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Research Article

Environmental Effects and Carbon Sequestration Potential of Returning Agricultural Waste to Field By Carbonization

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Abstract

Carbon emissions from human activities have brought enormous pressure to stop global warming. In recent years, carbonization technology has been fully developed as an effective means of biomass resource utilization. The carbonization of agricultural waste to produce biochar can improve the application potential of agricultural waste in the fields of energy and environment. Biochar has been gradually applied in the field of soil improvement in recent years and has shown a good potential for carbon sequestration and emission reduction. It has become a key research topic in the fields of agriculture, environment, and energy. The physical and chemical properties of biochar and its many effects in soil improvement have been fully studied, confirming its excellent soil improvement performance. However, there is no clear conclusion about the carbon sequestration and emission reduction potential of biochar returning to the field. This paper briefly summarizes the biomass carbonization technology and the physicochemical properties of biochar, focusing on the soil advantages brought by the return of biochar to the field and its research progress on carbon sequestration and emission reduction. It is finally determined that the return of biochar to the field has a good potential for carbon sequestration and emission reduction. The carbon sequestration effect of biochar itself and the reduced greenhouse gas emissions after being applied to the soil can effectively offset the carbon emissions caused by human activities. And economic benefits still need to continue to study.

Keywords: Agricultural waste; Biochar; Carbonization; Carbon sequestration

Introduction

The utilization of agricultural waste as a resource is a key topic of research in various countries. Converting waste into biochar through carbonization is one of the main treatment methods. As the end product of biomass raw material resource utilization, biochar is produced by pyrolysis under anaerobic or anaerobic conditions and has high carbon content and large specific surface area.

In recent years, due to its excellent physical and chemical properties, biochar has been widely used in the field of returning to the field. Because of its high specific surface area and rich pore structure, it can effectively improve soil porosity, optimize soil structure, and improve soil water holding capacity [1-3]. Abundant elemental composition and surface functional groups can also introduce micronutrients needed for soil and plant growth [4,5], and retain nutrients. At the same time, returning biochar to the field can also sequester CO_2 in the form of Total Organic Carbon (TOC) and Soil Organic Carbon (SOC), showing obvious carbon sequestration and emission reduction potential [6,7].

Therefore, the carbonization of agricultural waste back to the field is a win-win option for soil improvement and carbon sequestration. In summary, this paper summarizes the current research on biomass carbonization technology and biochar returning to the field, summarizes the impact of biochar returning to the field on soil physical and chemical properties, and studies the carbon sequestration and emission reduction potential of biochar returning to the field. The application provides theoretical support (Figure 1).

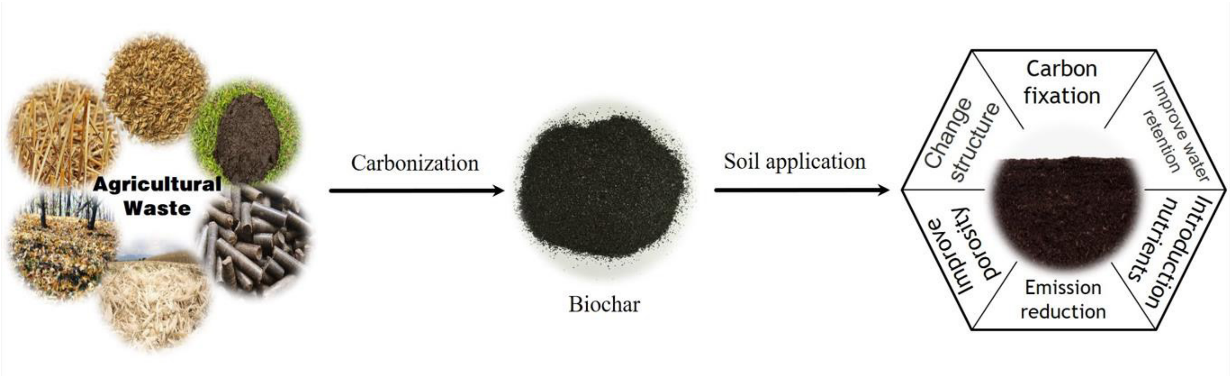

Figure 1: Carbon fixation and emission reduction of agricultural waste carbonization.

Preparation of Biochar from Agricultural Wastes

Carbonization technology

Carbonization technology refers to the process of heating agricultural waste, forestry waste, sewage sludge and other biomass raw materials in a low-oxygen or anaerobic environment to decompose the molecules to form biochar, bio-oil and non-condensable gas products, the main purpose is to obtain solid product biochar [8]. At present, the main methods of biomass carbonization include a series of methods such as traditional pyrolysis carbonization, hydrothermal carbonization, and microwave carbonization. Traditional pyrolysis carbonization is widely used, which has the advantages of large output, high efficiency and simple operation. Most biochar products are produced by traditional pyrolysis carbonization methods [9].

In the process of biomass pyrolysis and carbonization, the pyrolysis temperature and reaction time are important indicators related to the yield, performance, and physical and chemical properties of biochar. Rapid Pyrolysis (500 °C), slow pyrolysis (400 °C) and gasification (800 °C) [10]. Among them, temperature is the decisive factor for the physical and chemical properties and structural characteristics of biochar. The change of temperature will make the biochar produced from the same biomass raw material have huge differences in physical and chemical properties. Under normal conditions, high temperature will cause higher specific surface area and Pore volume [11].

Biochar is mainly produced from waste biomass. In theory, all biomass can be used as raw material for biochar production. At present, the raw materials used to prepare biochar mainly include straw, fruit shell, poultry manure, wood chips, bagasse and sludge. Biochars prepared from different biomass raw materials have different physicochemical properties, especially the chemical properties of biochars, such as elemental composition, H/C ratio, C/N ratio, and ash content. For example, the ash content of biochar produced from wood raw materials is usually lower than other biochars [12]. The ash content determines the quality and economic benefits of biochar. Low ash content means higher economic benefits, which is also the current market. The reason why there are more wooden biochar products.

However, the combination of biomass raw materials and carbonization technique affects the properties of biochar. There is no conclusive evidence to establish the surface features and process parameters of biochar, and the physicochemical properties of biochar produced by various types of biomass carbonization employing various process parameters are quite varied. Consequently, carbonization technology has consistently been a hot topic in the domains of agriculture, the environment, and energy.

Physical and chemical characteristics of biochar

Numerous researches have shown that the biomass feedstock and carbonization process factors influence the physicochemical properties of biochar. Its morphological traits are influenced by the morphology of the raw materials and the carbonization process's treatment techniques. Although the biochars produced by carbonizing various raw materials have various physical and chemical characteristics, their general compositions follow similar rules and they are all primarily made of carbon with doping of other elements.

The surface structure and pore structure of biochar, which are closely correlated with the carbonization temperature, are the primary manifestations of its physical qualities. Amorphous carbon with aromatic carbon structures gradually form at lower temperatures (around 400 °C); between 400 and 800 °C, aromatic structures are connected to form a relatively regular Layered structure, though the layers are still randomly arranged; and at higher temperatures (above 2000 °C), a more regular three-dimensional graphite structure can be further generated. The surface structure of biochar can be more fully described using XRD. Biochar is mostly made of amorphous carbon with a local crystal structure, according to the characterisation results of XRD [13]. The layers are joined to one another in the plane and resemble the layered stacking structure of graphene, although they are stacked arbitrarily [14]. As the carbonization temperature rises, more orderly stacking structures and an increase in the content of the carbon crystal structure are observed. The most significant element influencing the structure of all pyrolysis conditions is generally the greatest pyrolysis temperature for the creation of biochar. The structure of biochar is also influenced by additional pyrolysis factors, such as residence time, pressure, atmosphere, etc., however these factors are much lower than the pyrolysis temperature. By using BET measurements, the precise surface area data of biochar may be identified. The Tomczyk et al. [15] use BET analysis demonstrated that slow pyrolysis biochar has a greater specific surface area than fast pyrolysis biochar. However, Brown et al. [16] research found that when the carbonization temperature approached 750 °C, the specific surface area of biochar increased significantly. Biochar has significant application potential in the field of soil improvement because to its pore structure, which can effectively enhance soil porosity and improve soil water holding capacity. The carbonization temperature is also directly connected to the pore structure of biochar. In general, the relationship between the specific surface area and the biochar's pore volume is positive. Additionally, prior research has demonstrated that micropores (pore size < 2 nm) have the biggest influence on the material's specific surface area, adsorption efficiency, and other properties. The energy and reaction time needed for pore formation during the carbonization process are also obtained by the biochar feedstock as the carbonization temperature and reaction time rise [17].

The chemical makeup of biomass source materials has a significant impact on the chemical characteristics of biochar. There is no definite and agreed-upon understanding of the chemical characteristics of biochar due to the complexity and diversity of its constituent ingredients. The fixed carbon content in biochar is between 40% and 60%, followed by O, N, and H, and is the element with the highest concentration as a carbon material [18]. The composition of other elements is influenced by the raw material itself [12]. According to certain research, biochar made from raw materials such as wheat straw, corn straw, bagasse, and other herbal biomass is more likely to contain inorganic components than biochar made from wood [19-22]. Temperature will also have an impact on the elemental makeup of biochar. Metal components as Mg, Ca, P, K, Cu, Zn, Fe, and Mn have become more abundant in pig dung and straw biochar as the carbonization temperature has risen [23]. Biochar's chemical properties are generally based on the characteristics of the raw material from which it is made, and because it contains a lot of fixed carbon and nutrients like N, P, and K as well as other trace elements, it has better soil application potential and carbon sequestration and emission reduction potential (Figure 2).

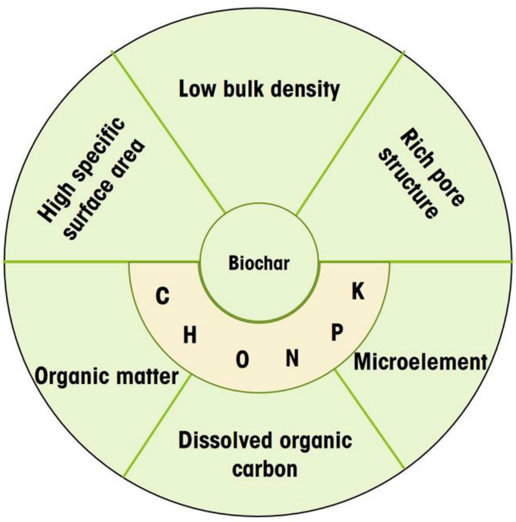

Figure 2: Physicochemical properties of biochar.

Overview of Soil Application of Straw Biochar

Effect of straw biochar application on soil physical properties

Numerous studies have shown that adding biochar to soil can enhance its physical and chemical characteristics. After being pyrolyzed at a high temperature, biochar has a large specific surface area and a rich pore structure that can effectively increase soil's ability to retain water, especially sandy soil with a rough texture [3]. According to the study, applying 5% and 25% biochar to sandy soil, respectively, boosted soil water retention by 370% and 260% compared to the blank control. According to Abrol et al. [24], the high specific surface area and many pores of biochar resulted in a decrease in the soil's water permeability and a correspondingly enhanced water retention period. Biochar can increase soil permeability, strengthen soil structure, enrich soil porosity, decrease soil bulk density, remove compaction, and promote the development of plant roots in addition to increasing soil's ability to hold water [25-28]. Laird et al. [29] findings show that adding biochar to the soil can dramatically lessen how compact it is. They found that adding $25g \cdot kg^{-1}$ of biochar can reduce density by $0.19g \cdot cm^3$.

Effect of straw biochar application on Soil Nutrients

For crops to grow normally, soil nutrients are a crucial requirement. The nutrient content of the soil can be successfully increased by adding biochar, which also aids in plant growth [30]. According to studies, biochar is a significant source of N, P, K, and other micronutrients. Particularly, livestock dung biochar has high levels of minerals that can support the growth of microorganisms and crops [4,5]. The key cations (K, Mg, Ca, Mn, Zn, and Cu) necessary for plant growth can be more readily available in soil after applying biochar [31]. The amount of organic matter and organic carbon in the soil can also be increased by adding biochar [32]. According to Liang et al. [33], biochar can adsorb small-sized organic molecules from the soil using its own pore structure and encourage the aggregation of these molecules. create organic soil material. After adding biochar to the soil for 5 months, Meng et al. [34] discovered that SOC dramatically increased. Additionally, the soil fertility can be effectively increased by the soluble organic carbon added by biochar. Biochar's rich functional groups and holes on the surface can also increase the availability of soil nutrients, improve nutrient uptake, and boost nutrient retention in the soil [35].

Effect of straw biochar application on crop growth

The effect of biochar on crops is a crucial area of biochar study. Numerous studies conducted recently have supported the impact of applying biochar to the soil on crops [29,36-38]. Studies on biochar's impacts on crops are now primarily short-term in nature and do not include long-term data, especially at the field scale. Through the addition of nutrients and physical components, biochar can change the pH of acidic soil, increase soil nutrient availability over time, and reduce nutrient loss [39,40]. It can also reduce agricultural non-point source pollution, increase fertilizer use efficiency, and decrease fertilizer application in agricultural production [41-43]. According to several research, biochar can enhance soil nitrogen fixation [44,45] and plant uptake of nitrogen [46]. Biochar greatly increased crop output in the aforementioned experiments, particularly in pot experiments. However, in other studies, biochar had no discernible impact on crop yields. For instance, there was no discernible change in crop yield between various treatments in certain tests with lower biochar application rates [47]. There is still a dearth of systematic study on the long-term effects of biochar application on crops, and it is unclear when biochar will start to affect crops in the field or how much it will affect agricultural yield. The coupling of various crop species, soil conditions, biochar types, and carbonization process parameters is mostly to blame for this, which makes the influencing elements excessively complex and fraught with uncertainty. The unknown elements are magnified in long-term applications. Therefore, how to choose appropriate biochar in various soils to create a good influence on soil and crops is a crucial problem, and it is also one of the barriers preventing the growth of the biochar industry and the widespread use of biochar.

Carbon Sequestration and Emission Reduction Potential of Biochar Application

Carbon fixation and storage capacity of biochar

The greatest share of the world's greenhouse gas emissions, CO_2, are attributable to human activity, which has increased pressure to reduce global warming and greenhouse gas emissions. Soil is an essential component of nature and a significant source of greenhouse gas emissions that contribute to climate change and global warming. 20% of all CO_2 emissions are caused by the respiration of soil and plant roots [48]. However, agricultural soil is also one of the most significant carbon sinks and a key tool for lowering greenhouse gas emissions and stabilizing CO_2 levels. In the absence of carbon sequestration, plants will naturally release the CO_2 they have taken in during photosynthesis back into the atmosphere through respiration and mineralization. Utilizing carbonization technology, biomass wastes like plants and cereals can be transformed into fixed carbon. The majority of CO_2 can be fixed once it has been added to the soil, and only approximately 5% can be turned into CO_2 through mineralization, which has a significant potential for carbon sequestration [49]. Biochar has a highly aromatic structure and great corrosion resistance due to high temperature carbonization. It can combine with soil minerals to form aggregates, stay in the soil for a long time, and aid in the storage of carbon.

Emission reduction capacity and carbon reduction capacity of biochar

Emission reduction capacity of biochar: The fundamental way that biochar's capacity to reduce emissions is demonstrated is by the fact that, when applied to soil, it enhances the amount of nutrients and organic matter present, decreases the need for chemical fertilizers, and effectively prevents N_2O emissions from chemical fertilizers. decrease. N_2O has a 298-fold greater potential to cause global warming than CO_2 as a greenhouse gas [50]. According to studies, the use of nitrogen fertilizers in agriculture has a direct impact on N_2O emissions [51]. Currently, it is thought that agricultural soils are the source of 84% of anthropogenic N_2O emissions [52]. Applying biochar to soil has been shown to reduce N_2O emissions, which may be because it speeds up denitrification or because it increases aeration, which lowers N_2O emissions during denitrification [53-55]. According to research by Alisial et al. [56], applying biochar to soil can cut N_2O emissions by as much as 64.9%. The return of sawdust biochar to the field can reduce N_2O emissions by 31.5%, according to a study by Pokharel et al. [57].

Carbon reduction capacity of biochar: The carbon reduction potential of biochar is mainly attributed to its effective suppression of CO_2 and CH_4 emissions, with obvious carbon reduction potential. Lehmann et al. [58] were the first to evaluate the emission reduction potential of biochar, and the evaluation results showed that, Changing from the traditional "slash-burn" agricultural farming mode to "slash-carbon" on a global scale will obtain a carbon sequestration and emission reduction potential of 0.19~0.21×10^9 tC·a^{-1}, It can offset 12% of the carbon emissions caused by land changes caused by human activities (1.7×10^9 tC·a^{-1}). But Lehmann's assessment only considers the carbon sequestration capacity of biochar itself, ignoring the other aspects of biochar's emission reduction potential. Woolf et al. [59] comprehensively considered the potential carbon sequestration potential of biochar from various applications. Its research shows that the application of biochar technology can achieve a carbon reduction potential of 1.0~1.8×10^9 t per year, and the cumulative potential can reach 66~130×10^9t (calculated as CO_{2e}) after a hundred years. Half of the potential comes from biochar's own carbon sequestration, about 30% comes from renewable energy production instead of fossil energy use to reduce emissions, and the rest comes from greenhouse gas emissions reductions such as CH_4 and N_2O. Roberts et al. [60] selected crop straw, yard waste and energy crops, and studied the emission reduction effect of biochar preparation and soil application in the slow carbonization production process. The conclusion is that the total greenhouse gas emission reduction in the biochar production process is about 870 kgCO_{2e}·t^{-1} dry biomass raw material, and the contribution of biochar carbon sequestration is about 65%. The evaluation results of Hammond et al. [61] show that the carbon reduction potential of biochar technology using different biomass raw materials is 0.7~1.3 tCO_{2e}·t^{-1} raw materials; through the analysis of life cycle stages, it can be seen that the largest emission reduction is the biochar itself. Carbon sequestration (40%-50%), followed by the impact of biochar on greenhouse gas emissions during agricultural production (25%-40%).

Biochar will perform the role of carbon reduction by reducing CH_4 emissions in addition to conventional CO_2 emissions after being applied to the soil [62]. According to a study by Liu et al. [63], applying biochar to rice soil can cut CH_4 emissions by as much as 91.2%. The capacity of various forms of biochar to reduce carbon varies. Bamboo charcoal biochar has a lesser capacity to reduce carbon than straw biochar, which has a capacity of 51.1%. According to a study by Feng et al., adding biochar to soil can improve microbial oxidation of CH_4 and decrease CH_4 emissions while also increasing soil porosity.

Conclusion and Recommendations

Currently, a resource-use technique that is mature and effective is carbonization of agricultural waste. Carbon sequestration, trash management, and energy production can all be accomplished at once by using agricultural waste biomass for biochar manufacturing and soil application. The likelihood of carbon sequestration is good, and agricultural output is increased. Waste has a lot of application potential in the fields of environment and energy. The technology for carbonizing biomass is currently advancing quickly. The physical and chemical characteristics of biochar and its use in soil have been the subject of several investigations. It has been proven that biochar can alter soil porosity, enhance soil water holding capacity, decrease soil bulk density, improve nutrient content and fertility, and has a particular beneficial impact on fostering the growth and development of crops in the soil. Due to a variety of its own physical and chemical characteristics, biochar has excellent carbon sequestration and emission reduction potential. Through both its own carbon sequestration and its influence on greenhouse gas emissions during agricultural production, biochar can successfully offset carbon emissions brought on by human activities. The kind of biochar source material also has some bearing on how well it can sequester carbon and reduce emissions. The capacity of biomass for reducing emissions and sequestering carbon can be maximized with the right biomass raw materials. In order to maximize carbon sequestration and emission reduction, the right biochar should be chosen before being applied to the area. However, there is currently a dearth of pertinent economic and environmental impact studies on the use of biochar for carbon sequestration and emission reduction. Theoretically, field carbon sequestration and emission reduction offer enough support, encouraging the quick development and widespread use of biochar returning to fields.

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Conflict of interest

No conflict of interest.

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