Effects of Biochar-based Fertilizer on the Yield of Green Pepper (*Zanthoxylum armatum* var. *novemfolius*) and Soil Nutrient Content

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Abstract [**Objectives**] This study was conducted to investigate the effects of biochar-based fertilizer on high yield and quality of green pepper (*Zanthoxylum armatum* var. *novemfolius*) and soil nutrient status. [**Methods**] With green pepper and pepper field soil as the research subjects, four treatments were set up, namely, conventional fertilization (T_1), conventional fertilization + biochar (T_2), biochar-based fertilizer 1 (T_3), and biochar-based fertilizer 2 (T_4). [**Results**] The application of biochar-based fertilizer increased green pepper yield by 9.37%-51.12%, with the order of increase being $T_4 > T_3 > T_2 > T_1$. In terms of soil nutrients, biochar-based fertilizer raised soil pH by 6.67%-53.33%, with the order of increase being $T_3 > T_4 > T_2 > T_1$. The initially strongly acidic soil gradually shifted to weakly acidic and approached neutral, indicating significantly improved soil acidity. The application of biochar-based fertilizer increased the contents of soil organic matter, available nitrogen, available phosphorus, available potassium, available copper, available zinc, available iron, and available manganese. It significantly enhanced green pepper yield, improved soil acidity, and elevated soil nutrient levels. Considering yield, nutrient uptake, and soil nutrient content, biochar-based fertilizer 2 (T_4) was identified as the optimal treatment. [**Conclusions**] This study provides a theoretical basis for improving green pepper yield and soil amendment.

Key words Biochar-based fertilizer; Acid soil; *Zanthoxylum armatum* var. *novemfolius*; Yield
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Fertilizer is a key factor in agricultural production, and scientific fertilization has always been a critical issue. Currently, excessive fertilization is a widespread problem. Overuse of chemical fertilizers not only reduces farming profitability but also triggers a chain of issues, including soil acidification, fertility degradation, and environmental pollution. With advancements in modern agricultural technology, growing consumer interest in organic food, and increased environmental awareness, biochar-based fertilizers have been widely adopted in agricultural production[1]. Biochar-based fertilizer is a carbon-based fertilizer produced by combining chemical fertilizer with biochar as a nutrient slow-release carrier. It not only leverages biochar's advantages in soil improvement but also provides sustained nutrient release according to crop requirements[2-3]. Studies show that biochar-based fertilizer offers benefits such as high carbon content, reduced fertilizer use with enhanced efficiency, and sustained nutrient supply, demonstrating promising potential in improving soil physicochemical properties, decreasing chemical fertilizer input, and promoting crop growth[4-6]. Under biochar fertilization treatment, both the cation exchange capacity and total organic carbon content in soil increase, effectively enhancing the retention of nutrients in the topsoil layer[7]. Yang *et al.*[8] demonstrated that biochar-based fertilizer significantly improved the content of nitrogen, phosphorus, and potassium in soil, with the most notable enhancement observed in soil organic matter and potassium levels. Gao *et al.*[9] investigated the effects of biochar-based fertilizer and biochar application on soil organic carbon components. The results revealed that both biochar-based fertilizer and biochar effectively increased the total organic carbon content in soil, with significantly better improvement effects than applying equivalent amounts of carbon or NPK nutrients alone. Mao *et al.*[10] found that applying biochar-based fertilizer improved the chemical composition coordination of tobacco leaves and enhanced their quality. This improvement may be attributed to the high carbon content and strong biotic/abiotic stability of biochar-based fertilizer, which effectively increases soil organic matter content, regulates the soil carbon-to-nitrogen ratio, and improves the soil microbial environment. These changes promote more balanced soil nutrient supply, ultimately leading to higher tobacco leaf quality.

Currently, China has conducted considerable research on the application of biochar-based fertilizer, and their influence is progressively increasing. In recent years, the number of published studies on biochar-based fertilizer has shown a steady upward trend, including research on crops such as corn[11-12], rice[13-14], and peanut[15-16], among others. In this study, a comparative experiment was conducted at the pepper base in Nanhua Village, Weixinghu Subdistrict, Yongchuan District, Chongqing, to compare biochar-based fertilizer application with conventional fertilization and biochar-amended fertilization. The subsequent analysis focused on biological indicators, yield, quality, soil acidity, and

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soil nutrient content of green pepper (*Zanthoxylum armatum* var. *novemfolius*). The findings provide a series of conclusions, which will better assist in improving soil acidity, enhancing peppercorn quality, and increasing yield in a rational and scientific manner at this cultivation base.

Materials and Methods

Experimental materials

The experimental site was located in Nanhua Village, Weixinghu Subdistrict, Yongchuan District (Hou Liangqian Pepper Base, with acidic soil pH of 4.7). The soil type was reddish-brown purple soil. The planting specification of 'Jiuyeqing' (*Z. armatum* var. *novemfolius*) was 2.5 m × 2.0 m, averaging 1 950 plants/hm^2 per hectare.

Product 1: Rice husk biochar, produced by Nanjing Sanju Biomass New Materials Technology Co., Ltd., pH 10.0, organic matter ≥80%; product 2: biochar-based fertilizer 1 (developed by Chongqing University of Arts and Sciences), organic matter 25%, biochar 20%, NPK 30% (15-5-10); product 3: biochar-based fertilizer 2 (developed by Chongqing University of Arts and Sciences), organic matter 10%, biochar 15%, NPK 40% (22-8-10).

Experimental design

This experiment adopted a controlled experimental method using *Z. armatum* var. *novemfolius* as the material. Four treatments were set in total with five plants per treatment.

Treatment 1 (T_1, control): Conventional fertilization (following local farmers' routine practices, including sprout-promoting fertilizer (late January to early February): high-nitrogen fertilizer (25-8-10), 300 – 400 g/plant, applied based on leaf-fall conditions, fruit-strengthening fertilizer (early to mid-April): high-potassium fertilizer (15-5-25), 250 – 500 g/plant, shoot-promoting fertilizer (mid-September): balanced fertilizer (15-15-15), 250 g/plant, and overwintering fertilizer (November to December): balanced fertilizer, 250 g/plant).

Treatment 2 (T_2): Conventional fertilization + product 1 (biochar applied at 2 kg/plant in March).

Treatment 3 (T_3): Product 2 (15-5-10, applied at 400 g/plant in March and another 400 g/plant after harvest in July).

Treatment 4 (T_4): Product 3 (22-8-10, applied at 300 g/plant in March and another 300 g/plant after harvest in July).

Measurement items and methods

Pepper yield During the harvest period, three pepper plants with similar growth vigor were selected from each treatment for harvesting. The fresh weight was measured, and then the pepper leaves and fresh peppercorns were collected and dried in the laboratory.

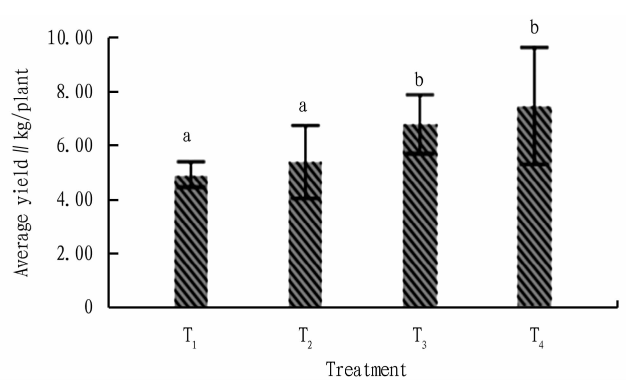
Soil nutrient content After harvesting peppercorns, surface soil samples (0 – 15 cm) were collected using a 3 – 5-point mixed sampling method, air-dried indoor, sieved with a 2 mm sieve, and stored in bags for analysis. Soil pH was measured using a pH meter. Organic matter was determined by the potassium dichromate volumetric method-external heating method. Available nitrogen was measured using the alkali-hydrolyzable diffusion method. Available phosphorus was analyzed by the 0.5 mol/L $NaHCO_3$ method. Available potassium was determined via NH_4OAc extraction followed by flame photometry. The determination of exchangeable calcium and magnesium adopted the ammonium acetate exchange-atomic absorption spectrophotometry method. Available sulfur was determined by the phosphate-HOAc extraction-$BaSO_3$ turbidimetric method. Available Fe, Mn, Cu, and Zn were analyzed using the DTPA-TEA extraction-AAS method.

Data statistics and analysis Microsoft Excel 2016 and IBM SPSS Statistics 26.0 software were employed for statistically processing and plotting of the experimental data.

Results and Analysis

Effects of biochar-based fertilizer on the yield of green pepper

Fig. 1 shows that different fertilization treatments significantly affected the yield of green Sichuan pepper. Multiple comparison results indicated no significant difference ($P > 0.05$) between conventional fertilization (T_1, 4.91 kg/plant) and biochar-amended treatment (T_2, 5.37 kg/plant). Similarly, there was no significant difference between the biochar-based fertilizer treatments T_3 (6.75 kg/plant) and T_4 (7.42 kg/plant). However, both treatments T_3 and T_4 significantly outperformed the conventional fertilization group ($P < 0.05$). Compared with T_1, the yields of T_2, T_3, and T_4 increased by 9.37%, 37.47%, and 51.12%, respectively. Among them, treatment T_4 containing 15% biochar and 40% NPK (22-8-10) showed the most significant yield improvement. The results indicated that biochar-based fertilizer was more effective in enhancing yield than biochar addition alone, demonstrating a notable synergistic effect. The optimal ratio of organic matter to biochar may be a key factor in promoting the yield increase of green pepper.



Error bar chart: 95% confidence interval.

Fig. 1 Effects of different fertilization treatments on yield

Effects of biochar-based fertilizer on soil pH and nutrient content

Soil pH, as a core physicochemical indicator, regulates ion activity and influences crop growth through processes such as toxic substance formation under extreme acidity/alkalinity and structural compaction. In cropping systems, soil nutrient levels directly affect crop growth and development. Therefore, maintaining balanced soil pH and nutrient content is of significant practical importance for achieving high and stable yields of Sichuan pepper and increasing farmers' income.

Soil pH As shown in Fig. 2, the pH values of various treatments were 4.5, 4.8, 6.9, and 6.0, respectively, indicating overall acidic soil conditions in the pepper garden. Treatments T_3 and T_4 showed significant increases in soil pH, and compared with T_1, treatments T_2, T_3 and T_4 exhibited values increasing by 6.67%, 53.33%, and 33.33%, respectively. The soil transitioned from strongly acidic to weakly acidic and approached neutral, with the pH levels ranking as $T_3 > T_4 > T_2 > T_1$. The application of biochar-based fertilizer effectively alleviated soil acidity, creating more favorable conditions for pepper tree growth and thereby enhancing the yield of green Sichuan pepper.

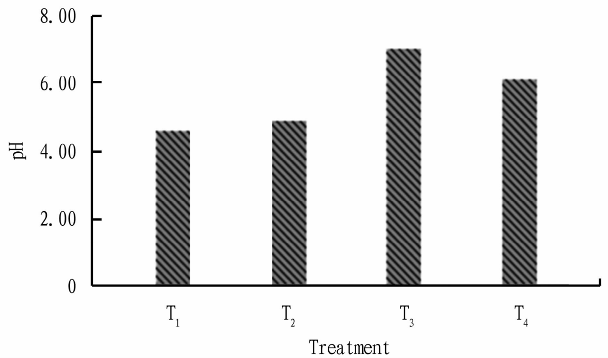


Fig. 2 Effects of different fertilization treatments on soil pH

Soil organic matter Soil organic matter consists of plant and animal residues at various decomposition stages, serving as a natural binding agent that promotes soil aggregate formation and significantly improves aeration and water permeability. It not only enhances plant growth by regulating soil physicochemical properties but also serves as a key indicator of soil fertility and quality[15]. As shown in Fig. 3, soil organic matter content increased under different treatments, and the measured values were 15.3, 15.2, 14.7, and 17.0 g/kg, respectively. When compared with China's soil nutrient classification standards[16], the organic matter content (10 – 20 g/kg) in this pepper garden was classified as deficient. Although the biochar-based fertilizer treatment (T_4) did not exceed this threshold, it still increased organic matter by 11.11% compared with conventional fertilization (T_1), demonstrating its effectiveness in improving soil organic matter levels and providing potential for sustained soil fertility enhancement.

Soil macronutrients Macronutrients are essential nutritional elements required in relatively large quantities by plants during normal growth and development, serving as important components of organic matter.

Hydrolyzable nitrogen effectively reflects soil nitrogen supply capacity. As shown in Fig. 4, the application of biochar and biochar-based fertilizers significantly increased soil alkali-hydrolyzable nitrogen content (88.7, 108.6, 99.0, and 103.6 mg/kg for treatments T_1 – T_4, respectively). The pure biochar treatment (T_2) showed the most notable increase of 22.45%. According to soil fertility classification standards (60 – 90 mg/kg as deficient, 90 – 120 mg/kg as appropriate), conventional fertilization (T_1) resulted in nitrogen deficiency, while biochar-amended treatments elevated soil nitrogen to appropriate levels (those of T_3 and T_4 increased by 11.61% and 16.80%, respectively).

Available phosphorus serves as an indicator of soil phosphorus supply capacity, with its content reflecting both phosphorus storage and supply capacity. As shown in Fig. 5, biochar-based fertilizer significantly enhanced soil available phosphorus content (the soil available phosphorus content was 50, 67, 100, and 103 mg/kg for treatments T_1 – T_4, respectively). According to the available phosphorus adequacy standard (> 40 mg/kg indicates extremely rich content), conventional fertilization (T_1) already reached high phosphorus levels. However, biochar-based fertilizer treatments (T_3, T_4) showed remarkable increases of 92.3% and 98.08% compared with T_1, while the value of pure biochar treatment (T_2) only increased by 28.52%.

The content of available potassium in soil reflects its potassium supply capacity. Fig. 6 demonstrates that biochar-based fertilizer application significantly enhanced soil available potassium levels. The measured values were 290, 345, 735, and 1 050 mg/kg for treatments T_1 – T_4 respectively. According to fertility standards (> 200 mg/kg indicates very rich content), the conventionally fertilized soil (T_1) already contained abundant potassium, while biochar-based fertilizer treatments further substantially increased the levels, with T_3 and T_4 showing 153.45% and 262.06% improvements, respectively.

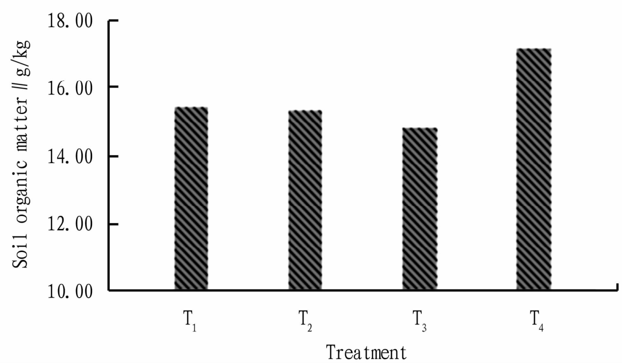


Fig. 3 Effects of different fertilization treatments on soil organic matter

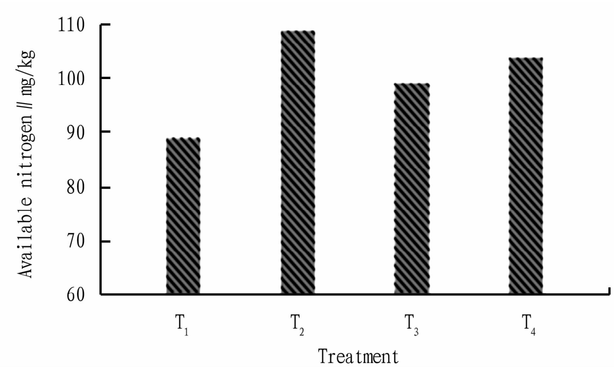


Fig. 4 Effects of different fertilization treatments on soil available nitrogen

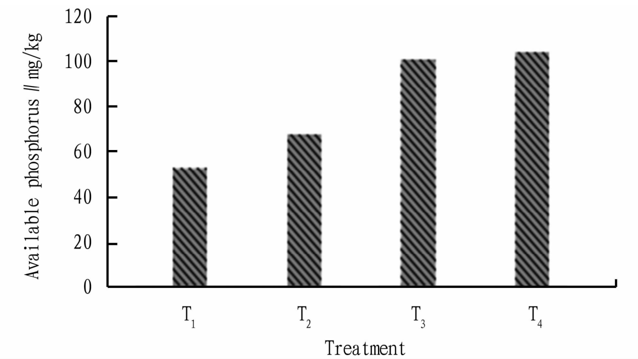


Fig. 5 Effects of different fertilization treatments on soil available phosphorus

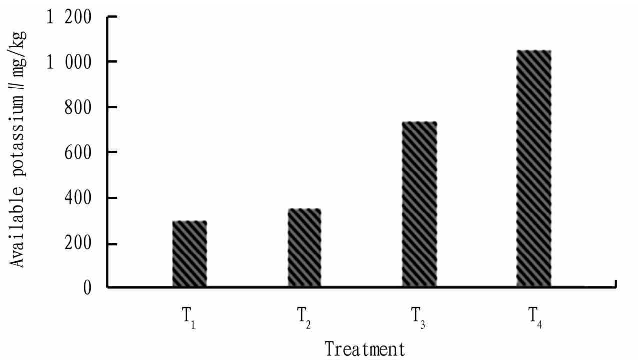


Fig. 6 Effects of different fertilization treatments on soil available potassium

Soil micronutrients As crucial limiting factors in plant physiological metabolism, micronutrients exist in low concentrations in soil, but they serve as key indicators for assessing soil nutrient balance.

As shown in Fig. 7, the available copper content increased significantly after biochar-based fertilizer application, with values of 0.200, 0.131, 0.491, and 0.106 mg/kg for treatments $T_1 - T_4$ respectively. Treatmen T_3 showed the most notable improvement with a 145.5% increase rate, indicating that the biochar-based fertilizer application of T_3 was most effective in enhancing available copper content.

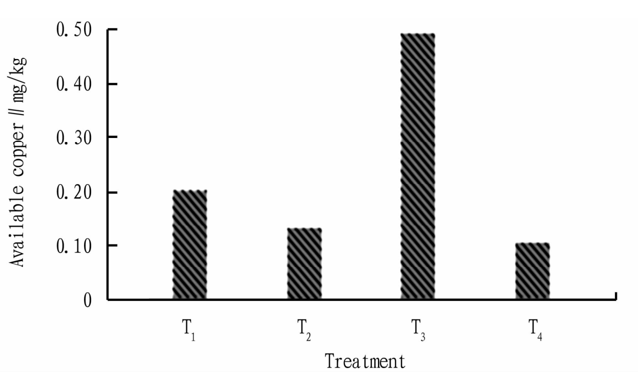


Fig. 7 Effects of different fertilization treatments on soil available copper

As shown in Fig. 8, the conventional fertilization treatment (T_1 2.14 mg/kg) already reached rich levels of available zinc, while the biochar-based fertilizer treatments (T_3 3.59 mg/kg, T_4 4.84 mg/kg) achieved significant increases of 67.76% and 126.17% respectively. Notably, the high-ratio biochar-based fertilizer treatment (T_4) elevated zinc content to extremely rich levels, demonstrating the remarkable effectiveness of biochar-based fertilizer in enhancing available zinc content.

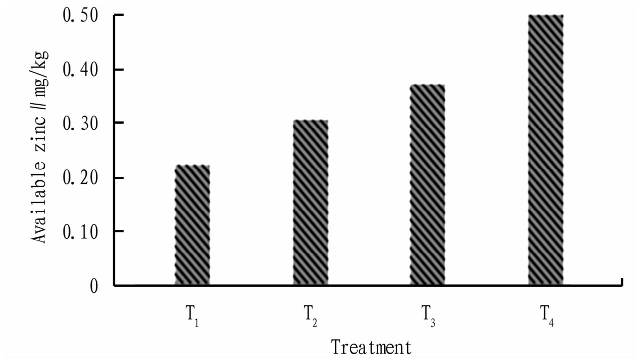


Fig. 8 Effects of different fertilization treatments on soil available zinc

From Fig. 9, it can be seen that the available iron content under conventional fertilization was already at a rich level. After the application of biochar and biochar-based fertilizers, the content increased further, and the available iron conetents were 11.8, 19.44, 11.57, and 12.94 mg/kg, respectively. In terms of available iron, biochar treatment T_2 was more effective in increasing its content, with an improvement rate of 64.75%.

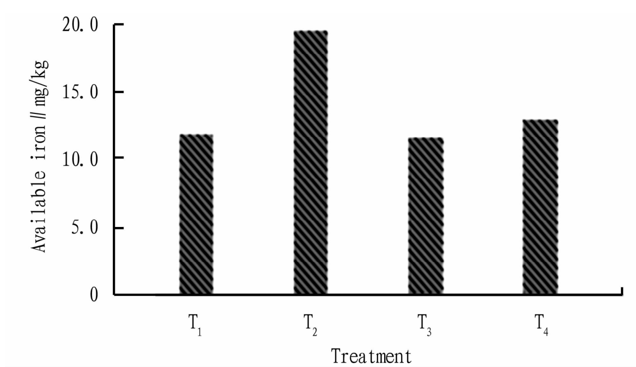


Fig. 9 Effects of different fertilization treatments on soil available iron

From Fig. 10, it can be seen that the available manganese content was already at a rich level. After treatment with biochar-based fertilizer, the content further increased, and the levels were 118, 120, 229.6, and 138 mg/kg in sequence. Compared with T_1, the increases in available manganese for T_2, T_3, and T_4 were 1.69%, 94.58%, and 16.95%, respectively. Among them, treatment T_3 showed the highest improvement in available manganese content, indicating that biochar-based fertilizer has a significant enhancing effect on available manganese levels.

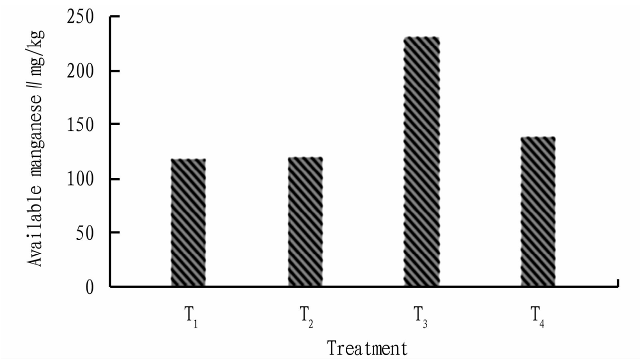


Fig. 10 Effects of different fertilization treatments on soil available manganese

Conclusions and Discussion

Compared with conventional fertilization and biochar application alone, the use of biochar-based fertilizer significantly enhanced pepper yield, mitigated soil acidification, and improved soil nutrient contents. Biochar-based fertilizer combines and amplifies the advantages of both biochar and conventional fertilization, better meeting crop nutrient demands while effectively reducing the loss of chemical fertilizer.

The study of Zhang *et al.* [17] showed that the application of biochar-based fertilizer increased fresh pepper yield by 12.0% – 32.8% and dried pepper yield by 12.6% – 31.6%. Xu *et al.* [18] indicated that the use of biochar organic fertilizer enhanced the plant height of mustard and significantly increased tuber yield. Schulz *et al.* [19] demonstrated that the sole application of biochar slightly promoted a range of biological growth in crops, whereas blending biochar with mineral fertilizers (i.e., biochar-based fertilizer) significantly enhanced crop growth. Thus, it can be concluded that applying biochar-based fertilizer yields better effects on crops.

Li *et al.* [20] found that applying biochar and biochar-based fertilizer significantly increased the pH of acidified tea garden soil, and the soil pH increased with the dosage of biochar-based fertilizer increasing. In low-carbon agricultural practices, the use of biochar-based fertilizer not only enhances soil pH but also improves soil nutrient retention capacity, leading to increased yield[21]. Overall, applying biochar-based fertilizer at varying rates in acidic soils can markedly elevate soil pH level.

The application of biochar-based fertilizer can directly increase soil nutrient content and also influence the migration and transformation of existing nutrients in the soil[22]. Based on the soil nutrient data after fertilizer application in this experiment, it can be concluded that biochar-based fertilizer indeed further enhances soil nutrient levels.

Compared with conventional fertilization and biochar application alone, biochar-based fertilizer significantly affected the yield of green pepper, increasing production by 9.37% – 51.12%, with the order of increase being $T_4 > T_3 > T_2 > T_1$. The application of biochar-based fertilizer also raised soil pH by 6.67% – 53.33%, with the order of increase being $T_3 > T_4 > T_2 > T_1$. Therefore, the strongly acidic soil is shifted toward weak acidity and became gradually closer to neutrality, indicating effectively improved soil acidity.

Soil nutrients were also improved to varying degrees under the treatment of biochar-based fertilizer. The application of biochar-based fertilizer increased the levels of soil organic matter, available nitrogen, available phosphorus, available potassium, available copper, available zinc, available iron, and available manganese. The application of biochar-based fertilizer significantly increased the yield of green pepper, improved soil acidity, and enhanced soil nutrient content. Overall, the treatment of biochar-based fertilizer 2 (T_4) demonstrated the most effective improvement in green pepper yield, nutrient uptake, and soil nutrient enrichment.

References

[1] XIAO ZX, ZHANG Z, LIU DH, *et al.* Effects of reducing biochar based fertilizer application on rice yield, nutrient uptake and cost-benefit in middle-low yield field[J]. Chinese Agricultural Science Bulletin, 2025, 41(11): 123 – 131. (in Chinese).

[2] LIU ZC, MEI A, CHEN RS, *et al.* Research progress on the improvement of pepper planting field soil by biochar and biochar-based fertilizers [J]. Northern Horticulture, 2025(9): 138 – 145. (in Chinese).

[3] LIAO ZZ, ZHENG MY, YAO F, *et al.* Effects of biochar-based fertilizer on soil nutrients and rhizosphere fungi community structure and function in tobacco planting soil[J]. Soil and Fertilizer Sciences in China, 2024 (5): 39 – 47. (in Chinese).

[4] XIAO L, FENG WX, LUO ZZ, *et al.* Effects of biochar and biochar-based fertilizer on forest growth and soil fertility[J]. Journal of South China Agricultural University, 2025, 46(3): 358 – 369. (in Chinese).

[5] CEN YY, HUANG BY, ZHANG GL, *et al.* Research progress on preparation and agricultural application of biochar-based fertilizer[J]. Jiangsu Agricultural Sciences, 2024, 52(8): 15 – 22. (in Chinese).

[6] ZHANG JN, ZHANG XX, SUN HF, *et al.* Research status and prospect of biochar-based fertilizer under the background of "double carbon"[J]. Journal of Zhejiang Agricultural Sciences, 2023, 64(12): 2825 – 2830. (in Chinese).

[7] FU ZQ, LIU Z, MA CH, *et al.* Effects of biochar and biochar-based fertilizers on soil quality and plant growth[J]. Journal of Zhejiang Agricultural Sciences, 2024, 36(7): 1634 – 1645. (in Chinese).

[8] YANG JF, JIANG T, HAN XR, *et al.* Effects of continuous application of biochar-based fertilizer on soil characters and yield under peanuts continuous cropping[J]. Soil and Fertilizer Sciences in China, 2015(3): 68 – 73. (in Chinese).

[9] GAO MY, JIANG T, HAN XR, *et al.* Effects of applying biochar-based fertilizer and biochar on organic carbon fractions and contents of brown soil[J]. Scientia Agricultura Sinica, 2018, 51(11): 2126 – 2135. (in Chinese).

[10] MAO J, HE XB, CHANG D, *et al.* Effect of biochar fertilizer on yield and quality of flue-cured tobacco in Central Henan [J]. Journal of Henan Agricultural Sciences, 2019, 48(2): 48 – 53. (in Chinese).

[11] DU SR. Nutrient release characteristics of biochar-based fertilizer and its effect on maize growth[D]. Hohhot: Inner Mongolia Agricultural University, 2024. (in Chinese).

[12] DENG SH, HE SX, LIANG FZ, *et al.* Application effect of biochar-based fertilizer on maize[J]. Phosphate & Compound Fertilizer, 2019, 34(5): 39 – 40, 47. (in Chinese).

[13] QIAO Y, HU C, GUO WH, *et al.* Effects of biochar based chemical fertilizers on rice yield and fertilizer utilization efficiency[J]. Tianjin Nongye Kexue, 2025, 31(4): 50 – 55. (in Chinese).

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it is advisable to conduct concentration tests before application to determine the appropriate dosage. Additionally, a safe interval period should be established, and the times of spray applications should be minimized. It is strictly prohibited to use plant growth regulators with strong toxicity or long residual period near and after harvest, so as to reduce the residual amouns in vegetables.

References

[1] SUI XY, ZHOU ZL, ZHANG WQ, *et al*. Effect of chitosan seed coating on seed germination and seedling properties of cucumber and pepper[J]. Journal of East China University of Science and Technology: Natural Science Edition, 2002(6): 637 – 639. (in Chinese).

[2] YU HS, WU HZ, YANG B. Recent advances of chitosan in suppression of plant diseases[J]. Natural Product Research and Development, 2000 (3): 94 – 97. (in Chinese).

[3] YU HS, WU HZ, ZHANG YM, *et al*. Effect of water-soluble chitosan on rice bakanae disease and rapeseed Sclerotinia sclerotiorum[J]. Jiangsu Agricultural Sciences, 1998(5): 38 – 40. (in Chinese).

[4] HE R, LIU AP, CAO YG. An issue of safety in using plant growth regulators[J]. Chinese Journal of Health Inspection, 2003(2): 99 – 101. (in Chinese).

[5] ZHAO L. Effects of plant growth regulators on plants[J]. Dingxi Science and Technology, 2013(3): 28 – 29. (in Chinese).

[6] XIN PY, LUO SB, DUAN AA. Effects of plant growth regulators on rooting and growth of *Schefflera bodinieri* cuttings[J]. Journal of Southwest Forestry University: Natural Sciences, 2007(5): 18 – 20. (in Chinese).

[7] LIU L, QIAN QQ, ZHANG ZY. Effects of different plant growth regulators on plant regeneration from callus tissue and callus induction of lettuce (Lactuca sativa) in vitro[J]. Journal of Zhejiang Agricultural Sciences, 2004(4): 7 – 8. (in Chinese).

[8] ZHAO JZ, LIU GB, ZHANG HL, *et al*. Effects of plant growth regulator on cutting propagation of *Platycladus orientalis* franco and adventitious root formation[J]. Northern Horticulture, 2020(10): 77 – 86. (in Chinese).

[9] HAN HW, WANG JY, ZHANG YW. Study on keeping flowers and keeping fruits of Badam apricot by plant growth regulating agent[J]. Xinjiang Agricultural Sciences, 2001(2): 66 – 68. (in Chinese).

Editor: Yingzhi GUANG Proofreader: Xinxiu ZHU

(Continued from page 46)

[14] YANG D, YANG TY, HE N, *et al*. Effects of applying the biochar-based fertilizer on the fertility of saline paddy soil and rice yield[J]. Chinese Journal of Soil Science, 2024, 55(6): 1676 – 1684. (in Chinese).

[15] LIU MQ. Effects of long-term application of biochar and biochar-based fertilizer on nutrient regulation in rhizosphere soil and peanut growth [D]. Shenyang: Shenyang Agricultural University, 2023. (in Chinese).

[16] YE BW. Effects of biochar-based fertilizer combined with organic fertilizer on soil nutrients and yield in main peanut producing areas in northern China[D]. Shenyang: Shenyang Agricultural University, 2019. (in Chinese).

[17] ZHANG M, WEI QQ, GOU JL, *et al*. Effects of different dosage of biochar-based fertilizer on quality and efficiency of hot pepper in Guizhou [J]. Journal of Nuclear Agricultural Sciences, 2019, 33(7): 1457 – 1464. (in Chinese).

[18] XU X, XIAO B, YANG M, *et al*. Effect and benefit analysis of biochar-based fertilizer on the characteristics, yield and quality of mustard tuber [J]. Journal of Anhui Agricultural Sciences, 2021, 49(18): 164 – 167. (in Chinese).

[19] SCHULZ H, GLASER B. Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment[J]. Journal of plant Nutrition and Soil Science-zeitschrift Fur Pflanzenernahrung Und Bodenkunde, 2012, 175(3): 410 – 422.

[20] LI CJ, YANG WH, ZHOU BQ. Effects of biochar based fertilizer on soil nutrients, tea output and quality in an acidified tea field[J]. Chinese Journal of Soil Science, 2021, 52(2): 387 – 397. (in Chinese).

[21] JIANG LN, SUO LN, LIANG LN, *et al*. Effects of biochar-based fertilizer application on yield, quality, nutrient absorption and soil properties of Chinese cabbage[J]. Soil and Fertilizer Sciences in China, 2023 (7): 23 – 31. (in Chinese).

[22] JIN HF, KONG GF, LI FZ, *et al*. Effects of biochar-based fertilizer on physical and chemical properties of paddy soil, crop yield, and fertilizer reduction[J]. Journal of Zhejiang Agricultural Sciences, 2024, 65(2): 262 – 267. (in Chinese).

Editor: Yingzhi GUANG Proofreader: Xinxiu ZHU