Remediation of Heavy Metal Pollution in Soil by Biochar

Jiaxiao Han *

College of Grassland Science, Shanxi Agricultural University, Jinzhong 030699, China

* Corresponding Author Email: 20201209425@stu.sxau.edu.cn

Abstract. Soil is an important resource for human survival and life, but with the economy and society developing, industrial pollution, agricultural chemicals, domestic sewage, and so on have entered the soil, causing serious soil heavy metal pollution. Soil pollution has concealment and hysteresis. Pollutants in soil are not easy to diffuse and dilute as in water and atmosphere, so they are easy to accumulate in soil and exceed the standard. Due to the demand for environmental protection, the restoration of soil is imminent. Under anoxic conditions, the solid material of the raw material after high-temperature pyrolysis is biochar. It is a soil improvement and adsorption material with high porosity and strong adsorption capacity, so it is widely used in soil remediation of heavy metal pollution. The essential concepts of biochar remediation of soil heavy metal pollution and the factors influencing biochar remediation of heavy metal polluted soil are therefore reviewed in this work and this paper also expounds on the advantages of biochar compared with other remediation methods such as phytoremediation and physical remediation.

Keywords: Heavy Metal Pollution; Biochar; Physical repair; Bioremediation; Chemical repair

1. Introduction

Because heavy metals cannot be broken down by soil microbes, the phenomenon known as "soil heavy metal pollution" occurs when the background level of heavy metal components in the soil exceeds the acceptable range, so excessive heavy metals are deposited by long-term human activities [1]. Soil heavy metal pollution has become a global problem. Heavy metal pollution in the soil will inhibit the normal growth of crops, resulting in a decrease in crop yield and quality. Soil pollution can cause surface water and groundwater to be polluted and also pose a health threat to the human body through the food chain. Heavy metal contamination from sources like lead and cadmium is extremely harmful to people. Some heavy metal pollution will affect the normal growth and development of people, some will damage the liver, skin, etc., and some will even lead to death. At present, there are a large number of farmlands polluted by heavy metals, so how to repair and utilize these soils is the main problem.

Studies have shown that there are physical, biological, and chemical methods for the treatment of heavy metal-contaminated soil and its use. Physical repair includes engineering repair, high-temperature pyrolysis, etc. Bioremediation includes phytoremediation, microbial remediation, etc. Chemical repair includes electrokinetic remediation, washing remediation, and other methods. Physical methods have problems such as reducing soil fertility, repairing costs, and affecting the ecology of native soil. Although the biological method has low cost and no secondary pollution, the repair time is long [2]. Chemical repair requires the use of chemical reagents, and the repair cost is high. The practice has proved that the utilization of biochar not only has low cost but also has a wide range of raw materials. Therefore, based on the previous research results, this paper provides an overview of the method by which heavy metal-contaminated soil is remedied using biochar, as well as the elements that influence this process. And its advantages compared with other remediation methods.

2. The Mechanism of Biochar Remediation of Heavy Metal-Contaminated Soil

Adsorption, co-precipitation, and complexation are the three primary components of biochar's remediation mechanism for soil with heavy metal contamination. The goal of using biomass to remediate polluted soil is to alter the heavy metals' current condition rather than their overall

concentration. The toxicity of heavy metals is determined by their bioavailability. Liang Jiayi et al. studied the effect of biochar on available cadmium in soil and found that biochar application could significantly reduce the content of available cadmium in soil [3]. With the increase of biochar application, the content of available cadmium in soil decreased first and then increased. The loose porous structure on the surface of biochar makes it have a large specific surface area. When biochar is prepared at a higher temperature, its ash and carbon contents rise while its oxygen and hydrogen contents fall, resulting in the development of a very stable aromatic structure [4,5]. The higher surface adsorption capacity of biochar is due to its aromatic ring molecular structure and porous characteristics. Most biochars are alkaline, which is mainly related to their aromatic conjugated structure. Biochar has precipitation and complexation effects on the remediation of heavy metals in soil. Precipitation is an important mechanism for biochar to immobilize heavy metals. Metal ions precipitate under alkaline conditions. Heavy metal ions in soil will generate metal hydroxides, metal phosphates, and other precipitates, which are precipitated in the form of precipitates [6]. In order to create metal complexes that can lessen the mobility and toxicity of heavy metals, a lot of organic functional groups on the surface of biochar must coordinate with the ions of those metals. This process is known as complexation [7].

3. Factors Affecting the Remediation of Heavy Metal-Contaminated Soil by Biochar

3.1. Type of Raw Materials

The sources of raw materials for the manufacturing of biochar are somewhat varied, including primary biomass, secondary biomass, and treated biomass (Table 1). Depending on the types of raw materials used, biochar's physical and chemical characteristics change. As a result, the adsorption capacity of biochar for heavy metals will vary depending on the source material. Liang et al. investigated biochar's impact on soil cadmium availability. Biochars from different raw materials have different effects on reducing soil available cadmium content. The most significant decrease in soil available cadmium content was 36.04 % by domestic waste made of sludge, municipal waste, and other solid waste, followed by straw, wood, and shell slag were 29.70 %, 20.87 %, 18.29 % [3].

Table 1. Source classification of biochar

Type	Representative biomass	Characteristic	Reference
Native biomass	Plant waste: straw, branches, shell	High calorific value, structural organic matter, nutrient inequality.	[8]
Secondary biomass	Sewage sludge, animal waste	Low calorific value, nutrient enrichment, and high moisture content.	[9]
Processing biomass	Sugarcane bagasse, beet pulp, dregs	Caloric value, nutrients, and moisture are unequal.	[10]

3.2. pH of Biochar

The effect of biochar precipitation of heavy metals is related to pH values. The higher the PH, the stronger the adsorption effect of biochar. On the contrary, the lower the PH, the hydrogen ions in the solution will compete with the metal cations for adsorption, which will inhibit its adsorption. According to Liu Guocheng et al.'s research, the pH range of 2 to 5 improved the capacity of biochar to adsorb lead ions. At pH 6, the adsorption of Pb^{2+} by some biochar decreased, and the optimum adsorption pH of Pb^{2+} by biochar was 5 [11].

3.3. Preparation Methods and Conditions of Biochar

The preparation methods and conditions such as temperature, pressure, etc. can influence heavy metal removal effects. According to a large number of experiments, high-temperature biochar is generally beneficial to the removal of heavy metals. Xie et al. used Chinese medicine residue as raw material to prepare biochar at 300 °C and 500 °C. The results showed that the residual state of biochar at 300 °C and 500 °C increased by 22.38 % and 20.11 %, respectively, and the biochar prepared at 300 °C was better than that at 500 °C [12]. Liang Jiayi et al. found that the biochar produced by pyrolysis at high temperatures ($T \geq 600$ °C) had the best effect on reducing the available cadmium in soil by 45.10 % through the study of the available cadmium content in soil by biochar at different preparation temperatures [3].

3.4. Biochar Dosage

The dosage of biochar has a significant effect on the adsorption effect. In general, increasing the dosage of biochar will be more conducive to the adsorption of metal ions. A variety of metal-contaminated soils were treated with biochar created by the pyrolysis of corn straw by Tang et al. and found that the application of biochar could passivate the heavy metal forms in the soil, and the effect increased with the increase of biochar application [13]. With an increase in passivation culture time and application volume, Cd and Zn's passivation effect in soil increased dramatically. Zhou et al. showed that the passivation effect of cadmium and zinc in soil increased significantly with the increase of application amount through the study of passivation and remediation of cadmium and zinc co-contaminated soil by biochar [14].

4. Advantages of Biochar Remediation of Contaminated Soil

Compared with traditional remediation methods, biochar has the following advantages in the treatment of soil contaminated with heavy metals. First of all, the use of plant waste, sewage treatment sludge, and other raw materials to produce biochar can reduce the pollution caused by the existence of waste in the environment. Secondly, the application of biochar to soil can store carbon in the soil for a long time, which is conducive to the balance and stability of the soil ecosystem; The application of biochar is beneficial to the maintenance of nutrients in the soil, and can also regulate the physical and chemical properties of the soil, reduce production costs, improve soil quality and crop yield.

5. Limitations

According to the current research status, when using biochar to remove heavy metals from soil, there are still a few issues that need to be addressed. First of all, the properties of biochar prepared under different conditions are different, and the effects obtained in the application are also different. Therefore, further research is needed to select the optimal preparation process. Whether the adsorption capacity of biochar will be affected by coexisting elements, such as other heavy metals and inorganic salt ions, remains to be studied. At the same time, the repair time and adsorption saturation of biochar should also be studied in depth. Additionally, biochar has a limited capacity for adsorbing heavy metals from soil. If the adsorption saturation is reached, it will not be able to continue to repair the contaminated soil. From a long-term perspective, it is also worth paying attention to how the application of biochar will change after a long time and whether it will increase the toxic substances in the soil.

6. Conclusion

This paper reviews the process by which heavy metal-contaminated soil is remedied with biochar and the variables that have an impact on that process and expounds on the advantages of biochar remediation by comparing it with other methods of remediation of contaminated soil. Biochar

remediation of heavy metal contaminated soil is mainly based on its strong adsorption capacity and precipitation reaction and complexation of heavy metals. The application of biochar for heavy metal contaminated soil is to change the existence of heavy metals, and cannot change the total amount of heavy metals in the soil. The toxicity of heavy metals is determined by their bioavailability. The solution to remediating heavy metal-contaminated soil and raising soil quality is to decrease the bioavailability of heavy metals. The degree of BC remediation of heavy metal-contaminated soil by biochar depends on the raw material, pH, dosage, and production temperature of biochar. There are several potential applications for the technology of utilizing biochar to treat heavy metal-contaminated soil. Compared with other remediation technologies, it is more efficient and safer. It not only has the effect of adsorbing and fixing heavy metals, but also can regulate the physical and chemical properties of soil, improve soil quality and crop yield, and improve the soil carbon cycle.

However, there are still some shortcomings in this paper. There is no systematic exposition of the mechanism of different biochars for soil heavy metal remediation, and the variables influencing biochar's ability to clean up contaminated soil are not all-inclusive. Because soil is an important resource for human survival. Once the soil is polluted, it will pose a great threat to human survival if it is not treated and repaired in time. Therefore, the remediation of contaminated soil needs to be timely and effective. In view of the high difficulty in repairing contaminated soil, in future development, it is necessary to combine the actual situation and characteristics of contaminated soil to ensure environmental friendliness.

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