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Growth, Seed Yield, Mineral Nutrients and Soil Properties of Sesame (*Sesamum indicum* L.) as Influenced by Biochar Addition on Upland Field Converted from Paddy

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Abstract: Sesame is an important oilseed crop cultivated worldwide. However, research has focused on biochar effects on grain crops and vegetable and there is still a scarcity of information of biochar addition on sesame. This study was to assess the effect of biochar addition on sesame performance, with a specific emphasis on growth, yield, leaf nutrient concentration, seed mineral nutrients, and soil physicochemical properties. A field experiment was conducted on an upland field converted from paddy at Tottori Prefecture, Japan. Rice husk biochar was added to sesame cropping at rates of 0 (F), 20 (F+20B), 50 (F+50B) and 100 (F+100B) t ha^{-1} and combined with NPK fertilization in a first cropping and a second cropping field in 2017. Biochar addition increased plant height, yield and the total number of seeds per plant more in the first cropping than in the second cropping. The F+50B significantly increased seed yield by 35.0% in the first cropping whereas the F+20B non-significantly increased seed yield by 25.1% in the second cropping. At increasing biochar rates, plant K significantly increased while decreasing Mg whereas N and crude protein, P and Ca were non-significantly higher compared to the control. Soil porosity and bulk density improved with biochar addition while pH, exchangeable K, total N, C/N ratio and CEC significantly increased with biochar, but the effect faded in the second cropping. Conversely exchangeable Mg and its plant tissue concentration decreased due to competitive ion effect of high K from the biochar. Biochar addition is effective for increasing nutrient availability especially K for sesame while improving soil physicochemical properties to increase seed yield, growth and seed mineral quality.

Keywords: sesame; rice husk biochar; nutrient concentration; cropping

1. Introduction

Sesame (*Sesamum indicum* L.) is an important oilseed crop cultivated worldwide for its edible oil and food [1]. Sesame seeds contain high oil content (44–58%), proteins (18–25%), carbohydrates

(13.5%), ash (5%) [2], and mineral components, such as K (815 mg/100 g), P (647 mg/100 g), Mg (579 mg/100 g) and Ca (415 mg/100 g) [3]. This contributes to its health and nutritional benefits. Therefore, demand for sesame seeds is increasing due to the increasing knowledge on their dietary and health benefits, but there has been limited research on sesame evidenced by low yield in most growing areas hence hampering its adoption and expansion in the world [4]. Although sesame has been reconsidered a local specialty crop in Japan [5], the production of sesame is still low. For instance, the Food and Agriculture Organization (FAO) in 2016 estimated that 11 tons of sesame seeds were produced from an area of 21 hectares [6]. With the increase in abandoned paddy fields estimated at 360,000 ha by the year 2010, farmers were encouraged to convert such fields into cultivation of upland crops, such as wheat and soybeans [7,8], including sesame. However, crop yield on upland fields converted from paddy may decrease due to declining soil fertility status of the paddy soils that could require soil amendment with organic materials [9].

Biochar is a soil amendment produced from thermal decomposition of organic materials through pyrolysis and it has the potential to increase crop yields [10,11]. Earlier research has shown that biochar addition can improve plant growth and soil quality [12–14]. The positive responses in crop yield on biochar addition were attributed to improved soil properties, such as a decrease in soil bulk density, and subsequent increase in porosity and water holding capacity [15,16], increase in the cation exchange capacity (CEC) which enhances the retention of basic nutrients, [17], increased uptake of N and its availability in soil [18], adsorption of soil phytotoxins [19,20], liming effects [21], and increased plant nutrient concentration [22,23]. For instance, cultivation on sandy soils using biochar increased maize yield by 150% and 98% over the control at rates of 15 t ha^{-1} and 20 t ha^{-1} respectively [23]. It has also been reported that rice husk biochar addition at 41.3 t ha^{-1} significantly increased rice grain yield by 16–35% attributed to increased water holding capacity, available N and cation exchange capacity (CEC) [24]. Zhang et al. [25] also reported an increase in rice yields of 14% over the control in paddy soils with wheat straw biochar rate of 40 t ha^{-1}. Furthermore, it has been shown that rice husk biochar addition rates of up to 50 t ha^{-1} significantly increased maize seed protein by 27% compared to without biochar while increasing plant height by 23% compared with control [26]. The authors attributed these increases to the increase in soil fertility status improving nutrition required for maize grain quality improvement. There are also several reports on an increase in plant height, growth and grain quality with biochar application in crops [27–29], which indicate a positive effect of biochar on crops.

Biochar addition to soils is expected to promote sustainable crop production through a positive effect on yield, but these may depend on the cropping seasons. For instance, Cornelissen et al. [30] studied the effect of rice husk biochar and cacao shell biochar applied to Indonesia Utisol soil at rates of up to 15 t ha^{-1} and found that the maize yield with rice husk biochar become lower and faded in the second cropping while with cacao shell biochar was highest in the second cropping through third and fourth, but faded in the fifth cropping seasons. In addition, biochar applied to soil and tested over four cropping seasons on acidic soil in Brazil showed positive effects in the first cropping, but these faded in the following cropping [31]. Carter et al. [32] also reported a high yield of lettuce and cabbage in the first cropping, but yield decreased significantly in the third cropping with rice husk biochar rates of up to 167 t ha^{-1} field equivalent. Furthermore, rapeseed yield with wheat straw biochar faded after third cropping that suggested biochar needed to be applied after every three years to maintain positive effects on crop yield [33]. These lack of positive responses of crop yield could be attributed to the changes in biochar chemistry over time as it ages in the soil environment [34]. Hence, the properties of biochar responsible for crop improvement may be altered consequently leading to no effect on growth and yield.

Several pieces of research have focused on biochar effects on grain crops, such as rice, maize, wheat and vegetable of which plant growth responses to biochar addition varied [19,21,24,27,28,32]. However, there is still a scarcity of information of biochar addition on sesame [35,36], indicating a need to generate understanding of how biochar addition can effectively be used to increase sesame production. An earlier research has shown that rice and saw dust biochar addition at 10 t ha^{-1}

significantly increased sesame seed yield by 55.5% compared to without biochar attributed to improved soil physico-chemical properties, such as bulk density and porosity, increased pH, total N, K, Mg and CEC after biochar addition on a highly leached ultisols with low base saturation and strongly acidic soils [36]. Although in a pot experiment, biochar addition to sesame has been shown to significantly increase plant height at increasing rates where the optimal rate of 11.21 g kg^{-1} (equivalent to 22.42 t ha^{-1}) was obtained beyond which biochar decreased pant height becoming harmful to sesame growth [35]. The authors attributed this negative effect on sesame growth to increase in pH due to biochar application on already neutral soil that had pH 6.4 before the experiment. Furthermore, coconut shell biochar addition at 10 t ha^{-1} on sandy coastal has been shown to increase sesame yield when grown on sandy coastal soil [37]. Therefore, biochar addition shows positive results on sesame. However, crop responses to biochar application depend on biochar type, application rates, soil properties and climatic conditions [38]. It important to explore the utilization of biochar in sesame to understand how seed yield and growth are influenced on upland fields converted paddy in Japan under different field climatic conditions, paddy soils with low pH and higher biochar rates in order to close existing gaps on biochar use for sesame.

In this study, we hypothesized that biochar addition would increase sesame growth, yield and nutrient availability with increasing rates of biochar in first and second cropping. To investigate the effect of biochar addition on sesame performance, we cultivated sesame on two fields of first and second cropping on upland field converted from paddy. The specific objectives this study were to determine the effect of biochar addition on the (a) growth and yield of sesame in the first and second cropping; (b) leaf tissue nutrient concentration and seed mineral nutrient contents; and (c) soil physicochemical properties of the upland field converted paddy under continuous cropping.

2. Materials and Methods

2.1. Experiment Site

This field experiment was conducted in 2017 at the Tottori Prefecture, Japan (35°29′14.85′′ N, 134°07′47.01′′ E). Most precipitation occurred between June to September during the cultivation period. The total monthly rainfall received in the region in 2017 were 66.5, 158.5, 161 and 224.5 mm in June, July, August and September respectively. The average daily maximum temperatures were 24.2 °C in June, 30.6 °C in July, 30.5 °C in August and 26.0 °C in September favorable for sesame growing. The region has primarily one sesame crop harvested per year. The dominant soil at this site was classified as Cambisols [39].

2.2. Soil and Biochar Properties

Analysis of the basic physicochemical properties of the soil samples (0–15 cm) taken from the experiment field before sowing in 2016 indicted that the topsoil had a pH (1:5 H_2O) of 5.39; electrical conductivity (EC) of 0.05 dSm^{-1}; bulk density, 1.27 g cm^{-3}; porosity, 49.09%; total C, 26.25 g kg^{-1}; total N, 2.29 g kg^{-1}; C/N ratio, 11.46; available P (Truog-P), 6.99 mg kg^{-1}; exchangeable K, 109.62 mg kg^{-1}; exchangeable Ca 1931.22 mg kg^{-1}; and exchangeable Mg 383.29 mg kg^{-1}. The commercial rice husk biochar added to the study soils was manufactured and bought from a local store in Tottori, Japan. The rice husk biochar was surface applied by hand in June 2016 in the old field and then in June 2017 in the newly opened field before sesame sowing and immediately incorporated into the soil to a depth of 0–15 cm with base fertilizer utilizing a rotatory power tiller. The rice husk biochar had a pH of 10.47 and EC of 1.66 dSm^{-1} determined from biochar suspension (1:5 w/v, biochar: water) mechanically shaken for 1 h and measured with a pH and EC meter (Horiba Aqua Cond Meter F-74). Total C and N were analyzed by dry combustion on the CN-corder (Macro corder JM 1000CN, J-Science Co., Ltd., Kyoto, Japan) and reported as C, N and C/N ratio of 39.76%, 0.51% and 78.26, respectively. The rice husk biochar had available P of 647.94 mg kg^{-1} determined according to Troug method [40]. Exchangeable K, Ca, and Mg in the rice husk biochar were K, 3640.73 mg kg^{-1}, 1207.78 mg kg^{-1};

and 369.26 mg kg^{-1} respectively, determined upon extraction of biochar with 1 N ammonium acetate (pH 7.1) and analysed by atomic absorption spectrophotometer (Model Z-2300, Hitachi Co., Tokyo, Japan). The biochar cation exchange capacity (CEC) was 7.53 $cmol_c$ kg^{-1}, measured by the 1N (pH 7.1) ammonium acetate (NH_4OAc) as described by Chapman [41]. The bulk density of the biochar was determined by measuring the weight of compacted biochar in 100 cm^3 steel cylinders and was found to be 0.29 g cm^{-3} whereas the ash content was measured by igniting the biochar sample at 550 °C for 5 h in a muffle furnace and found to be 38.04%.

2.3. Experimental Design and Treatments

In this study, we conducted the experiment on two different plots: One in which sesame was previously cultivated with rice husk biochar for one year (season) and a new field where sesame had not been cultivated before. Each of these fields measuring 10.5 m by 6.5 m were divided into micro plots measuring 2.4 m by 1.9 m (4.56 m^2) onto which biochar was incorporated. Each micro plot was separated by 0.4 m as buffer space. The one-year old sesame field had rice husk biochar rates of 0, 20, 50 and 100 t ha^{-1} applied already in the previous year's cultivation. This field was under cropping in 2016 with biochar and sesame, but due to typhoon winds that destroyed the sesame plants, we could not collect data. Therefore, in 2017, the new field opened adjacent to the old field received a similar amount of rice husk biochar treatments at the start of the experiment. The new field and old field are considered as first and second cropping respectively.

Prior to sowing, all fields were ploughed by a power tiller, harrowed to a fine tilth and basal inorganic fertilizer applied at a rate of N—P_2O_5—K_2O, 70:105:70 kg ha^{-1}, including dolomite ($CaMg(CO_3)_2$) at a rate of 1000 kg ha^{-1}. Sesame cultivar 'Gomazou' was planted on ridges of 75 cm wide separated by 40 cm and plant spacing of 45 cm between rows and 15 cm between plants. Sowing date was 11th July 2017 in which five sesame seeds were sown per hole, then thinned to two plants at 14 days after sowing and then one plant per hole at 21 days after sowing. The fields were kept without weeds by hand weeding whenever necessary until harvesting at the on 22nd September 2017. Growth was determined by measuring plant height, height of lowest capsule and number of branches while the seed yield and 1000-seed weight were determined after drying sesame seeds in a greenhouse. The growth and seed yield were determined by randomly selecting ten plants per replicates in each treatment whereas the total number of seeds per plant was calculated after obtaining a weight of 1000 seeds and total seed weights from 10 plants.

2.4. Sampling and Analyses

2.4.1. Plant Sampling

For leaf tissue nutrient concentration analysis, three representative plants were selected at the reproductive stage (50 Days After Sowing) whereas remaining plants were used for growth and yield determination at harvest. Mature leaves from the representative samples were separated from stem and roots and oven dried at 72 °C until a constant weight was attained (after a week). Leaf samples were then ground to fine powder and digested in a mixture of concentrated H_2SO_4 (98%) and H_2O_2 (30%) for P, K, Ca and Mg concentration. Plant P concentration was determined colorimetrically with a spectrophotometer at 420 nm (Model U-5100, Hitachi Co., Tokyo, Japan). Plant K, Ca, and Mg concentration was determined by using an atomic absorption spectrophotometer (Model Z-2300, Hitachi Co., Tokyo, Japan). The plant N was determined from the ground sample with the dry combustion method on a CN Corder machine (Macro corder JM 1000CN, J-Science Co., Ltd., Kyoto, Japan).

For the seed mineral nutrient, the analysis was conducted on sesame seeds after harvesting and drying. Seed mineral nutrient concentrations were determined by means of dry ashing as described by Estefan et al. [42]. Ground sesame seed samples (1.0 g) was placed in a crucible, ignited, and burnt to ash in a muffle furnace at 550 °C for 5 h. The ash was cooled and dissolved into 5 mL of 2 N HCl, diluted to 50 mL in a volumetric flask with reverse-osmosis water, and filtered through Advantec 110-mm filter paper. Phosphorous (P) concentration was determined from the filtrates by means of the ammonium vanadate-ammonium-molybdate yellow colorimetric method using a spectrophotometer (Model U-5100, Hitachi Co., Tokyo, Japan), with absorbance measured at 420 nm. The seed K, Ca and Mg contents were determined from the filtrates by means of atomic absorption spectrophotometry (Model Z-2300, Hitachi Co., Tokyo, Japan). The seed N concentration was measured by means of the dry combustion method using a CN-corder (Macro corder JM 1000CN, J-Science Co., Ltd., Kyoto, Japan) and the values of total N values (%) were multiplied by the N factor 6.25 to obtain crude protein values (N $\times$ 6.25%) [43].

2.4.2. Soil Sampling

To evaluate the effect of the rice husk biochar addition on soil physical properties, soil samples from fields were collected at 0–15 cm from the sesame fields after harvest. Three soil phases in each biochar treatment of the first and second cropping were calculated from two samples collected per replication at the top 10 cm layer by applying a soil three-phase meter (Model DIK-1130, Daiki Rika Kogyo Co., Ltd., Saitama, Japan) to a 100 cm^3 undisturbed soil core. The surface soil bulk density and porosity were determined on the undisturbed soil cores collected using sampling cores of 100 cm^3 after oven drying at 105 °C for 24 h.

For chemical analysis, at harvest, soil samples were collected with a trowel to a depth of 15 cm, air dried, and passed through a 2-mm sieve. Soil suspension (1:5 w/v soil: water) was used to measure pH and electrical conductivity with a pH meter and EC meter (Horiba Aqua Cond Meter F-74). Total C and N were analysed by dry combustion on the CN-corder (Macro corder JM 1000CN, J-Science Co., Ltd., Kyoto, Japan). Soil exchangeable K, Ca, and Mg were extracted in 1 N ammonium acetate (pH 7.1), and analysed by using an atomic absorption spectrophotometer (Model Z-2300, Hitachi Co., Tokyo, Japan). Cation exchange capacity (CEC) was measured by the 1N (pH 7.1) ammonium acetate (NH_4OAc) extraction methods in which the NH_4^+ saturated soil was equilibrated with 10% KCl and steam distilled by micro–kjeldhal distillation before titration with 0.1 N H_2SO_4 [41] and expressed to $cmol_c$ kg^{-1} soil. Soil available P was determined using 0.002 N H_2SO_4 (pH 3.0) in ammonium sulphate solution according to Troug method [40]. The P concentration in soil samples was measured by the ammonium molybdate–ascorbic acid method at an absorption wavelength of 710 nm on a spectrophotometer (Model U-5100, Hitachi Co., Tokyo, Japan).

2.5. Data Analyses

All results were the means of the three replicates. Data were analyzed using one-way analysis of variance (ANOVA) using SPSS version 22.0 (SPSS for windows Inc., Chicago, Illinois, USA) to evaluate the measured parameters as affected by the different rates of biochar addition. The pairs of means were also compared on significant ANOVA tests using Tukey's honestly significance difference (HSD) test ($p < 0.05$). A nonlinear regression analysis was utilized to investigate the relationship between sesame seed yield, plant height and the biochar rates. When considering the differences between the cropping fields, a two-way analysis of variance was used with the different biochar treatments and cropping as two fixed factors.

3. Results

3.1. Effect of Rice Husk Biochar on the Growth and Yield Components of Sesame

The plant height, height of the lowest capsule, number of branches per plant and 1000-seed weight as affected by varying rates of biochar addition in first and second cropping fields are shown in Table 1.

Table 1. The plant height, height of the lowest capsule, number of branches per plant and 1000-seed weight of sesame under the different biochar treatments in different cropping.

Cropping	Biochar Treatment	Plant Height (cm)	Height of First Capsule (cm)	Number of Branches/Plant	1000-Seeds Weight (g)
First cropping	F	140.60 ab	68.12 a	1.72 b	2.16 a
	F+20B	137.85 b	64.26 a	2.03 b	2.08 a
	F+50B	157.63 a	67.48 a	3.01 a	2.23 a
	F+100B	152.47 ab	70.37 a	2.07 ab	1.97 a
Second cropping	F	114.42 b	55.93 a	2.34 a	1.93 a
	F+20B	134.71 ab	57.50 a	2.29 a	2.13 a
	F+50B	124.30 ab	58.14 a	2.48 a	2.03 a
	F+100B	139.63 a	59.02 a	2.45 a	2.03 a
Source of variation					
Biochar (B)		**	ns	ns	ns
Cropping (C)		***	***	ns	ns
B × C		*	ns	ns	ns

Means followed by different lowercase letters within a column in the same cropping are significantly different $p < 0.05$ according to the Tukey test. *** Significant at $p < 0.001$; ** Significant at $p < 0.01$; * Significant at $p < 0.05$; ns, Non-significant.

The biochar rate showed a significant influence on the plant height with a significant interaction between biochar and cropping. However, there were no significant differences in the height of lowest capsule and 1000-seed weight and number of seeds per plant although a number of branches per plant and 1000-seed weight were higher compared to the control in the first and second cropping respectively. In comparison with the control (F), the plant height of the F+50B was non-significantly higher in the first cropping by 10.8% whereas the F+100B was significantly higher in the second cropping by 18.1%. There were no significant differences between control with F+20B and F+50B. The number of branches per plant in the first cropping were significantly increased by 42.7% in the F+50B treatment compared to the control that indicated biochar increased vegetative growth of the sesame. However, in the second cropping, this significant effect was not observed although the F+50B and F+100B treatments tended to have a greater number of branches per plant compared to the control and no significant interaction between biochar addition and cropping was observed.

The seed yield and a total number of seeds per plant of sesame affected by varying rates of biochar in the first and second cropping are shown in Figure 1.

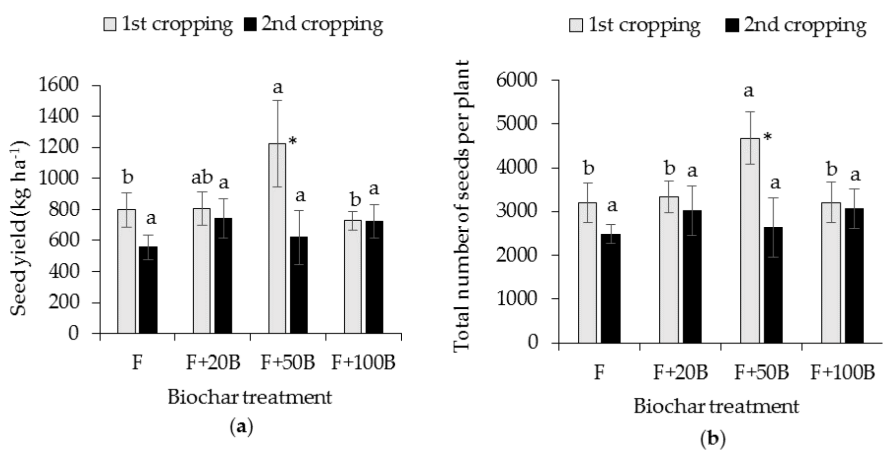

Figure 1. (**a**) The seed yield; (**b**) total number of seeds per plant as affected by rice husk biochar treatments. The bars represent the standard deviation of triplicates. Different lower case letters indicate significant difference ($p < 0.05$) among treatment means. * Significant difference ($p < 0.05$) between first and second cropping of the F+50B treatment.

The higher rate of biochar addition significantly improved the seed yield of sesame in the first cropping. In comparison with the control (797 kg ha^{-1}), the F+20B and F+50B treatments significantly increased seed yield by 0.9% and 35.0% (1226 kg ha^{-1}) whereas the F+100B significantly decreased seed yield by 9.4% (Figure 1a). However, there were no significant differences between control, F+20B and F+100B treatments. The increase in the seed yield was accompanied by an increase in the total number of seeds per plant (Figure 1b). The number of seeds per plant significantly increased by 31.7% in the F+50B treatments whereas there were no significant differences between the number of seeds per plant in the control, F+20B and F+100B although F+20B and F+100B increased by 2.4% and 0.2% respectively over the control. In the second cropping field, biochar addition did not significantly influence seed yield and the number of seeds per plant. However, the positive effects of biochar addition were observed. In comparison with the control, the seed yield of sesame in the second cropping increased in the F+20B, F+50B, F+100B treatments by 25.1%, 10.1% and 23.0% respectively. Similarly, the total number of seeds per plant non-significantly increased in the F+20B, F+50B, F+100B treatments by 17.6%, 5.5% and 19.1% respectively. In both the first and second cropping, the addition of biochar improved sesame yield with F+50B and F+20B showing higher seed yield compared to the control.

The analysis of variance indicated that the biochar rate did not exhibit statistically significant influences on both the seed yield and total number of seeds per plant while cropping exhibited a statistically significant ($p < 0.01$) influence and the interaction between the biochar rate and cropping was significant ($p < 0.01$). As the biochar addition increased, the sesame seed yield and number of seeds per plant increased and then decreased. A positive nonlinear relationship between the two cropping seed yields, plant height and biochar rates were observed (Figure 2). The determination coefficient (R^2) and the significance for the overall plant height were higher than that of seed yield indicating growth of sesame was significantly influenced more than seed yield.

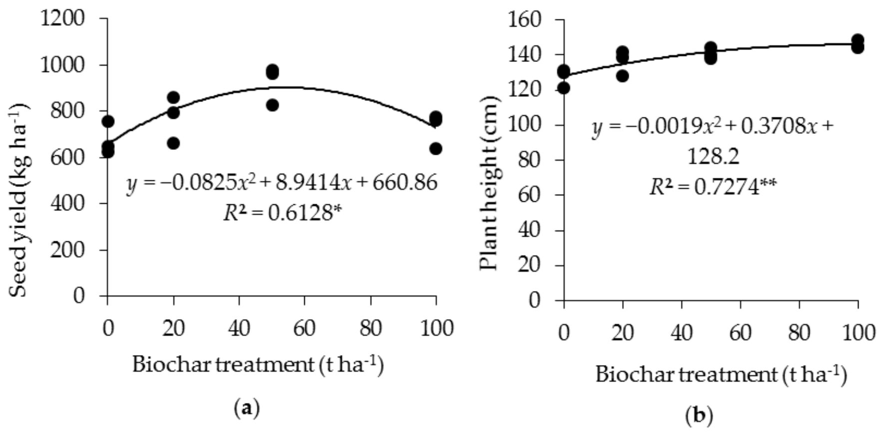

Figure 2. (**a**) The seed yield; (**b**) plant height response to rice husk biochar treatments. Relationships were fitted to first and second cropping data. * Significant at $p < 0.05$; ** Significant at $p < 0.01$.

The plant height showed a tendency to increase with the increasing rate of biochar without decreasing at high addition rates indicated by the nonlinear relationship. However, this increase in the plant height at the rate of biochar, above 100 t ha^{-1}, did not result into a significant increase in seed yield.

3.2. Effect of Rice Husk Biochar on the Leaf Tissue and Sesame Seed Nutrient Concentration

The leaf nutrient concentrations of sesame plants as affected by varying rates of biochar addition in the first and second cropping fields are shown in Table 2. The F+50B treatment significantly increased the leaf K concentration by 41.4% compared with the control in the first cropping and although there were no significant differences in leaf Mg concentration between control with biochar rates, the F+50B had a significantly higher leaf Mg than F+20B and F+100B in the first cropping. Biochar addition did not have a statistically significant effect on the leaf N, P and Ca concentrations in the first cropping. In the second cropping field, biochar addition did not have a statistically significant effect on any of the leaf nutrient concentrations. However, a non-significant increase in the N and K were observed compared to the control whereas leaf P increased in the F+20B, F+50B, but decreased in the F+100B. The leaf Ca and Mg concentrations were all non-significantly lower compared to the control.

Table 2. The leaf nutrient N, P, K, Ca and Mg of sesame under the different biochar treatments in different cropping.

Cropping	Biochar Rate	N (%)	K (%)	P (%)	Ca (%)	Mg (%)
First cropping	F	2.79 a	2.89 b	0.70 a	1.72 a	0.36 ab
	F+20B	2.99 a	3.10 ab	0.68 a	1.66 a	0.33 b
	F+50B	3.26 a	4.94 a	0.71 a	1.98 a	0.49 a
	F+100B	3.31 a	3.46 ab	0.67 a	1.58 a	0.32 b
Second cropping	F	2.91 a	2.41 a	0.44 a	1.53 a	0.35 a
	F+20B	3.04 a	2.69 a	0.49 a	1.47 a	0.34 a
	F+50B	3.15 a	2.75 a	0.51 a	1.46 a	0.32 a
	F+100B	3.11 a	2.49 a	0.44 a	1.33 a	0.30 a
Source of variation						
Biochar (B)		ns	**	ns	ns	*
Cropping (C)		ns	***	*	ns	*
B × C		ns	ns	ns	ns	*

Means followed by different lowercase letters within a column in the same cropping are significantly different $p < 0.05$ according to the Tukey test. *** Significant at $p < 0.001$; ** Significant at $p < 0.01$; * Significant at $p < 0.05$; ns, Non-significant.

The analysis of variance indicated that the biochar rate ($p < 0.01$) and cropping ($p < 0.001$) exhibited statistically significant influences on the concentration of leaf K, but no significant interaction whereas leaf Mg indicated significant ($p < 0.05$) interaction between biochar rates and cropping. The concentration of leaf P, Mg and K were significantly decreased by in the second cropping compared with first cropping irrespective of biochar addition.

The crude protein and mineral nutrient contents of sesame seed affected by varying rates of biochar addition in the first and second cropping fields are shown in Table 3.

The higher rates of biochar addition except in the F+100B, improved the crude protein, P, K, and Ca in the first cropping. However, there were no significant differences between biochar rates and control in the crude protein, P, Ca and Mg in first cropping. In comparison with control, the F+50B and F+100B treatments significantly increased the seed K content by 12.1% and 10.7% respectively whereas there was no significant difference between F+20B and control in the first cropping. However, no significant effect of biochar addition on seed K was observed in the second cropping. Biochar addition in the second cropping field significantly improved the crude protein content of sesame seeds. The crude protein of the F+50B and F+100B treatments were significantly higher than that of the control by 10.9% and 9.6%, respectively, whereas there were no significant differences between the F+20B treatment and control although an increase by 7.4% occurred in the F+20B compared with control. In the second cropping, biochar addition did not have a statistically significant effect on the seed P, K, Ca and Mg. The analysis of variance indicated that the biochar rate ($p < 0.01$) exhibited statistically significant influences on the seed K content, but no significant interaction between biochar rates and cropping. The content of seed crude protein, P, Ca and Mg were not significantly influenced by either biochar rates or cropping.

3.3. Effect of Biochar on Soil Physico-Chemical Properties in First and Second Cropping Fields

The soil physical properties of bulk density and porosity as affected by varying rates of biochar addition in the first and second cropping fields are shown in Figure 3. Biochar addition in the first and second cropping fields significantly decreased soil bulk density with increasing rates of biochar.

The F+100B treatments significantly decreased bulk density to 0.76 g cm^{-3} compared to the control (1.09 g cm^{-3}) in the first cropping and to 1.01 g cm^{-3} from 1.15 g cm^{-3} in the control of the second cropping field (Figure 3a).

Table 3. The seed macronutrient mineral nutrient contents of sesame seeds under the different biochar treatments in different cropping after harvesting.

Cropping	Biochar Rate	Crude Protein (%)	mg/100 g Seed			
			P	K	Ca	Mg
First cropping	F	20.0 a	612.6 a	744.7 b	1222.2 a	419.0 a
	F+20B	19.8 a	640.7 a	794.9 ab	1275.6 a	416.2 a
	F+50B	20.6 a	636.6 a	846.7 a	1321.5 a	409.6 a
	F+100B	19.1 a	617.6 a	833.8 a	1280.8 a	403.2 a
Second cropping	F	18.9b	560.6 a	820.9 a	1252.2 a	396.9 a
	F+20B	20.4 ab	640.7 a	794.6 a	1419.7 a	398.7 a
	F+50B	21.2 a	617.3 a	857.6 a	1315.5 a	389.8 a
	F+100B	20.9 a	608.9 a	859.0 a	1382.3 a	422.4 a
Source of variation						
Biochar (B)		ns	ns	**	ns	ns
Cropping (C)		ns	ns	ns	ns	ns
B × C		ns	ns	ns	ns	ns

Means followed by different lowercase letters within a column in the same cropping are significantly different $p < 0.05$ according to the Tukey test. ** Significant at $p < 0.01$; ns, Non-significant.

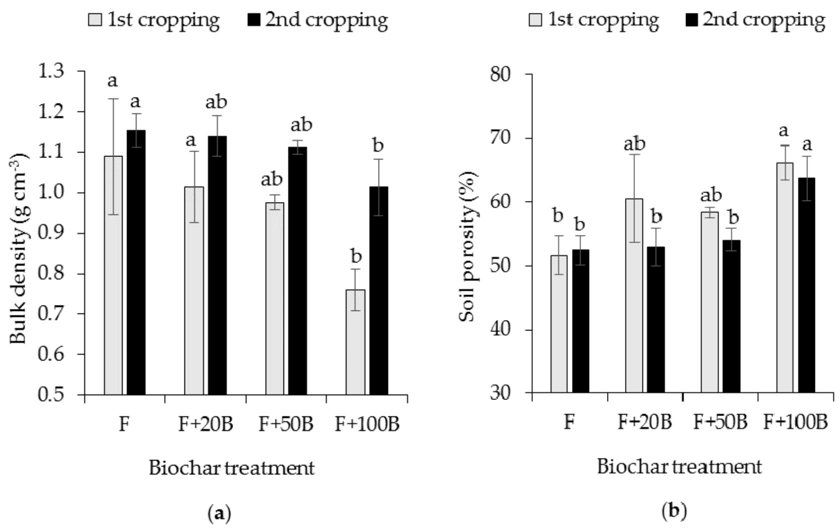

Figure 3. (**a**) The soil bulk density; (**b**) and soil porosity as affected by rice husk biochar treatments. The bars represent the standard deviation of triplicates. Different letters indicate significant difference ($p < 0.05$) among treatment means.

Similarly, the F+100B treatments significantly increased soil porosity to 66.1% compared to the control (51.6%) in the first cropping and to 63.7% from 52.4% in the control of the second cropping field (Figure 3b). In both the first and second cropping, the addition of biochar improved the physical property of the soil with higher rates of biochar addition. The analysis of variance indicated that the biochar rate exhibited statistically significant influences on both the soil bulk density ($p < 0.001$) and porosity ($p < 0.001$) (Table 4). Although the cropping had a significant influence on soil bulk density ($p < 0.001$) and porosity ($p < 0.05$), there were no significant interactions between the biochar rate and cropping.

Table 4. The soil chemical properties of sesame under the different biochar treatments in different cropping after harvesting.

Cropping	Biochar Rate	pH	EC (dSm^{-1})	TN (g kg^{-1})	C/N	P (mg kg^{-1})	CEC (cmol$_c$ kg^{-1})	Exchangeable Cations		
								K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})
First cropping	F	5.65 b	0.10 ab	2.40 a	10.1 c	13.3 a	9.9 b	190.7 c	3272.2 a	281.6 a
	F+20B	5.52 b	0.18 a	2.40 a	14.4 bc	46.4 a	12.3 ab	292.6 bc	3303.7 a	250.0 ab
	F+50B	5.97 ab	0.09 b	2.60 a	25.1 b	20.9 a	12.5 ab	408.0 b	2217.1 a	224.6 ab
	F+100B	6.38 a	0.12 ab	2.89 a	50.6 a	31.2 a	14.5 a	686.1 a	1683.5 a	198.1 b
Second cropping	F	5.54 a	0.08 b	2.09 b	10.3 c	40.2 a	11.5 b	179.5 b	3213.1 a	248.7 a
	F+20B	5.84 a	0.08 b	2.18 ab	15.6 bc	19.1 a	13.2 ab	158.8 b	1326.6 a	215.8 a
	F+50B	5.49 a	0.20 a	2.29 ab	19.1 b	36.9 a	12.9 ab	447.4 a	2575.9 a	244.7 a
	F+100B	5.68 a	0.09 b	2.53 a	31.4 a	33.5 a	14.3 a	386.6 a	1767.3 a	215.8 a
Source of variation										
Biochar (B)		ns	*	*	***	ns	***	***	ns	*
Cropping (C)		ns	ns	**	**	ns	ns	**	ns	ns
B × C		ns	***	ns	**	ns	ns	**	ns	ns

Means followed by different lowercase letters within a column in the same cropping are significantly different $p < 0.05$ according to the Tukey test. *** Significant at $p < 0.001$; ** Significant at $p < 0.01$; * Significant at $p < 0.05$; ns, Non-significant.

The soil chemical properties affected by varying rates of biochar addition in the first and second cropping fields are shown in Table 4.

Biochar addition in the first cropping significantly increased soil pH, EC, C/N ratio, exchangeable K and soil cation exchange capacity (CEC) compared to the control while the soil exchangeable Mg was significantly decreased. The F+100B treatment significantly increased soil pH by 0.73 units compared to the control (5.65) whereas the soil EC of the F+20B and F+50B were significantly different while of the control was not statically different from F+100B treatment. The C/N ratio significantly increased with increasing biochar rates by 4.3, 15.0 and 40.5 in the F+20B, F+50B and F+100B treatments respectively which indicated high carbon content in the soil with biochar treatments. The biochar addition significantly increased the soil exchangeable K with increasing rates of biochar treatments. The exchangeable K significantly increased by 101.9, 217.3 and 495.4 mg kg^{-1} in the F+20B, F+50B and F+100B respectively. Conversely, the exchangeable Mg significantly decreased by 31.55, 57.0 and 83.5 mg kg^{-1} in the F+20B, F+50B and F+100B respectively. However, there were no significant differences between the F+20B and F+50B treatments. The higher rates of biochar addition improved the soil CEC. The F+100B treatment significantly increased the CEC by 4.7 $cmol_c$ kg^{-1} compared to the control. In the first cropping, there were no significant effect of biochar addition on the available P and exchangeable Ca. However, these parameters showed higher values in the biochar addition treatments compared with the control, except exchangeable Ca which tended to decrease in the F+50B and F+100B treatments.

In the second cropping field, the addition of biochar significantly influenced soil EC, total N, C/N ratio, exchangeable K, and CEC whereas biochar did not show a significant effect on the soil pH, available P, exchangeable Ca or Mg. The F+50B treatment significantly increased soil EC by 0.12 dSm^{-1} compared to the control and no obvious significant differences were observed between the control, F+20B and F+100B treatments. The total N and C/N ratio significantly increased with increasing biochar rates and the in the F+100B treatments were significantly higher by 0.4 g kg^{-1} and 21.0 for total N and C/N ratio respectively when compared with control. The F+50B and F+100B treatments significantly increased exchangeable K by 267.9 and 207.1 mg kg^{-1} compared with the control. However, there was no significant difference between control and F+20B treatment. Similar to the first cropping, the higher rates of biochar addition improved the soil CEC. The F+100B treatment significantly increased the CEC by 0.23 $cmol_c$ kg^{-1} compared to the control.

In the second cropping, there was no obvious significant effect of biochar addition on the soil pH, available P and exchangeable Ca and Mg. However available P, exchangeable Ca and Mg were non-significantly decreased in the biochar addition treatments compared to the control. The analysis of variance indicated that the biochar rate exhibited statistically significant influences on EC, total N, C/N ratio, exchangeable K and Mg, and CEC whereas cropping significantly influenced total N, C/N ratio and exchangeable K (Table 4). There were also significant interactions between biochar rates and cropping for EC, C/N ratio, and exchangeable K that indicated an improvement of continuous cropping soil with biochar.

4. Discussion

4.1. Effect of Biochar on Soil Physico-Chemical Properties in First and Second Cropping Fields

Biochar additions significantly improved the soil physical properties of bulk density and porosity in both first and second cropping fields. A similar finding was reported in sesame that rice husk and saw dust biochar application at 10 t ha^{-1} significantly increased soil porosity and decreased the bulk density of a highly leached acidic Ultisol soil [36]. The increase in soil porosity and decrease in bulk density after biochar addition allow easy root penetration for water and nutrient absorption as a result of increased water holding capacity and reduced tensile strength of the soil [14–16]. This increase in soil porosity and decrease in bulk density is attributed to the low particle density and high porosity of the rice husk biochar compared with soil which enables the soil to hold more water and air [44].

In our study, the rice husk biochar used had a low bulk density of 0.29 g cm^{-3} which therefore greatly increased the soil porosity and decreased the soil bulk density after biochar addition on the upland field converted paddy soil. In addition, decreasing the bulk density and increasing soil porosity by biochar addition is important in the second cropping since continuous cropping results into a deterioration in the soil physical quality [45]. This suggests the integration of rice husk biochar in continuous cropping systems would improve soil conditions and overall crop performance.

Furthermore, biochar addition in the first cropping significantly increased soil pH with increasing rates of the rice husk biochar. Our result agrees with other findings that biochar addition increased soil pH [46,47]. Therefore, with rice husk biochar addition to slightly acidic upland field converted from paddy, the acidity would gradually be decreased due to the liming effect of the biochar. Rice husk biochar has been reported to increase soil pH of tea garden soil (acidic soil) from 3.33 to 3.63 [47]. In our study, increase in soil pH could be due to the alkaline nature of the biochar used since the rice husk biochar had a pH of 10.47 besides its high ash content (38.04%). The ash content of biochar plays important role in increasing soil pH and consequently determines the soil CEC [48]. This positive effect on soil pH was only observed in the first cropping. Our study showed that biochar in the second cropping did not have a significant effect on the soil pH. The pH of the control did not significantly differ from the biochar treatments in the second cropping. The addition of dolomite to increase soil pH and alleviate acidity in the second cropping possibly affected biochar liming effect. Whereas the biochar had a liming effect in the first cropping, this effect could have been offset by the addition of dolomite in the second cropping. This suggested that addition of both dolomite and biochar may not be good and could lead to loss of functional properties of biochar in the subsequent cropping although this hypothesis remains untested. However, Cornelissen et al. [30] reported that rice husk biochar addition on acidic Ultisol soil of Indonesia showed a less pronounced effect on the soil pH as the cropping season increased due to decreasing liming potential, which also agrees with our result. In addition to pH, biochar addition showed tendency to increase soil EC especially in the second cropping that could be attributed to the highly soluble minerals contained in the rice husk biochar that was readily added into the soil.

Although biochar addition significantly increased the soil total N and C/N ratio, possibly N immobilization occurred with increasing biochar rates. Similar findings have been reported that with biochar addition indicating an increase in the soil total C from 2.27% to 2.78% and total N from 0.24% to 0.25% [11]. In addition, research indicates that microbial immobilization of N with a C/N ratio of biochar above 16 occurs [46,49]. Furthermore, an increase in the soil total N, added from the rice husk biochar may not indicate N availability to plants and microbes [50]. Hence, the increase in the C/N ratio with increasing rates of biochar in both the first and second cropping could possibly be high enough to immobilize N thereby limiting N availability to sesame plant. The non-significant effect on soil available P and exchangeable Ca suggested the rice husk biochar had little ability to supply these nutrients. Possibly, the high Ca and P in the biochar was insoluble and remained in its micro-porous fabric of the biochar [51]. Limwikran et al. [51] reported that rice husk biochar could not readily release Ca into soil thus acted as a sink rather than a source for exchangeable Ca.

On the other hand, the biochar addition significantly increased the soil exchangeable K with increasing rates of biochar treatments whereas exchangeable Ca and Mg tended to decrease although not significantly different between biochar rates. This is contrary to Wang et al. [48] and Carter et al. [35] who reported the increase in the exchangeable cations Ca, Mg and K with rice husk biochar addition. In our study, only exchangeable K was significantly increased with increasing biochar rates. Wang et al. [47] reported that with biochar application, K levels in soil increased from 42 to 324 mg kg^{-1}. The rice husk biochar used had an ash content of 38.04% that was very high to increase soil K content in the soil. A similar increase in the exchangeable K was observed and attributed to high ash content in rice husk biochar and being a source of K itself (3640.73 mg kg^{-1} K in the rice husk biochar used) [12,52]. This increased exchangeable K with biochar addition could also be due to the increased soil pH which enhances release K into the soil [53]. Due to the increase in soil K, rice husk biochar could enhance crop growth and yield, including sesame on soils where K is a limiting factor.

Our study also showed that the higher rates of biochar addition improved the soil CEC which agrees with the findings of Ndor et al. [36] who reported increased CEC with rice husk and saw dust biochar in sesame cultivation. The biochar addition on a strongly acidic soil decreased in soil acidity through an increase in pH and the increasing the soil CEC thereby retaining nutrients into the soil for sesame [36]. In our study, the observed increase in the soil pH due to biochar addition and the rice husk biochar CEC (7.53 $cmol_c$ kg^{-1}) itself could also have increased the soil CEC. The increase in soil CEC levels is in agreements with findings of Laird et al. [54] who reported that biochar treatment increased soil CEC from by 4 to 30% more than the control while Jien and Wang [55] reported the CEC of a highly weathered soil was raised from 7.41 to 10.8 $cmol_c$ kg^{-1} after biochar application. In our study, the increase in the soil CEC is the indicator of nutrient retention suggesting that rice husk biochar could improve soil nutrient status in continuous cropping as observed in the second cropping. Similar results have shown that rice husk biochar addition to acid sulfate soils in Indonesia has been reported to increase CEC, in addition to improving soil porosity and exchangeable K [56]. Therefore, our result suggests that cultivation of sesame with rice husk biochar could improve not only soil physical properties promoting proper plant growth, but also hold sufficient nutrients through an increase in CEC upland fields converted paddy soils.

4.2. Effect of Rice Husk Biochar on the Leaf Tissue and Sesame Seed Nutrient Concentration

Biochar addition did not have a significant effect on leaf tissue N, P and Ca concentration and their contents in the sesame seeds. Overall, biochar addition had a significant influence on the leaf tissue K and Mg concentration of, and content of the seeds. Our result agrees with other findings, including a meta-analysis from different studies that biochar addition had no significant effect on plant tissue N and P concentrations whereas it increased the K tissue concentration [50,57]. Although the overall effect of biochar addition was not significant on crude protein, a significant increase in the crude protein content was observed in the second cropping suggesting an increase in protein synthesis in sesame. This could be attributed to the adequate supply of soil K from biochar allowing increased plant tissue K concentration. Potassium, K is an important nutrient that plays a significant role in protein synthesis in plants [58]. Hence, adequate supply of K from the rice husk biochar could enhance protein quality of sesame seeds. In addition, the increase in the crude protein content could be attributed to the slight increase in soil total N with biochar compared to the control in the second cropping. A similar finding shows that biochar addition (from acacia) of up to 50 t ha^{-1} in maize cropping system increased maize grain protein by 13% compared without biochar [26]. Therefore, it could be speculated that the protein content of sesame is increased with rice husk biochar addition although leaf tissue N concentration did not show statistical significance.

Biochar addition significantly increased leaf tissue K concentration and K content in the sesame seeds especially in the first cropping attributed to the high K content in the rice husk biochar reflected in the higher soil exchangeable K compared to the control. The soil K concentration in the 50 t ha^{-1} was twice the value in the control whereas it tripled in the 100 t ha^{-1} compared to control suggesting the rice husk biochar could possibly replace the 70 kg K_2O ha^{-1} inorganic fertilizer rate supplied to sesame in this study as a K source. A meta-analysis of several pieces of research shows that biochar addition treatments performed better than fertilizer at increasing plant tissue K concentration [50]. Hence, rice husk biochar with a high K content could be an alternative source of K fertilizers for sesame especially for resource poor farmers. Conversely, the leaf tissue Mg concentration tended to decrease compared to the control in the first cropping indicating that increasing biochar rates and cropping, the leaf tissue Mg concentration of sesame is significantly decreased that could influence seed yield at high rates of biochar addition. The content of Mg in the sesame seeds with biochar addition was also non-significantly lower than the control indicating the negative effect of high increasing rates of biochar addition on the sesame seed quality. Koyama and Hayashi [59] also found a similar decrease in the Mg concentrations in rice straw tissue with an increase in rice husk biochar addition rate up to 2 kg m^{-2} (equivalent to 20 t ha^{-1}). Our result also agrees Syuhada et al. [60] who found out that biochar addition at 10 and 15 g kg^{-1} from oil palm feedstock applied on to podsol soils significantly increased concentration and uptake of K while decreasing the Mg concentration in maize tissue. They attributed the low uptake of Mg to competitive ion effect between the uptakes of Mg and K. Although we did not measure the dry matter yield, the increased nutrient concentrations of K also implies high uptake of K since nutrient uptake is governed by the concentration of nutrients in plant tissues and the dry matter yield. Usually competitive ion effect occurs when there is a high concentration and uptake of K in plant tissue which decreases the concentration and uptake of Mg [61–63]. Major et al. [12] also found a similar decrease in the concentration of Mg in maize seeds in high wood biochar addition treatments (8 and 20 t ha^{-1}) attributed to declining stock of Mg in the soil due to this ion competition effect. In our study, the F+50B treatment significantly increased the leaf tissue K concentration by 41.4% compared with the control and increased seed K content by 12.1% in the first cropping, whereas Mg content in the seeds non-significantly decreased by 0.7%, 2.3% and 3.9% in the biochar addition of F+20B, F+50B and F+100B respectively. Therefore, the competitive ion effect is likely to occur when higher rates of the rice husk biochar with a high content of K is applied in sesame due to luxury consumption and decreased uptake of Mg. This could negatively affect yield and mineral quality of sesame.

4.3. Effect of Rice Husk Biochar on the Growth and Yield Components of Sesame

Biochar addition increased the overall sesame yield compared with the control that was consistent with Ndor et al. [36] who reported significant increase in the seed yield of sesame to 925 kg ha^{-1} in the 10 t ha^{-1} rice husk and sawdust biochar compared with the 595 kg ha^{-1} in the control in a field experiment. In particular, the yield increase with biochar addition, in the first cropping, suggested that sesame positively responds to biochar. In addition, 10 t ha^{-1} of coconut shell biochar added together with chicken manure to sesame resulted into higher seed weight per plant than the control on a sandy coastal soil [38]. In our study, the 50 t ha^{-1} (35.0% increase over control) in the first cropping significantly increased the sesame seed yield that could be attributed to increased number of seeds per plant rather than increase in the seed weight since there was no significant increase in the 1000-seed weight with biochar addition. The significant increase in the number of branches per plant with the biochar treatments in the first cropping could explain the increase in the total number of seeds per plant consequently increasing sesame yield. A similar increase in the number of branches per plant was reported that increased the seed yield of rapeseed (*Brassica napus* L.) with biochar addition [64]. In the second cropping, the F+20B (20 t ha^{-1}) non-significantly increased seed yield by 25.1% compared with control. The non-significant differences between the biochar treatments in the second cropping could be attributed to loss in the functional properties of the biochar although the seed yield increased in the 20 t ha^{-1}. This finding agrees with the recent report that rice husk biochar on acidic Ultisol soil of Indonesia at 15 t ha^{-1} significantly increased maize yield only in the first season, but the effect faded from the second season onwards [30].

The biochar addition also significantly increased sesame plant height in both the first and second cropping; and that could possibly explain the increase in the seed yield. It has been reported that poultry litter biochar at an optimal rate of 11.21 g kg^{-1} (equivalent to 22.4 t ha^{-1}) significantly increased sesame plant height [35], which is consistent with our results. The increase in the seed yield and plant height at 50 t ha^{-1} of rice husk biochar for sesame cropping on upland field converted paddy is consistent with other researchers who applied high biochar rates and obtained good crop performance [24,65]. Haefele et al. [24] reported that rice husk biochar applied at 4.13 kg m^{-2} (equivalent to 41.3 t ha^{-1}) in on Humic nitisols (pH 4.3) increased grain yield of rice by 16–35% at Sinilioan Phillipines whereas Schulz et al. [65] observed increased growth of oat plants with addition of 100 t ha^{-1} of composted biochar to sandy and loamy soil. Several pieces of field research indicated that biochar addition increased crop growth and yield [12,13]. For instance, cultivation on sandy soils using biochar increased maize yield by 150% and 98% over the control at rates of 15 t ha^{-1} and 20 t ha^{-1} respectively [23]. Zhang et al. [25] also reported an increase in rice yields of 14% over control in paddy soils with wheat straw biochar rate of 40 t ha^{-1}. However, the highest rate of 100 t ha^{-1} tended to have a negative effect on sesame in our study, which is consistent with the finding of Chan et al. [14]. The decrease in the seed yield in the 100 t ha^{-1} compared to 50 t ha^{-1} suggested the biochar addition rate had exceeded the beneficial amount. At this rate, the possible release of toxic substances like heavy metals and polycyclic aromatic hydrocarbons (PAHs) from biochar could have suppressed plant growth [66]. In addition, the low yield in the 100 t ha^{-1} is likely as a result of nutrient imbalances and N immobilization [67,68]. The decrease in the seed yield at 100 t ha^{-1} could be partly explained by the increased adsorption of available inorganic N at this high biochar addition rate. For instance, research shows that biochar addition improves the retention capacity of NH_4^+-N through enhanced CEC [69]. In our study, the increased CEC could have increased ammonium adsorption in the first cropping with 100 t ha^{-1} rice husk biochar rate. However, the adsorption of inorganic N onto biochar surfaces could decrease ammonia and nitrate losses from soil, but could as well potentially lead to the slow release of these nutrients to plants [70].

Although, the leaf tissue N concentration tended to increase non-significantly with biochar rates in the first cropping, the increase in growth and yield could be entirely attributed to an increase in the leaf tissue K concentration in sesame plant. Our study agrees with a meta-analysis of biochar research showing that biochar addition treatments performed better than fertilizer at increasing plant tissue K concentration and plant tissue N is unaffected by biochar addition thereby influencing yield [50]. On the other hand, our results indicated that leaf K concentration was significantly reduced by continuous cropping, but with the biochar addition, the concentration of K significantly increases. Therefore, the higher seed yield, number of seeds per plant and plant height compared to the control in the second cropping is attributed to this increased leaf K suggesting seed yield decline under continuous cropping could be recovered by adding more K fertilizer. This also suggests future research should consider comparing and contrasting biochar addition with more K fertilizer rates for sesame cropping. The increased seed yield was due to this increased K concentration due to the rice husk biochar addition. Moreover, the leaf tissue K concentration was above the adequate level of 2.4% required for sesame growth since K plays a significant role in increasing the internodes lengths consequently increase in sesame plant height [43]. However, the lower leaf tissue K concentrations in the second than first cropping accompanied by the low soil exchangeable K suggested a decrease in availability of K could have led to the lack of positive effect of rice husk biochar rates on sesame yield in the second cropping. Similar effects of lack of positive effect of biochar on crop yields have been attributed to decreasing nutrient contents in biochar addition after its addition [31]. This could suggest that the benefit of K addition from rice husk biochar could decrease over time affecting sesame yield. Therefore, the lack of non-significant effect on leaf tissue K concentration in the second cropping suggested K was the most determinant factor on growth and seed yield.

Furthermore, the non-significant effect on K concentration in sesame in combination with factors that affected the rice husk biochar properties in the second cropping could have contributed to low yields in the second cropping. For instance, the first cropping field had fresh biochar applied whereas the second cropping field had old biochar that could have influenced sesame yield due to biochar aging effect on the temperate soil. The meta-analyses by Biederman and Harpole [50] shows that the effect of biochar addition is less pronounced on temperate climate soils and freshly added biochar could perform better than the old or aged biochar. In our study, the seed yield did not show significant differences between biochar rates in the second cropping which also agrees with Persaud et al. [67] who reported no beneficial effect of rice husk biochar in on yield in the second cropping. The authors observed increase in above ground biomass of pak choy (*Brassica rapa* subsp. *chinensis*) by 32.81% in the 25 t ha^{-1} application rate (0, 5, 25 and 50 t ha^{-1}) to acidic Tabela sandy soil of Guyana in the first cropping compared with the control and attributed to increasing soil pH, exchangeable cations, CEC, and decrease in soil bulk density that is also consistent with our results. Therefore, improvement in the soil chemical properties and physical properties by the rice husk biochar enhanced sesame productivity especially in the first cropping. However, these benefits could deteriorate with an increase in the number of cropping as the biochar becomes old. For instance, changes in the physico-chemical properties as a result of aging when incorporated into the soil have been reported [71]. In our study, the porosity tended to decrease in the second cycle suggesting biochar particles had been crushed or broken down as a result of continuous cropping during tillage operation. The particles of biochar may also break and become smaller with time due to the physical interaction with drainage water [72]. With tillage, the particles could have been degraded and the ashes contents of the biochar increased leading to easy leaching in drainage water affecting soil pH that depends on the ash content. Thus, the lack of significant effect of the rice husk biochar in the second cropping could partly be due to leaching of the alkaline ashes [73,74]. Furthermore, the no effect on the second cycle could be attributed to the loss in the properties of biochar to adsorption and immobilization of heavy metals, polycyclic aromatic hydrocarbons (PAHs), phthalates etc. from the soil [75]. A study found that fresh rice husk biochar had a higher adsorption capacity for toxic compounds than aged one [76]. In addition, rice husk biochar addition up to 30 t ha^{-1} is reported to have a high affinity to removed cadmium from aqueous solutions when mixed in soil, attributed to high surface charge (net negative charge) of the bio-sorbents, thereby eliminating inhibition effect of cadmium (Cd^{2+}) on plant growth and improve yield [77]. Therefore, the fresh biochar as observed in the first cropping could have absorbed toxic heavy metals and other compounds that would hinder sesame growth and yield. The decrease in ability to increase pH, adsorb potential heavy metals, and overall changes in the physical properties of the rice husk biochar could be possible factors that led to the low yield in the second cropping.

Nonetheless, the rice husk biochar addition to sesame improved growth and yield at increasing rates; it could be recommended to apply rates not exceeding 50 t ha^{-1}. Although sesame is considered a high value oilseed crop, higher rates than 50 t ha^{-1} are not economically feasible under field conditions. The higher biochar rates are not economically feasible in most farming systems due to high costs [78,79]. Given the temperate climate where soils have favorable properties for plant production than tropical soils, large quantities of biochar may be required to achieve significant positive effects on yield as observed in this study [68]. However, further studies are needed to determine the optimal rice husk biochar rate while considering the cost and benefits of sesame cultivation on upland fields converted paddy.

5. Conclusions

The results demonstrated that sesame seed yield, plant growth and mineral content are improved with the biochar addition on upland field converted paddy. The biochar addition increased plant height with significant interaction in both cropping fields whereas the seed yield was only significantly influenced in the first cropping. The higher rate of biochar addition significantly improved the seed yield of sesame in the first cropping whereas in the second cropping field, biochar addition did not significantly influence seed yield and the number of seeds per plant. Among the seed mineral nutrients, K content was most increased by biochar. The overall improvement in the sesame growth, seed yield and mineral contents especially K was attributed to mainly increased K availability, soil pH, CEC, improved porosity and bulk density. Our study also suggests that rice husk biochar addition may not have a long lasting effect on sesame yield on upland field converted paddy since the positive effect of biochar tended to fade in the second cropping as its biochar aged suggesting one-time application would not be sufficient. However, further investigations are still required to clarify the non-significant influence of biochar addition on seed yield and growth of sesame in the second cropping when biochar had been incorporated in the first cropping to uncover the mechanisms underlying these processes with biochar addition in long-term field trials.

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supervised the research and contributed in the discussion of the results; C.W. wrote the paper; E.N. revised the final draft manuscript.

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