

Effects of biochar on soil properties and agricultural runoff nutrients in new cultivated farmland in the Yellow River Basin

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Abstract. [Objective] Biochar was used as a soil conditioner to analyze the effects of biochar on soil moisture, conductivity and nutrients in new cultivated land and agricultural runoff nutrients in the Yellow River Basin. [Methods] In Caoxian County, Heze City, Shandong Province, a field experiment was conducted with rice as the test crop, and the biochar application rates were set at 0 t/hm² (CK), 4.5 t/hm² (C1), 9 t/hm² (C2) and 13.5 t/hm² (C3) treatments were used to determine soil water content, electrical conductivity, soil nutrients and agricultural runoff nutrients under different treatments, and to analyze the effects of biochar on rice yield, as well as its correlation with soil physicochemical properties and agricultural runoff nutrients. [Results] Compared with the control, the application of biochar had a significant effect on soil water content, and the increase of soil volume water content decreased with the increase of biochar application amount. In August and September, the soil conductivity treated by C1 and C2 was significantly higher than CK, and there was no significant difference in the rest of the rice growth period. The application of biochar could promote the absorption and utilization of soil nutrients, but had no significant effect on soil pH. C1 and C2 treatments generally increased the nutrient content of farmland regression water, and C3 treatments generally reduced the nutrient content of farmland regression water. The application of biochar could increase the yield of rice, especially the C2 treatment, which was 8.49%. The correlation analysis showed that soil total phosphorus, total potassium and available phosphorus were significantly positively correlated with rice yield, and soil nitrate nitrogen and SO₄²⁻ contents were significantly negatively correlated with rice yield. The total nitrogen, total potassium and nitrate nitrogen in agricultural runoff were significantly positively correlated with rice yield. [Conclusion] The application of biochar can increase soil moisture, affect soil nutrients and electrical conductivity, and help to increase nutrient content in new created cropland in the Yellow River basin, and can be used as a soil amendment for new created cropland in the Yellow River basin. The recommended application amount is 9 t/hm².

Key words: Biochar; New created farmland; Soil properties; Agricultural runoff; Yellow River Basin

1. Introduction

With the rise of ecological protection and high-quality development in the Yellow River Basin as a national strategy, responding to China's strategic deployment and adapting to the development needs, increasing land resources and solving the problem of food shortage have become one of the key agricultural tasks in the Yellow River Basin [1]. The main problems facing the new created cropland in the Yellow River Basin are that the soil nutrients are depleted, the soil is coarse and loose, and the local ecological environment is fragile, which is not conducive to crop growth and threatens the security of local food production [2]. Therefore, it is urgent to speed up the soil improvement of the new created farmland, and it is also an important guarantee for the continuous development of the ditch reclamation project.

Soil amendments are one of the important ways to improve soil quality in new cultivated land. They can improve water and fertilizer utilization efficiency and increase crop yield by retaining soil water and nutrients. As one of the important soil amendments, biochar is a kind of black solid substance rich in aromatic stable organic carbon, which is mainly produced by pyrolysis and carbonization of biomass such as crop straw under partial or complete hypoxia conditions at high

temperature and low speed [3, 4]. Many studies have shown that the addition of biochar can effectively improve soil fertility by changing soil physical and chemical properties and microbial activities [5, 6, 7]. Therefore, soil water and nutrient retention effects can be achieved by using biochar to improve the new created farmland in the Yellow River basin in this experiment, and its effects on soil water and nutrient and rice growth in the new created farmland in the Yellow River basin are analyzed in order to provide scientific basis for its application.

2. Materials and methods

2.1 Overview of the study area

The study site was located in ZhangCaiyuan Village, Weiwan Town, Caoxian County, Heze City, Shandong Province (115°37'E, 34.86°N). The soil type was aquic soil with basic physical and chemical properties: pH 7.92, total nitrogen (TN) 1.22g/kg, total phosphorus (TP) 1.38g/kg, total potassium (TK) 20.71g/kg, organic matter (OM) 23.00g/kg, available phosphorus (AP) 40.27mg/kg, available potassium (AK) 151.90mg/kg, Cl^- 0.22g/kg, SO_4^{2-} 1.06g/kg.

2.2 Experimental design

The field positioning experiment of biochar addition was conducted from May to October 2022, with a total of 4 treatments, each treatment randomly distributed, with 3 replicates, and a total of 12 experimental plots, each of which covered an area of 50 m². Specific treatments were no biochar (CK), 4.5 t/hm² (C1), 9 t/hm² (C2) and 13.5 t/hm² (C3) biochar. In this study, all treatments applied base fertilizer (May 13, 2022) was 600 kg/hm² compound fertilizer (N-P₂O₅-K₂O:15-15-15); Topdressing three times (June 5, June 26 and July 20, 2022), each time 150 kg/hm² urea (40%N). The appropriate amount of biochar was applied when the bottom fertilizer was applied, and all biochar and fertilizer were mixed and rotary tillage was carried out at a depth of 20 cm. Other agronomic practices are in line with local practices.

2.3 Test material and sample determination

The tested biochar was made from cotton straw by incomplete combustion at 800 °C, and its basic characteristics were as follows: total nitrogen content was 4.88 g/kg, total phosphorus content was 0.83g/kg, total potassium content was 15.98 g/kg, pH was 8.60, density was 0.297 g/cm³, and carbon content was 73%. Shengdao 1826 was selected as the rice variety provided by Shandong Academy of Agricultural Sciences.

The impurities visible to the naked eye are removed from the collected samples in time. The pH was measured with a convenient pH meter. Total nitrogen was determined by Kjeldahl method. Total phosphorus was determined by spectrophotometer. Total potassium and available potassium were determined by flame photometer. Available phosphorus was determined by molybdenum-antimony resistance colorimetric method. Ammonium nitrogen (NH_4^+) and nitrate nitrogen (NO_3^-) were measured by flow analyzer. Organic matter was determined by potassium dichromate method. SO_4^{2-} was determined by ultraviolet spectrophotometer. Cl^- was determined by chloride precipitation method.

2.4 Statistical Analysis

SPSS20.0 software was used to conduct one-way ANOVA to compare the significance of differences in soil physicochemical properties and gas emission fluxes between treatments. Person correlation coefficient was used to analyze the correlation between gas emission fluxes and influencing factors, and the significance level was selected as $P < 0.05$. Graphics drawing using Origin8.5 software. All results are expressed as mean \pm standard deviation.

3. Results

3.1 Effects of biochar on soil water content in new cultivated farmland

As can be seen from Fig.1, on June 10, the difference of soil water content between biochar application treatments and the control reached a significant level ($P < 0.05$), and the soil water content of C1, C2 and C3 treatments increased by 7.22%, 11.00% and 16.46%, respectively, compared with CK treatment. On July 14, compared with CK, in addition to C3 treatment, C1 and C2 treatment significantly increased soil water content, reaching 10.16% and 10.33%, respectively. On August 10, compared with CK, in addition to C3 treatment, C1 and C2 treatment significantly increased soil water content, reaching 14.36% and 12.92%, respectively. On September 4, the difference of soil water content between biochar application treatment and control reached a significant level, and the soil water content of C1, C2 and C3 treatment increased by 15.51%, 10.73% and 8.60%, respectively, compared with CK treatment. On October 15, compared with CK, in addition to C3 treatment, C1 and C2 treatment significantly increased the soil water content, which reached 46.52% and 28.06%, respectively. It can be seen that the application of biochar has a significant effect on soil water content, and with the increase of biochar application amount, the increase of soil water content decreases.

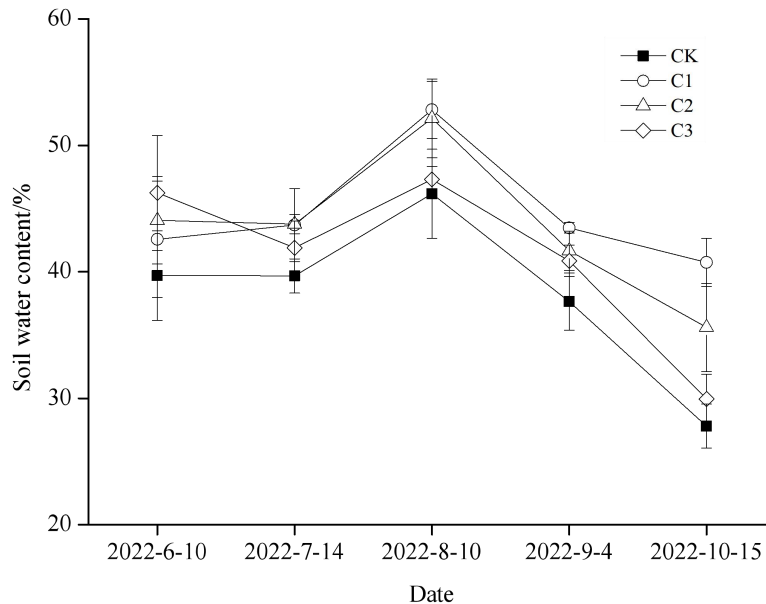


Fig.1 Effect of biochar on soil water content of new cultivated farmland

3.2 Effects of biochar on soil conductivity in new cultivated farmland

As can be seen from Fig. 2, there was no significant difference in soil conductivity between biochar application treatment and CK on June 10, July 14 and October 15 ($P > 0.05$). On August 10, compared with CK, both C1 and C2 treatments significantly increased the soil conductivity, reaching 24.80% and 13.33%, respectively. On September 4, the differences of soil conductivity between biochar application and CK reached a significant level ($P < 0.05$), and the soil conductivity of C1, C2 and C3 treatment was increased by 20.63%, 18.10% and 12.70%, respectively, compared with CK treatment. It can be seen that the application of biochar has a tendency to increase soil conductivity, but with the increase of biochar application amount, the increase of soil conductivity decreases.

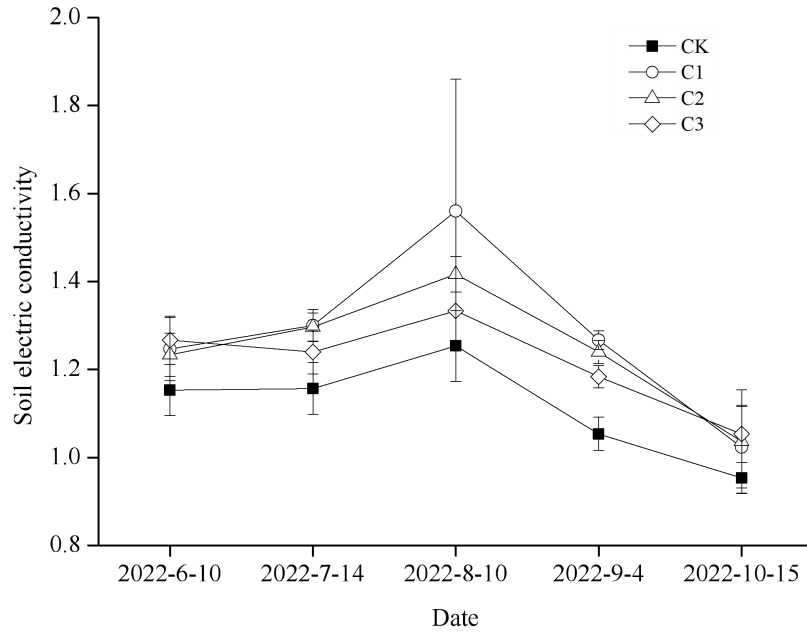


Fig. 2 Effect of biochar on soil conductivity of new cultivated farmland

3.3 Effects of biochar on soil pH and nutrient content in new cultivated farmland

Table 1 shows that biochar didn't significantly affect soil pH in new cultivated farmland. Compared with CK, C2 treatment significantly increased soil total nitrogen content, while C3 treatment significantly decreased soil total nitrogen content. The contents of total phosphorus, total potassium and available phosphorus in soil were significantly increased by biochar treatment. Except for C2 treatment, other treatments significantly reduced soil available potassium content. The application of biochar significantly reduced the content of ammonium nitrogen in soil. Except C1 treatment, other treatments significantly reduced soil nitrate nitrogen content and soil organic matter. The application of biochar significantly reduced the SO_4^{2-} content in soil. Biochar didn't significantly affect soil Cl^- in new cultivated farmland.

Table 1 Effect of biochar on soil pH and nutrient content in new cultivated farmland

Treat ment	pH	TN g/kg	TP g/kg	TK g/kg	SP mg/kg	SK g/kg	NH_4^+ mg/kg	NO_3^- mg/kg	OM g/kg	SO_4^{2-} g/kg	Cl^- g/kg
CK	8.27± 0.06a	0.82±0 .02b	0.52± 0.03b	15.16± 0.41b	6.35±0 .13d	0.21± 0.01a	22.27± 1.14a	1.64±0 .19a	14.83± 1.67a	0.22± 0.02a	0±0a
C1	8.31± 0.06a	0.84±0 .02ab	0.67± 0.05a	16.46± 0.18a	14.07± 0.40a	0.16± 0.01b	10.52± 0.24c	1.71±0 .12a	15.68± 0.17a	0.18± 0.01b	0.03± 0.01a
C2	8.30± 0.05a	0.88±0 .01a	0.75± 0.06a	16.59± 0.49a	12.46± 1.07b	0.23± 0.03a	15.76± 0.45b	0.43±0 .08c	10.20± 0.61b	0.15± 0.01c	0.02± 0.01a
C3	8.28± 0.04a	0.77±0 .03c	0.71± 0.05a	16.55± 0.50a	9.76±0 .16c	0.17± 0.01b	11.11± 0.72c	1.12±0 .12b	10.93± 1.33b	0.15± 0.01c	0.02± 0.01a

Note: Different lowercase letters indicate significant difference among treatments at $P < 0.05$ level.

3.4 Effects of biochar on pH and nutrient content of agricultural runoff in new cultivated farmland

Table 2 shows that compared with CK, only C3 treatment significantly increased the pH of agricultural runoff. The application of biochar significantly increased the total nitrogen content of agricultural runoff. Except for C3 treatment, other treatments significantly increased the total phosphorus and total potassium content of agricultural runoff. The application of biochar significantly increased the content of available phosphorus and decreased the content of available

potassium. Only C3 treatment significantly increased the NH_4^+ content of agricultural runoff . Except C3 treatment, other treatments significantly increased the content of NO_3^- in agricultural runoff .

Table 2 Effect of biochar on pH and nutrient content of agricultural runoff in new cultivated farmland

Treatment	pH	TN $\mu\text{g/mL}$	TP $\mu\text{g/mL}$	TK $\mu\text{g/mL}$	SP $\mu\text{g/mL}$	SK $\mu\text{g/mL}$	NH_4^+ $\mu\text{g/mL}$	NO_3^- $\mu\text{g/mL}$
CK	7.72 \pm 0.07 b	1.53 \pm 0.3 5c	0.93 \pm 0.4 5b	3.68 \pm 1.05 c	0.48 \pm 0.14 c	3.16 \pm 1.21 a	0.94 \pm 0.2 9b	0.28 \pm 0.21 c
C1	7.69 \pm 0.10 b	2.68 \pm 0.0 6b	1.34 \pm 0.2 8b	5.24 \pm 0.49 b	0.94 \pm 0.07 a	2.01 \pm 0.10 b	1.24 \pm 0.0 5b	1.33 \pm 0.07 b
C2	7.81 \pm 0.09 ab	4.85 \pm 0.4 5a	2.11 \pm 0.0 1a	10.98 \pm 0.9 6a	0.85 \pm 0.07 ab	3.27 \pm 0.07 a	1.16 \pm 0.1 2b	2.56 \pm 0.19 a
C3	7.89 \pm 0.03 a	2.34 \pm 0.2 8b	0.84 \pm 0.0 9b	3.85 \pm 0.69 bc	0.67 \pm 0.09 b	2.74 \pm 0.07 ab	2.14 \pm 0.1 0a	0.08 \pm 0.07 c

Note: Different lowercase letters indicate significant difference among treatments at $P < 0.05$ level.

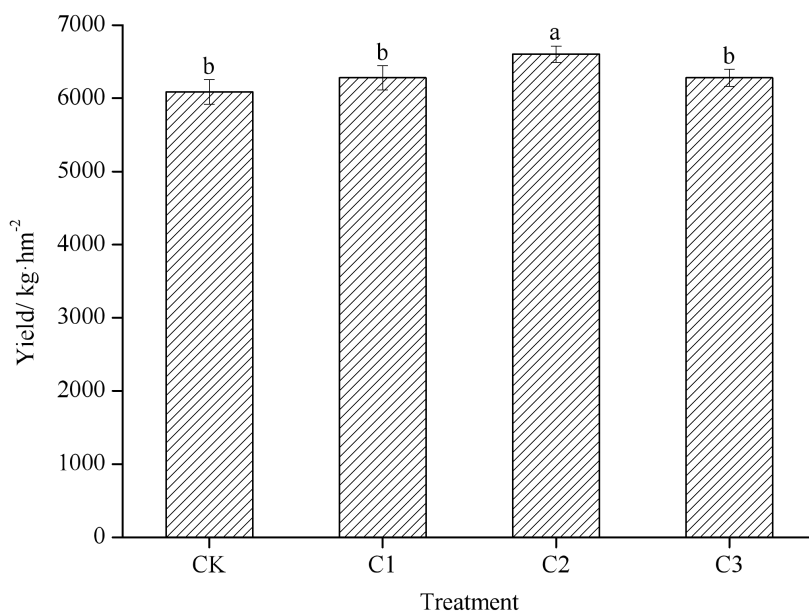


Fig. 3 Effect of biochar on rice yield

3.5 Effects of biochar on rice yield

Fig. 3 shows that the application of biochar could promote the increase of rice yield, in which C2 treatment is the most significant, up to 8.49%. In general, with the increase of biochar application, rice yield increased first and then decreased, which indicates that for the new cultivated farmland in the Yellow River Basin, due to the constraints of precipitation and soil nutrients, the more biochar application is not the better, but the proper amount is better. According to the results of this experiment, the appropriate application amount of biochar is 9 t/hm².

3.6 Correlation between soil physical and chemical properties, agricultural runoff nutrients and rice yield

As can be seen from Table 3, soil total phosphorus, total potassium, available phosphorus were significantly positively correlated with rice yield, indicating that the increase of Soil total phosphorus, total potassium, available phosphorus could promote the increase of rice yield. Soil nitrate nitrogen and SO_4^{2-} contents were significantly negatively correlated with rice yield, which indicated that the decrease of soil nitrate nitrogen and SO_4^{2-} would promote the increase of rice yield.

Table 3 Correlation analysis of soil physical and chemical properties and rice yield
(Spearman correlation coefficient)

Index	pH	TN	TP	TK	SP	SK	NH ⁺ ₄	NO ⁻ ₃	OM	SO ₂ ⁻ ₄	Cl ⁻	Yield
pH	1	-0.03	0.1	0.1	0.34	-0.01	-0.25	-0.24	-0.25	-0.45	0.34	0.17
TN		1	0.23	0.06	0.46	0.52	0.17	-0.35	0.06	0	0.03	0.46
TP			1	0.85*	0.71*	-0.02	-0.67*	-0.65*	-0.56	-0.79*	0.70*	0.66
TK				1	0.73*	-0.19	-0.73*	-0.40	-0.38	-0.71*	0.78*	0.66*
SP					1	-0.23	-0.74*	-0.25	-0.05	-0.56	0.85*	0.58*
SK						1	0.69*	-0.57	-0.33	0.08	-0.51	0.40
NH ⁺ ₄							1	0.08	0.17	0.67*	-0.91*	-0.25
NO ⁻ ₃								1	0.88*	0.74*	-0.08	-0.71*
OM									1	0.79*	-0.11	-0.45
SO ₂ ⁻ ₄										1	-0.61*	-0.59*
Cl ⁻											1	0.32

Note: “*” means significant correlation at the $P < 0.05$ level

As can be seen from Table 4, the contents of total nitrogen, total potassium and nitrate nitrogen in agricultural runoff were significantly positively correlated with rice yield, which indicates that the increase of total nitrogen, total potassium and nitrate nitrogen content in agricultural runoff is conducive to the improvement of rice yield. The relationship between agricultural runoff nutrients and yield is actually indirect. For example, the increase of total nitrogen content in agricultural runoff means the increase of total nitrogen content in farmland, which is conducive to the growth and development of rice.

Table 4 Correlation analysis of agricultural runoff nutrients and rice yield
(Spearman correlation coefficient)

Index	pH	TN	TP	TK	SP	SK	NH ⁺ ₄	NO ⁻ ₃	Yield
pH	1	0.18	-0.12	0.05	-0.15	0.12	0.67*	-0.08	0.47
TN		1	0.83*	0.94*	0.59*	0.11	-0.08	0.93*	0.83*
TP			1	0.92*	0.65*	0.39	-0.42	0.90*	0.55
TK				1	0.55	0.36	-0.31	0.93*	0.74*
SP					1	-0.15	-0.04	0.64*	0.44
SK						1	-0.30	0.07	-0.05
NH ⁺ ₄							1	-0.39	0.16
NO ⁻ ₃								1	0.74*

Note: “*” means significant correlation at the $P < 0.05$ level

4. Discussion

Previous studies have shown that biochar has water retention, and the application of biochar in farmland can increase soil water content [8, 9, 10]. According to the results of this experiment, the increase of soil water content decreased with the increase of biochar application amount. There may be the following reasons: First, the paddy soil moisture is sufficient, and the water absorption potential of biochar is not fully utilized, resulting in the difference of soil water content is much smaller than the difference of biochar application amount [11]; Second, biochar has both water adsorption and water release in the soil, and the water adsorption is rapid, while the water release is slow. If the biochar only adsorbs water in the soil but does not release water, the phenomenon of undetectable soil water will occur. In this experiment, soil water content fluctuated, which was not

only affected by precipitation, but also showed that biochar had a certain repeatability on soil water adsorption and release.

Soil conductivity represents the sum of various cations and anions in the soil leaching solution, and is positively correlated with the total amount of soluble ions in the soil solution [12]. The measurement of farmland soil conductivity is affected by soil moisture, nutrients (ions), soil temperature, pH and crop absorption and utilization, and can only be used as a reference for evaluating soil nutrient status [13, 14]. According to the results of this experiment, both C1 and C2 treatments significantly increased the soil conductivity during the relatively abundant soil moisture period (August 10 and September 4) when rice was growing rapidly. In the rest period, the application of biochar had no significant effect on the soil conductivity. In the early period, the no significant difference was probably due to the fact that biochar had just been applied and its effect had not yet appeared [15, 16]. The non-significant difference in the later stage may be due to the absorption and utilization of soil nutrients in the middle and later stages of rice growth, the reduction of soil nutrient ion concentrations, and the lack of soil nutrients in the new created farmland, resulting in no significant difference in soil conductivity between the application of biochar treatment and the control [17, 18, 19].

The reason why the application of biochar can increase the yield is that it can improve the utilization efficiency of soil water and nutrients by using its adsorption function. Most studies have shown that adding biochar can improve soil fertility and increase crop yield [20, 21, 22]. On the one hand, the addition of biochar improved the ability of crops to absorb nitrogen [23]. On the other hand, biochar can improve the physical and chemical properties of soil by increasing the content of soil organic matter, thereby improving soil fertility and increasing crop yield [24, 25]. In addition, biochar itself carries some nutrients for crop absorption and utilization, which can be confirmed from the data of agricultural runoff [26, 27]. In this experiment, the adsorption performance of biochar on soil water and nutrient ions was used to analyze its effects on soil nutrients and crop yield. The results showed that the application of biochar could increase soil nutrient content, promote the utilization efficiency of soil nutrients by rice, and improve rice yield. However, it also increases the risk of nutrient loss and non-point source pollution in farmland. Attention should be paid to the amount and frequency of application when applying biochar. Previous studies have found that a one-time application of biochar can increase crop yields over a longer period of time and reduce nutrient loss [28, 29].

5. Conclusion

The application of biochar to new cultivated farmland in the Yellow River Basin could increase soil water content, soil nutrient absorption and utilization, and increase rice yield. Therefore, biochar can be used as a soil amendment for new cultivated farmland, and the recommended application amount is 9 t/hm².

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