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Application of Biochar in Non-destructive Soil Remediation

Jian Gao

Shaanxi Provincial Land Engineering Construction Group Co.,Ltd., Xi 'an, Shaanxi 710075, China

Abstract

Biochar has attracted great attention due to its loose porous structure, excellent heavy metal adsorption performance, and providing suitable living conditions for microbial growth and activity. Biochar used for soil remediation can improve soil characteristics and promote pollutant removal. Discussing the impact of biochar on soil application in the context of sustainable development can help to understand and select biochar with suitable properties, and maximize its beneficial effects on soil remediation.

Keywords

Biochar; Microorganisms; Joint Repair; Heavy Metal Pollution; Soil.

1. Introduction

With the acceleration of urbanization and industrialization, the problem of heavy metal pollution in soil in China is becoming increasingly serious. The 2014 National Soil Pollution Survey Bulletin pointed out that the total exceeding standard rate of soil in China is 16.1%, and the exceeding standard rate of farmland soil points is 19.4%; The main types of pollution are drones, accounting for 82.8% of the overall exceeding standard points, including (Cd), mercury (Hg), arsenic (As), copper (Cu), lead (Pb), chromium (Cr) Zinc (Zn), nickel, and nickel are the main inorganic pollutants. "2021 China Ecological Environment Status Bulletin The detailed investigation of soil pollution in China shows that the main pollutant affecting the environmental quality of agricultural land is heavy metals. Therefore, the remediation of soil heavy metal pollution is imperative. Heavy metals in soil have characteristics such as long residual time, strong concealment, and high toxicity. Heavy metals in soil can affect crop growth, reduce yield, and enter the human body through the food chain, posing a threat to health. Therefore, repairing soil heavy metal pollution is a guarantee of food security. Microbial remediation refers to the use of indigenous or exogenous microorganisms for complexation, integration, precipitation, and other processes to enrich and passivate heavy metals and reduce their migration ability. Microbial remediation technology has the advantages of being green, environmentally friendly, cost-effective, and capable of in-situ remediation of heavy metal contaminated soil. However, microbial growth and reproduction are significantly affected by soil environmental conditions, and microbial colonization is easily affected by soil acidity, alkalinity, nutritional status, heavy metal concentration, and other physical and chemical properties. It is often eliminated due to inability to adapt to the environment. Therefore, it is necessary to choose appropriate carriers to increase the survival rate of microorganisms in heavy metal contaminated soil, Improve the efficiency of microbial remediation.

Biochar is a carbon rich substance produced by high-temperature pyrolysis of different organic waste in a low oxygen environment. Due to its multiple structures and large surface area, it can serve as a carrier for microorganisms. On the one hand, it provides shelter for microorganisms, and on the other hand, it provides nutrients for microorganisms, improves their survival activity, and enhances the remediation effect of heavy metal contaminated soil. Biochar also has strong carbon sequestration ability and various environmental benefits. Its preparation and use can significantly reduce the amount of CO that should be discharged into the atmosphere

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through combustion, thereby reducing greenhouse gas emissions and protecting the atmospheric environment. It plays an important role in achieving the goal of "carbon peaking, carbon neutrality" and mitigating climate change.

2. Immobilization Characteristics of Biochar

As a low-cost organic carbon, biochar is influenced by the pyrolysis mechanism and interaction of the main components such as inorganic matter, cellulose, hemicellulose, lignin, etc. inherent in the raw material. At the same time, many factors in the preparation process directly affect the characteristics of biochar, such as biomass raw material, pyrolysis temperature, residence time, and pyrolysis gas flow rate at pyrolysis temperature. These factors even directly determine the physicochemical properties of biochar, such as pH value, cation exchange capacity (CEC), specific surface area, surface functional groups, and element concentration. The influence of raw materials and preparation temperature on the performance of biochar is particularly crucial.

Some studies suggest that the type of raw materials is the primary influencing factor for the performance of biochar in remediation of heavy metals in soil. The main raw materials used to prepare biochar currently come from agricultural waste, forest waste, livestock manure, and municipal sewage sludge. Wang et al. found that through pyrolysis of three different raw materials, each material can be synthesized into four different particle sizes, resulting in the synthesis of twelve different types of biochar. Higher pyrolysis temperatures can lead to an increase in the surface area and degree of carbonization and granulation of biochar, thereby enhancing the adsorption capacity of biochar for heavy metals in polluted soil. The different physical properties of various biochar, such as surface properties and pore structure, depend on the heating temperature degrees.

3. Microbial Effects of Biochar

3.1. The Protective Effect of Biochar on Microorganisms

Biomass that has undergone heat treatment has a porous structure rich in carbon, while the diameter of most soil microorganisms is smaller than the average pore size of biochar. Therefore, the rough surface and porous structure of biochar facilitate microbial colonization. For example, studies have shown that fungal hyphae can penetrate the pores of biochar. Microbial cells adhere to the micropores of biochar through hydrophobic attraction, electrostatic force, or precipitation, avoiding the toxicity of soil pollutants and increasing the abundance of microorganisms in the environment. As an excellent carrier and barrier for maintaining microbial activity, biochar avoids direct contact between some microorganisms and pollutants, leading to cell shrinkage or rupture, indirectly promoting the removal efficiency of soil pollutants.

3.2. Biochar Provides the Necessary Nutrients for Microorganisms

During the growth process, microorganisms decompose or absorb dissolved organic and inorganic substances provided by biochar, improving the structure of microbial communities and promoting microbial proliferation. There are various inorganic mineral elements in biochar, such as nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, etc., which can enrich the soil nutrient pool and improve soil productivity. Research has found that with the improvement of biochar, the proportion of nutrient elements that can be extracted from soil has increased from 60% to 670%, and the potassium content in the soil has increased from 42 mg/kg to 324 g/kg. Biochar is rich in carbon content, but due to its high stability in aromatic structure, most of the carbon cannot be utilized by microorganisms. However, there are also partially dissolved organic carbon (DOC) that can be utilized by microorganisms. As fertilizers, their slow release

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can bring long-lasting benefits to microorganisms. The changes in raw materials, carbonization degree, and carbonization temperature of biochar can affect the composition of DOC, which also leads to diverse biological effects of different biochar. Usually, biochar prepared by low-temperature heat treatment has higher DOC content.

3.3. Improving Soil Properties with Biochar

Firstly, due to the complex connections between biochar and soil substances, biochar can serve as a binder material to improve soil structure and correspondingly promote microbial activity. Porous biochar affects soil porosity and bulk density by changing the gap between biochar and soil particles, giving microorganisms more room to move. Some studies have shown that adding 4% biochar to soil, Soil bulk density decreased by 35% Secondly, biochar is usually slightly alkaline and can increase soil pH, which helps to increase the diversity of microbial communities. Generally, in highly biologically active soil environments, the pH value is almost neutral, but the specific biological activity depends on the type of microorganisms, as bacteria may produce greater reactions due to small changes in soil pH, thereby affecting the entire microbial community. Then, soil CEC is the fundamental characteristic of soil One of the qualities indicates the ability of soil to retain exchangeable cations (K^+, Ca^{2+}, Mg^{2+}), which affects the availability and accessibility of soil nutrients and pollutants, soil structural stability, soil fertility, and soil buffering capacity. Due to the diverse raw materials and pyrolysis conditions of biochar, different types of biochar can improve soil CEC to varying degrees and contribute to nutrient retention and reduce leaching. Finally, the main impact of biochar on soil enzyme activity is its adsorption on substrates or enzymes. The contact between substrates and enzymes and the small molecules released by biochar can act as regulators of specific enzymes. The impact of biochar on changes in soil properties also affects enzyme activity, thereby responding to soil quality and nutrient availability. Therefore, biochar improves soil properties to obtain better microbial survival conditions and affects microbial activity.

4. Removal of Pollutants by Biochar

The removal of pollutants from soil by biochar mainly relies on organic pollutants such as antibiotics and halogenated compounds (polycyclic aromatic hydrocarbons), as well as inorganic substances such as heavy metals. These pollutants are directly affected by the long-term adverse effects of related substances on soil environmental quality and human health. Their commonality is that the natural degradation rate is slow or even difficult to degrade, and the microbial toxicity is strong.

The adsorption characteristics of biochar on antibiotics can further increase the contact between microorganisms and antibiotics, promoting the biodegradation of antibiotics in soil. On the one hand, biochar with rich functional groups and high porosity can adsorb antibiotics through surface complexation, pore filling electrostatic attraction, and other effects. On the other hand, extracellular polymeric substances secreted by microorganisms can cover the surface of biochar and interact with antibiotics through electrostatic attraction, accelerating the degradation rate. In addition, biochar modification can improve soil properties, alter microbial community structure, and effectively promote the biodegradation of antibiotics. Research has shown that with the increase of biochar dosage, the dry weight of bacteria shows a linear increase relationship, indicating that high concentration biochar can significantly promote microbial growth by providing higher attachment area and sufficient nutrients. Biochar can alter the fatty acid composition of bacteria and increase gene expression, indicating that biochar enhances bacterial activity and adaptability to antibiotics. The industrial and agricultural production process involves the discharge of various halogenated compounds, such as polychlorinated biphenyls, organochlorine pesticides, polycyclic aromatic hydrocarbons, etc., which pose a serious threat to the soil environment. Due to their

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carcinogenicity, mutagenicity, and teratogenicity, they are often prioritized pollutants. Research has shown that soil with and without biochar can remove polycyclic aromatic hydrocarbons. The addition of biochar significantly increases the number of soil microorganisms, soil organic matter content, and soil enzyme activity, which helps to improve soil properties and promote the biodegradation of polycyclic aromatic hydrocarbons. Microbial cells attached to biochar can be exposed to high concentrations of polycyclic aromatic hydrocarbons, resulting in higher utilization of polycyclic aromatic hydrocarbons adsorbed on the surface of biochar by microorganisms. Microorganisms can form a biofilm on the surface of biochar, which facilitates the transportation of polycyclic aromatic hydrocarbons from contaminated soil to the degrading microbial community. Microorganisms with excellent degradation characteristics can effectively reduce the concentration of pollutants on the cell surface. In addition, the biochar microbial composite system can prevent microorganisms from being harmed by saline soil, successfully treating saline soil contaminated with polycyclic aromatic hydrocarbons. The maximum removal efficiency of polycyclic aromatic hydrocarbons reaches 58.64%, expanding the application environment for polycyclic aromatic hydrocarbon biodegradation.

5. Prospect

The production and use of biochar can effectively alleviate the treatment and disposal of agricultural waste, reduce environmental pressure, and achieve resource recycling and sustainable agricultural development. In addition, the application of biochar in heavy metal contaminated soil can increase soil carbon sink, reduce greenhouse gas (CO, CH-N, O) emissions, and have a dual promoting effect on the dual carbon target. Therefore, the widespread application of biochar has significant social, environmental, and economic benefits. When biochar is combined with microorganisms, biochar enhances the remediation effect of microorganisms by increasing their survival rate and growth and reproduction rate, thereby enhancing the combined remediation effect on heavy metal contaminated soil. In recent years, the combined remediation of heavy metal contaminated soil by biochar and microorganisms has become a research hotspot. This article summarizes the research progress of biochar and its combined microbial remediation of heavy metal contaminated soil, and focuses on analyzing the remediation mechanism and influencing factors. It is worth noting that biochar has a positive effect on microorganisms, but there are still potential hazards, such as the final destination of biochar, soil nutrient retention, and the impact of microbial activity. It is also necessary to establish a long-term environmental risk assessment system.

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