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Effect of Modified Biochar with Organic Fertiliser on the Growth and Development of Chinese Rose

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Abstract

In order to reduce the waste of resources and environmental pollution caused by excessive application of chemical fertilizers, improve the utilization rate of fertilizers, and promote the large-scale and high-quality development of the Chinese rose industry. In this experiment, corn stover biochar, phosphoric acid modified biochar and organic fertilizer were used as test materials, and the effects of mixed application of modified biochar and organic fertilizer on the growth and development of Chinese rose as well as soil physicochemical properties were investigated by using the method of pot planting test. The results showed that modified biochar with organic fertilizer had the most significant effect on the enhancement of soil pH, organic matter content and soil carbon-to-nitrogen ratio. After 120 d of planting, modified biochar with organic fertilizer had the most significant effect on the enhancement of plant height and crown width of Chinese rose; both organic fertilizer and modified biochar with organic fertilizer significantly increased the chlorophyll content of Chinese rose. The number of flowers and the number of branches were the highest in the modified biochar with organic fertilizer treatment. In conclusion, the application of modified biochar with organic fertilizer can better improve the soil pH, and increase the soil organic matter content and carbon-to-nitrogen ratio to change the biological traits of Chinese rose. The results of this study provide a theoretical basis for the reduction of chemical fertilizers and the resource utilization of agricultural wastes and guarantee the sustainable development of the cut flower industry.

Keywords

Biochar, Modified Biochar, Chinese Rose, Organic Fertiliser

1. Introduction

The wide application of chemical fertilizers has played a key role in increasing food production and ensuring food security. However, over time, the effect of chemical fertilizers in increasing yields is diminishing, and the problem of over-fertilization is serious, which not only places a heavy burden on the environment, but also affects the quality and safety of agricultural products [1] [2] [3]. For example, excessive use of chemical fertilizers can lead to the overgrowth of crops and reduce their resistance to pests and diseases [4]. In the context of global advocacy of resource conservation, efficient fertilization, loss reduction and environmental protection, finding effective ways to avoid resource wastage has become the key to achieving sustainable agricultural development [5] [6]. Fresh-cut flowers occupy an important place in the flower market. For example, in Yunnan, the annual use of chemical fertilizers per 667 m^2 of flower greenhouses is more than 200 kg, a figure that is 5 to 25 times higher than that of developed countries, and much higher than the average of 10 times in China. In view of this, the study of how to rationally apply fertilizers as well as develop appropriate fertilizer formulations to improve the yield and quality of fresh-cut flowers while reducing the use of chemical fertilizers has become a hot issue in the current research field [7] [8].

Biochar is a carbon-rich solid substance that is produced through the thermal cracking of biomass in an oxygen-deficient environment and is composed mainly of carbon molecules [9]. Its surface is rich in hydroxyl groups, olefins, organic oxygen functional groups, and pore structure, properties that help improve soil physicochemical properties and soil fertility, as well as increase crop yields. Some studies have shown that the use of a small amount of biochar and half of a mixture of inorganic and organic fertilizers can effectively stimulate the growth of soybean plants [10]. Liu Ming *et al.* [11]. found that biochar can promote nutrient uptake in rapeseed, and that when biochar is used in conjunction with organic or inorganic fertilizers, it not only enhances soil fertility but also enriches the microbial community in the soil.Anna Rita Rivelli *et al.* [12]. studied the effects of co-application of biochar and inorganic or organic fertilizers on soil properties, growth and nutrient content of Swiss chard, and found that the co-application of biochar and organic fertilizers had a positive effect on soil properties and leaf nutrient content. Li Kun *et al.* [13]. investigated the response of quality and yield of red dragon fruit to organic fertilizer compounded with biochar and found that the interaction of organic fertilizer and biochar significantly affected the reducing sugar, soluble protein, anthocyanin, and Vc content of the pulp of the last batch of dragon fruit.

Currently, there are many reports on the effects of biochar with organic or inorganic fertilizers on the yield, quality and soil nutrients of cash crops [14] [15] [16], Moreover, most of the biochar used in the previous research is virgin biochar (virgin biochar has the disadvantages of low nutrient content, limited slow-release effect, unstable supply in the market, hard texture, high density, negative impact of high-temperature treatment process, and poor adsorbent se-

lectivity), and it is less likely to use modified biochar with organic or inorganic fertilizers; coupled with the fact that acid-modified biochar has been receiving more and more attention and research in recent years. Based on this, this study takes acid modification of biochar as the starting point, and selects phosphoric acid as the modifier through preexperimentation to investigate the effects of mixed application of unmodified biochar, phosphoric acid-modified biochar and organic fertilizer on the growth and development of moonflower as well as on the physicochemical properties of soil. The results of the study provide a theoretical basis for the sustainable development of the cut flower industry and the reduction of fertilizer application, as well as technical support for the resource utilization of solid wastes generated in the production process of plateau characteristic agriculture.

2. Materials and Methods

2.1. Biochar Preparation

The biochar material was selected from corn stover, which was prepared at the Soil Fertilization and Pollution Remediation Engineering Research Center of Yunnan Province. Corn stover was ground and sieved through a 100-mesh sieve, and then the powdered corn stover was put into a tube furnace to be heated to 500˚C and kept for 2 h. N_2 was passed into the furnace during the process of preparation to ensure that the whole pyrolysis process was carried out in the anaerobic condition. The prepared corn stover biochar was sealed and dried in a wide-mouth bottle and stored for use, which was recorded as MB.

2.2. Biochar Modification

Preparation of phosphoric acid-modified biochar: 2.0 g of crushed and sieved biochar MB was taken and mixed with phosphoric acid solution with a volume concentration of 20% at a ratio of 20 g:50 mL, and then shaken at a constant temperature at 25˚C for 12 h. It was taken out and left to stand for 1 h, filtered, and then dried at a constant temperature. Phosphoric acid-modified biochar was obtained, which was recorded as KB.

2.3. Potting Test

2.3.1. Test Materials

The potting test was carried out in the greenhouse at the back of Yunnan Agricultural University, and the Chinese rose used was purchased from Yajingxuan Green Plant Horticulture Company, with the variety of "Cold Beauty". Organic fertilizer was purchased from Kunming Nongjiale Limited Liability Company, and the physicochemical properties of biochar, modified biochar, organic fertilizer and other test materials are shown in Table 1.

2.3.2. Test Methods

Biochar mixed with organic fertilizer 1:1 was applied as basal fertilizer and one-time basal fertilizer was applied. A total of six treatments were set up in the

experiment, CK (no biochar and organic fertilizer), T1 (5.4 g biochar), T2 (5.4 g organic fertilizer), T3 (5.4 g modified biochar), T4 (2.7 g biochar + 2.7 g organic fertilizer), and T5 (2.7 g modified biochar + 2.7 g organic fertilizer), each of which was repeated three times. The pots were filled with 3 kg of soil (The application rate of organic fertilizer and biochar was converted according to the fertilizer application rate of 4500 kg/ha in the field, and 1.8 g of organic fertilizer was applied to 1 kg of potting soil). The specific program is shown in Table 2.

2.3.3. Measurement Items and Methods

The main indicators of the Chinese rose are: plant height, crown width and functional leaf chlorophyll content. Measurement methods: plant height was measured using a meter scale; crown width was measured using a straightedge; leaf chlorophyll was measured using a SPAD502-type chlorophyll meter, and the measurement site was the top leaflet of five leaflets, and each sample was repeated five times.

Soil pH: Soil-water ratio of 1:2.5 potentiometric method, weighing 10 g of 40-mesh sieve soil samples in a conical flask, adding 25 ml of deionized water, put into the constant temperature oscillator oscillation for 30 min, remove the 30 min after resting with a pH meter to determine the pH value of the supernatant. Soil organic matter: according to "NY 1121.6-2006 Agricultural Industry Standard Determination of Soil Organic Matter", potassium dichromate external heating method was used to determine the organic matter content. Soil total nitrogen: Half trace Kjeldahl method was used. Soil carbon and nitrogen ratio: soil carbon and nitrogen ratio formula: C/N = SOC/SAN, where: C/N is soil carbon and nitrogen ratio, SOC is soil organic carbon content ($g \cdot kg^{-1}$), SAN is soil alkaline dissolved nitrogen content ($g \cdot kg^{-1}$).

Table 1. Materials for testing.

Materials	pH	Organic matter ($g \cdot kg^{-1}$)	Alkaline nitrogen decomposition ($g \cdot kg^{-1}$)	Quick-acting phosphorus ($g \cdot kg^{-1}$)	Quick-acting potassium ($g \cdot kg^{-1}$)
Soil	5.83	5.42	0.04	0.02	0.08
Organic fertilizer	7.11	46.23	0.46	0.10	21.64
MB	8.87	621	73.62	36.81	51.74
KB	8.21	589	77.62	38.81	49.08

Table 2. Experimental design.

Serial number	Treatments	Codes	Biochar dosage (g)	Fertilizer dosage (g)
CK	Blanks	CK		
T1	Biochar	MB	5.4	
T2	Organic fertilizer	OF		5.4
T3	Modified biochar	KB	5.4	
T4	Biochar + Organic fertilizer	MOF	2.7	2.7
T5	Modified biochar + Organic fertilizer	KBOF	2.7	2.7

2.4. Data Analysis

The experimental data were processed with Microsoft Excel 2016, plotted with Origin 2021, and analyzed statistically and correlatively with SPSS 26.0 software for the organized data.

3. Results and Analysis

3.1. Effect of Modified Biochar with Organic Fertilizer on Soil pH Value

Different treatments could enhance the soil pH of the Chinese rose, as shown in Figure 1. Among all the treatments, the T5 treatment had the most significant effect on soil pH enhancement compared with CK, which was significantly enhanced by 0.38 units compared with CK, and the soil pH value was 6.21. All other treatments enhanced soil pH, with the T1, T2, T3 and T4 treatments enhanced by 0.1, 0.28, 0.23 and 0.36 units compared with CK. It indicated that the application of biochar alone, modified biochar, organic fertilizer and the combination of biochar and organic fertilizer could enhance the soil pH value of the Chinese rose, among which the combination of modified biochar and organic fertilizer had the most significant effect on the enhancement of soil pH value of the Chinese rose.

3.2. Effect of Modified Biochar with Organic Fertilizer on Soil Organic Matter

Soil organic matter is an important indicator of soil fertility, which not only provides plants, animals and microorganisms with nutrients needed for survival, but also reduces soil viscosity and increases the number of soil microorganisms. As can be seen from Figure 2, among all the treatments, all treatments significantly increased the organic matter content of Chinese rose soil compared with CK treatment, and T1, T2, T3, T4 and T5 treatments significantly increased by 64.76%, 69.93%, 16.79%, 109.96% and 152.58%, respectively, compared with CK. Among them, the T5 treatment had the most significant effect on the enhancement of soil organic matter content in the Chinese rose. This suggests that modified biochar with organic fertilizers can significantly enhance the organic matter content in the soil of Chinese rose.

3.3. Effects of Modified Biochar with Organic Fertilizer on Soil Carbon to Nitrogen Ratio

Biochar has a stable aromatic hydrocarbon structure that is introduced into the soil through the formation of SOC (Soil Organic Carbon), which is difficult to break down in a short period of time and does not trigger significant chemical changes. Biochar significantly enhanced the TN (total soil nitrogen) content, mainly because its porous structure and larger area make it highly adsorbent, which can absorb a large amount of ammonium ions and reduce nitrogen loss, thus increasing the nitrogen content [17] [18] [19] [20]. Different treatments had different effects on the carbon-to-nitrogen ratio of the Chinese rose soil, as can be seen in Figure 3. Among all the treatments, all the treatments increased

the soil carbon to nitrogen ratio of Chinese rose compared with CK, and the soil carbon to nitrogen ratio was ranked from high to low as T5 > T2 > T4 > T1 > T3 > CK. Compared with CK, there were significant differences among the treatments of T1, T2, T4, and T5 to increase the soil carbon to nitrogen ratio of Chinese rose, with the most significant difference in the T5 treatment, which was enhanced by 105.65% compared with CK. The results indicated that the modified biochar with organic fertilizer was better than other treatments in improving the soil carbon and nitrogen ratio of Chinese rose.

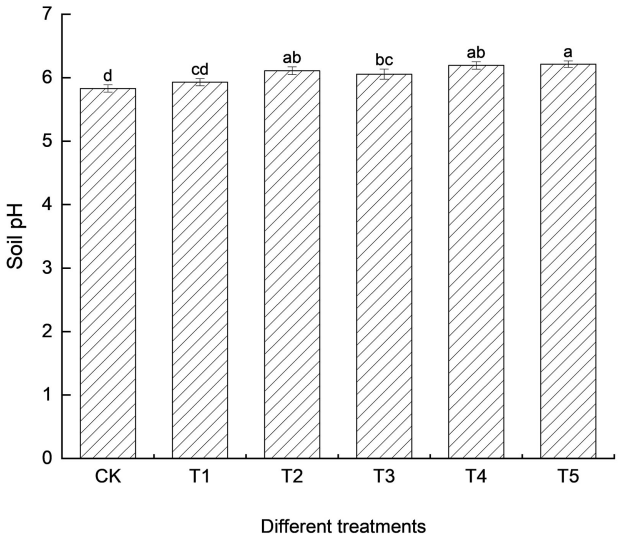

Figure 1. Effect of different treatments on soil pH. Notes: CK (no biochar and organic fertilizer), T1 (5.4 g biochar), T2 (5.4 g organic fertilizer), T3 (5.4 g modified biochar), T4 (2.7 g biochar + 2.7 g organic fertilizer), and T5 (2.7 g modified biochar + 2.7 g organic fertilizer).

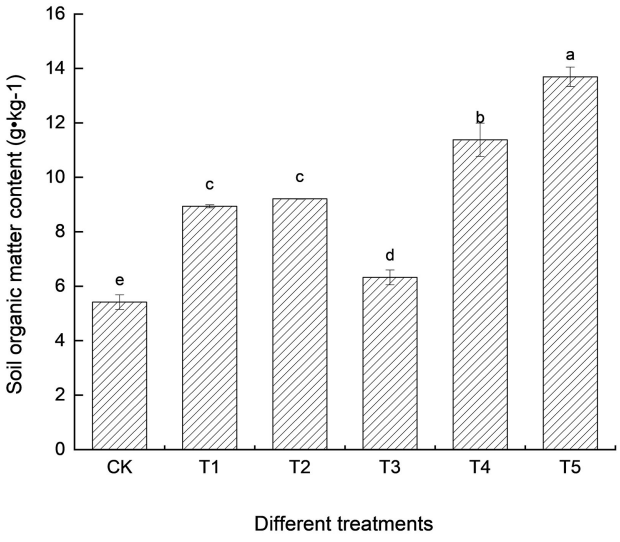

Figure 2. Effect of different treatments on soil organic matter content.

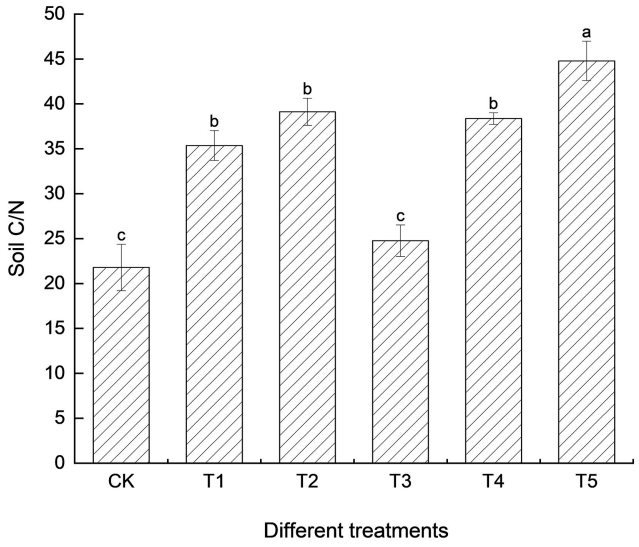

Figure 3. Effect of different treatments on soil carbon to nitrogen ratio.

3.4. Effect of Modified Biochar with Organic Fertilizer on the Height of Chinese Rose Plants

Different treatments had different effects on the height of Chinese rose plants at different periods, as shown in **Figure 4**. With the growth of Chinese rose, among all treatments, T2, T4 and T5 treatments significantly enhanced the height of Chinese rose plants compared with CK. After 120 d of planting, the T2, T4 and T5 treatments had the most significant effect on the height of the Chinese rose plant, which was significantly increased by 54.55%, 49.48% and 81.72%, respectively, compared with CK. Among them, the T5 treatment was better than the T2 and T4 treatments, and the T5 treatment had the most significant effect on the plant height of the Chinese rose, with a significant increase of 81.72% compared with that of CK, which indicated that the combination of modified biochar and organic fertilizer had a better effect on the plant height of the Chinese rose than that of the application of biochar, organic fertilizer, or the combination of biochar and organic fertilizer alone.

3.5. Effect of Modified Biochar with Organic Fertilizer on Crown Width of Chinese Rose

The different treatments had different effects on the crown width of the Chinese rose at different periods, as shown in **Figure 5**. All treatments significantly increased the Chinese rose crown width after 40 d, 60 d, 80 d and 100 d of planting compared with CK. After 120 d of planting, T2, T4 and T5 treatments significantly increased the Chinese rose crown width by 44.44%, 48.16% and 64.83%, respectively, compared with CK. Among them, the T5 treatment improved the crown width of the Chinese rose better than the T2 and T4 treatments, and the T5 treatment improved the crown width of the Chinese rose most significantly, by 64.83% compared with the CK, which indicated that the combination of

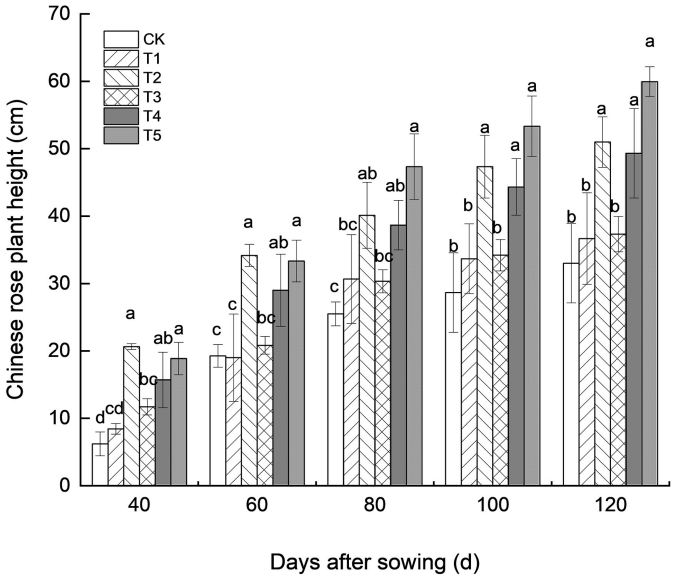

Figure 4. Effect of different treatments on the height of Chinese rose plants.

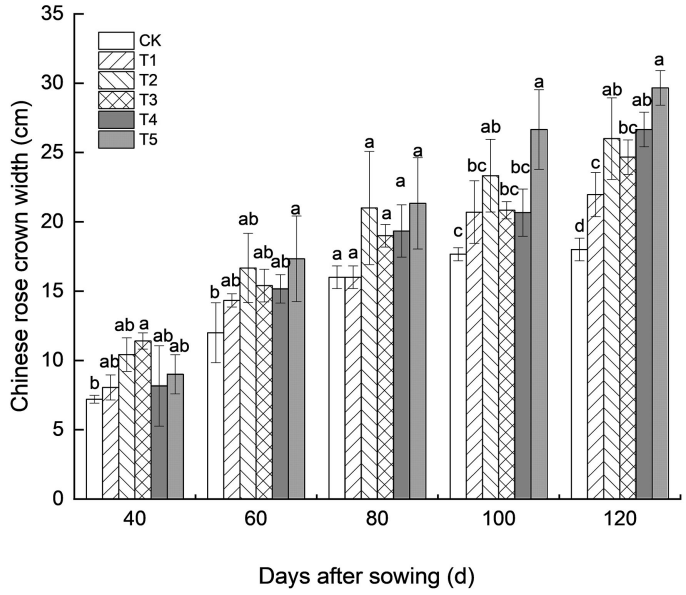

Figure 5. Effect of different treatments on crown width of Chinese rose.

modified biochar and organic fertilizer had a better effect on the crown width of the Chinese rose than the application of biochar, organic fertilizer, or the combination of biochar and organic fertilizer alone.

3.6. Effect of Modified Biochar with Organic Fertilizer on the Chlorophyll Content of Chinese Rose

The application of biochar can increase the chlorophyll content of leaves [21] [22] [23], and the higher the amount of biochar application the more obvious its

promotional effect, and the content of chlorophyll affects the physiological indicators of plants. The effects of different treatments on the chlorophyll content of Chinese rose at different periods were also different, as can be seen in Figure 6. Among all treatments, T2 and T5 treatments significantly increased the chlorophyll content of Chinese rose compared with CK at different periods of Chinese rose growth. After 120 d of planting of Chinese rose, the treatments ranked from high to low for Chinese rose chlorophyll content were T2 > T5 > T4 > T1 > T3 > CK, which increased by 15.94%, 11.13%, 8.50%, 5.06%, and 0.45%, respectively, compared with CK. Among them, the T2 treatment had the most significant effect on the improvement of chlorophyll content of Chinese rose. It indicated that the application of modified biochar alone was better than the application of biochar alone and the combination of biochar and organic fertilizers in improving the chlorophyll content of Chinese rose.

3.7. Effect of Modified Biochar with Organic Fertilizer on the Number of Flowers and Number of Branches of Chinese Rose

The number of flowers is an important factor in determining the value of ornamental flowers, and different treatments had different effects on the number of flowers and branches of Chinese rose, as shown in Figure 7. Among all the treatments, the other treatments significantly increased the number of flowers and branches compared with CK, and the T5 treatment had the best effect on the number of flowers and branches, with three flower heads under the T5 treatment, which increased by one flower head compared with that of CK, and four branches under the T5 treatment, which increased by one branch compared with that of CK. This indicated that the modified biochar with organic fertilizer could increase the number of flowers and branches of Chinese rose.

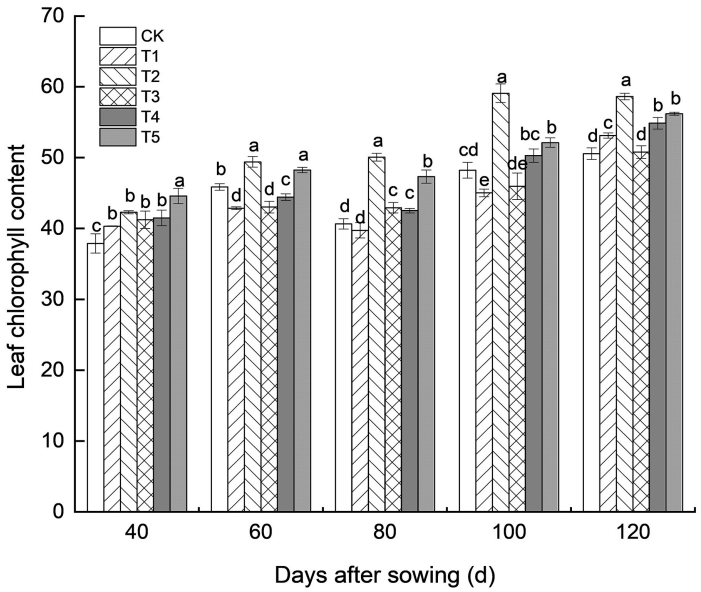

Figure 6. Effect of different treatments on the chlorophyll content of Chinese rose.

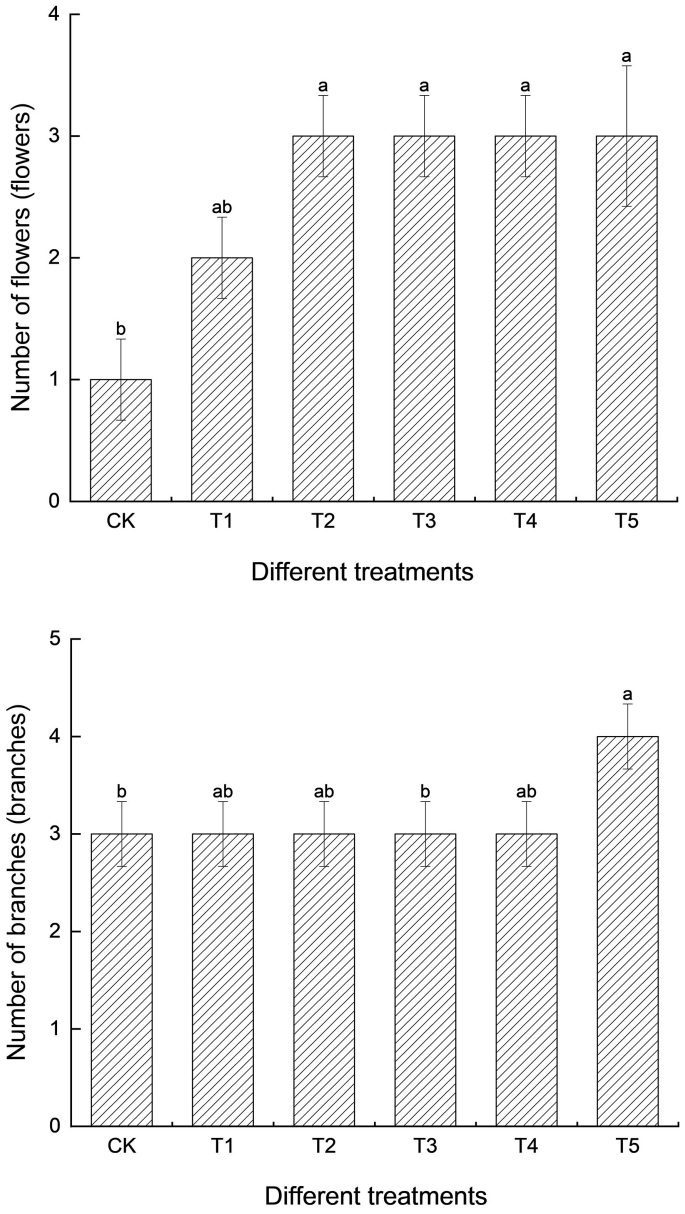

Figure 7. Effect of different treatments on the number of flowers and branches of Chinese rose.

3.8. Correlation Analysis

The correlation analysis of potting soil pH, organic matter, and carbon-to-nitrogen ratio with Chinese rose plant height, crown width, chlorophyll content, number of branches, and number of flowers is shown in **Table 3**. The plant height of Chinese rose was significantly positively correlated with soil pH, organic matter and carbon to nitrogen ratio ($P < 0.05$); the crown width and number of flowers of Chinese rose were highly significantly positively correlated with soil pH ($P < 0.01$), and the crown width of Chinese rose was also significantly positively correlated with organic matter and carbon to nitrogen ratio; the chlorophyll content of moonflower leaves was significantly positively correlated with soil carbon-to-

Table 3. Correlation analysis between soil indicators and aboveground parts of the Chinese rose.

	Height of plants (cm)	Width of crown (cm)	Chlorophyll	Branch number (branch)	Number of flowers (flower)
pH	0.886*	0.975**	0.669	0.508	0.920**
Organic matter	0.904*	0.843*	0.703	0.72	0.598
Carbon to nitrogen ratio	0.892*	0.814*	0.863*	0.591	0.621

Note: * $P < 0.05$; ** $P < 0.01$.

nitrogen ratio ($P < 0.05$). In summary, the biological indicators (plant height, crown width, chlorophyll content, number of branches and flowers) of Chinese rose were closely related to soil pH, organic matter, and carbon to nitrogen ratio. Therefore, the dosing of modified biochar with organic fertilizer can change the biological traits of Chinese rose by improving soil pH, soil organic matter content and carbon-to-nitrogen ratio.

4. Discussion

4.1. Effect of Biochar with Organic or Inorganic Fertilizers on the Growth and Development of Food Crops

In Chinese rose cultivation, we often assess the growth condition and flower quality by observing indicators such as the thickness of the stem, the height of the plant, the diameter of the flower, the length and width of the petals, and the flower color. Mixing and applying biochar and organic fertilizers can increase the soil void ratio and optimize the soil structure, thus promoting the healthy growth of plant roots [24] [25]. In addition, the unique pore structure of biochar creates a good living space for soil microorganisms, enhances their activity, and helps plants better absorb nutrients from the soil [26]. This phenomenon is consistent with the results of the study by Hui Liu and her team, which found that the combined use of biochar and phosphate fertilizer could optimize the structure of the soil and help the crops to better absorb the required nutrients during their growth and development [27]. And the study of Martínez-Gómez Á and his team found that the application of biochar in soil had an effect on plant growth, which is consistent with the results of this experiment (**Figures 4-7**) [28]. Researchers such as Hannan [29] and Shi W [30] found that the addition of biochar enhances the functioning of the soil and increases the aboveground and belowground biomass, thus improving the microenvironment for plant growth, and the same exists with this study (**Figures 4-7**).

Studies have demonstrated that the use of biochar-based fertilizers can significantly enhance crop quality and yield. This effect has not only been verified in grain crops such as rice, wheat, and maize [31] [32] [33], but also in terms of improving the total crop yield, biochar mixed with other fertilizers showed higher stability and efficiency compared to traditional fertilizers [34] [35]. In the present experiment, we found that Chinese rose using biochar under different

treatment conditions showed excellent performance both in terms of growth and flower quality, which is in line with the findings of Bu X [36], Jóisman Fachini [37], and others (**Figures 4-7**). They also found that biochar treated with different treatments had different effects on crops. It is worth mentioning that biochar with fertilizers had a more significant effect on flower growth when compared to the common composite fertilizers. This is mainly attributed to the fact that biochar can combine with calcium in the soil to generate calcium carbonate and effectively immobilize iron ions, while its strong adsorption capacity can adsorb key elements such as phosphorus, potassium, and calcium in the soil, which improves the fertility of the soil and further promotes the growth of Chinese rose [38] [39] [40].

4.2. Effect of Biochar with Organic or Inorganic Fertilizers on Soil Properties

Through this experiment, we can see that under proper application conditions, biochar with organic fertilizer can significantly improve the growth of Chinese rose (**Figures 4-7**). The application of biochar with organic fertilizer can significantly increase the organic matter content in the soil, increase the soil pH, and increase the C/N ratio in the soil, which may be related to the structure of the biochar itself (**Figures 1-3**). The alkalinity of biochar itself applied to the soil can effectively increase soil pH [41]. Biochar contains varying concentrations of alkaline ash which is added directly to the soil in the form of Ca, Mg, K and Na oxides, hydroxides and carbonates. The results of Zhao Weibin *et al.* [42]. showed that the application of biochar can improve the soil structure, thus increasing the water retention capacity and pH of the soil, while the mixed application of biochar and organic fertilizers has a greater impact on the increase of nutrients in the soil. This means that biochar-based fertilizers can increase the nutrient levels in the soil in the short term and effectively promote the growth of Chinese rose. Organic fertilizers are rich in a variety of nutrients, which helps to improve the nutrient utilization of the soil. Combined with the application of biochar, it has the effect of fixing and maintaining nutrients in the soil, which in turn optimizes the nutrient supply and yield of the crop. It has been found that a variety of nitrogen forms, such as NO_3^--N, NH_4^+-N, and nitrogen-containing organic functional groups, are present in biochar, all of which contribute to increasing the nitrogen content of the soil [43]. In addition, the large specific surface area of biochar endowed it with a strong nitrogen adsorption capacity, which enhanced the conversion efficiency and availability of nitrogen in the soil, which is in line with our findings. Biochar with organic fertilizer significantly increased the carbon to nitrogen ratio in the soil (**Figure 3**).

5. Conclusion

All treatments enhanced soil pH, organic matter content and soil carbon-to-nitrogen ratio, with the T5 treatment having the most significant enhancement effect. All treatments also increased plant height, crown width, chlorophyll content, flower

number and branch number of Chinese rose, with the T5 treatment having the most significant effect. Correlation analysis showed that the biological indexes (plant height, crown width, chlorophyll content, number of branches and number of flowers) of Chinese rose were closely related to soil pH, organic matter and carbon to nitrogen ratio. Therefore, the combination of modified biochar and organic fertilizer can better improve soil pH, soil organic matter content and carbon to nitrogen ratio to change the biological traits of Chinese rose. The results of the study provide a theoretical basis for the reduction of chemical fertilizer application and the resource utilization of agricultural waste, and guarantee the sustainable development of fresh cut flower industry.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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