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Study on the carbon sequestration effect of biochar in vegetable fields

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Abstract. This study was conducted using a field experiment methodology aimed at assessing the effects of biochar application on tomato growth and soil properties in greenhouse greenhouses. Biochar, a carbon-rich material produced by pyrolysis of biomass under anoxic conditions, has attracted attention for its potential in soil amelioration, carbon sequestration, and soil fertility enhancement. In this experiment, three biochar application levels of 0, 20, and 40 t/ha were designed to investigate the effects of different application rates on soil chemical properties and tomato growth.The study results showed that biochar application significantly increased soil pH by 0.05 to 0.1 units, which was beneficial in regulating acidic soil. Meanwhile, biochar application significantly increased total soil carbon content by 7.5 to 28.8%, indicating its effectiveness in enhancing soil carbon sequestration capacity. Although the enhancement of total soil nitrogen content by biochar was small (3.1 to 7.8%), this increase had a positive effect on crop growth. Considering the cost-effectiveness, this study recommends a one-time application of 40 t/ha of biochar, which can maintain the effect for at least 2 years, reducing the need for frequent applications and the associated economic costs.This study provides recommendations for optimization of biochar application and provides a scientific basis for sustainable agricultural development. By improving soil properties and increasing crop yields, this study contributes to the promotion of green development of agriculture and ecological civilization, and the realization of carbon and nutrient cycling in agroecosystems.The significance of this research focuses on evaluating the effects of biochar on soil properties and tomato production, thereby providing a scientific basis for fine-tuning application levels. Such optimization promotes sustainable farming practices, reduces agricultural waste emissions, enhances carbon and nutrient dynamics within agroecosystems, and reinforces the scientific foundation essential for progressing green agricultural development and building an ecological civilization.

Keywords: Biochar, Vegetables, Carbon sequestration, Soil organic carbon.

1. Introduction

In recent years, China's vegetable cultivation area has grown rapidly. Facility cultivation in the process of rapid development also caused a variety of problems, the producers in order to pursue higher economic interests, a large number of fertilizer applications, resulting in different degrees of secondary salinization and salt damage to the soil of the facility vegetable land, crop growth and development physiological disorders, yield reduction is increasing, and these are serious impediments to and threats to the sustainable development of the facility agriculture [1]. Improving the quality of soil for facility

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cultivation and increasing the yield and quality of vegetables are issues of concern in vegetable cultivation[2].

Due to its good water holding and fertilizer retention properties, biochar can be applied to the soil as an amendment to improve the soil environmentto improve crop yield and quality. However, current studies on different application rates of biochar have not been able to introduce a generalized range of optimal biochar application rates, which need to be determined according to different soil types and crop species. In this paper, biochar is applied as a soil conditioner in greenhouse vegetable cultivation to analyze its effect on soil nutrient supply, and explore a green and sustainable way of facility agriculture production. At the same time, it also provides a basis for the rational application of biochar in greenhouse vegetable cultivation. Based on the fact that biochar has a stable carbon structure is difficult to decompose by microorganisms, and that can form carbon sinks in agricultural soils, the present study summarized the effects of different doses of biochar on the soil properties of vegetable fields, compared the different carbon sequestration effects, and elucidated carbon sequestration by biochar in the soil of vegetable fields.

2. Literature review

Biochar has gained a lot of interest lately for its use as a soil conditioner in agriculture. Studies show that biochar can improve soil architecture, increase the amount of organic matter in the soil, and improve the soil's capacity to hold onto fertilizers and water.[3,4]. In greenhouse vegetable cultivation, the application of biochar can not only increase soil pH and alleviate soil acidification, but also significantly increase the total soil carbon content, thus enhancing the carbon sequestration capacity of the soil [2,3]. In addition, the enhancement effect of biochar on total soil nitrogen content was not significant. However, it still helped to increase soil nitrogen content overall, promoting crop growth [5,6].

While the utilization of biochar positively influences the cycling of carbon and nitrogen in soil, it is essential to ascertain the ideal quantity of biochar based on various soil classifications and the specific needs of crops. The results of biochar application in the existing literature are inconsistent, which may be related to factors such as the source of biochar, preparation method, and application method [8,9]. In addition, the effect of biochar application on greenhouse gas emissions is one of the hotspots of current research, which shows that biochar can reduce N2O emissions during nitrogen fertilizer application, thus reducing the contribution of agricultural activities to climate change [5][7].

In summary, biochar, as an environmentally friendly soil amendment material, plays an important role in improving soil fertility and promoting sustainable agricultural development. Future studies should further explore the optimal strategies for biochar application and its long-term effects in different agroecosystems.

3. Test materials and methods

3.1. Test materials

The experiment was conducted from 2020 to 2021 in the vegetable growing area of Fengxian District, Shanghai (N30°53', E121°23'). The area has a subtropical monsoon climate with abundant rainfall and heat, with an average temperature of 155.5 ℃ and an annual precipitation of 1004.6 mm. The soil type for the test was sandy loam, and the main properties of the soil were as follows: 17.2 g/kg of organic carbon, 2.0 g/kg of total nitrogen, 69.3 mg/kg of quick-acting phosphorus, 82.9 mg/kg of quick-acting potassium, and pH 6.7. The biochar for the test was a commercially available biochar. The test biochar was commercially available.

3.2. Experimental design

The experiment was done in a facility vegetable plot. Biochar was added into different small areas with different rates and inputs, while a portion of the soil was kept without biochar for the control experiment. A total of four treatments were set up: 1) no charcoal treatment (CK); 2) biochar addition of 10 t/ha (C1); 3) biochar addition of 20 t/ha (C2); and 4) biochar addition of 40 t/ha (C3). A one-way completely randomized trial with biochar was selected and each treatment was repeated three times. Tomatoes and peppers were planted consecutively from 2020 to 2021. According to the experience of local farmers, tomato needs to be slowed down for 20 d after transplanting.Each fertilizer plot was fertilized in May 2020 with equal physical quantity, i.e., the total mass of fertilizer applied in each plot was equal. Field management measures such as pest control, weeding, watering, etc. were the same in all plots. All tomatoes and peppers were harvested and soil samples were collected.

3.3. Sample collection and measurement methods

Soil samples were collected before transplanting vegetable seedlings. Five soil samples were randomly taken from the 0-20 cm surface layer of each plot with a soil auger and mixed into one mixed sample. The samples were air-dried indoors to remove visible roots and stones, and then passed through sieves of 1 and 0.15 mm aperture, respectively. The soil samples were mixed with deionized water at a soil-water ratio of 2.5:1 and shaken horizontally for 2 h. The pH and EC of the soil were determined using a pH meter (6500, Jenco, USA) and a conductivity meter (DDSJ-318, Jingke, China), respectively, and the above water samples were passed through a 0.45 μm filter membrane and determined by using an organic carbon analyzer (TOC-L, Shimadzu, Japan). Soil samples were ground to 100 mesh soil samples, and TC (%) and TN (%) contents of the soil were determined by an elemental analyzer (Vario EL cube, Elementar, Germany).

3.4. Data processing

The experimental data were processed using Microsoft Excel software.

4. Results

4.1. Soil pH change

As shown in Figure 1, soil pH after biochar application ranged from 6.58 to 6.65, which was an increase of 0.05 to 0.1 units compared to the control group without biochar application.This adjustment, while modest in scale, plays a crucial role in modulating soil pH, enhancing the soil ecosystem, and fostering the growth of crops.. The alkaline nature of biochar helps to neutralize soil acidity, especially under acidic soil conditions, and this enhancement helps to increase soil pH, thereby creating a more suitable growing environment for crops. However, changes in pH also need to be controlled within a certain range to avoid adverse effects on crop growth from too high or too low pH values. Therefore, the application strategy of biochar should take into account the initial pH of the soil and the pH preference of the crop in order to achieve optimal soil improvement

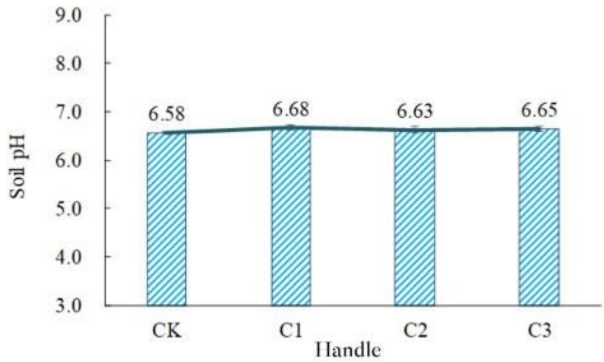

Figure 1. Soil pH.

4.2. Soil EC change

As shown in Figure 2, the EC values of the soils in this study ranged from 414.0 to 490.0 uS/cm, indicating that the salt content of the soils increased after biochar application. Soil EC values increased by 5.7% to 18.4% in the treatment group with biochar application compared to the control group without biochar addition, and this change may be related to the increase in the concentration of soluble salts in the soil after biochar application. This increase reflects, to some extent, the effect of biochar on soil salinity conditions, but further analysis of its potential impact on crop growth is also needed. A moderate increase in soil EC may help to provide nutrients needed by crops, but an EC that is too highmay lead to soil salinization and affect crop growth and development. Therefore, the amount and frequency of biochar application need to be precisely adjusted according to soil characteristics and crop needs to ensure that soil EC values are maintained within appropriate ranges to promote healthy crop growth.

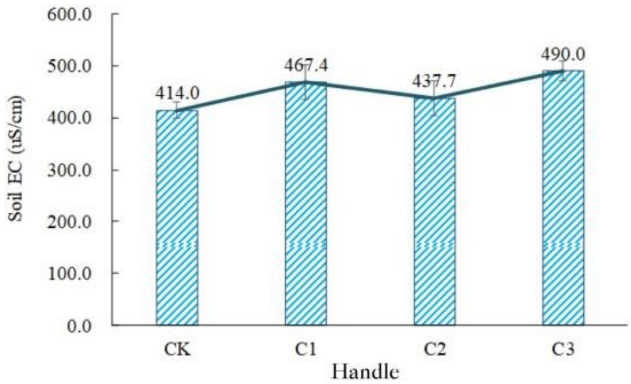

Figure 2. Soil EC.

4.3. Changes in total soil carbon content

As shown in Figure 3. The increase in soil TC ranged from 7.5% to 28.8%, indicating that biochar, as a supplementary source of organic carbon, effectively increased the organic carbon stock in the soil. This increase plays an important role in increasing the carbon sequestration capacity of the soil, improving soil structure and enhancing soil fertility. Soil organic carbon is a key indicator of soil fertility and soil biological activity, and the increase in its content helps to improve soil water and fertilizer retention, thus providing better growing conditions for crops. Furthermore, the enhancement of soil total carbon (TC) is beneficial for alleviating global climate change, given that soil serves as a durable carbon reservoir, contributing to the diminishment of carbon dioxide levels in the atmosphere.

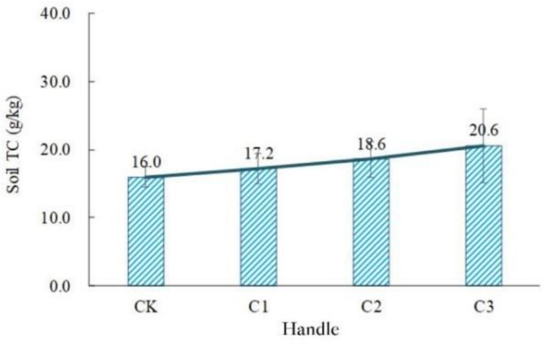

Figure 3. Soil TC.

4.4. Changes in total soil nitrogen content

The values varied from 2.93 to 3.16 g/kg, as illustrated in Figure 4. Comparing with the control group lacking biochar application, we observed an increase in soil total nitrogen concentration in the treatment group with biochar, ranging from 3.1% to 7.8%. This increase, however minimal, positively influenced soil nitrogen levels and enhanced crop development. Nitrogen is a crucial ingredient for plant growth, and enhancing soil nitrogen levels can augment crop output. The beneficial impact of biochar application

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on soil nitrogen levels indicates that it may enhance nitrogen retention in the soil by adsorbing and immobilizing nitrogen, hence minimizing nitrogen loss.

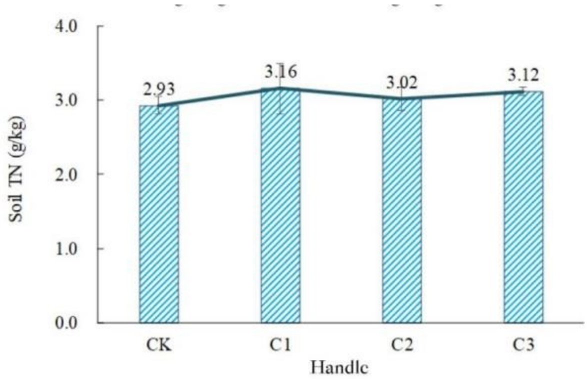

Figure 4. Soil TN.

4.5. Changes in soil carbon to nitrogen ratio

As shown in Figure 5, the soil C/N ratio in this study ranged from 5.46 to 6.60, and the application of biochar increased the C/N ratio by 0% to 20.9% compared to the control. This change is important for the balance of the soil ecosystem because an appropriate C/N ratio helps to promote microbial growth and activity, which enhances the decomposition of organic matter and nutrient cycling in the soilThe application of biochar may have modified the soil carbon-to-nitrogen ratio by enhancing the input of organic carbon, consequently influencing both the structural composition and functional dynamics of the soil microbial community. These modifications hold promising implications for enhancing soil fertility and supporting crop development.

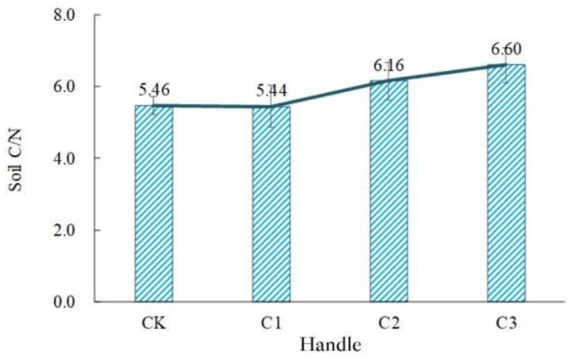

Figure 5. Soil C/N.

5. Discussion

The effect of biochar as a soil amendment on soil properties is multifaceted and involves factors such as type of biochar, application rate, soil type, and climatic conditions. The research revealed that the application of biochar markedly elevated soil pH levels, which is particularly critical in the acidic soils of the Southern region. This increase in pH is instrumental in mitigating soil acidification, consequently enhancing soil structure and promoting crop productivity However, in northern regions, especially calcareous soil regions, elevated soil pH may adversely affect soil quality.

The effect of biochar application on soil pH is short-term, and over time, soil pH may gradually return to its original level as a result of anthropogenic activities such as agricultural tillage, fertilization, and irrigation. This change is related to the natural buffering capacity of the soil and the organic acids secreted during crop growth. The buffering effect of the soil is able to neutralize excess alkaline or acidic substances and maintain the relative stability of soil pH.

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In terms of total soil carbon (TC) content, the results of this study showed that soil TC increased significantly with the increase of biochar application. This finding confirms the effectiveness of biochar as an exogenous organic matter input into the soil, which can directly increase the organic carbon content in the soil. The chemical composition of biochar is predominantly characterized by densely packed aromatic structures embellished with various surface functional groups. These attributes confer exceptional stability to biochar within the soil matrix, rendering it highly resistant to an array of external physical, chemical, and biological influences. It has been estimated that the retention time of biochar in soil can range from 1000 to 10,000 years, further illustrating its potential as a long-term carbon reservoir.

The enhancement of soil total nitrogen (TN) content by biochar application was not as significant as that of TC, but still contributed to the overall increase in soil N content. This phenomenon may be related to the ability of functional groups on the surface of biochar to adsorb nitrogen from the soil, thereby reducing nitrogen loss. However, the effect of biochar on soil N content was not stable, which may be related to factors such as the source of biochar, application method, soil microbial activity, and soil management practices. Therefore, future studies need to further investigate the long-term effects of biochar application on soil N cycling and how to improve soil N use efficiency by optimizing biochar application strategies.

In summary, the utilization of biochar has demonstrated beneficial influences on the enhancement of soil characteristics, notably in elevating soil pH and the concentration of soil organic carbon. Nevertheless, further comprehensive investigation is required to understand the impact of biochar on soil nitrogen levels.

6. Conclusion

This paper investigated the effect of biochar application on soil properties in vegetable plots, especially onimproving soil organic carbon content and pH. By applying different levels of biochar (0, 20 and 40 t/ha) in greenhouse tomato growing. It was found that biochar application significantly increased the total soil organic carbon content, and this increase was positively correlated with the amount of application. In addition, biochar could also increase soil pH, which has a positive effect on the regulation of acidic soil. Although the effect of biochar on the enhancement of soil total nitrogen content was not significant, it still contributed to the overall increase in soil nitrogen content. After considering the balance of cost and effect, this paper recommends that the appropriate application rate of biochar is 20 t/ha under the conditions of this experiment.

In the aftermath of the experiment, this paper presents three key findings. Firstly, the application of biochar led to a notable increase in the total organic carbon content of the soil, demonstrating that biochar functions as an effective soil conditioner, significantly enhancing carbon storage and contributing to soil carbon sequestration while improving soil fertility. Secondly, the application of biochar also resulted in an elevation of soil pH, which positively impacts acidic soil conditions, enhances soil buffering capacity, and creates a more favorable environment for crop growth. Lastly, in terms of cost-effectiveness coupled with soil enhancement, a biochar application rate of 20 t/ha yielded optimal results in this study, effectively improving soil properties without incurring excessive input costs.

The shortcoming of this paper is that the time period of the study was relatively short and the effect of biochar application on soil properties in the long term could not be fully observed. In addition, this study mainly focused on the effects of biochar on soil chemical properties, and future research could further explore the effects of biochar on soil biological activity, microbial community structure, and the cycling of other nutrients in the soil.

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