MPs, which could harm their survival and health (Helmberger et al 2020).

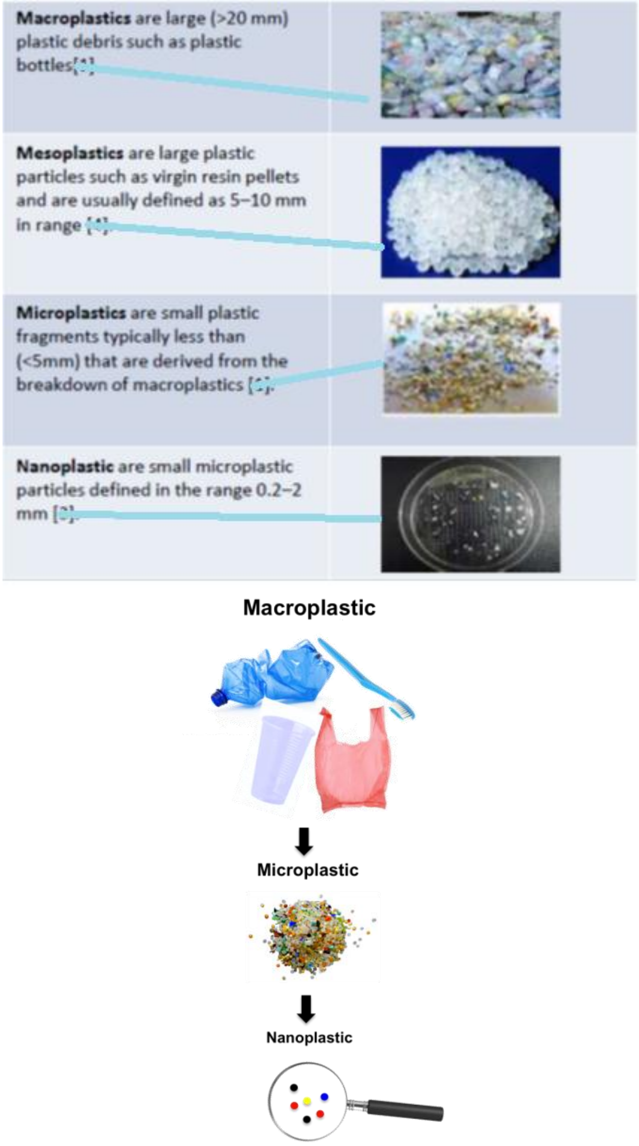

Fig. 1. Plastic classes in nature based on the size
Source: UNEP, 2015 and http://www.planetexperts.com/macro-meso-micro-but-what-about-nanoplastic/, 2015Accessed on July 2, 2022

It is crucial to understand how MPs affect our terrestrial environments, particularly the soil environment. Despite the important role of soil in protecting biodiversity, facilitating nutrient cycling, and producing food, this issue has received little attention in recent years. According to a survey, soils likely receive significantly more plastic debris than oceans (Helmberger et al 2020). Through several pathways, such as soil amendments, irrigation, sludge, mulching, flooding, atmospheric inputs, and litter or road runoff, they can damage terrestrial systems (Helmberger et al 2020). Microplastic accumulation in plants can have a direct impact on the environment and have consequences on the sustainability of agriculture and the safety of food (Yu et al., 2021b).

2. Microplasticpollution in Soil, its sources and fate

Because of the lack of information regarding soil degradation processes and the wide variety of plastic kinds and sizes, it is currently difficult to establish a realistic time scale for MP decomposition and release of components (Leifheit et al., 2021).

Numerous soils with a variety of uses, including agricultural soils, pastures, forest soils, industrial areas, and distant floodplains, are usually polluted by MPs. Microplastics concentrations in some heavily contaminated locations can reach up to 6.7% of the soil weight (Wang et al., 2022). Primary microplastics are plastics made at the microscopic level for industrial and domestic use, such as plastic pellets, fibers, films, seeds, and powders used in cosmetics like sunscreen, personal care items like facial scrubs and cleansers, and products for kids. They can also be materials used in air-blasting technology or products made through the ship-breaking process. The physical, chemical, and biological breakdowns of the bigger plastic products, such as primary MPs, over time produce secondary MPs(Pirsaheb and Makhdoumi 2020). Microplastics are also accumulated as a result of improperly disposing of agricultural plastic films, and film-like MPs are regarded as a typical agricultural source (Zhang et al., 2020, Corradini et al., 2021, Yang et al., 2021). Applying soil amendments like compost and sludge to agricultural fields can transport and spread MPs from urban garbage drains (Corradini et al., 2021). In other circumstances, accidental plastic waste would be the primary ingredient. Strangely, even washing machines have the potential to manufacture additional MP fibers (Zhang et al., 2020). These MPs might arrive at farms through water treatment facilities. The possibility that tumble dryers could be a source of MPs is appealing to consider. When very small particles or fibers go airborne (for instance, from landfill or surface dump), they have the potential to spread further. From there, they could reach terrestrial systems and the soil through atmospheric deposition. The development of secondary MP may be also facilitated by geophagous soil animals, notably earthworms. In their gizzards, they may grind up fragile plastic particles that they digest into MP. Anecic earthworms, which make vertical tunnels but feed close to the soil surface, may even help to facilitate the soil's incorporation of surface-deposited plastic fragments. A considerable proportion of plastic mulching leftovers stay in the soil as a result of poor management procedures, and MPs accumulate in the soil as a result of soil deterioration by UV radiation and physical erosion processes (Zhu et al., 2019).

Under natural circumstances, the remaining plastic waste gradually degrades into small fragments (i.e., MPs). MPs are destroyed by UV rays, thermal oxidation, physical abrasion, and biodegradation effect. During these methods, MPs change the chemical structure of their polymer, such as chain cleaving, disproportionation, an increase in O2-containing functional groups, etc. Soil MPs are mobile, thus, through agricultural practices and sediment deposition, they can migrate short distances (such as ploughing). It was found that MP movement related to bioturbation, and it has been discovered that some earthworm and collembolan species can transmit MPs from the topsoil to the deep soil. Additionally, there is data that suggests MPs can move far distance through soil erosion and runoff, wherein they can infiltrate water bodies and even the ocean (Zhu et al ., 2019).

Microplastics can be found in deep subsoils as well as top soils (Liu et al., 2018). Because of several characteristics, including direct UV exposure, comparatively high temperatures, and enhanced oxygen use, topsoil offers a potential environment for the breakdown of MPs (Chae and An, 2018). The decomposition and movement of MPs will also be impacted by soil animals and microbes, agricultural practices, and other processes, however, this degradation rate is very slow (Ali et al., 2014; He et al., 2018). The physical properties of MPs also determine their existence and fate, as well as how they interact with the environment, including particlesmobility and pathways. Usually, atmospheric and hydrodynamic factors determine how the MPs behave. Other elements that influence the dispersion, resuspension, and sinking rates of the MP particles include their sizes, densities, and morphologies (Koutnik et al., 2021).

Through a variety of mechanisms, including agricultural cultivation, soil fractures, or the disturbance of soil organisms, MPsin topsoil may also get into deeper soils (He et al., 2018). Leaching is the most typical method of introducing soil MPsinto deep soil and even groundwater among these processes (Rillig et al., 2017).

3. The effects of microplastic on soil and its organisms

Once in the soil, MPs can accumulate and cause many negative consequences in the soil ecosystem (Fig. 2). Microplastics could disrupt soil quality and nutrient cycling by changing the physical properties of the soil, reducing its fertility, and disturbing the local microbial community. Additionally, it was discovered that earthworms' consumption of MPscaused it to pass down the food chain, which could endanger terrestrial carnivores and possibly people (Zhu et al., 2019). Earthworm movement can also act as a conduit for MP transport downward, possibly into groundwater systems (Anik et al., 2021). Yang et al. (2021) reported that numerous changes in the soil's physicochemical properties, such as porosity, enzymatic activity, microbiological activity, plant growth, and yield, are driven by MPs. Microplastic plays a significant role in the transportation of harmful substances such as plasticizers, organochlorine pesticides, phthalates, antibiotics, polycyclic aromatic hydrocarbons, and potentially toxic metals due to their pervasive nature, large specific surface area, and strong hydrophobicity. Even though the research on the presence and distribution of MPs in soils has not been fully conducted, it has been discovered that MP pollution does exist in soil matrices around the world (Yang et al., 2021, Yu et al., 2021a).

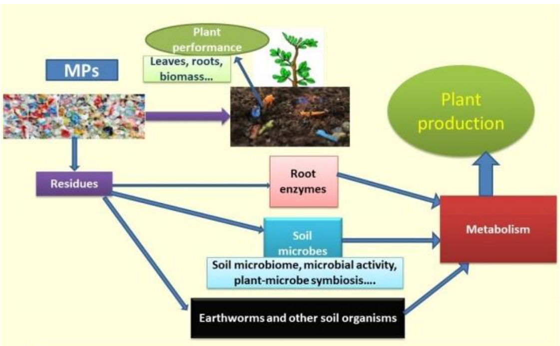

Fig. 2. The effect of microplastic on soil microbes
Source: Modified from de Souza Machado et al. (2019) and Sajjad et al. (2022)

Depending on the MP's properties, the accumulation of MP in soil may affect soil parameters. In fact, how MPs interact with soil particles may depend on their structure. For instance, after fibers are absorbed into soil aggregates, their linear shape may cause the soil structure to become unstable (de Souza Machado et al., 2019). Additionally, the molecular chain arrangement and functional group of MP may affect their ability to absorb other compounds like heavy metals or antibiotics, which may have an impact on the soil's characteristics and microbial activity. For instance, phenanthrene had a high capacity for sorption in polyethylene (PE), and this compound, together with its nitrogen heterocyclic counterparts, might limit microbial activity in the soil. Studies have also revealed that certain polymer kinds, such as PE, PP, and PVC, may have varying sorption capabilities for particular compounds. For instance, PS had a higher sorption capacity for polycyclic aromatic hydrocarbons than PET, PVC, PE, or PP, whereas PE had a higher sorption capacity for hydrophobic chemical substances like pesticides and solvents (de Souza Machado et al., 2019). As well, MPs have the potential to accumulate in the food chains, harming soil biota at various trophic levels and even whole ecosystems (Yu et al., 2021).

3.1. The effect of microplastic on soil microorganisms

Once released into the soil, MPs might remain and accumulate, eventually harming the biodiversity and development of soil organisms (Fig. 3) (Chae and An, 2018; De Souza Machado et al., 2018). Depending on the concentration and chemical composition of the MP, MP additions to soil have different impacts on the overall microbial community compositions and activities. The main processes might be inferred to be in the alteration of soil parameters, particularly bulk density, which enhances soil aeration and may subsequently boost aerobic microorganisms; or, more broadly, MP causes a change in the composition of the microbial community (Leifheit et al., 2021). By facilitating soil biogeochemical cycles, microorganisms contribute significantly to soil ecosystems. As a result, changes to microbial communities brought about by MP may change biogeochemical cycling, which may then have an impact on the overall functions and services of the soil ecosystem. For instance, the carbon cycle is impacted by MPs in soil through altering soil microbial activity, litter breakdown, and plant development. It was discovered that the genera Pedomicrobium, Mycobacterium, and Hyphomicrobium may thrive even in the presence of large concentrations (7%) of MPs made of low-density polyethylene (LDPE) (Palansooiya et al., 2022). As well, MPs may alter the microbial ecosystems in soil, which might impact enzymatic processes. In fact, it has been shown that MPs may influence the availability of nutrients and/or substrates. This is probably owing to MPs absorption or competition with microbes for physicochemical niches. The shape and type of MPs may also be important. For instance, depending on the polymer type, PE and polyvinyl chloride (PVC) MPs may improve the activity of enzymes like urease and acid phosphatase whereas PP, PES, and PVC may either suppress or promote the activity of the enzyme soil fluorescein diacetate hydrolase. Similarly, MPs may harm enzymes associated with C, N, and P-cycling, including phosphatase, cellobiosidase, β-D-glucosidase (engaged in cellulose degradation), N-acetyl-β-glucosaminidase (involved in chitin breakdown), and N-acetyl—glucosaminidase (Zhao et al., 2021). As well, Gharahiand Zamani-Ahmadmahmoodi (2022) found that the addition of MPs to the soil altered the soil properties, soil microorganisms and microbial activity. As well, they found an increase in soil respiration and cumulative CO_2 in the soil treated with MPs compared to the control. This means that the soil polluted with MPs may be a source of CO_2 which potentially increase the impacts of climate change.

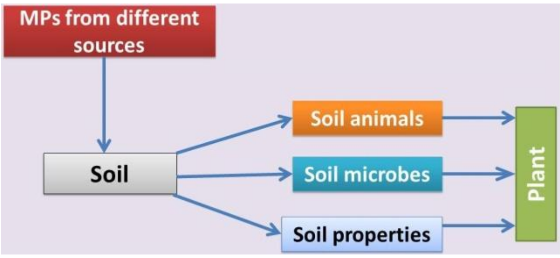

Fig. 3. The effect of microplastic on soil microbe
Source: Modified fromWang et al. (2020)

A variety of taxa, including pathogens and bacteria that break down plastic, were more prevalent in MPs-polluted soil, suggesting that MPs can serve as a unique microbial habitat and possibly alter the biological processes of soil ecosystems. Despite the focus on the impacts of MPs pollution on soil microorganisms, studies of these effects on the microbial community—particularly the interconnections between plants, soil, and microbes—are few. Understanding how MPs affect microbial communities and below-ground C flow is crucial because even small changes in plant-soil-microbe systems caused by the addition of MPs may have significant long-term effects on a variety of soil ecosystem services (such as C storage, nutrient cycling, and pollutant attenuation) (Zang et al., 2020).

4. The effect of microplastic on plants

Plants are foundational living organisms in the terrestrial ecosystem. They act as producers of the ecosystem as well as the initial bioaccumulation point. Because MPs are so common in soils, they inevitably interact with terrestrial plants. Therefore, it is critical to comprehend how plant communities and MPs interact (Yu et al., 2021b, Wang et al., 2022, Zhang et al. 2022). Soil pollution with MPs indicates suffering pant community in this soil from different levels of MP pollution in plants (Yu et al., 2021b). The possible impacts of MPs on terrestrial plants are creating growing concerns because of the significance of plants in terrestrial ecosystems and the ongoing discharge of MPs. Exposure to MPs can have a variety of consequences on terrestrial plants in terms of morphology, physiology, and even community structure (Wang et al., 2022). For example, it is reported that plastic film can increase water evaporation from the soil, which might result in more severe droughts and encourage the development of drought-tolerant plants in the community (Yu et al,. 2021b). They can either be adsorbed onto the surface of the roots or absorbed by the roots, fruits, and vegetables, where they then accumulate in their structures. Different MP types, sizes, shapes, and concentrations have different effects on plants. As a result, different MP types have diverse effects on plant growth, as seen in experiments with *Lactuca sativa*, *Triticum aestivum*, *Allium fistulosum*, and *Phaseolus vulgaris* such as reduced biomass, contracting responses, affecting productivity and community structure (Lu et al., 2021, Yu et al. 2021b). According to Huang et al. (2021), seeds exposed to MPs for 8 hours experienced delayed germination. This may be because the MPs physically blocked the pores in the seed capsule, preventing the seeds from absorbing water. Additionally, Polystyrene may stick to the root surfaces and physically obstruct the root pores. When roots come into touch with MPs with sharp edges, they may sustain a physical injury. Additionally, some fibrous MPs have the potential to entangle young plant roots and hinder their development. Qi et al. (2018) found that Macro- and microplastic letters have adverse effects on blow and above-ground wheat plants through both vegetative and reproductive growth. According to Zang et al. (2020), MPs have a detrimental influence on plant development, affecting both above- and below-ground yield.

Uncertainty still exists regarding the cytotoxicity and genotoxicity of MPs to plants, and little research has been done on the genetic toxicological mechanismsof MPs (Lu et al., 2021). Therefore, Lu et al. (2021) exposed the roots of *V. faba* to polystyrene MPs (10 nm) for 24, 48, and 72 hours to determine their cytotoxicity and genotoxicity. Then, a detailed investigation of the vitality, micronucleus rate, and reactive oxygen species metabolism of *V. faba* root border cells were carried out, along with a transcriptome sequencing analysis. The findings show that polystyrene MP treatment could greatly increase the percentage of late apoptotic cells and dead cells, indicating that polystyrene MPs could be able to cause root margin cells to undergo apoptosis or thanatosis. Additionally, the rate of micronuclei in root samples exposed to polystyrene is noticeably higher and can reach a maximum of 4.89 times that of the control group. As well, Lu et al. (2021) found that the root sample processed with MPs has a much lower mitotic index than the control group, sometimes as low as 16.80%. Additionally, polystyrene treatment can raise the level of reactive oxygen and lower anti-oxidase activity, leading to extremely substantial oxidative stress. Pehlivan and Gedik (2021) reported that to develop a predictive, all-encompassing model, the morpho-physiological and molecular responses in maize seedlings exposed to the most common MP types (PP, PET, PVC, PS, and PE) with varying particle sizes (75-150 mm and 150-212 m) and combinations (PP+PET+PVC+PS + PE and mix) were examined. The accumulation of endogenous H2O2 along with the biochemical imbalance at lower sized (75-150 mm) MPs in particular at the MP mix, which included cell membrane instability, fewer photosynthetic pigments, and a conjectural restriction on the photosynthetic capacity, demonstrated that the larger the particle size, the better the ability of cells to repair damage under MP-caused xenobiotic stress. However, the research is rare on the plants and still needs more attention.

5. Remediation techniques for the pollution by MPs

Photodegradation, thermo-oxidative degradation, hydrolytic degradation, and biodegradation by microorganisms are all natural processes those breakdown plastics. Photodegradation caused by UV radiation from the sun is the first step in the natural deterioration process. This gives the polymer the activation energy required to incorporate oxygen atoms and start thermo-oxidative breakdown. Through this process, the polymer can be further broken down into a smaller structure with a molecular weight that is favorable to microbial decomposition. The carbon in the polymer may either be converted by microbes into carbon dioxide or incorporated into biomolecules. Plastics may not totally decompose for more than 50 years due to how slow this process is (Chellasamy et al., 2022). Thus, it is critical to developing MPs removal technologies; for instance, including MPs removal procedures in wastewater treatment will decrease the quantity of MPs that reach soil ecosystems as a result of sewage irrigation (Guo et al., 2020). Physical remediation technique, however, is regarded as inefficient in the MPs cleanup from contaminated environments. Likewise, the use of synthetic chemicals for remediation the MPs contaminated areas is a less appealing technique because of its complexity, non-greener character, and polymer and environmental variability. As a result, given the environmental hazard posed by MPs, there are urgent need to create cost-effective and ecologically sustainable remediation techniques (Zhou et al., 2022). Microorganisms can be involved in the MPs remediation in the soil and initially target MPs' surface area. Because plastic is hydrophobic, the hyphae of soil fungus connect to the surface layer by making hydrophobins. Contrarily, bacterial cell surface hydrophobicity is mostly responsible for colonising hydrophobic substrates (Zhang et al., 2021).

6. Biochar application for remediation of microplastic pollution

To enhance soil quality and remediate ~~its~~pollution, soil additives such as compost, animal manure, biochar, biosolids/sewage sludge, and plant residues are widely employed. Because of its unique characteristics for enhancing soil physicochemical and biological properties, biochar utilization has been chosen among them as a promising strategy (Fig. 4) (Ren et al., 2021, Osman et al., 2022, Palansooriya et al., 2022). Biochar is a solid form that is produced when biomass is pyrolyzed at a temperature below 700 °C with little or no oxygen. The end product has high carbon content and good adsorption properties, enabling it to filter out both organic and inorganic pollutants from the environment. Raw materials for biochar manufacturing, various wastes like as straw, faces, and sludge have been investigated (Ambaye et al., 2021) (Fig. 5). It was demonstrated that biochar might speed up the breakdown rate of organic pollutants as a consequence of boosting microbial activity or microbial use of the organic pollutants on the biochar, thus affecting microorganisms either directly or indirectly. By altering the properties of the soil, biochar might either directly offer nutrients and protection to the soil microorganisms or create a better living habitat for them. Additionally, biocharmight directly affect the characteristics of dissolved organic carbon (DOC) by releasing DOC into soil solution after application. Since biochar's DOC is labile and more prone to biodegradation than biochar, it is crucial in regulating microbial activity and biodegradation than biochar (Ren et al., 2021).

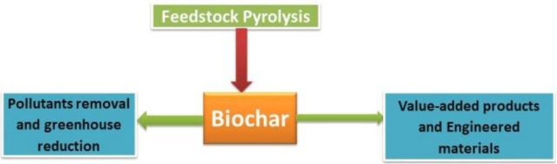

Fig. 4. Biochar application for soil and water remediation and other environmental purposes
Source: modified from Osman et al. (2022)

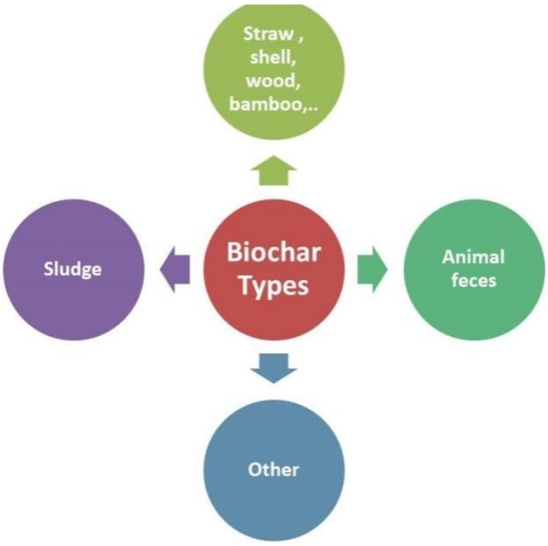

Fig. 5. Biochar types
Source: modified fromAmbaye et al. (2021)

Osman et al. (2022) reported that biochar can be used to remove many pollutants from the environment such as organic chemicals, heavy metals, antibiotics, and MPs. Biochar can modify MPs in the medium through sorption and/or implicit microbial biodegradation. It has been demonstrated that magnetic biochar, or iron (II, III) oxide-biochar, is efficient at immobilizing MP particles in soil and groundwater. The used magnetic-biochar also improved the separation of MPs from other pollutants, such as heavy metals, by speeding up the oxidation process. The efficient sorption of MPs and biochar with the pollutants may have aided the separation process. Biochar can be utilized to boost the microbial niche during anaerobic digestion in addition to the adsorption mechanism, which will help the decomposition of micro/nano-plastics. Particularly, biochar can enhance direct interspecies electron transfer in anaerobicdigestion processes by encouraging the growth *pseudomonas stutzeri* and *pseudomonas putid* as effective plastic biodegrading bacteria.

7. Conclusions

As a result of the increasing use of microplastic in many human activities, we became lived in a plastic world. Plastic is breakdown gradually in the environment to many natural factors such as light, temperature, and many other factors resulting in spreading the microplastic in many environments. Microplastic in the environment causes many harmful effects such as on aquatic organisms and terrestrial organisms and finally reaches humans through the food chain which causes many health risks. The negative impacts of microplastic on the aquatic environment have been studied well, however, its negative effects on the terrestrial ecosystems haven't been studied well. Microplastic has many negative impacts on soil properties, soil nutrient cycling, and soil quality. As well, it affects negatively soil organisms and soil microbes. It affects microbial activities, enzymatic activities and plant growth and yield. However, uncertainty still exists with respect tothe cytotoxicity and genotoxicity of microplastic to plants. Plastics subject to natural factors may partially decompose slowly and this process takes more than 50 years. There is still a gap in knowledge about physiochemical methods of plastic remediation. However, there is published information in this regard including the use of biochar. Thus, future research should focus more on the effects of microplastic on soil, plant and microorganisms, as well as remediation of microplastic especially through using eco-friendly techniques.

Conflicts of interest

There are no conflicts to declare.

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