



# Effects of Biochar on Paddy Soil Fertility Under Different Water Management Modes

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## Abstract

In order to ascertain the effects of biochar on paddy soil fertility under different water management modes, two types of biochar as rice straw biochar (RSC) and rice husk biochar (RHC) were applied into two types of paddy soils, sandy loam (soil I) and silty loam (soil II). Five biochar application rates as 0 (CK), 5 (C1), 10 (C2), 20 (C3), and 50 (C4) g kg<sup>-1</sup> were used under three water management modes, i.e., flooded irrigation (FI), intermittent irrigation (II), and wet irrigation (WI); all treatments are incubated for 60 days. The biochar application increased soil water holding capacity (WHC) (0.88–47.93%), pH (–0.03–1.61 units), cation exchange capacity (CEC) (0.1–3.4 cmol kg<sup>-1</sup>), soil organic matter (SOM) (2.35–229.31%), total nitrogen (TN) (4.88–86.84%), available phosphorus (P) (0–171.74%), and potassium (K) (0.25–14.47 times). The increased nutrient content of soil I was higher than that of soil II, and the increase by RSC was significantly greater than that by RHC. In addition, the II mode or WI mode was more beneficial to increase soil pH, available P, and CEC. The water management modes, biochar types, and its dosage, as well as soil type and their interaction, had remarkable effects on soil improvement of paddy soil fertility. The study showed that biochar applied under intermittent and wet irrigation modes offers a good potential for the improvement of paddy soil fertility than flooding irrigation mode.

**Keywords** Biochar · Water management modes · Paddy soil fertility · Soil physical and chemical properties · Soil improvement

## 1 Introduction

China has a large population, with 60% of the population relying on rice as a staple food. Jiangxi province is one of the main rice-producing areas in China and plays a pivotal role in ensuring national food security and safety. However, the soil texture of the paddy field in this area is mainly sandy loam and silty loam, and the soil fertility is relatively low. The yield of rice is closely related to soil fertility. So far, chemical fertilizers are widely used in order to ensure the stable production of rice. However, the application of chemical fertilizer is not considered sustainable for improving soil fertility and maintain rice yield. Many evidences indicate that long-term

and excessive use of chemical fertilizers (N fertilizer) will lead to more severe soil acidification (Tao et al. 2019; Guo et al. 2010). Furthermore, long-term cultivation can also lead to soil degradation, such as the soil organic matter depletion (De Meyer et al. 2011). Therefore, it is necessary to find a sustainable way to improve soil fertility of paddy field.

Biochar is a type of charcoal with highly aromatic and stable carbon-rich compounds produced by pyrolysis of organic matter (mainly plant or animal residues) at relatively low temperature (< 700 °C) under anoxic or limited oxygen condition (Antal and Gronli 2003; Lehmann et al. 2006; Demirbas 2004). Due to its enrichment in essential nutrients and mineral elements such as potassium, as well as a well-developed pore structure and surface area, alkaline properties and strong cation exchange capacity (Zwieten et al. 2010; Glaser et al. 1998; Cheng et al. 2006; Cornelissen et al. 2004; Lehmann et al. 2003; Atkinson et al. 2010), biochar has become a research hotspot in the field of agricultural application in the last decade, especially for sustained improvement of soil fertility (Gao et al. 2017; Ahmed et al. 2016; Agegnehu et al. 2017; Tan et al. 2017).

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Many studies have revealed that biochar can maintain soil moisture and improve soil fertility (Madari et al. 2017; Jačka et al. 2018). Laghari et al. (2015) applied biochar on two different sandy desert soils and found that water holding capacity of two sandy soils increased by 11% and 14%, water retention capacity increased by 28% and 32%, total carbon (C) increased by 11% and 7%, total phosphorus (P) increased by 70% and 68%, and total potassium (K) increased by 37% and 42%, respectively. In addition, previous studies indicate that the selection of biochar feedstock is a key factor for soil improvement. For example, biochar prepared from peanut shells at 300 °C and 400 °C significantly decreased the soil bulk density and increased the pH, cation exchange capacity, and soil organic matter content (Wang et al. 2017). However, studies have also shown negative results where manure-derived biochar failed to improve the cation exchange capacity in sandy and silt loam soils (Subedi et al. 2016). Similarly, miscanthus biochar significantly increased soil available water content and cation exchange capacity and decreased soil pH compared with the biochar prepared from other sources such as rice straw, wheat straw, maize straw, kitchen waste, sewage sludge, eucalyptus wood, maize cobs, and poultry litter (Khan et al. 2017). Furthermore, the improvement of soil physicochemical properties by biochar is confined in the soil type. Zhai et al. (2015) have reported that application of 8% maize residue biochar in two soils for 42 days of incubation, soil Olsen-P, was substantially increased in fluvo-aquic soil than in the Red earth. Some studies suggest that soil hydraulic properties had different responses to the biochar feedstock and soil texture (Lim et al. 2016; Villagra-Mendoza and Horn 2018). Previous researchers have done a lot of research on improving soil by biochar on different factors.

However, there are few reports on the improvement of paddy soil by biochar, especially under different water management conditions. In the production practice, three kinds of water management methods are usually adopted in paddy field, namely, flooded irrigation, intermittent irrigation, and wet irrigation. An incubation experiment was conducted to investigate the effect of biochar on soil fertility under the three water management modes. Two types of biochar derived from rice straw and rice husk along with two kinds of soil texture were selected. Changes on soil properties such as WHC, pH, TN, available P, available K, and soil SOM and CEC were determined. It is anticipated that the biochar's potential to improve the fertility of paddy soil may vary under different water management modes, such as biochar has greater potential for improving soil fertility under intermittent irrigation mode. And we hypothesize that only part of the soil chemical properties will differ under different water conditions.

## 2 Materials and Methods

### 2.1 Soils

Two major paddy soil types in Jiangxi Province, soil I (sandy loam) and soil II (silty loam), were collected from the typical paddy soil with low fertility at the depth of 0 to 20 cm. Both soil I and II were sampled from the paddy fields located in southern and northern parts of Jiangxi Province, China. Soil properties are listed in Table 1.

### 2.2 Biochar

Two types of biochar derived from crushed rice straw (herein referred as RSC) and from rice husk (herein referred as RHC) were produced in the laboratory at Jiangxi Agricultural University. Air-drying and crushing was performed at a water content level below 16% followed by compacting and filling with 300-mL ceramic crucible. The crucible was covered in a muffle furnace under oxygen-limited pyrolysis for 2 h at 700 °C (according to the author's previous research results, the pyrolysis temperature of rice straw and husk has higher ash, phosphorus content, and pH value at 700 °C). The heating rate was kept at 20 °C min<sup>-1</sup> (Zhai et al. 2015). The properties of the two biochars are listed in Table 2.

### 2.3 Experimental Design

Biochar and soil incubation experiment was conducted in the Key Laboratory at Jiangxi Agricultural University, China. The experiment was laid out in a two-factorial randomized block design consisting of three different water management modes combined with five biochar dosages, namely, 0 (CK), 5 (C1), 10 (C2), 20 (C3), and 50 (C4) g kg<sup>-1</sup> with three replicates. Four batches in total: two biochars (rice straw biochar and rice husk biochar) applied to two soils (sandy loam and silty loam) respectively.

Three hundred grams of each soil sample was sieved through 2-mm size. Final amount of two soils was mixed with two biochars into a 500-mL plastic bowl for incubation. The FI treatment was maintained at a water depth of 15–20 mm; the II treatment was carried out in a 15–0-mm circulation mode followed by drying at 15-mm water depth under natural conditions. The mixture of soils was kept for 2 days before adding water to a depth of 15 mm until naturally dried, thereby circulating; the WI treatment was maintained at the maximum soil water content without water layer. Soil water content, soil pH, soil total nitrogen, available phosphorus, available potassium, soil organic matter, and cation exchange capacity were determined after 60 days of incubation at room temperature.

**Table 1** Properties of the selected soils

Properties	TN (g kg <sup>-1</sup> )	Available P (mg kg <sup>-1</sup> )	Available K (mg kg <sup>-1</sup> )	SOM (g kg <sup>-1</sup> )	pH	CEC (cmol kg <sup>-1</sup> )
Soil I	0.78	10.93	88.39	14.95	6.25	7.13
Soil II	1.02	22.17	133.51	15.15	6.30	9.65

TN, total nitrogen; P, phosphorus; K, potassium; SOM, soil organic carbon; CEC, cation exchange capacity

## 2.4 Biochar Properties Analysis

Biochar recovery refers to the ratio of the feedstock mass (rice straw and rice husk) after carbonization to the original mass. Weigh 1 g of biochar samples into a 30-mL ceramic crucible which has been burned to constant weight, and then, ash it in the muffle furnace at 800 °C for 4 h for ash content determination. The pH was measured with the pH-water (1:20 w/v) method by using a pH meter. Biochar TN and TP were digested with H<sub>2</sub>SO<sub>4</sub>-H<sub>2</sub>O<sub>2</sub>, TN was determined using the Kjeldahl nitrogen method, and TP was measured by molybdenum antimony colorimetric method. Biochar organic carbon (OC) was determined by oil bath heating potassium dichromate volumetric method, and cation exchange capacity was measured with the EDTA-ammonium salt express analysis (Chintala et al. 2014).

## 2.5 Soil Properties Analysis

WHC was determined using the direct drying method after unified saturation (Laghari et al. 2015). SOM was determined by oil bath heating potassium dichromate volumetric method and available P was measured by molybdenum antimony colorimetric method (Wu et al. 2014). Soil pH was measured with the pH-water (1:5 w/v) method by using a pH meter (Pandian et al. 2016). Soil TN was determined using the Kjeldahl nitrogen method, and the available K was extracted by 1 mol L<sup>-1</sup> NH<sub>4</sub>OAc determined using the flame photometric method (Berihun et al. 2017). Soil cation exchange capacity was measured with the EDTA-ammonium salt express analysis (Chintala et al. 2014).

## 2.6 Data Analysis

Statistical analysis was performed using Excel 2010 and SPSS 17.0. A least significant difference (LSD) tests detected the

statistical significance between the groups, where the significance level was 0.05.

## 3 Results

### 3.1 Biochar and Soil Moisture Content

Biochars (RHC and RSC) improved the soil water retention capacity in two paddy soils under different water management modes (Fig. 1). The WHC for both soils under C4 treatment was significantly higher than C1, C2, C3, and control treatments of biochar. The average increase in WHC by RHC and RSC of soil I was 6.53% and 18.61% (Fig. 1a) and of soil II was 8.70% and 19.66% (Fig. 1b), respectively. The WHC of soil II was increased as compared with soil I under the same biochar application rate. RSC was found to be superior than RHC in maintaining the moisture in terms of soil moisture content (Fig. 1).

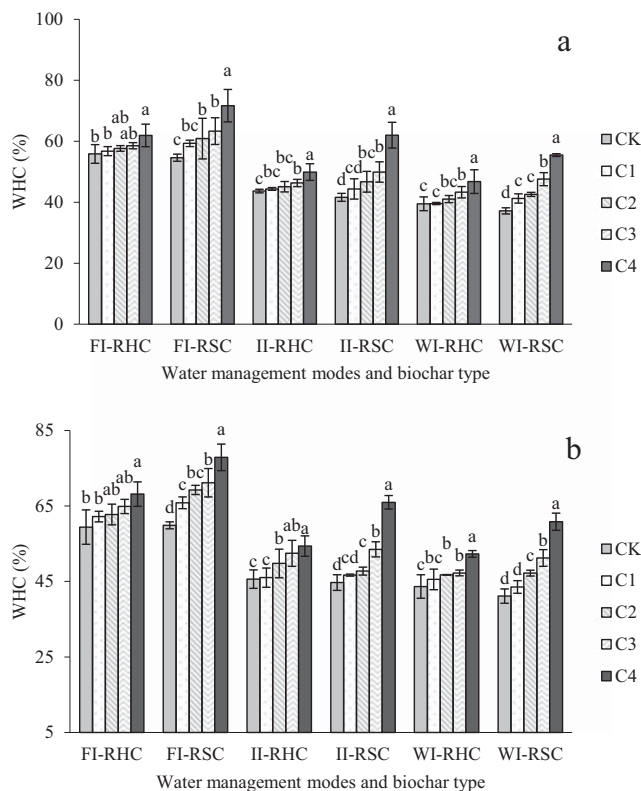
### 3.2 Effect of Biochar on Soil pH

The pH of the two paddy soils both increased with the ascendant biochar application rate and significantly increased with higher pH range by RSC (Table 3). The pH of the two soils with control treatment (CK) was weakly acidic. RSC changed the pH of both soils into neutral with C3 dosage, whereas the soil pH was measured as alkaline with C4 dosage of biochar. Under FI water management mode, the pH of soil I was increased from 0.06 to 0.61 and 0.29 to 1.61 units by RHC and RSC, respectively. The pH of soil II in FI mode was also increased in range of 0 to 0.24 and 0.17 to 1.32 units by biochar. Similarly, pH increased in other modes of water management such as II mode ((0.13–0.62 and 0.21–1.51 units in soil I) (0.03–0.27 and 0.01–1.15 units in soil II)) and WI mode ((0.04–0.63 and 0.19–1.54 units in soil I) (–0.03–0.27 and

**Table 2** Properties of the biochar

Properties	Particle size (mm)	Recovery (%)	Ash content (%)	TN(g kg <sup>-1</sup> )	TP(g kg <sup>-1</sup> )	OC(g kg <sup>-1</sup> )	pH	CEC(cmol kg <sup>-1</sup> )
RHC	<2	30.61	30.65	6.8	4.22	490.59	10.05	20.71
RSC	<2	29.57	36.81	10.7	4.29	510.38	10.63	43.39

TN, total nitrogen; TP, total phosphorus; OC, organic carbon; CEC, cation exchange capacity



**Fig. 1** Effects of biochars on WHC in two paddy soils under different water management modes. *FI*, flooded irrigation; *II*, intermittent irrigation; *WI*, wet irrigation; CK, C1, C2, C3, and C4 was the biochar dosage 0, 5, 10, 20, and 50 g kg<sup>-1</sup>. **a** Biochar applied in soil I, **b** biochar applied in soil II; the error bar in the figure is standard deviation, on which different letters indicate significant difference at the same water management modes and biochar type ( $p < 0.05$ )

0.08–1.32 units in soil II) by RHC and RSC, respectively. The pH of soil I was higher than that of soil II under the same application rate of both biochar types. Based on the pH values of the two soils, water management modes can be prioritized as II > WI > FI.

### 3.3 Effects of Biochar on Soil Nutrients

#### 3.3.1 Total Nitrogen

The addition of biochar significantly increased the TN content in both soils (Fig. 2). The C1 dosage of RHC significantly increased the TN of soil I (Fig. 2a), whereas C4 treatment increased the TN significantly in soil II (Fig. 2b). TN was significantly increased by RSC with each treatment in soil I; however, only C3 and C4 treatments showed significant increase in TN in soil II. Soil TN amount was significantly increased under application of RSC dosages C3 and C4 as compared with RHC dosages. Compared with CK, RHC and RSC increased the TN content of soil I by 5.53–41.31% and 12.08–83.53%, and soil II by 5.44–23.57% and 6.67–66.02%, respectively. No significant difference of TN was observed under different water management modes using the same type of soil and biochar dosage.

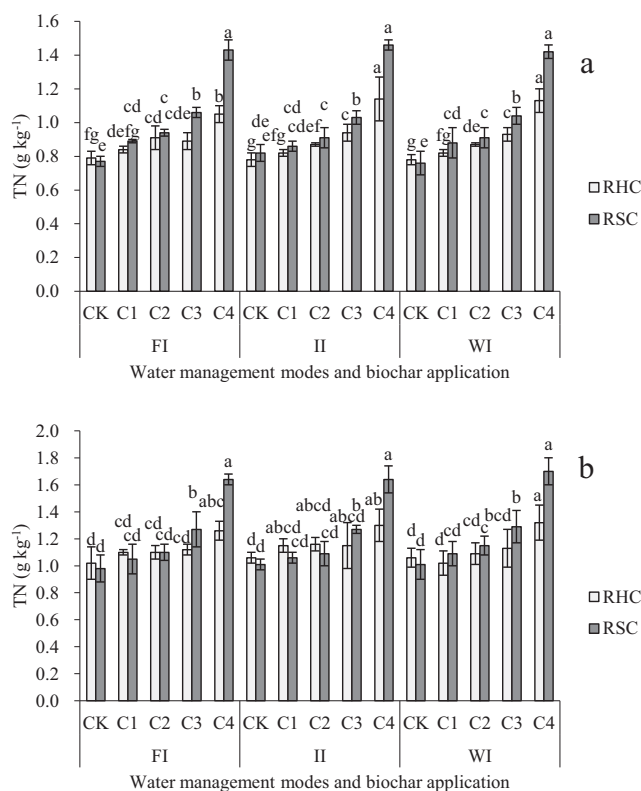
#### 3.3.2 Available P

RHC and RSC showed a direct link with the increase in the available P content in two soils compared with CK (Fig. 3); a significant increasing trend in the available P in soil was observed at C3 dosage of biochar and it reached to its highest level with C4 dosage of RHC or RSC. RHC and RSC increased the available P in FI mode by 4.4 and 19.81 mg kg<sup>-1</sup> and 4.45 and

**Table 3** The soil pH in different treatments

Water management modes	Biochar dosage	Soil I		Soil II	
		RHC	RSC	RHC	RSC
FI	CK	6.19 ± 0.01f	6.19 ± 0.02 g	6.31 ± 0.06cd	6.19 ± 0.11 g
	C1	6.25 ± 0.07ef	6.48 ± 0.02e	6.31 ± 0.06cd	6.36 ± 0.03ef
	C2	6.30 ± 0.06def	6.69 ± 0.09d	6.32 ± 0.06cd	6.48 ± 0.06cd
	C3	6.47 ± 0.03bc	6.98 ± 0.01c	6.38 ± 0.02bcd	6.80 ± 0.04b
	C4	6.80 ± 0.05a	7.80 ± 0.04b	6.55 ± 0.06a	7.51 ± 0.08a
II	CK	6.22 ± 0.07ef	6.32 ± 0.04f	6.32 ± 0.06cd	6.39 ± 0.07de
	C1	6.35 ± 0.04cde	6.53 ± 0.05e	6.35 ± 0.04bcd	6.38 ± 0.06e
	C2	6.41 ± 0.04bcd	6.75 ± 0.06d	6.41 ± 0.08bc	6.52 ± 0.04c
	C3	6.51 ± 0.05b	7.02 ± 0.04c	6.45 ± 0.07b	6.82 ± 0.08b
	C4	6.84 ± 0.12a	7.83 ± 0.02ab	6.59 ± 0.01a	7.54 ± 0.09a
WI	CK	6.24 ± 0.08ef	6.35 ± 0.05f	6.31 ± 0.08cd	6.27 ± 0.05fg
	C1	6.28 ± 0.11def	6.54 ± 0.05e	6.28 ± 0.06d	6.35 ± 0.06ef
	C2	6.38 ± 0.08bcd	6.75 ± 0.04d	6.33 ± 0.05cd	6.44 ± 0.06cde
	C3	6.51 ± 0.08b	7.01 ± 0.01c	6.38 ± 0.01bcd	6.81 ± 0.07b
	C4	6.87 ± 0.15a	7.89 ± 0.04a	6.58 ± 0.03a	7.59 ± 0.09a

*FI*, flooded irrigation; *II*, intermittent irrigation; *WI*, wet irrigation; CK, C1, C2, C3, and C4 was the biochar dosage 0, 5, 10, 20, and 50 g kg<sup>-1</sup>. Different letters within the same column indicate significant difference between treatments ( $p < 0.05$ )

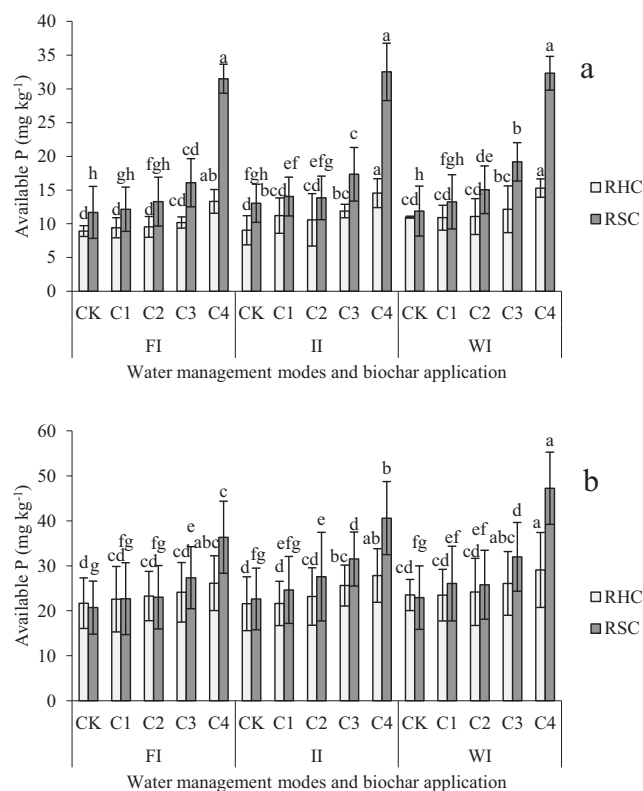


**Fig. 2** The TN of different treatments. TN, total nitrogen; FI, flooded irrigation; II, intermittent irrigation; WI, wet irrigation; CK, C1, C2, C3, and C4 was the biochar dosage 0, 5, 10, 20, and 50  $\text{g kg}^{-1}$ . **a** Biochar applied in soil I, **b** biochar applied in soil II; the error bar in the figure is standard deviation, on which different letters indicate significant difference at the same biochar type ( $p < 0.05$ )

15.65  $\text{mg kg}^{-1}$  in soil I (Fig. 3a) and II (Fig. 3b), respectively; in II mode by 5.5 and 19.47  $\text{mg kg}^{-1}$  and 6.28 and 17.97  $\text{mg kg}^{-1}$  in soil I and II, respectively; in WI mode by 4.3 and 20.42  $\text{mg kg}^{-1}$  and 5.56 and 24.32  $\text{mg kg}^{-1}$  in soil I and II, respectively. The available P content in soils showed a trend of WI > II > FI at the same biochar dosage. However, increase in the available P content in two soils by RSC was significantly higher than that by RHC.

### 3.3.3 Available K

A significant difference among treatments of RHC and RSC dosages was observed for the available K content in two soils (Fig. 4). RHC and RSC increased the available K content, in FI mode, by 0.43–3.56 and 2.40–13.43 times and 0.39–2.49 and 1.67–10.67 times in soil I (Fig. 4a) and II (Fig. 4b), respectively; in II mode, increased by 0.46–3.99 and 2.03–12.63 times, and 0.40–2.57 and 1.50–10.08 times in soil I and II, respectively; in WI mode, increased by 0.40–3.98 and 2.48–14.47 times, and 0.25–2.38 and 1.74–10.75 times in soil I and II, respectively. A higher amount of the available K content was observed in RSC; however, no significant difference was detected among the three water management modes.



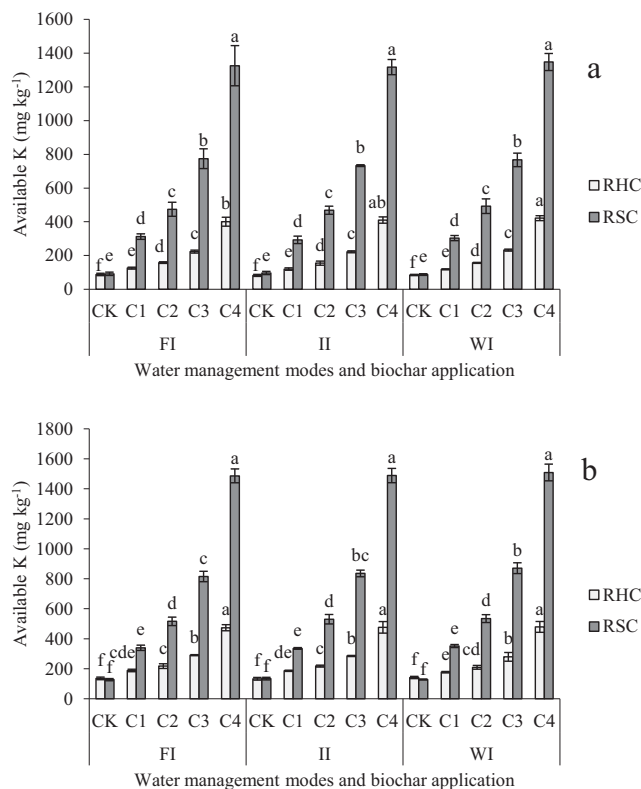
**Fig. 3** The status of the available P contents of different treatments. FI, flooded irrigation; II, intermittent irrigation; WI, wet irrigation; CK, C1, C2, C3, and C4 was the biochar dosage 0, 5, 10, 20, and 50  $\text{g kg}^{-1}$ . **a** Biochar applied in soil I, **b** biochar applied in soil II; the error bar in the figure is standard deviation, on which different letters indicate significant difference at the same biochar type ( $p < 0.05$ )

### 3.3.4 Soil Organic Matter

The contents of SOM in soil I and soil II increased with the ascendant biochar application dosage and a significant increase was observed by C4 (C3) dosage of RHC (RSC) (Fig. 5). Compared with CK dosage, in FI mode, RHC and RSC increased the SOM by 2.21–11.86 and 5.07–29.79  $\text{g kg}^{-1}$ , and 4.06–14.62 and 4.75–30.59  $\text{g kg}^{-1}$  in soil I (Fig. 5a) and II (Fig. 5b), respectively; in II mode, 0.53–18.23 and 2.76–27.70  $\text{g kg}^{-1}$ , and 0.39–11.60 and 3.53–29.12  $\text{g kg}^{-1}$  in soil I and II, respectively; in WI mode, 0.36–15.92 and 2.09–28.82  $\text{g kg}^{-1}$ , and 0.31–19.59 and 0.71–25.92  $\text{g kg}^{-1}$  in soil I and II, respectively. However, SOM contents did not show significant difference under different water management modes.

### 3.4 Effects of Biochar on CEC of Paddy Soil Under Different Water Management Modes

The CEC increase caused by biochar application has been shown in Table 4 with significant values under different water management modes for both paddy soils. The CEC by RHC was in range of 0.1–1.2 and 0.1–1.4  $\text{cmol kg}^{-1}$  for soil I and II,

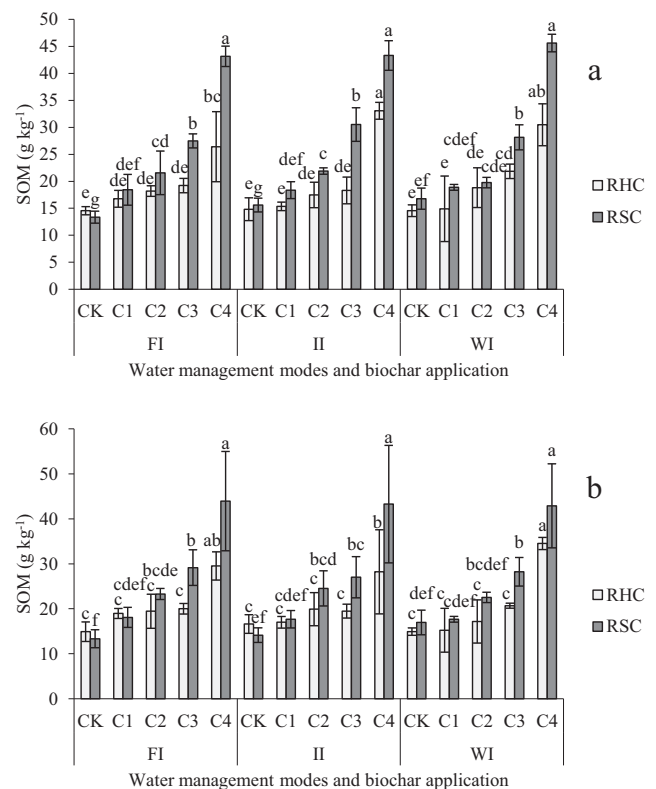


**Fig. 4** The status of the available K contents of different treatments. FI, flooded irrigation; II, intermittent irrigation; WI, wet irrigation; CK, C1, C2, C3, and C4 was the biochar dosage 0, 5, 10, 20, and 50 g kg<sup>-1</sup>. **a** Biochar applied in soil I, **b**: biochar applied in soil II; the error bar in the figure is standard deviation, on which different letters indicate significant difference at the same biochar type ( $p < 0.05$ )

respectively. Similarly, the CEC by RSC was in range of 0.4–2.9 and 0.2–3.4 cmol kg<sup>-1</sup> for soil I and II, respectively. RHC maximum increased the CEC of soil I by 1.06, 1.18, and 1.14 cmol kg<sup>-1</sup>, and soil II by 1.34, 1.36, and 1.32 cmol kg<sup>-1</sup> under the FI, II, and WI modes, respectively. RSC maximum increased the CEC soil I by 2.66, 2.76, and 2.86 cmol kg<sup>-1</sup>, and soil II by 3.36, 3.39, and 3.43 cmol kg<sup>-1</sup> under the FI, II, and WI modes, respectively. The effect of water management modes on the CEC of two soils was II ≈ WI > FI without significant difference. It was concluded that biochar could improve the fertilizer retention ability of paddy soil, and RSC is a better choice than RHC.

#### 4 Discussion

Appropriate soil moisture and pH are key factors to ensure crop growth and development along with CEC, an important indicator of soil fertility, fertilization capacity, and buffer capacity. It has been reported earlier that biochar enhances the WHC via decrease in soil bulk density, increase in total pore volume and water holding capacity, as well as by its porosity, huge surface area, and surface



**Fig. 5** The soil organic matter (SOM) contents of different treatments. FI, flooded irrigation; II, intermittent irrigation; WI, wet irrigation; CK, C1, C2, C3, and C4 was the biochar dosage 0, 5, 10, 20, and 50 g kg<sup>-1</sup>. **a** Biochar applied in soil I, **b** biochar applied in soil II; the error bar in the figure is standard deviation, on which different letters indicate significant difference at the same biochar type ( $p < 0.05$ )

functionality (Agegnehu et al. 2017; Tan et al. 2017). And there was a possible mechanism that water molecules were bound through polar hydrogen bonds to O-H and C-O-H (Jačka et al. 2018). In our study, RHC and RSC (application rate 50 g kg<sup>-1</sup>) increased the soil water content of sandy loam by 6.53%, 18.61%, and of silty loam by 8.70% and 19.66%, respectively. Similarly, Laghari et al. (2015) reported that pine sawdust-derived biochar (application rate 22 t ha<sup>-1</sup>) increased the soil water holding capacity by 11% and 14% and water retention capacity by 28% and 32% in the Kubuqi and the Thar Desert soils, respectively.

Biochar itself is rich in ash that can increase the soil pH by neutralizing the acid ions Al<sup>3+</sup> and H<sup>+</sup> in soil (Zwieten et al. 2010). In the present study, an increase in pH of sandy loam (0.63 and 1.61 units) and silty loam (0.27 and 1.32 units) soils was observed with the application of RHC and RSC, respectively. Our results are consistent with the findings of Berihun et al. (2017), who found a significant increase in soil pH and decrease in soil acidity. In addition, biochar showed a significantly higher pH increase in sandy loam than in silt loam (Table 3). El-Naggar et al. (2018) reported that the sandy soil is more sensitive to the addition of biochar than sandy loam soil due to its lower buffering capacity.

**Table 4** The cation exchange capacity (CEC) under different treatments

Water management modes	Biochar dosage	Soil I (cmol kg <sup>-1</sup> )		Soil II (cmol kg <sup>-1</sup> )	
		RHC	RSC	RHC	RSC
FI	CK	7.13 ± 0.06gh	7.16 ± 0.04gh	9.66 ± 0.02g	9.65 ± 0.01e
	C1	7.26 ± 0.09f	7.58 ± 0.04e	9.77 ± 0.03f	9.86 ± 0.03d
	C2	7.42 ± 0.06cd	7.79 ± 0.05d	9.98 ± 0.04e	10.08 ± 0.10c
	C3	7.61 ± 0.04b	8.38 ± 0.03c	10.21 ± 0.04c	10.72 ± 0.05b
	C4	8.19 ± 0.04a	9.82 ± 0.04b	11.00 ± 0.03a	13.01 ± 0.03a
II	CK	7.06 ± 0.10h	7.18 ± 0.04g	9.65 ± 0.03g	9.64 ± 0.06e
	C1	7.18 ± 0.04fg	7.65 ± 0.07e	9.82 ± 0.03f	9.85 ± 0.05d
	C2	7.37 ± 0.06de	7.87 ± 0.05d	10.03 ± 0.03de	10.09 ± 0.03c
	C3	7.60 ± 0.07b	8.39 ± 0.07c	10.33 ± 0.04b	10.74 ± 0.08b
	C4	8.24 ± 0.02a	9.94 ± 0.08a	11.01 ± 0.03a	13.03 ± 0.03a
WI	CK	7.09 ± 0.07gh	7.10 ± 0.08h	9.68 ± 0.05g	9.65 ± 0.02e
	C1	7.18 ± 0.03fg	7.49 ± 0.03f	9.77 ± 0.03f	9.88 ± 0.03d
	C2	7.29 ± 0.11ef	7.86 ± 0.01d	10.05 ± 0.07d	10.07 ± 0.05c
	C3	7.52 ± 0.04bc	8.38 ± 0.04c	10.28 ± 0.02b	10.80 ± 0.06b
	C4	8.23 ± 0.06a	9.96 ± 0.03a	11.00 ± 0.02a	13.08 ± 0.07a

FI, flooded irrigation; II, intermittent irrigation; WI, wet irrigation; CK, C1, C2, C3, and C4 was the biochar dosage 0, 5, 10, 20, and 50 g kg<sup>-1</sup>

Different letters within the same column indicate significant difference between treatments ( $p < 0.05$ )

The increase of soil CEC may be attributed to the higher ash content and pH of biochar (Table 2). Our results showed that biochar increased the cation exchange capacity of soil by 0.93–40.28%. Similarly, Laird et al. (2010) and Pandian et al. (2016) have demonstrated the increase of CEC by 4–30% and 7.14–16.07% compared with controls in their studies. In addition, we found that the increase of CEC in silty loam by two biochar types was greater than that applied in sandy loam (Table 4). Similarly, different biochar types such as paddy straw (PB), amur silvergrass (AB), and umbrella tree (UB) have been reported for a significant increase in CEC of sandy soils and a minor increase in sandy loam soil by PB (El-Naggar et al. 2018).

Soil organic matter (SOM) is an important component of soil and indicator of soil fertility. SOM and nutrients (NPK) have direct interaction with the soil fertility. The increase of SOM may be attributed to the content of organic carbon in biochar (RHC 490.59 g kg<sup>-1</sup>, RSC 510.38 g kg<sup>-1</sup>, Table 2), which agrees with Karimi et al. (2019). Also, Karimi et al. (2019) found that the increase of soil TN may be due to the significant increase of inorganic nitrogen concentration in soil by biochar. The application of biochar increases the available P concentration in soil, which may be caused by the enhanced microbial activity and the release of initial phosphorus (Karimi et al. 2019; Motaghian et al. 2019). In addition, the available K increased the most significantly in soil treated with biochar among the tested elements. Amin (2020) found that bagasse pith vinasse biochar increased the soil available K

concentration as the biochar contains high amounts of potassium itself. Our results are consistent with the previous studies in terms of the increase in soil organic matter, total nitrogen, available phosphorus, and available potassium with addition of biochar (Wang et al. 2017; Rékási et al. 2019; Yao et al. 2017; Berihun et al. 2017; Wu et al. 2014; Muhammad et al. 2014; Bhattacharjya et al. 2016).

The properties of biochar depend on raw materials and pyrolysis conditions (Weber and Quicker 2018), which determines the potential for improving soil fertility. In this study, rice straw biochar enhanced stronger soil water holding capacity than rice husk biochar, which may be due to more specific surface area and pore structure of rice straw biochar than rice husk biochar (Wang et al. 2016). Previous studies have reported the degree of soil pH improvement varied by biochar types (Wang et al. 2017; Rékási et al. 2019; Yao et al. 2017; Pandian et al. 2016). Soil CEC is also affected by biochar in relation to soil type and biochar type and time of application in soil (Agegnehu et al. 2017; Gul et al. 2015). In this study, biochar significantly increased the CEC of both soils, and the increase of CEC by RSC was higher than that of RHC. It may be attributed to the higher ash content, cation exchange capacity, and pH value of RSC (Table 2). Also, our results show that the fertilization effect of biochar on sandy loam is better than that of silty loam, and RSC is better than RHC. Similarly, Muhammad et al. (2014) indicated that different types of biochar induced different chemical changes such as increased dissolved organic carbon and total C and N in soil. Bornø

et al. (2018) also illustrated that biochar and soil properties and the status of phosphorus in the soil affect the bioavailability of phosphorus. It can be observed from Table 2 that the parameters (nutrient elements) of RSC are higher than RHC, which may be the reason why RSC can improve soil fertility higher than RHC.

The effects of biochar on soil chemical properties in paddy fields under different water management conditions have not been reported before. Our results show that the pH values of paddy soils under three water management modes at the same biochar application were higher in II as compared with WI and FI modes. Among different modes, WI mode had the best effect on increasing available phosphorus and potassium content in soil by biochar application. However, biochar effect on SOM and TN could not differentiate under different water management modes, which indicates the need of further dynamic and long-term study.

## 5 Conclusion

Improvement in the soil pH, cation exchange capacity, nutrient content, and water holding capacity of paddy soil with the application of biochar has been demonstrated in our study. Increase in the biochar dosage resulted in enhancement of soil fertility, reaching to a significant level with biochar dosage of 50 g kg<sup>-1</sup>. Different water management modes combined with biochar application had an interactive effect on soil properties. Compared with flooding irrigation, intermittent and wet irrigation might be a better choice to improve the paddy soil fertility by biochar application, because the soil has higher pH, available phosphorus, and cation exchange capacity under these two water management modes. Furthermore, biochar improved fertility of sandy loam soil in a higher degree than silty loam soil, and rice straw biochar was more effective than rice husk biochar on paddy soil fertility improvement. Therefore, rice straw biochar combined with intermittent or wet irrigation can be used to improve soil fertility in low-fertility paddy fields (especially sandy loam soil). However, future studies are still needed to evaluate the long-term impact of rice straw biochar on nutrient bioavailability and soil fertility.

**Authors' Contributions** Le Chen, Xiaohua Pan, and Yongjun Zeng conceived and designed research. Le Chen, Mengjie Liu, Qiancong Zhou, Siwei Zhan, and Yingchi Chen conducted experiments. Le Chen analyzed data and wrote the manuscript. Asjad Ali provided a language help. All authors read and approved the manuscript.

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## Compliance with Ethical Standards

**Conflict of Interest** The authors declare that they have no conflict of interest.

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