Research Progress of Biochar in Memediation of Contaminated Soil

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Abstract: Biochar is a carbon-rich material produced by pyrolysis and carbonization of biomass raw materials (mainly agricultural wastes) under complete or partial hypoxia. Because of its excellent structural properties, it is often applied to contaminated soil as a remediation agent and soil amendment agent. In recent years, biochar has attracted widespread attention in environmental remediation, and has become a research hotspot in current environmental science. This paper introduces the biochar treatment of soil pollution by introducing the concept, preparation method and physicochemical properties of biochar. The research progress of biochar in the treatment of heavy metal contaminated soil in recent years was reviewed. The effect of biochar on the bioavailability of heavy metals in soil was discussed. However, there are still some shortcomings in current research and remediation methods. It is expected to find environmentally friendly, scientific and reasonable materials and technologies to repair soil pollution.

1. Introduction
The soil has the ability to support the growth and reproduction of plants and microorganisms. It is a complex mixture of soil particles and water and gas. The soil is the basis for human survival and development, and it is also a fragile non-renewable resource [1]. However, with the modernization of cities and the development of agricultural production, a large number of toxic and harmful pollutants enter the soil through various ways, exceeding the self-purification capacity of the soil, resulting in soil pollution. The total over-standard rate of soil in China is 16.1%. The main types of pollution are inorganic, such as Cd, Hg, As and Cu. The over-standard number of inorganic pollutants accounts for 82.8% of the total over-standard number. Soils contaminated by heavy metals have poor fertility, and the plants in which they grow have high levels of heavy metals. When humans or animals are ingested, heavy metals accumulate in the body, causing poisoning, and even more serious threats to human life. At present, the new research direction of environmental pollution is the application of biochar technology to repair the soil polluted by heavy metals, and at the same time to treat the wastes from agriculture and animal husbandry. Based on the latest research progress of biochar at home and abroad, the preparation process, physical and chemical properties of biochar were summarized in order to provide reference for future research on biochar remediation of heavy metal contaminated soil.

2. Biochar overview

2.1. Preparation technology of biochar
The traditional technology of biochar preparation is mainly through pyrolysis technology. The new
methods and technologies of biochar preparation mainly include oxygen-limited pyrolysis and microwave heating (When microwave heating, the heat in the system is evenly distributed, which belongs to internal heating mode. It has great application prospects, but due to the high price of equipment for preparing biochar, it has not been widely promoted [2]), laser and plasma pyrolysis technology, hydrothermal carbonization technology (mild reaction conditions, high yield of biochar, is considered to be an ideal method for preparing biochar [3]).

2.2. Properties of biochar

2.2.1. Elemental composition of biochar. Biochar is rich in various elements, mainly C, H, O, N, etc., of which the content of carbon is relatively high, about 65% to 95% [4-6]. The main components of biochar are alkyl and aromatic. When the pyrolysis temperature is high, the content of C and P in biochar increases. During the pyrolysis process, some nutrients in the biomass are concentrated and enriched. The content of P, K, Ca and other elements in the prepared biochar is higher than that of the original biomass material [7].

2.2.2. pH of biochar. Soil acidity and alkalinity seriously affect soil fertility and plant growth, which is one of the important indicators reflecting soil characteristics. The ash of biochar is rich in salt-based ions. If biochar is used as soil amendment in soil, the level of soil hydrogen ions and exchangeable aluminum ions can be reduced, and the pH of the soil can be significantly increased. Because the biochar produced by pyrolysis at high temperature has more ash, less acid volatile matter and higher pH value, the biochar produced at high temperature has better effect than that produced at low temperature in the improvement of acidified soil.

2.2.3. Characteristics of specific surface area and pore structure of biochar. The surface of the biochar contains a number of loose porous structures which together constitute the specific surface area of the biochar. The specific surface area of biochar is not only affected by the type of raw material, but also by its cracking temperature. In general, the specific surface area of biochar increases as the cracking temperature increases. And some researchers found that the specific surface area of biochar increased from 12 m²•g⁻¹ to 307 m²•g⁻¹ when the pyrolysis temperature increased from 150 ℃ to 500 ℃. The pore size of biochar determines the specific surface area of biochar. According to the pore size of biochar, the pore size of biochar can be divided into macropore (> 50nm), micropore (< 2nm) and micropore (< 0.9nm). The macropores not only have a great influence on the aeration and water holding capacity of the soil, but also provide a good environment for the survival of microorganisms and the adsorption of heavy metals. Small pores play an important role in the transfer of biochar and the adsorption of fixed molecules. Due to the porosity of biochar, the application of biochar can improve soil aeration and reduce anaerobicity, thereby inhibiting denitrification and affecting soil nitrogen cycling [8]. Biochar pores can also absorb and store nutrients, slowly release nutrients into the soil, improve nutrient utilization, and then affect the growth and development of plants.

3. Biochar rehabilitation of heavy metal contaminated soil

Biochar has a relatively large specific surface area, a high pH value and a cation exchange capacity, which can increase the amount of electrostatic adsorption of heavy metals on the soil. The adsorption of biochar on heavy metal contaminated soil is mainly to repair the contaminated soil by increasing the cation exchange capacity of the soil. The higher the amount of cation exchange, the greater the total amount of adsorption of metal cations by the soil colloid. The heavy metal ions are fixed in the soil colloid, and the bioavailability of heavy metals in the soil is reduced, which achieves the purpose of repair. Since the pH of the biochar itself is alkaline, the addition of soil to the soil increases the pH of the soil, and the negative charge on the surface of the colloidal particles increases, and the amount of soil cation exchange also increases.

The polluted soil remediated by biochar can improve fertility and water holding capacity, and also
improve the yield and quality of crops [9]. There are several main factors affecting the remediation of heavy metal contaminated soil by biochar: ① The amount of biochar added. Some studies have found that adding biochar prepared by pyrolysis of Mexican clove to potted soil of tomatoes, the greater the amount of biochar added, the better the fixation effect of heavy metals [10]. The addition of biochar to heavy metal contaminated soil can significantly increase soil pH, conductivity and cation exchange capacity, as well as reduce the concentration of extracted heavy metals [11]. ② A raw material for preparing biochar. For example, when the corncob biochar is modified by an acidic reagent, the pores on the surface of the biochar increase, the specific surface area increases, the ash content is significantly reduced, and the adsorption of ammonia nitrogen is enhanced. Different raw materials, different biochar physical and chemical properties, fixed heavy metals are also different. ③ The pyrolysis temperature at the time of preparation of biochar. In a certain range, with the increase of pyrolysis temperature, the organic matter in biomass decomposes continuously, the content of carbon element increases continuously, the hydrophilicity and polarity weakens continuously, and the adsorption capacity increases [12]. For example, with the increase of pyrolysis temperature, the adsorption of Cd in soil by biochar increases [13]. ④ The type of contaminated soil. Different types of soil have different physical and chemical properties, and the degree of heavy metal pollution is also different, and the biochar remediation effect will also be significantly different.

4. Research progress in the application of biochar to adsorb heavy metals in soils at home and abroad

4.1. Domestic application of biochar to repair heavy metal pollution

The main cause of heavy metal pollution in soil is the high bioavailability of metals such as chromium, cadmium, lead and copper. Plants can absorb heavy metal ions through the roots and accumulate them, and humans can cause problems such as poisoning after ingestion, thus threatening health. Some studies have found that adding biochar and montmorillonite (1:1) to the compound contaminated soil can significantly reduce the mobility of copper, lead, zinc and cadmium in the soil [14]. Adding biochar-based fertilizer to the soil where rapeseed is grown can not only improve the physical and chemical properties of the soil, but also reduce the absorption and accumulation of heavy metal ions such as lead and cadmium in the edible parts of rapeseed. The application of biochar and compound fertilizer can effectively reduce the accumulation of cadmium in the edible parts of crops. Therefore, the combination of biochar and other related materials can be used as a remediation method for heavy metal contaminated soil.

4.2. Study on the application of biochar to repair heavy metal pollution in foreign countries

Biochar has a certain adsorption effect, which can fix heavy metal ions in a stable state, and has a great influence on soil fertility, which is of great significance to the sustainable development of the environment [15]. The combination of biochar and other materials is also a new way to control heavy metals contaminated soil and promote plant growth. By combining biochar with fixed nitrogen bacteria, the soil available nitrogen content is increased [16], and the heavy metal content of the edible parts of plants is significantly reduced [17]. Foreign scientists have studied a method of adding manganese oxide to rice husk biochar, which can improve the adsorption capacity of Pb^{2+}, and the cost is lower [18]. Due to the interaction between heavy metal ions, adding a certain amount of biochar into soil will affect the adsorption efficiency of different metal ions [19]. In the soil contaminated by organic matter and heavy metals, in order to avoid waste, the type and quantity of biochar should be fully considered to scientifically and effectively control and repair contaminated soil.

5. Deficiencies of biochar in remediation of heavy metal contaminated soil

The biochar prepared by different biomass has different properties, and the cation and pollution degree of heavy metal pollution have a great influence on the repairing effect. Therefore, biochar has different remediation mechanisms for heavy metal contaminated soils, especially for heavy metals, organic
compounds and petroleum hydrocarbons. Therefore, the repair methods should be further studied. The present situation of soil pollution at home and abroad is very serious. Biochar produced by different biomass does not match soil improvement in different areas. The environmental pollution caused by excessive use of chemical fertilizers, pesticides and industrial pollutants is more complex, which brings many uncertainties to pollution control.

6. Research prospects
(1) China has abundant waste biomass resources. Due to the large regional differences, there are large differences in biomass types. At present, there is no systematic study on the process and parameters of biochar production from pyrolysis of waste from different sources, and the effects of biochar properties and characteristics on soil improvement in different regions of the country. (2) Biochar prepared from wastes from different sources has different effects on the repair of heavy metals in soil. It is particularly important to select biochar suitable for local soil conditions and heavy metal pollution types. In the future, we should develop and produce high-efficiency biochar products in combination with local soil conditions and pollution characteristics, combined with local waste biomass resources. (3) Some biomass carbon produced by agricultural wastes (sludge, etc.) contains a small amount of heavy metals, while pyrolysis at high temperature can change the content of organic pollutants. As the total amount of raw materials decreases, the concentration of toxic substances may increase. Long-term ecotoxicology tests were conducted on different soils to evaluate the environmental safety of biochars from different biomass sources. (4) Despite the potential advantages of biochar, the application of biochar in soil pollution control has not been developed on a large scale due to the different properties of biochar raw materials (oxygen-containing functional groups, specific surface area, aromatic compounds structure, cation exchange capacity, porous, etc.). At present, the research on the interaction mechanism between biochar and target heavy metals and the environmental limitations of biochar application are very limited. In order to understand the properties of biochar and the constraints of interaction between biochar and soil environment, long-term positioning experiments should be conducted on different types of soils to evaluate the effects of biochar on soil fertility improvement and remediation of heavy metal pollution.

Therefore, biochar should be used as a carrier, combined with other materials, and comprehensive application can achieve effective repair effects. Promoting the idea that biochar can remediate heavy metal contaminated soil and choosing the best biochar remediation scheme in environmental remediation can better play the role of biochar.

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