

Study Progress on the Ecological Effects of Biochar in Soil

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Abstract. Soil is an indispensable and important part of human production and life, and biochar, as an important form of utilization of biomass energy, can be widely used in soil conditioning and crop conditioning. Currently, a systematic framework for studying biochar's ecological impact on soil is still required. This paper briefly introduces the basic preparation method of biochar, structural characterization of biochar, and briefly describes its basic properties. By adsorbing pollutants with a high specific surface area and strong adsorption, biochar can be used to clean up heavy metal contamination in soil. It can also boost soil fertility by increasing enzyme activity and organic carbon content, as well as by reducing bulk weight and increasing cation exchange to increase soil fertility retention capacity. In addition the moderate addition of biochar can also play a positive role in crop conditioning to a certain extent. The purpose of this paper is to summarize the basic theories and research related to the study of the ecological effects of biochar in soil by introducing the typical preparation methods and basic properties of biochar, so as to facilitate the subsequent further research.

Keywords: Soil; Biochar; Soil Conditioning; Crop Conditioning.

1. Introduction

Soil is an important part of the ecosystem and the most active carbon reservoir, and its quality directly affects biota, human life and food security, but the soil and the agricultural environment are increasingly polluted by pollutants. In recent years, a variety of substances including soil conditioners have been adopted to improve the soil. Biochar, also known as biomass charcoal, is rich in carbon and is an incomplete combustion product obtained by pyrolytic carbonization of biomass under conditions of complete or partial anoxia. Its various properties such as porous structure, high specific surface area, stable structure, and excellent chemical properties make it widely favored in soil conditioning, remediation of heavy metal pollution, and absorption and fixation of greenhouse gases.

Biochar has gradually become the focus of extensive attention at home and abroad. Its role in mitigating and improving the global ecological environment and enhancing and promoting sustainable development has been increasingly recognized and promoted. Through a long time of research and testing by scientific researchers, China has made a series of gains in the R&D and application of biochar, especially in the conversion of agricultural and forestry waste biomass into biochar technology and the industrialization of R&D and promotion of its use, which has reached the world's advanced level. Many developed countries, including the United Kingdom and the United States, have also devoted themselves to biochar-related scientific research and set up "biochar research centers", which have made a series of achievements in theoretical system and technology development [1].

The main objective of this paper is to review the preparation and properties of biochar and the effects of its application on soil and soil crops in the context of increasing soil pollution and wider application of biochar. Firstly, the common preparation methods of biochar, such as pyrolysis and carbonization, are briefly introduced, followed by the structural characterization of biochar and its basic properties. Based on these basic properties, biochar has a range of applications in soils and effects on crops.

2. Biochar

2.1. Preparation of Biochar

2.1.1 Slow pyrolysis

Pyrolytic preparation of biomass has been reported thousands of years ago and is categorized into slow pyrolysis, fast pyrolysis, and varying residence time, rate of heating, and method of heating (Fig. 1) [2]. Slow pyrolysis, also known as conventional carbonization, involves heating the biomass at lower temperatures (350-450 °C) so that biomass with larger particle sizes (> 1 mm) can be prepared under prolonged pyrolysis. This method is less expensive and the pH of the biochar produced is generally neutral. Slow pyrolysis maximizes the yield of solid products due to its lower temperature as well as heating rate and longer residence time. Tian et al. [3] showed that the corn stover biochar prepared by slow pyrolysis had excellent pore and skeletal structure, and the rate of sulfur adsorption was very good and could reach 26.9%.

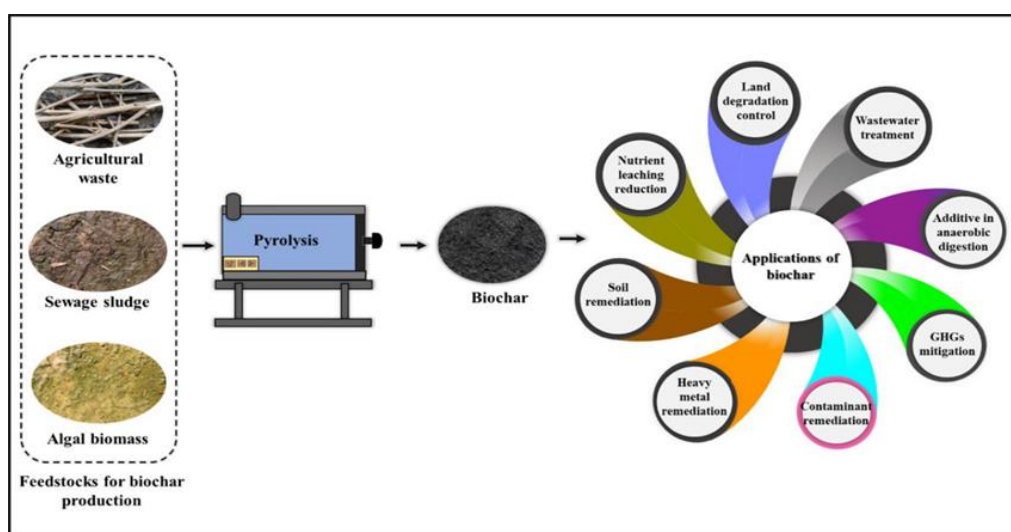


Fig 1. Schematic diagram of biochar production through various pyrolysis processes. https://ars.els-cdn.com/content/image/1-s2.0-S0048969722056613-ga1_lrg.jpg

2.1.2 Rapid pyrolysis

Rapid pyrolysis, which involves the rapid heating of biomass feedstock at moderate temperature (450-550 °C) in an anaerobic environment, realizes the preparation of biochar. However, Kim et al. [4] found that the biochar yield was reduced by about 50% at high temperatures compared to slow pyrolysis at low temperatures by preparing biochar from just pine as feedstock.

2.1.3 Hydrothermal carbonization

Hydrothermal carbonization refers to the preparation of biochar in an aqueous medium at a certain temperature (180-250 °C). The biomass raw material feedstock is first hydrolyzed, the monomer is dehydrated and polymerization reaction occurs, and finally biochar is generated through aromatization reaction. The feedstock is mostly high-moisture biomass, which eliminates the need for drying, saves time, and results in higher yields. The biochar produced by this method has low ash content and good hydrophobicity.

2.1.4 Baked charcoal

Baking charring, also known as microwave thermal cracking, is a new type of technology. Under anaerobic or oxygen-limited conditions, the realization of conventional pyrolysis based on the incorporation of microwave heating technology, a short period of time can be realized biomass cracking, and promote the biomass in the cracking to obtain the organic vapors and low molecules, the steam quickly cooled, to achieve the preparation. The preparation of biochar in this way ensures uniform heating and easier control of the reaction process.

2.2. Structure and Properties

2.2.1 Structural characterization of biochar

The structure and properties of biochar feedstocks prepared from different feedstocks, reaction temperatures, and preparation methods vary very much. The biomass is formed by reconstruction after the process of pyrolytic carbonization such as loss of water, volatilization of active substances, fracture and collapse [5]. The "skeleton" structure is stabilized aromatic compounds and minerals, and the pore structure consists of aromatic compounds and other groups with different properties. Most of the pores of biochar are dominated by micropores. The temperature of carbonization affects the structure of biochar; the higher the temperature, the more amorphous carbon is converted to graphite microcrystalline structure, making the structure more stable (Fig. 2) [6].

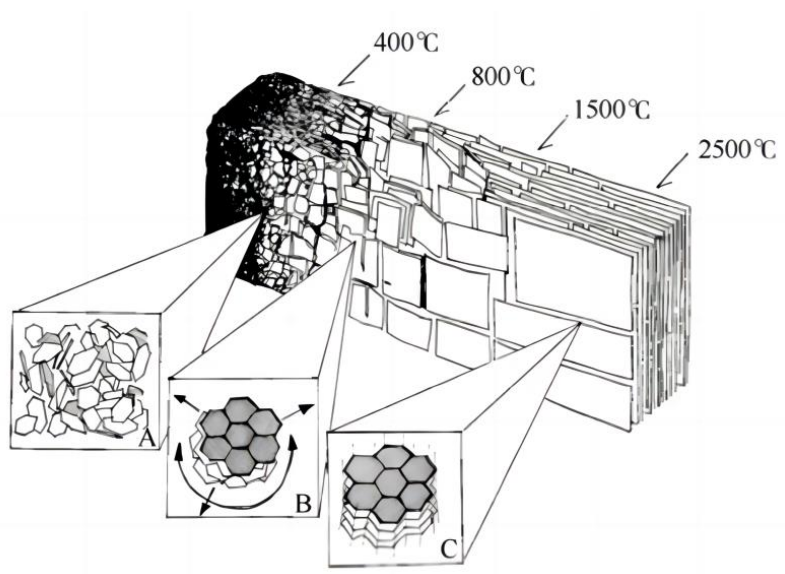


Fig 2. Schematic characterization of biochar structure at different carbonization temperatures. A is increase of aromatic carbon in the structure of biochar, mainly amorphous carbon. B is increase of turbo-layered aromatic carbon in the structure of biochar. C is the structure of biochar tends to be graphitized. <https://www.taylorfrancis.com/books/edit/10.4324/9780203762264/biochar-environmental-management-johannes-lehmann-stephen-joseph>

2.2.2 Basic properties of biochar

Biochar mainly contains elements such as C, O, H, N, K, Ca, Na, Mg, etc. The elemental composition of biochar is mainly determined by the raw material of biomass, and the content of C and alkali metals increases with the increase of temperature, and the content of N, H, O and other elements decreases with the increase of temperature.

Biochar is generally alkaline and a few are acidic. The decomposition of acidic functional groups will be accelerated at higher temperatures, which also promotes the formation of alkaline ionic compounds, leading to an increase in pH. In addition the charring residence time also affects the pH, which is manifested as the longer the time, the higher the pH. Currently the pH of biochar has almost covered acidic, alkaline, neutral almost all reaction situations.

Biochar has a large specific surface area, which gives it very good adsorption properties and is widely used as a carrier and adsorbent material. Because of its good adsorption properties, biochar is widely used in pollutant prevention and control, and has great potential for application in various fields. Carbonization temperature has an effect on surface area, and studies have shown that below 400 °C, biochar will increase in volatiles and increase in specific surface area as the temperature rises; however, at temperatures higher than 800 °C, the structure of biochar will collapse due to the high temperature, resulting in clogging of pore sizes.

Biochar has good hydrophobicity because of the reduction of oxygen-containing functional groups on its surface during carbonization. The water-holding property of biochar is due to its rich microporous structure that makes it more adsorbent to water (Fig. 3) [7].

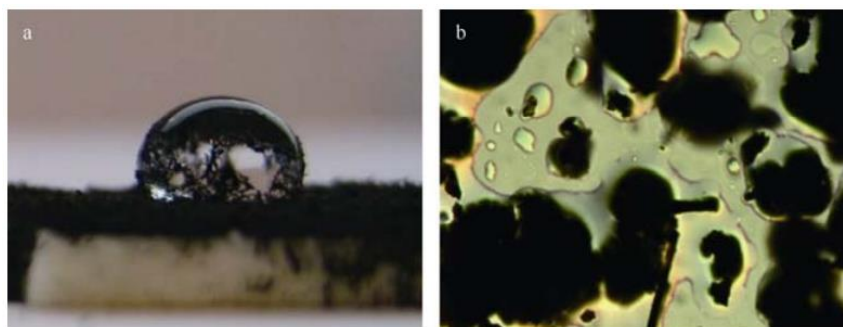


Fig 3. Two cases of biochar with water. <https://core.ac.uk/reader/13747999>

Biochar contains high C and has a stable aromatic carbon structure, giving it high stability. Among the biomass feedstocks, lignin is the most stable component. The higher the lignin content in the feedstock, the higher the content of aromatic C formed by charring, and the higher the stability of biochar.

3. Biochar in the Soil

3.1. Soil Conditioning

Biochar, as a representative soil conditioner, helps to increase the carbon content level of soil in practical application and the content of crops planted on such soil will also be significantly increased. Soil biomass charcoal will affect soil fertility, through the use of biochar, for soil fertility degradation of land can also play a positive role in enhancing soil fertility, replenish the loss of organic matter in the soil. Biochar is processed through a cycle of physical deposition, burial or weathering, and reacts with soil fulvic acid to form a soil carbon pool, which ultimately results in improved soil fertility.

Compared with other soil organic matter, biochar has much better cation uptake properties. Due to its own chemical inertness, it has CO₂ fixation function, and its addition to the soil can effectively reduce the amount of greenhouse gas methane produced in the soil.

In addition, the addition of a certain amount of biochar can also be a certain degree of heavy metal pollution after the farmland restoration, increase crop yields at the same time, reduce the amount of unnecessary chemical fertilizers, in promoting crop content and quality enhancement at the same time, but also reduce the situation of agricultural surface pollution. Zhang Liping showed [8], in the heavy metal cadmium contaminated potted plants after adding a certain amount of biochar to the soil, will significantly improve the nitrogen fixation capacity of soybeans, to promote the growth of soybeans, in the low concentration of contaminated soil in the flowering period, just 1% of biochar can be soybean rhizobacteria nitrogen-fixing enzyme activity enhanced by 53.66 times, and the nitrogen content of the soybean leaves increased by 13.7%, the height of soybean plant increased by 14.6%.

3.2. Affecting Soil Properties

3.2.1 Influence on soil capacity

Soil bulk density is closely related to soil pore space, and it can show the degree of soil looseness and soil structure. As biochar is applied to the soil it reduces the soil's weight capacity. Because of the small weight capacity of biochar, its application into the soil can reduce the soil weight capacity. A study by Chen et al. [9], based on a 3-year positioning experiment in a high-yield farmland in the North China Plain, found that the soil bulk density of two samples decreased by 4.5% and 6.0%, respectively, after the application of biochar.

3.2.2 Influence on soil aggregate structure and water content

Soil with good aggregate structure has multi-stage pores, which is conducive to changing soil aeration, water permeability and water retention capacity, and also has a good coordinating effect on soil fertility. Soil granular structure can affect the good growth of crop roots, and biochar can improve soil granular structure well, thus promoting crop growth. Biochar improves soil water permeability and aeration. Biochar also improves water holding capacity, reduces soil weight, improves soil structure, changes soil physical properties, and ultimately improves soil fertility and promotes crop growth.

3.2.3 Influence on soil pH

When biochar is produced and prepared, its pH is affected by the temperature and its ash contains more alkali-generating minerals and carbonates, which ultimately makes the biochar generally alkaline. The alkaline nature of biochar directly affects the pH of the soil.

3.2.4 Influence on soil cation exchange capacity

Zhang et al. [10] found that biochar could increase soil CEC content by 57.25% to 155.30% compared with the control, and the increase in the amount of biochar increased the CEC, which also indicates that biochar has a very significant effect on CEC.

3.2.5 Influence on soil nutrients and organic carbon

Soil nutrients are essential nutrients for crop growth and one of the most important sources of nutrients for crops, and soil nutrients include a wide range of elements such as nitrogen, phosphorus and potassium. Soil organic carbon is not only a core indicator for soil quality assessment of arable land, but also an important part of the global carbon cycle. The application can have a good nutritional effect by increasing the carbon content without increasing the release of soil carbon dioxide.

3.2.6 Influence on enzymes in the soil

Soil enzyme activity is related to soil microbial activity, and changes in soil enzyme activity can reflect the active degree of soil material metabolism and fertility level to a certain extent. The study of Zhang [11] showed that biochar, as a soil conditioner, plays a key role in improving the effect of soil enzymes.

3.3. Application of Configuration

3.3.1 Protection of microorganisms by biochar

Biochar can play an immobilizing role for microorganisms. Heat-treated biomass has a carbon-rich porous structure, so the rough surface and porous structure of biochar helps microorganisms colonize the soil, and microbial cells attach to the micropores of biochar through a number of effects, avoiding soil pollutants that are toxic to them and increasing the abundance of microorganisms in the environment. Biochar can avoid cell shrinkage or rupture of certain microorganisms due to direct contact with pollutants, indirectly improving the removal efficiency of soil pollutants.

3.3.2 Biochar provides nutrients needed by microorganisms

Biochar contains a variety of inorganic mineral elements, which can enrich the soil nutrient pool and improve soil productivity, and is rich in carbon, which can bring long-lasting benefits to microorganisms through its slow release as a fertilizer. Biochar is rich in functional groups that provide nutrient reserves.

4. Biochar for Crop Conditioning

4.1. Effect of Biochar on Crop Nutrient Uptake

Wang Yong et al. [12] found that biochar could significantly promote the uptake of phosphorus and potassium in rice. However, the study of Zhang et al. [13] found that the nutrient uptake of wheat

plants was not significantly affected by biochar application, which also indicates that biochar has a yield increasing effect on crops within a certain range, which will not always increase with the amount of use.

4.2. Effect of Biochar on Crop Growth

Biochar is able to increase the fruiting rate of crops, among other things, thus significantly increasing crop yield and favoring growth and yield. Zhou et al. [14] showed that the concentration of 5.0% of biochar significantly increased the plant height and dry matter accumulation of rice seedlings, and the concentration of 10.0% to 15.0% of biochar caused the plant height to reach the highest value, and then further increase the amount of biochar added will make the plant height and dry matter accumulation decline. Therefore, in the process of crop growth and development, the appropriate amount of biochar is beneficial to the growth of crops, while the single pursuit of high amounts of biochar application does not have a significant effect on the growth of crops, and even sometimes will be too much to inhibit the effect. The promotion effect of biochar on crops is not only affected by the amount of biochar added, but also by the characteristics and application amount of biochar, the fertility and original nature.

5. Conclusion

Biochar has good environmental benefits and has strong application prospects in agriculture, industry and environment. When utilizing biochar, the preparation methods at different temperatures and under different environments should be chosen reasonably in order to maximize the utilization. The stable structure and high surface area of biochar can adsorb various pollutants in the soil and remediate the soil contaminated by heavy metals. Biochar can increase soil fertility by replenishing organic carbon content and improving the effectiveness of enzymes, and can also improve soil fertility by decreasing soil bulk density, improving soil granular structure, and increasing soil cation exchange. Through soil conditioning, adding biochar in the right amount can promote the absorption of soil nutrients by crops, which is also beneficial to the growth of crops to a certain extent. At present, the ecological effect of biochar in soil still needs to deepen the relevant basic theories and research, in order to complete the construction of biochar theory and technology support system. Further research on biochar is of great practical significance for agroforestry integration, pollution monitoring and soil and crop conditioning.

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