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Effects of biochar produced from rice straw and oil cake on soil nutrients, growth, yield and nutrient content of wheat (*Triticum aestivum L.*)

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Abstract

A pot experiment was conducted to assess the comparative effects of biochar and conventional inorganic NPK fertilizers on wheat growth and nutrient content as well as certain soil chemical and nutritional properties. Biochar produced from oil cake and rice straw were mixed with soils at rates of 0, 1, 2, 3, 4 and 5% (w/w) and inorganic NPK fertilizer was also mixed separately with soils at rates of 0, ¼, ½, ¾ and 1 of the recommended rate. Biochar increased the fresh weight and dry weight of wheat plant parts significantly. The root biomass and grain yield with oil cake biochar (OCB) were relatively higher than with rice straw biochar (RSB). Biochar application at a 4-5% rate produced maximum wheat root, straw and grain yield which were comparable to the recommended inorganic 1 NPK rate. The study revealed that oil cake biochar (OCB) was more effective in increasing soil organic carbon (OC), whereas rice straw biochar (RSB) was found to be more effective in raising soil pH, soil electrical conductivity (EC) and decreasing soil exchangeable acidity. A similar effect on soil cation exchange capacity (CEC) was also observed with both types of biochar. The soil available ammonium N (NH_4^+-N), Olsen P and K content increased with increasing rates of both biochar and inorganic NPK in soils after the harvest of plants. Applying biochar at a rate of 5% resulted in the highest effect on the soil's chemical and nutritional properties. Maximum N, P and K concentrations in wheat root, straw and grain were found at 4-5% biochar rates, which were significantly higher than inorganic NPK fertilizer rates.

Keywords

biochar; inorganic fertilizer; nutrient; sustainable amendments; wheat

Introduction

Agriculture in Bangladesh is largely dependent on inorganic chemical fertilizers, leading to soil acidification, compaction, water eutrophication, greenhouse gas emissions and various other environmental concerns (1). Another significant threat to global food safety is the decline in organic matter (OM) content in agricultural soils which is an important component influencing soil health. Worldwide, the application of organic matter from plant and animal sources to soils has been obviously linked to better soil health and plant growth response, especially in tropical agricultural soils with relatively lower OM contents (2). However, the fundamental restriction in employing such organic matter is its ease of decomposition, thus its application must be repeated year after year for long-term soil fertility management (3).

Biochar has recently received a lot of interest in agricultural applications because of its good physical and chemical qualities (4). Biochar is a carbon-rich solid material formed by heating biomass, such as wood, manure or crop residues, in a closed space with little to no airflow (5). It is generated by pyrolysis (thermal decomposition) of plant and animal biomaterials at temperatures below 700 °C in oxygen (O_2)-limited circumstances for use as a soil supplement (4). During the pyrolysis, the carbon in organic matter is stabilised and it increases its resistance to chemical and biological breakdown enabling it to stay stable in the soil for extended periods of time and not being emitted into the atmosphere as would be the case with biomass decomposition (6). Farmers acknowledge biochar for its potential to lower soil density, improve soil porosity and water retention and enhance nutrient management (7). In addition, biochar increases base saturation, decreases nitrate levels in the soil, inhibits acidification and creates the conditions for increased microbial activity (8). Biochar has been found to increase total crop production by 2-3 times (9), while also capturing gigatons of carbon from the atmosphere, lowering greenhouse gas emissions, reversing soil degradation and offering other advantages (10).

Applying biochar to the soil may promote plant growth and biomass production by enhancing the cation exchange capacity (CEC), retention of accessible nutrients in the soil and availability of essential plant nutrients (11). The use of biochar improves soil chemistry, stabilises pH, electrical conductivity (EC) and other characteristics, increases water-holding capacity and absorbs toxic substances to help restore wastelands and barren areas, all of which are beneficial to plant development (12). However, the degree to which biochar enhances plant development and soil properties and functions may depend on a variety of factors, including the kind and rate of biochar application, soil types, climate and others (13). One of the most beneficial attributes of biochar is its water retention capacity in soil. It could have a greater influence on the water-holding capacity of sandy soils than that of silty and loamy soils, which can be attributed to the porous structure of biochar (14). Substantial public funding has been invested worldwide to achieve the targeted aims of using biochar. Algae are currently being considered as a suitable feedstock for biochar. However, under the present economic conditions of Central Europe, the production cost of algae biochar is several 100 times higher than the cost of conventional biochar terrestrial plants and biowaste. To gain social acceptance, it is suggested that efforts focus on improving the cost-effectiveness of algae biochar (15).

For Bangladesh, biochar may be a preferable option in terms of soil health and sustainable agriculture. Although biochar has been the focus of much research worldwide over the last ten years, Bangladesh has seen very few biochar-related studies. Bangladesh has the capacity to generate biochar to address these issues because of the abundance of biomass that is available (16). We employed 2 different forms of biochar made from mustard oil cake and rice straw in this investigation. Therefore, the selection of these unprocessed biomaterial sources was predicated upon their nutritional makeup. The nutritional makeup of oil cake and rice straw differs. Compared to rice straw (i.e., <1% N, 0.1% P and >1% K) (17), the oil cake has comparatively greater N and P contents (i.e., 5% N, 1% P and 1% K) (18), but lower K levels. However, rice straw and oil cake are potentially appealing biomaterials in the process of creating biochar for soil amendment, given the abundance and accessibility of raw biomaterials. The goal of the current study was to measure how different rates of applying mineral fertilizer and biochar separately affected crop growth, nutrition and soil qualities in pot settings at Bangladesh's Chittagong University. Drawing from prior research, our hypothesis was that the use of biochar can enhance crop growth, yield and nutrient content by altering the physical, chemical and nutritional characteristics of the soil. This study set out to investigate 3 specific goals: (i) to see how biochar affected wheat growth, yield and nutrition; (ii) to see how biochar affected certain chemical and nutritional aspects of the soil; and (iii) to compare the impacts of biochar with inorganic NPK fertilizers. A research hypothesis formulates that the additions of biochar could improve plant growth and soil properties.

Materials and Methods

Preparation of experimental materials

Oil cake and rice straw were collected from local sources and were air-dried to reduce excess moisture. Biochar was produced by using a two-barrel stacked retort technique (19). The pyrolysis temperature was in the range of 350–450 °C. The biochar was ground and then run through a 2 mm sieve. Surface soil (Aquept) of the Pahartali series was collected from a fallow area to minimize the impact of previous fertilizer applications. The collected soils were ground and put through a 4 mm sieve to use in the pot experiment. A sub-sample was also air dried, sieved through a 2 mm size sieve and then kept for laboratory analysis.

Pot experiment

Moist soil equivalent to 5 kg (oven dry weight basis) was mixed with oil cake biochar (OCB) and rice straw biochar (RSB) at rates of 0, 1, 2, 3, 4 and 5% (w/w) and with 5 rates of NPK fertilizer (0, ¼, ½, ¾ and 1). The rate of 1 NPK was considered as the recommended dose (i.e. N : P : K = 140 : 60 : 100 kg ha^{-1}) for wheat (*Triticum aestivum*) (20). The NPK were applied in the form of urea (N), triple super phosphate (P) and murate of potash (K) fertilizers. A completely randomised experimental design (CRD) with 3 replications was used to arrange the pots. After pot preparation, the pots were watered up to the field capacity and kept for 2 weeks to be in equilibrium. After equilibrium, 10 seeds of wheat (variety: BARI Gom-25) were sown in each earthen pot and water was added to field capacity. After 10 days of emergence, 5 healthy seedlings of wheat were kept in each earthen pot and plants were grown for 3 months and 13 days. At plant harvest, the final sub-soil samples were taken from every earthen pot and allowed to air-dry before being analysed. Soil samples after plant harvest were used for the determination of chemical (pH, EC, exchangeable acidity, OC and CEC) and nutritional properties (available NH_4^+-N, Olsen P and K) using methods as mentioned below in the laboratory analyses sub-heading. Fresh weight and dry weight of plant parts were recorded after harvest. Dry weight was taken after drying in the air for a few days and then in an oven at 65 °C for 48 hr. Dry plant parts were then analysed for N, P and K concentration.

Laboratory analyses

The hydrometer method was used to analyse the size of the soil particles (21). Textural classes were determined by Marshall's Triangular coordinates (22). A glass electrode pH meter was used to determine the pH of the soil and the biochar in deionised water at a ratio of 1:2.5 (w/v) and 1:10 (w/v) respectively. A standard EC meter was also used to determine the EC of the soil and the biochars in deionised water at a ratio of 1:5 (w/v) and 1:20 (w/v) respectively. Exchangeable acidity in the soil (H^+ and Al^{3+}) was determined after extracting with 1.0 M KCl and then titrating with 0.01 M NaOH to pH 7.0 (23). The organic carbon (OC) was measured using the wet oxidation method (24). The cation exchange capacity (CEC) of the soils and biochars was measured using 1N NH_4OAc solution at pH 7.0 (25). The soil-available ammonium nitrogen (NH_4^+-N) was extracted using 1 M KCl solution (soil/solution ratio, 1:10) for 30 min on a reciprocating shaker. Soil-available phosphorus (Olsen P) was extracted using 0.5 M $NaHCO_3$ solution (pH 8.5) (soil/solution ratio, 1:20 w/v) for 30 min on a reciprocating shaker (26). The available potassium (K) in the soil was extracted with 1 N ammonium acetate (NH_4OAc) buffered at pH 7 (27). Nitrogen (N), P and K content in the soil, biochars and plant parts were determined after digestion with conc. H_2SO_4 + H_2O_2 + $LiSO_4$ digestion mixture (28). All reagents used were of analytical grade. Nitrogen in the extract and digests was determined by the micro-Kjehdahl distillation method. Phosphorus content in the soil extract and digests were measured colourimetrically utilising the ascorbic acid blue colour method (29). At a wavelength of 882 nm, absorbance was measured for phosphorus determination using a scanning spectrophotometer (UV-1800, Shimadzu, Japan). An atomic absorption spectrophotometer (AAS; Agilent 200 Series AA) was also used to measure the concentration of potassium in the solution.

Statistical analysis

The statistical software IBM SPSS Statistics 26 and Microsoft Excel were used for the analyses. Analysis of variance (ANOVA) was performed to compare treatments with respect to wheat yield and other measured parameters. Treatment means within each measured parameter were compared using Duncan's Multiple Range Test (DMRT) at the $p \leq 0.05$ level of significance.

Results and Discussion

Selected physico-chemical properties of soil and biochars

The physico-chemical properties of the soil and biochars used in the pot experiment are displayed in Table 1. The texture of the soil under study was sandy loam. The soil was acidic in nature (pH 5.9) and had low electrical conductivity (EC), low cation exchange capacity (CEC) and poor nutrient content. The amount of organic carbon (OC) and total N, P and K content in the soil were low. The pH of biochar samples was alkaline in nature where rice straw biochar (RSB) had a higher pH value (10.5) than oil cake biochar (OCB) (7.8). The amount of OC, CEC, N and P content were higher in OCB than RSB amendment but the K content was relatively higher in RSB than in OCB (Table 1). The properties of biochar materials vary with biochar feedstocks and pyrolysis conditions (16). Mostly, biochar is alkaline in nature (30). Biochar can supply macro and micronutrient elements which are inherently present in the original raw biomaterials (31).

Effect of different amendments on fresh and dry biomass of wheat

The fresh and dry biomass (g pot^{-1}) of wheat in different plant parts were increased with increasing rates of biochar and inorganic NPK fertilizer application to soils and these results were significantly higher than the control treatment (p < 0.05) (Table 2). In the control pot, fresh weights of root, straw and grain of wheat were 2.18 g, 5.55 g and 5.38 g, while the corresponding values in average across rates were 9.37 g, 12.93 g and 15.08 g in the OCB, 7.82 g, 14.43 g and 13.44 g in the RSB amendment and 13.22 g, 14.19 g and 15.68 g respectively, per pot in the NPK fertilizer application. The highest values of fresh root, straw and grain were 15.93 g (1 NPK), 20.67 g (5% RSB) and 19.75 g (5% OCB) respectively and the lowest value of fresh root, straw and grain were 2.18 g, 5.55 g and 5.38 g respectively as observed with control. Dry weights of root, straw and grain of wheat in the control pot were 1.42 g, 3.97 g and 3.19 g, while the corresponding values in average across rates were 4.43 g, 10.06 g and 9.91 g in OCB amendment, 3.79 g, 11.84 g and 8.06 g in the RSB amendment and 6.22 g, 12.35 g and 10.15 g respectively, per pot in the NPK fertilizer treatment. The highest values

Table 1. Some physico-chemical properties of the selected soil and biochars

Properties	Soil	OCB	RSB
Sand (%)	76	-	-
Silt (%)	10	-	-
Clay (%)	14	-	-
Texture	Sandy Loam	-	-
pH (H_2O)	5.9 (1:2.5 w/v)	7.8 (1:10 w/v)	10.5 (1:10 w/v)
EC (mS cm^{-1})	0.12 (1:5 w/v)	1.12 (1:20 w/v)	5.18 (1:20 w/v)
Ex. Acidity (cmol kg^{-1})	0.08	-	-
OC (%)	0.82	71.25	33.75
CEC (cmol kg^{-1})	16.5	58.80	46.15
Total N (%)	0.11	6.31	1.80
Total P (%)	0.08	1.89	1.04
Total K (%)	0.52	4.79	5.96

OCB - Oil cake biochar; RSB - Rice straw biochar; Ex - Exchangeable

Table 2. Effect of different amendments on the biomass (g pot^{-1}) yield of wheat

Treatment	Fresh biomass (g pot^{-1})			Dry biomass (g pot^{-1})		
	Root	Straw	Grain	Root	Straw	Grain
Control	2.18g	5.55g	5.38h	1.42e	3.97i	3.19f
1% OCB	6.60f	8.91f	11.93efg	3.57cd	6.71h	7.37cde
2% OCB	7.67ef	10.99ef	12.75def	4.23bcd	8.08gh	8.65bcd
3% OCB	8.48def	12.65de	13.63def	4.51bcd	9.13fg	8.92bc
4% OCB	10.69cd	14.47cd	17.36abc	4.71bcd	12.26cde	11.62a
5% OCB	13.40b	17.61b	19.75a	5.13bc	14.14abc	13.00a
1% RSB	6.14f	11.10ef	9.82g	3.10d	9.38fg	6.39e
2% RSB	6.77f	12.38de	12.31ef	3.64cd	10.11efg	7.74bcde
3% RSB	6.83f	12.99de	13.11def	3.76cd	10.35efg	8.05bcde
4% RSB	9.64de	15.00bcd	15.15cd	4.03bcd	13.18bcd	8.79bcd
5% RSB	9.70de	20.67a	16.79bc	4.44bcd	16.16a	9.31b
¼ NPK	10.30cd	10.89ef	11.22fg	4.20bcd	8.37gh	7.07de
½ NPK	12.41bc	12.57de	14.08de	5.45b	11.54def	8.87bc
¾ NPK	14.24ab	15.93bc	17.72ab	7.57a	14.68ab	11.75a
1 NPK	15.93a	17.37b	19.71a	7.66a	14.80ab	12.90a

OCB - Oil cake biochar, RSB - Rice straw biochar, NPK - Recommended inorganic NPK fertilizers; Values are the means of 3 replicates (n=3); Mean values within a column followed by the same letter(s) are not significantly different according to DMRT (Duncan's multiple range test) at $p < 0.05$

of dry root, straw and grain were 7.66 g (1 NPK), 16.16 g (5% RSB) and 13 g (5% OCB) respectively and the lowest value of dry root, straw and grain were 1.42 g, 3.97g and 3.19 g respectively as observed with control (Table 2).

The results showed that the root and grain biomass was relatively higher with OCB amendment than with RSB whereas the straw biomass was relatively higher with RSB than OCB amendment. At higher OCB rates (4–5%), the grain yield was statistically similar to 1 NPK rate and at higher RSB rates (4–5%) the straw biomass was statistically similar to 1 NPK rate. Irrespective of rates, the effect of OCB and RSB on the root biomass were statistically similar where at higher biochar rates (4-5%), the root biomass was significantly lower than with 1 NPK rate (Table 2). In this study, the above observed results thus indicate a positive impact of 2 different biochars on the biomass yield of wheat which has been agreed in other previous studies (2). Another study also found that applying biochar at rates of 30 to 60 t. ha^{-1} enhanced biomass and grain yields by as much as 30% in durum wheat (*Triticum durum* L.) (32).

Effect of different amendments on soil chemical properties after plant harvest

The effect of varying rates of biochar and inorganic NPK fertilizer on the chemical properties of soils at plant harvest in the pot experiment is given in Table 3. The soil pH value in the control pot was 6.26, while it increased from 6.47 to 7.17 with mean values of 6.84 in OCB and it also increased from 6.77–7.92 with a mean of 7.42 in RSB amended soil pots but in the cases NPK fertilizer treatment, no changes of soil pH were observed. The NPK amendment showed a similar pH as observed in the control soil pot. Between the 2 biochars, pH values with RSB were significantly higher than OCB (Table 3). The relatively higher pH value in the biochar-amended soils as compared to the control reflected the original pH of biochar. This indicates the ability of biochar to mediate soil pH for a longer time (33). The high concentration of base cations in biochar materials form carbonates or oxides during pyrolysis, raising the pH of the biochar which may affect the pH of the soil after application (34).

The behavior of soil EC in amended soil after plant harvest was found similar as observed for pH. In the control pot, EC was 103 µS cm^{-1}, while it increased from 129 to 234 µS cm^{-1} with mean values of 178 µS cm^{-1} in OCB and it also increased from 153–309 µS cm^{-1} with a mean of 237 µS cm^{-1} in RSB amended soil pots but in the cases of NPK fertilizer treatment, the soil EC values remained same as found in the control treatment (Table 3). The increased soil EC values with different biochar amendments were possibly attributable to the presence of high ash contents in biochar along with soluble basic elements released from the biochar (35). This fact could be related to a positive

Table 3. Effect of different amendments on soil chemical and nutritional properties at plant harvest of the pot experiment

Treatment	pH	EC (µS cm^{-1})	Ex. Acidity (cmol kg^{-1})	OC (%)	CEC (cmol kg^{-1})	Av. NH_4^+-N (mg kg^{-1})	Olsen P (mg kg^{-1})	Av. K (mg kg^{-1})
Control	6.26jk	103h	0.052a	0.78g	17.43j	37j	5.03g	26.73i
1% OCB	6.47i	129g	0.035cd	1.11e	21.71gh	106fg	10.83e	43.92f
2% OCB	6.69h	150f	0.033cde	1.44d	24.50f	120de	15.88d	50.20e
3% OCB	6.84f	176e	0.033de	1.73c	27.00de	130c	22.37bc	56.63c
4% OCB	7.06e	201d	0.023fg	1.96b	28.69bc	141b	33.09a	62.78b
5% OCB	7.15d	234c	0.019gh	2.37a	29.66ab	152a	35.26a	69.45a
1% RSB	6.77g	153f	0.028ef	0.94f	21.38gh	78i	8.83ef	48.10e
2% RSB	7.18d	195d	0.025fg	1.04ef	23.46f	99gh	14.93d	53.32d
3% RSB	7.52c	240c	0.021fgh	1.37d	26.15e	112ef	20.54c	58.07c
4% RSB	7.71b	287b	0.018gh	1.66c	27.93cd	120de	22.70bc	63.78b
5% RSB	7.92a	309a	0.016h	1.73c	30.14a	123cd	24.28b	69.43a
¼ NPK	6.29j	109h	0.052a	0.63h	19.62i	81i	6.14fg	31.59gh
½ NPK	6.25jk	103h	0.036cd	0.68gh	21.10gh	94h	6.37fg	32.67g
¾ NPK	6.21k	106h	0.045b	0.66gh	20.34hi	132c	6.54fg	31.03gh
1 NPK	6.20k	104h	0.040bc	0.67gh	22.03g	143b	6.83fg	29.13hi

OCB - Oil cake biochar, RSB - Rice straw biochar, NPK – Recommended inorganic NPK fertilizers; Ex.- Exchangeable; Av.- Available; Values are the means of 3 replicates (n=3); Mean values within a column followed by the same letter(s) are not significantly different according to DMRT (Duncan's multiple range test) at $p <$ 0.05

effect on some soil nutrient element ions for plant uptake (36). The increased EC in the biochar-treated soil might also be attributed to the higher pH (Fig. 1A).

Opposite of pH and EC, the soil exchangeable acidity decreased with the rates of biochar amendments. In the control soil pot, exchangeable acidity value was 0.052 cmol kg^{-1}, while it decreased from 0.035–0.019 cmol kg^{-1} with mean values of 0.029 cmol kg^{-1} in OCB and from 0.028–0.016 cmol kg^{-1} with the mean values of 0.022 cmol kg^{-1} in RSB amended soil pots but in the cases of NPK fertilizer treatment, the changes were not noticeable. The reduction of exchangeable acidity was higher with RSB than with OCB (Table 3). The decrease in soil exchangeable acidity with alkaline biochar may be attributable to the content of basic cations in biochar, as they displace the exchangeable Al^{3+} and H^{+} on soil exchange sites (37). The lower exchangeable acidity in the soil might also be attributed to the pH of the biochar-treated soil. This can be corroborated by the observed negative correlation between soil pH and exchangeable acidity at the harvest of wheat plants (Fig. 1B). Our findings are consistent with a prior study (38), which showed a considerable rise in soil pH and a decrease in soil acidity.

Biochar additions to soil increased soil organic carbon (OC) as observed for pH and EC. The OC value in the control pot was 0.78%, while it increased from 1.11 to 2.37% with mean values of 1.72% in OCB and from 0.94 to 1.73% with a mean of 1.35% in RSB amended soil pots but no such changes were found with NPK fertilizer treatment. The increase of soil OC in the biochar-treated soil could be attributed to the high content of organic carbon in biochar (39) which prevailed at the end of the experiment. This also indicates the recalcitrant nature of biochar which makes it more stable against decomposition and thus increases soil carbon storage (40). Soil OC is important because of its various essential roles in interfacial interactions as well as chemical, biological and physical soil processes (41).

Similar to soil pH, EC and OC, the CEC also increased with the rates of biochar. The soil CEC value in the control pot was 17.43 cmol kg^{-1}. In the OCB-amended soil, it increased from 21.71 to 29.66 cmol kg^{-1} with a mean value of 26.31 cmol kg^{-1}. In the case of RSB, CEC increased from 21.38–30.14 cmol kg^{-1} with a mean value of 25.81 cmol kg^{-1} but in the cases of NPK fertilizer treatment, the soil CEC values were slightly increased compared to control. The increased CEC in biochar-treated soil may be attributed to the high porosity and surface area of biochar (42). The CEC of fresh biochar can increase with time after the application in soil by developing surface functional groups and negative charges as biochar is aged with oxygen and water (43). In the current study, we found a significant positive relationship between soil pH and soil CEC and a negative relationship between soil pH and exchangeable acidity (Fig. 1). The increase of OC and CEC with the rates of biochar additions to the soil and strong positive relationship (Fig. 1D) between these 2 major components of soil indicates that biochar plays a strong role in improving the soil health. Similar to our results, another previous study also reported an increase in CEC in the soil treated with biochar in relation to an increase in soil pH and soil OC (16).

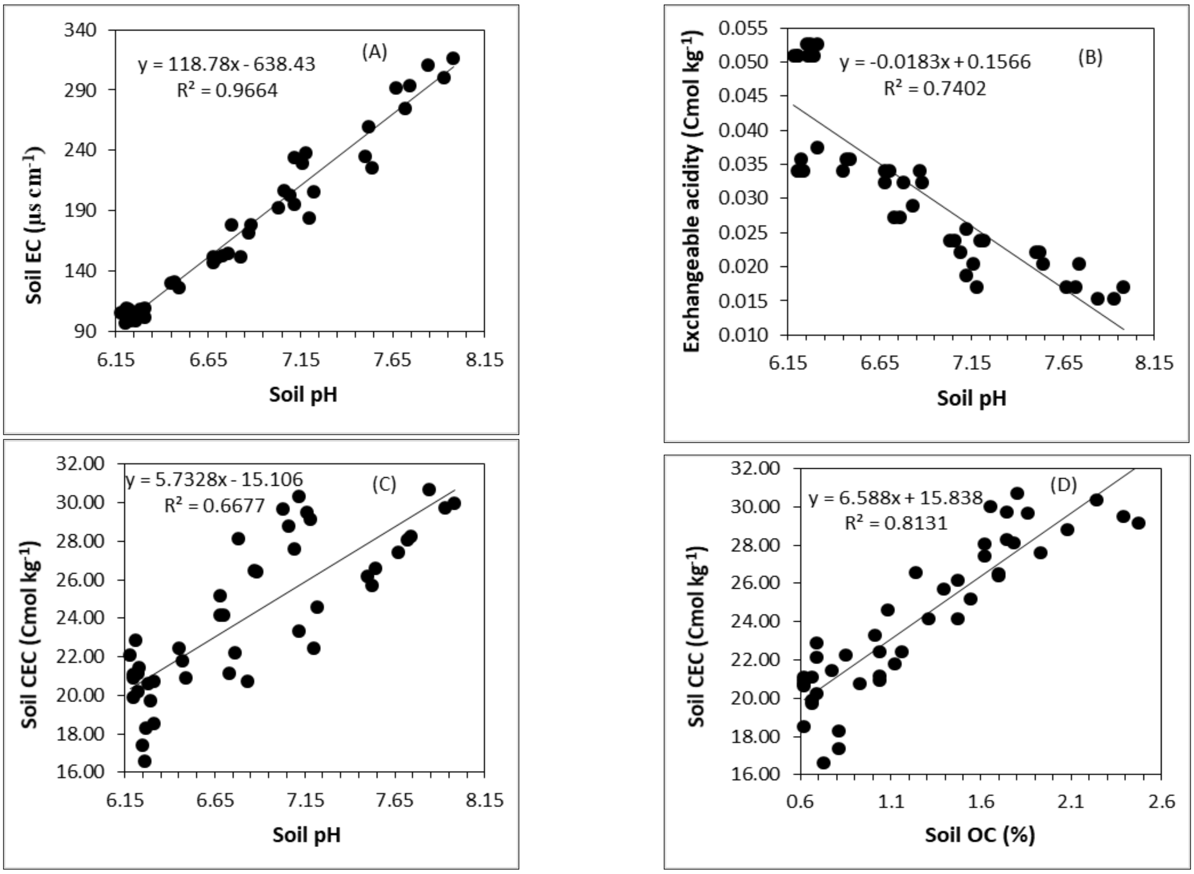

Fig. 1. (A) Relationship between soil pH and soil EC, (B) soil pH and soil exchangeable acidity, (C) soil pH and soil CEC and (D) relationship between soil OC and soil CEC of soils after wheat harvest.

Effect of different amendments on soil available NH_4^+-N, Olsen P and available K

Both biochar and NPK fertilizers increased NH_4^+-N with increasing their application rates (Table 3). The soil available NH_4^+-N value in the control pot was 37 mg kg^{-1}. The amount of NH_4^+-N increased from 106 to 152 mg kg^{-1} with mean values of 130 mg kg^{-1} in OCB, from 78 to123 mg kg^{-1} with a mean value of 106.4 mg kg^{-1} in RSB amended soil pots and from 81 to143 mg kg^{-1} with a mean value of 113 mg kg^{-1} in NPK fertilizer treatment. The soil available NH_4^+-N value with OCB was found significantly higher than RSB-amended soils. The highest soil available NH_4^+-N value was 152 mg kg^{-1} (5% OCB). The soil NH_4^+-N value with a 4% OCB rate was similar to the 1 NPK rate (Table 3). The increase of soil-available NH_4^+-N with different biochar amendments are agreed with the previous study that reported an increased soil-available NH_4^+-N and NO_3^--N by biochar made from rice and bamboo (44). A high C:N ratio and some labile organic portions of biochar may increase the microbial activity on native soil organic matter for N to enhance N mineralisation and availability in the soil (45).

Soil available P (Olsen P) only influenced the biochar and increased with increasing rates of biochar (Table 3). Olsen P value in the control pot was 5.03 mg kg^{-1}, while it increased from 10.83 to 35.26 mg kg^{-1} with mean values of 23.49 mg kg^{-1} in OCB and from 8.83 to 24.28 mg kg^{-1} with a mean of 18.26 mg kg^{-1} in RSB amended soil pots but in the cases NPK fertilizer treatment, no changes of soil Olsen P were observed indicating immobilisation of inorganic P as applied in the form of NPK fertilizer. The soil Olsen P value was found relatively higher in OCB-amended soil than in RSB and at higher biochar rates (4–5%) it was significantly higher with OCB amendment than with RSB amendment (Table 3). The present increase in soil available P with different biochar amendments may be ascribed to the P content of the biochar, the pH and the CEC of the biochar-treated soils. A previous study reported that P content in biochar ash increases the soil available P (46). Another study reported that the application of biochar improved P availability in soil by increasing soil pH and reducing the soluble Al and Fe (47). Biochar may also improve P availability in soil by decreasing phosphate retention capacity through the increase of surface negative charge as well as CEC in soil (48).

A similar effect on the soil available K was found in 2 different biochar amendments (OCB and RSB). The behaviour of NPK fertilizer on the soil available K was found similar as found in the case of soil available P. Soil available K value in the control pot was 27 mg kg^{-1}. In the OCB treatment it increased from 44 to 69 mg kg^{-1} with mean values of 57 mg kg^{-1}, with the RSB it increased from 48 to 69 mg kg^{-1} with a mean of 59 mg kg^{-1} but in the cases of NPK fertilizer treatment, the effect was not recognisable. The maximum soil available K was observed at higher biochar rates which was similar with both types of biochar (OCB and RSB) (Table 3). The available soil K increased with increasing rates of different biochar amendments could be attributed to the immediate release of K from the high ash content of biochar (49). Additionally, a prior study found that by enhancing the CEC in soil, biochar increased the amount of available soil K (50).

Effect of different amendments on the concentrations of N, P and K in different plant parts of wheat

In the present study, the concentration of N, P and K in root, straw and grain were increased with increasing rates of biochar (OCB and RSB) and in most cases with inorganic NPK fertilizer rates where maximum concentration observed with 4–5% biochar rates (Table 4). The concentrations of N in root, straw and grain of wheat in the control pot were 0.73%, 0.83% and 1.98% respectively, while the mean values of N in the same plant parts were 1.19%, 1.18% and 2.45% with OCB amendment, 1.10%, 1.14% and 2.51% with RSB and were 1.11%, 1.00% and 2.22% in the root, straw and grain with the NPK fertilizer treatment respectively. The concentrations of P in root, straw and grain of wheat in the control pot were 0.06%, 0.12% and 0.35% respectively, while the mean values of P in the same plant parts were 0.15%, 0.20% and 0.54% with OCB amendment, 0.11%, 0.18% and 0.58% with RSB and were 0.06%, 0.12% and 0.38% in the root, straw and grain with the NPK fertilizer treatment. The concentrations of K in root, straw and grain of wheat in the control pot were 1.22%, 1.88% and 0.73% respectively, while the mean values of K in the same plant parts were 1.94%, 2.76%

Table 4. Effect of different amendments on the concentration of N, P and K in different plant parts of wheat

Treatment	N (%)			P (%)			K (%)		
	Root	Straw	Grain	Root	Straw	Grain	Root	Straw	Grain
Control	0.73i	0.83i	1.98i	0.06hi	0.12i	0.35g	1.22f	1.88fg	0.73e
1% OCB	1.02g	1.11def	2.08hi	0.09g	0.15fg	0.47e	1.60d	2.30de	0.89d
2% OCB	1.17cde	1.13cde	2.26fg	0.12ef	0.17ef	0.51de	1.77c	2.52cd	1.03bc
3% OCB	1.20bc	1.17abcd	2.42de	0.14cd	0.20cd	0.55cd	1.98b	2.84bc	1.09ab
4% OCB	1.26ab	1.23abc	2.66c	0.18b	0.24ab	0.57c	2.09b	3.03b	1.13ab
5% OCB	1.32a	1.26a	2.81ab	0.22a	0.26a	0.58c	2.26a	3.11b	1.14ab
1% RSB	0.87h	1.01fg	2.19gh	0.06hi	0.12hi	0.50e	1.35ef	2.13ef	0.94cd
2% RSB	1.03fg	1.11def	2.36ef	0.09g	0.15fg	0.55cd	1.49de	2.60cd	1.09ab
3% RSB	1.14cde	1.13bcde	2.48d	0.11fg	0.18de	0.59bc	1.59d	3.00b	1.19a
4% RSB	1.19bcd	1.20abcd	2.70bc	0.13de	0.21c	0.62ab	1.79c	3.77a	1.20a
5% RSB	1.26ab	1.24ab	2.84a	0.15c	0.24b	0.64a	2.09b	3.87a	1.20a
¼ NPK	1.09ef	0.90hi	2.09hi	0.05i	0.11i	0.37fg	1.25f	1.85fg	0.84de
½ NPK	1.10e	0.97gh	2.15gh	0.06hi	0.14gh	0.37fg	1.25f	1.87fg	0.85de
¾ NPK	1.11de	1.09def	2.16gh	0.07h	0.11i	0.39fg	1.27f	1.90fg	0.89d
1 NPK	1.14cde	1.05efg	2.12h	0.06hi	0.11i	0.40f	1.32ef	1.67g	0.90d

OCB – Oil cake biochar, RSB – Rice straw biochar, NPK – Recommended inorganic NPK fertilizers; Values are the means of 3 replicates (n=3); Mean values within a column followed by the same letter(s) are not significantly different according to DMRT (Duncan's multiple range test) at $p < 0.05$

1.06% with OCB amendment, 1.66%, 3.07% and 1.12% with RSB and were 1.27%, 1.82% and 0.87% in the root, straw and grain with the NPK fertilizer treatment.

In most cases, our results showed that the N, P and K concentrations in different plant parts with different rates of biochar were significantly higher than the control but with inorganic NPK rates, these trends were not observed (Table 4). A relatively higher N and P concentrations in root and straw were observed with OCB than with RSB treatment but in grain, these nutrient concentrations were relatively lower with OCB than with RSB treatment. The results also showed that the K concentrations in roots with OCB treatment were relatively higher than with RSB treatment but in straw and grain, these nutrient concentrations were relatively higher with RSB than with OCB treatment. Overall, the N and P concentrations in the wheat plant were relatively higher with the OCB treatment and the K concentration in the wheat plant was relatively higher with the RSB treatment. These trends reflect the original nutrient content (N, P and K) of biochar amendments (OCB and RSB) as well as the availability of these nutrients in soil (Table 1 and Table 3). This can also be corroborated with the observed positive linear correlation(s) between the content of soil available nutrients (NH_4^+-N, Olsen P and K) and the concentrations of nutrients (N, P and K) in different plant parts of wheat (Fig. 2). Irrespective of rates, both biochar amendments dominated the uptake of N, P and K in plant parts (root, straw and grain) over the NPK fertilizer treatment which was opposite effect as observed in the case of wheat root growth (Table 2 and Table 4). However, the concentration of nutrients could also be decreased due to the dilution by plant growth (51). Thus, by enhancing the availability of essential nutrients like N, P and K in soil and their subsequent uptake by plants, the addition of biochar promotes plant development (38).

Conclusion

In agreement with researchers, it was confirmed that both biochars (OCB and RSB) enhanced wheat growth and improved soil properties. The biomass yields were highest at the 5% biochar application rate and were comparable with the 1 NPK rate. Overall, the OCB had a better effect than that of RSB biochar. The current study's findings demonstrated that the various biomaterials used to produce the biochar had differing effects on plant growth and soil properties. Thus, the use of biochar made from rice straw and oil cake would be a more effective and beneficial way to enhance the fertility and productivity of acidic sandy loam soil.

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Authors' contributions

MEH, KTO and MAK designed the experiment. MEH conducted the experiment and collected data under the guidance of KTO and MAK. MEH and MAK analyzed data, drafted and approved the manuscript.

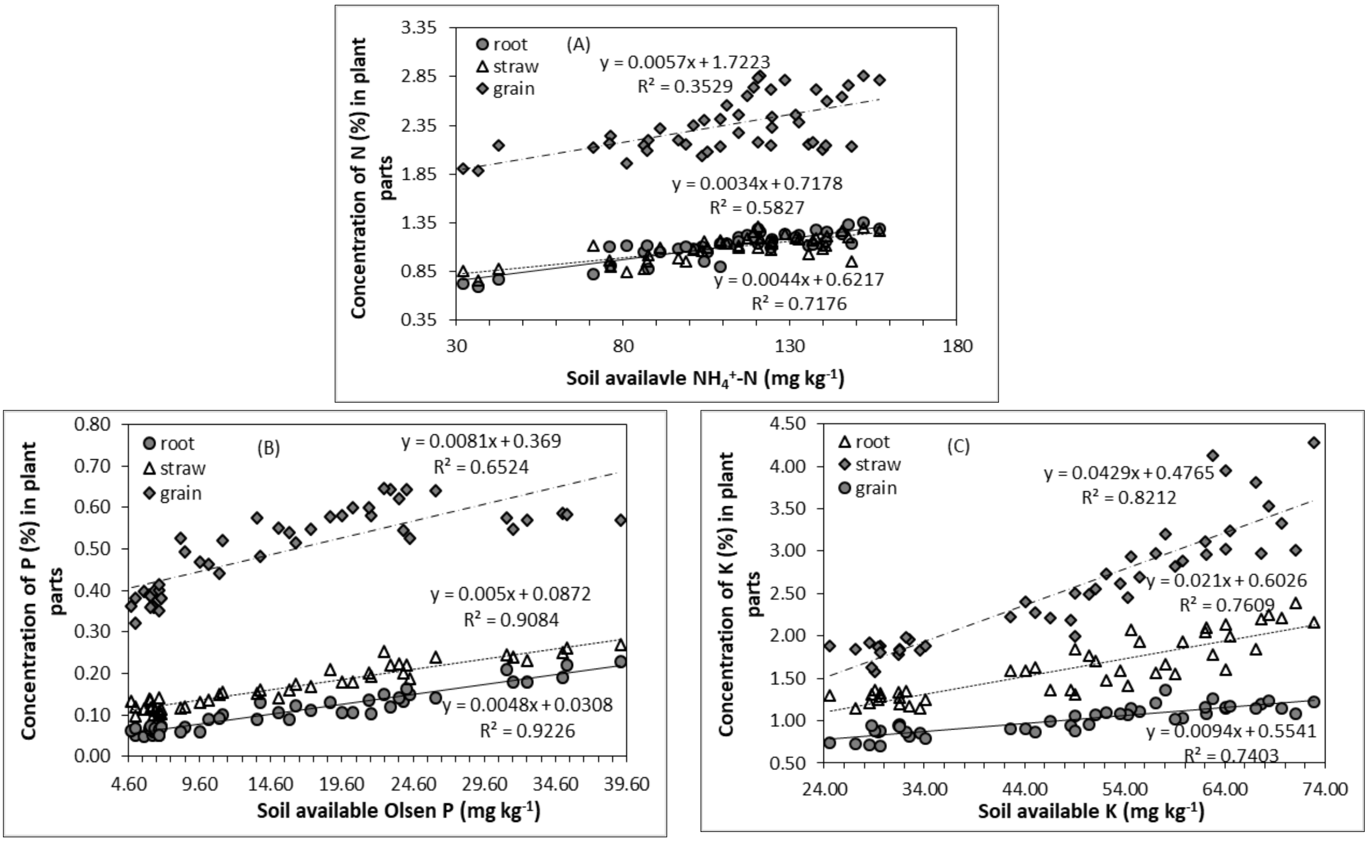

Fig. 2. Relationship between (A) NH_4^+-N in soil with the concentration of nitrogen in plant, (B) Olsen P in soil with concentration of P in plant and (C) available K in soil with concentration of K in plant (root, straw and grain) treated with 2 different types of biochar (OCB and RSB) and inorganic NPK fertilizer.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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