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Rice straw biochar amended soil improves wheat productivity and accumulated phosphorus in grain

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ABSTRACT

Biochar is a pyrolyzed biomass produced under limited oxygen or oxygen absent conditions. Few investigations have been conducted to determine the combined effect of biochar with chemical fertilizer on growth, yield and nutrient distribution pattern in root, shoot and grain in wheat as well as changes in soil physiochemical properties. This research was designed to study the combined effect of chemical fertilizer and rice straw-derived biochar on soil physio-chemical properties, growth, yield and nutrient distribution pattern within wheat plant tissue and grain. Results showed that rice straw biochar caused a significant decrease in soil pH and increase in soil organic matter as well as nutrients like total nitrogen (TN), potassium (K), magnesium (Mg) and boron (B) due to incubation. Result also showed that root biomass and straw did not differ between Bangladesh Agricultural Research Council (BARC) and ½ BARC + rice straw biochar treatment. Similarly, thousand grain weight and grain yield did not differ between the same treatments. The phosphorus concentration in wheat grain was highest in ½ BARC + rice straw biochar as compared to other treatments. The use of rice straw biochar in addition to the chemical fertilizers in wheat production systems is an economically feasible and practical nutrient management practice. Our findings urged that reduction of chemical fertilizer application is possible with supplementation of rice straw biochar.

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KEYWORDS
incubation; nutrient availability; partially decompose; pyrolysis process; translocation

1. Introduction

Biochar incorporation into agricultural soils has recently stimulated much scientific research due to its agronomic, financial, and ecological benefits (Khan et al., 2013). Biochar amendment to soil has the potential to improve soil fertility and increase crop yield (Liu et al., 2017). Biochar application to soils has been shown to improve soil physical and chemical properties (Liu et al., 2012). Recent reviews have highlighted that biochar application can also stimulate plant growth and yield (Biederman & Harpole, 2013).

Rice straw is an unique feedstock for biochar production, due to the high amount of silica found in the plant tissue (Shen, Zhao, & Shao 2014). This silica gives high ash content for rice straw biochar in comparison with other similar feedstock. Additional ash forms as product of the pyrolysis with high alkalinity seen by biochars high pH (Chintala et al., 2014). Generally, rice straw biochar is alkaline, regardless of pyrolysis temperature and residence time (Wu et al., 2012).

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Alkaline rice straw biochar can be used as a soil amendment for neutralizing acidity, improving soil fertility and sequestering C in acidic soils (Kuppusamy et al., 2016).

A study indicated that the combined application of biochar and chemical fertilizer had a better performance than either alone, in terms of soil properties and crop yield (Glaser et al., 2015). Likewise, another study showed that rice straw biochar has the potential to decrease dependence on chemical fertilizer for wheat production (Iqbal 2017). Rice straw biochar was used as a nutrient source in that study to achieve comparable yields with chemical fertilizer. However, there was no nutrient distribution pattern was studied in that study. Therefore, this study investigated the effects of rice straw biochar, chemical fertilizer and their interactions on soil properties, wheat growth and yield performance as well as nutrient distribution pattern in wheat plant tissue and grain. Our study will answer the following questions: (i) Can rice straw biochar utilize as a nutrient source? (ii) Does positive effect of rice straw biochar on wheat production? (iii) Can rice straw biochar reduce chemical fertilizer utilization? The hypothesis of this study was (i) Rice straw derived biochar amendment will improve nutrient availability of initial soil due to incubation. (ii) Rice straw biochar will reduce chemical fertilizer utilization for wheat production. (iii) Rice straw biochar will enhance nutrient uptake within wheat plant tissue.

2. Materials and methods

2.1. Soil collection

The soil used in the study was collected from an arable field located at the research farm (24.37° North latitude, 88.6° East longitude and 31-m elevation above the sea level) of the University of Rajshahi, Bangladesh. The soil was passed through a 4-mm sieve to eliminate coarse rock and plant material, thoroughly mixed to ensure uniformity and stored at 4 °C before use (not more than 2 weeks). The unwanted materials such as dry roots, grasses, hard stones were removed from the soil. The soil was mixed thoroughly before starting incubation experiment. A sub-sample of about 0.5 kg was taken, air dried, passed through a 2-mm sieve and used for the determination of physical and chemical characteristics. The initial soil basic properties and nutrient contents are shown in Table 1.

2.2. Rice straw biochar preparation

Rice straw was obtained from the research farm of the Department of Agronomy and Agricultural Extension, University of Rajshahi, Bangladesh. Oven dried rice straw was pyrolyzed using Muffle furnace (Gallonhop, England) as described by (Sánchez et al., 2009). In each cycle, 250 g of crushed rice straw was used for pyrolysis. Pyrex flask of 2 L capacity was used for this purpose. For the removal of vapors and gases from working area, a bended outlet composed of glass rod was used. To avoid the entry of oxygen in reaction chamber, high temperature resistant silicon grease was used to completely seal the junction of Pyrex flask and glass rod. The increase in muffle furnace temperature (per unit time) was adjusted at 8–9 °C min^{-1}. Twenty minutes' residence time was maintained after attaining final temperatures (400 °C) in reaction chamber of muffle furnace. After 20 min, muffle furnace was allowed to cool down to a temperature of

Table 1. Initial and incubated soil physiochemical properties and nutrient contents.

Soils	Soil pH	OM (%)	TN (%)	P (ppm)	K (me/100 g)	S (ppm)	Zn (ppm)	Ca (me/100 g)	Mg (me/100 g)	Cu (ppm)	Fe (ppm)	B (ppm)	Mn (ppm)
Initial	8.3	1.39	0.08	12.5	0.16	14.4	0.66	15.63	1.89	1.26	27.3	0.50	13.7
Incubated	8.0	1.89	0.10	7.90	1.11	94.3	0.40	15.89	8.13	0.72	6.2	0.81	10.5

Data were means of three replicates. Initial soil were measured immediate after soil sample collection. Incubated soil were measured after 5 months of incubation

40–50 °C. After cooling, the Pyrex flask was removed from the reaction chamber and rice straw biochar thus formed was collected.

2.3. Rice straw biochar characterization

A physico-chemical characteristic of rice straw biochar is given in Table 2. The ash content was estimated by heating biochar samples in a muffle furnace using the method of (Slattery, Ridley, & Windsor 1991). Biochar samples were shaken in distilled water on mechanical shaker for 90 min in a 1:20 solid:solution ratio and electrical conductivity (EC) and pH of rice straw biochar were measured. The cation exchange capacity of rice straw biochar was estimated by modified ammonium acetate compulsory displacement method (Gaskin et al., 2008).

The elemental analysis (P, K, Ca, Mg, Fe, Zn, Mn, and Cu) of rice straw biochar was done after wet digestion with nitric acid (HNO_3)- perchloric acid ($HClO_4$) (Jones Jr and Case, 1990). Calcium, Mg, and micronutrients (Fe, Zn, Mn, and Cu) were determined by atomic absorption spectrophotometer (AAnalyst 100, Perkin-Elmer, Norwalk, CT, USA). Phosphorus concentration was measured after developing yellow color by vanadate-molybdate method (Chapman & Pratt, 1962), on UV–visible spectrophotometer (UV-1201, Shimadzu, Kyoto, Japan). Potassium was determined on flame photometer (PFP7, Jenway, Staffordshire, UK). Nitrogen and carbon content in biochar were analyzed on Vario Micro CHNS-O Analyzer (Elementar Analysen systeme GmbH, Langenselbold, Germany).

2.4. Plants

The Bangladesh Agricultural Research Institute (BARI) released wheat variety BARI Gom 28 was used as a testing plant. The pedigree/cross of BARI Gom 28 was CHIL/2*STAR/4/BOW/CROW//BUC/PVN/3/2*VEE#10

CMSS95Y00624S-0100Y-0200M-17Y-010M-5Y-0M. The accession number was BAW 1141. The BARI Gom 28 was released in the year of 2012 (Paroda et al., 2012).

2.5. Incubation experiment

Sieved rice straw biochar (<0.5 cm) was mixed with soil (equivalent to 1000 g oven-dried weight) at a rate of 16.60 g rice straw biochar kg^{-1} soil. The soil was thoroughly mixed with rice straw biochar in several plastic jars after application of rice straw biochar. The plastic jars were covered

Table 2. Properties of rice straw biochar that produced at pyrolysis temperature of 400 °C.

Parameters	Units	Rice straw biochar
Chemical properties		
Ash content	%	39 ± 1.50
pH	in H_2O	8.70 ± 0.20
EC	dS m^{-1}	2.85 ± 0.08
CEC	cmol kg^{-1}	73 ± 2.0
Nutrient composition		
Total carbon	%	56 ± 1.90
Total nitrogen	g kg^{-1}	19.8 ± 0.92
Phosphorus	g kg^{-1}	2.0 ± 0.13
Potassium	g kg^{-1}	24 ± 1.23
Calcium	mg kg^{-1}	8.8 ± 0.28
Magnesium	mg kg^{-1}	5.7 ± 0.35
Zinc	mg kg^{-1}	60 ± 3.74
Manganese	mg kg^{-1}	117 ± 6.34
Iron	mg kg^{-1}	246 ± 10.18

Values were means of three replicates ± standard deviation ($n = 3$).

with plastic lids and a small hole was made to allow gas exchange and to maintain moisture loss, and then incubated at a constant temperature of 25 °C and 70% relative humidity. Soil moisture was adjusted after every 2 days by weighing several plastic jars and adding the required amount of distilled water when the loss was >0.05 g. After every incubation interval, selected soil properties and nutrient status were estimated.

2.6. Pot experiment

The soil used in pot study was the same, which was used in the incubation experiment. One kilograms of sieved soil/soil-rice straw biochar mixture was filled in each pot. There were total five treatments which include (i) Control (nothing was added); (ii) ½ BARC (Bangladesh Agricultural Research Council) recommended fertilizer for wheat production; (iii) BARC recommended fertilizer for wheat production; (iv) incubated rice straw biochar only; and (v) ½ BARC plus incubated rice straw biochar. These treatments were replicated three times and laid out in completely randomized design. The amount of fertilizer mixed within soil is shown in Table 3. The soil was thoroughly remixed in each pot after application of ½BARC and BARC fertilizers and was equilibrated for 1 week. Wheat seeds disinfected in 30% H_2O_2 (w/w) solution for 15 min were thoroughly washed and submerged in deionized water and were kept in an incubator at 30 °C. After germination, seeds with uniform appearance were chosen and planted in soils in several treatments. Twelve pre-germinated healthy wheat seeds (BARI Gom 28) were sown in each pot, which were thinned to seven after 1 week of germination. Pots were irrigated with de-ionized water to the level of 90% pot water holding capacity to avoid drought stress to plants. Water was maintained to the field capacity for all treatments through monitoring soil moisture by soil moisture meter (PMS-714; Made in Taiwan). All pots were kept in a greenhouse set to 14 hr day time with a light intensity of 350 µmol m^{-2} s^{-1}, 28 and 20 °C day and night temperatures, respectively, and a relative humidity of 60%–70%. The pots were completely randomized and re-positioned regularly during spraying or watering to minimize any effect of uneven environmental factors during wheat plant growth period.

2.7. Leaf area measurement

The leaf area was measured with the help of green leaf area meter at 35 days after sowing (DAS). The specification of the leaf is Model: GA-5; Tokyo Photo electric Company Limited; Made in Japan.

2.8. Plant harvest

Plants were harvested at maturity. Whole plants and roots with surrounding soils were removed from pots by gentle agitating of the pots to provide minimum disturbance to the roots and shoots. Intact plants were then lifted gently from the soil and shaken lightly to remove bulk soil

Table 3. Amount of BARC recommended fertilizer for wheat production added in each pot.

Fertilizer name	Amount added
Urea	135.24 mg/kg soil
Triple super phosphate (TSP)	19.76 mg/kg soil
Murate of potash (MP)	16.67 mg/kg soil
Gypsum ($CaSO_4$)	12.35 mg/kg soil
Zinc Sulphate ($ZnSO_4$)	5.8 mg/kg soil
Boric acid (H_3BO_3)	0.124 mg/kg soil
Magnesium Sulphate ($MgSO_4$)	–a
Organic matter (Cowdung)	2.47 g/kg soil

[a]No Mg was added due to BARC recommended available Mg was found in the collected soil. This fertilization was done on the basis of available nutrients in the initial soil.

from the roots. Whole plants including roots (after removal of bulk soil) were then placed in a leveled snap polythene bag as well as kept 20–30 min for air-dry.

2.9. Wheat yield contributing characteristic measurement

Total number of spikelets from each pot was calculated and then averaged to have number of spiklet per spike. Spike length was measured with a meter scale from the base to the tip of the spike and the average value was recorded as spike length. Biological yield was calculated from the following formula:

$$\text{Biological yield } \left(\text{t ha}^{-1}\right) = \text{Grain yield } \left(\text{t ha}^{-1}\right) + \text{Straw yield } \left(\text{t ha}^{-1}\right)$$

Harvest index was calculated on the ration of economic yield (grain yield) to biological yield and expressed in terms of percentage. It was calculated by using the following formula (Donald & Hamblin, 1976):

$$\text{Harvest index } (\%) = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

2.10. Root, shoot as well as grain carbon and nitrogen analysis

Roots were separated from the soil manually and were washed with distilled water and oven-dried at 65 °C for 48 hr, ground top truss through 0.5 mm sieve and stored prior to total nitrogen and carbon analysis. Root, shoot and grain samples carbon and nitrogen was determined by combustion using a Thermo Fisher Scientific FLASH 2000 Series CN Elemental Analyzer (Thermo Fisher Scientific, Waltham, MA, USA).

2.11. Nutrient analysis in root, shoot and grain

At harvest shoots were cut 0.5 cm from surface, dried in an oven at 65 °C for 48 hr and their dry weights were recorded. Similarly, roots were washed with deionized water dried in an oven at 65 °C for 48 hr and their dry weights were recorded. Wheat grin also dried in an oven at 65 °C for 48 hr and 1000 grain weight and grain weights were recorded. After drying the shoot, roots and grains were ground top truss through 0.5 mm sieve and stored prior to nutrient analysis. For the determination of other macro and micro nutrients ICPOES was used by dry ashing.

2.12. Measurement of soil properties

The pH of the bulk soil was determined in deionized water using a soil-to-solution ratio of 1:5. Organic carbon of the bulk soil samples was determined by wet oxidation method (Walkley & Black, 1934). Bulk soil organic matter content was determined by multiplying the percent value of organic carbon with the conventional Van-Bemmelen's factor of 1.724 (Piper, 1950). The nitrogen content of the bulk soil sample was determined by distilling soil with alkaline potassium permanganate solution (Subbiah & Asija, 1956). The distillate was collected in 20 ml of 2% boric acid solution with methylred and bromocresol green indicator and titrated with 0.02 N sulphuric acid (H_2SO_4) (Podder et al., 2012). Bulk soil available S (ppm) was determined by calcium phosphate extraction method with a spectrophotometer at 535 nm (Petersen et al., 1996). The soil available K was extracted with 1 N ammonium acetate (NH_4OAC) and determined by an atomic absorption spectrometer (Biswas et al., 2012). The available P of the bulk soil was determined by spectrophotometer at a wavelength of 890 nm. The bulk soil sample was extracted by Olsen method with 0.5 M sodium bicarbonate ($NaHCO_3$) as outlined by (Huq & Alam, 2005). The Zn in the bulk soil sample was measured by an atomic absorption spectrophotometer after extracting with DTPA (Soltanpour & Schwab, 1977).

2.13. Statistical analysis

Results were analyzed by a one-way or two-way analysis of variance (ANOVA) using Genstat 12th edn for Windows (Lawes Agricultural Trust, UK). One way ANOVA were conducted for treatment effects on growth and yield of wheat. Two-way ANOVA were conducted for treatment effects on nutrient distribution in root, shoot and grain of wheat. All the statistical testing was performed based on $p \leq 0.05$ for least significance difference (LSD).

3. Results

3.1. Changes in nutrient contents in soil due to incubation after rice straw biochar amendment

Rice straw biochar amendment changes in soil nutrient content due to incubation are shown in Table 1. Nutrients like total nitrogen (TN), K, Mg, and B content in soil increases due to incubation. In contrast, P, S, Zn, Cu, Fe, and Mn content declined in rice straw amended soil due to incubation. However, Ca content almost remains similar in initial soil and rice straw amended incubated soil. The TN, K, Mg, and B were increased by 0.02%, 0.95 meq/100 g, 6.24 meq/100 g, and 0.31 ppm, respectively due to incubation with rice straw biochar amendment. In contrast, P, S, Zn, Cu, Fe, and Mn content declined by 4.6, 79.9, 0.26, 0.54, 21.1, and 3.2 ppm, respectively in the rice straw biochar amended incubated soil. Similarly, soil organic matter increased by 0.50% and soil pH declined by 0.3 units in the rice straw amended incubated soil.

3.2. Bulk soil properties

Bulk soil chemical properties and macro nutrient content has been changed in several treatments (Table 4). Bulk soil pH declined significantly ($p \geq 0.05$) by 0.4 units at rice straw biochar treatment as compared to control treatment. In contrast, bulk soil organic matter increased significantly ($p \geq 0.05$) by 0.38% at ½ BARC plus rice straw biochar as compared to BARC treatment. Total nitrogen varied 0.080%–0.10% in several treatments. Bulk soil available p varied 13.1–14.2 ppm in several treatments. Interestingly, bulk soil available K was 3–4 times higher in both rice straw biochar only and ½ BARC plus rice straw biochar treatment as compared to other treatments.

The bulk soil micro nutrient contents were sown in Table 5. The bulk soil B content was highest in BARC followed by ½ BARC, ½ BARC plus rice straw biochar, control and rice straw

Table 4. Bulk soil physiochemical properties and macro nutrient contents that were used in both incubation and pot experiments.

Treatments	Soil pH	Organic matter (%)	TN (%)	P (ppm)	K ($cmol^+$/kg)	Ca ($cmol^+$/kg)	Mg ($cmol^+$/kg)	S (ppm)
Control	8.7 (±0.01)	1.34 (±0.04)	0.08(±0.01)	13.7(±0.06)	0.27(±0.009)	14.37(±0.06)	2.67(±0.08)	28.2(±0.09)
½ BARC	8.7(±0.01)	1.39(±0.06)	0.09(±0.01)	14.2(±0.1)	0.26(±0.010)	14.13(±0.09)	2.66(±0.09)	31.6(±0.05)
BARC	8.6(±0.02)	1.31(±0.09)	0.08(±0.01)	13.2(±0.09)	0.26(±0.011)	14.05(±0.11)	2.74(±0.11)	27.9(±0.03)
Rice straw biochar	8.3(±0.03)	1.57(±0.10)	0.09(±0.01)	13.1(±0.08)	0.96(±0.013)	13.34(±0.08)	2.67(±0.09)	40.2(±0.06)
½ BARC + rice straw biochar	8.4(±0.02)	1.69(±0.09)	0.10(±0.02)	13.8(±0.07)	0.95(±0.012)	12.79(±0.07)	2.69(±0.07)	35.3(±0.03)

All values were means of three replicates.
±Standard error.

Table 5. Bulk soil micro nutrient contents that was used in both incubation and pot experiments.

Treatments	B (μg/g)	Zn (μg/g)	Fe (μg/g)	Cu (μg/g)	Mn (μg/g)
Control	1.16(±0.01)	0.64(±0.07)	11.9 (±0.07)	0.78(±0.01)	10.0(±0.01)
½ BARC	1.63(±0.05)	0.75(±0.06)	12.2(±0.08)	0.79(±0.03)	9.0(±0.03)
BARC	1.82(±0.04)	0.91(±0.05)	7.4(±0.09)	0.80(±0.02)	7.7(±0.07)
Rice straw biochar	0.81(±0.07)	0.60(±0.09)	5.8(±0.05)	0.76(±0.04)	10.2(±0.01)
½ BARC + rice straw biochar	1.33(±0.02)	0.72(±0.08)	3.1(±0.03)	0.72(±0.05)	10.5(±0.03)

All values were means of three replicates.
±Standard error.

biochar was 1.82, 1.63, 1.33, 1.16, and 0.81 μg g^{-1} respectively. Same sequence was found for bulk soil Zn content. The highest bulk soil Fe content was found ½ BARC treatments was 12.2 μg g^{-1} and lowest bulk soil Fe content was found 5.8 μg g^{-1} at ½ BARC + rice straw biochar treatment. The Cu content in bulk soil did not change significantly ($p \geq 0.05$) by and it varies from 0.72 to 0.80 μg g^{-1} in several treatments. The Mn content in BARC and ½ BARC added bulk soil was 7.7 and 9.0 μg g^{-1} respectively and other treatments varies from 10 to 10.5 μg g^{-1}.

3.3. Wheat plant growth response

Leaf area at 35 DAS was highest in ½BARC plus rice straw biochar treatment as compared to other treatments (Figure 1). Leaf area at 35 DAS for ½ BARC plus rice straw biochar, ½ BARC, BARC, rice straw biochar and control treatment was 34.16, 30.98, 30.62, 23.41, and 20.14 cm^2 respectively.

Plant height at harvest did not significantly ($p \geq 0.05$) differ among several treatments (Figure 2 and Table 6). The plant height was tended to be highest at BARC among all treatments. The plant height for BARC, ½ BARC + rice straw biochar, rice straw biochar, ½ BARC, and control treatment were 64.88, 63.23, 62.53, 62.50, and 60.39 cm, respectively.

The shoot: root ratio for ½ BARC, BARC, ½ BARC + rice straw biochar, rice straw biochar only and control treatment were 0.86, 0.85, 0.75, 0.73, and 0.66, respectively (Figure 3).

3.4. Yield contributing parameters

Spike length was highly significant ($p \geq 0.001$) among treatments (Table 7). Spike length for BARC, ½ BARC + Biochar, ½ BARC, Biochar, and control treatment were 10.61, 10.01, 9.92, 9.48, and 8.93 cm, respectively (Figure 4).

Grain yield was highly significant ($p \geq 0.05$) from treatment to treatment (Table 7). The grain yield for BARC, ½ BARC + Biochar, Biochar, ½ BARC, and control treatment was 4.30, 4.05, 3.76, 3.72, and 2.93 g/pot, respectively (Figure 5).

Biological yield was highly significant ($p \geq 0.001$) from one treatment to other (Table 7). The biological yield for BARC, ½ BARC + Biochar, Biochar, ½ BARC, and control were 10.22, 9.91, 8.95, 8.74, and 7.72 g/pot, respectively (Figure 6).

Harvest index varied significantly ($p \geq 0.05$) from treatment to treatment (Figure 7). The harvest index for ½ BARC, BARC, Biochar, and ½ BARC + Biochar treatment were 42.69%, 42.06%, 41.98%, and 40.93%, respectively.

3.5. Plant tissue nitrogen

Nitrogen content was more in shoot followed by grain and root (Figure 8). The shoot N% was 3.69, 3.27, 3.22, 3.08, and 2.93 for rice straw biochar only, ½ BARC, rice straw biochar plus ½ BARC, BARC and control treatment, respectively. The highest N% in grain was found in ½

Table 6. Significance levels from the analysis of variance (ANOVA) for the main effects on growth response of wheat plant.

Source of variation	Leaf area at 35 DAS	Plant height at harvest	Shoot: root
Treatments	n.s.	n.s.	n.s.

where n.s.,* and *** represent probability of > 0.05, ≤ 0.05 and ≤ 0.001. Values were means of three replicates.

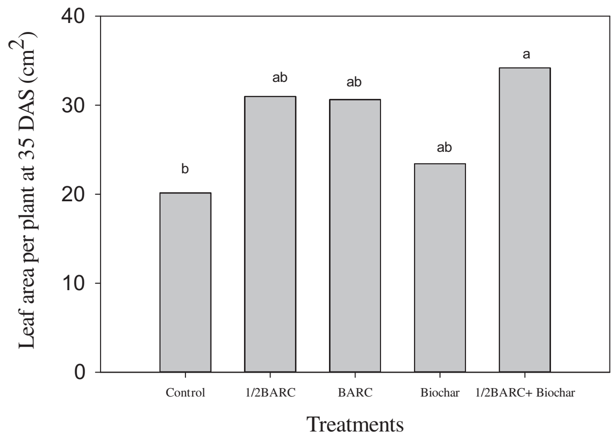

Figure 1. Leaf area per plant at 35 days after showing for wheat plant that grown in pot. Same letters are not significantly different data were means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

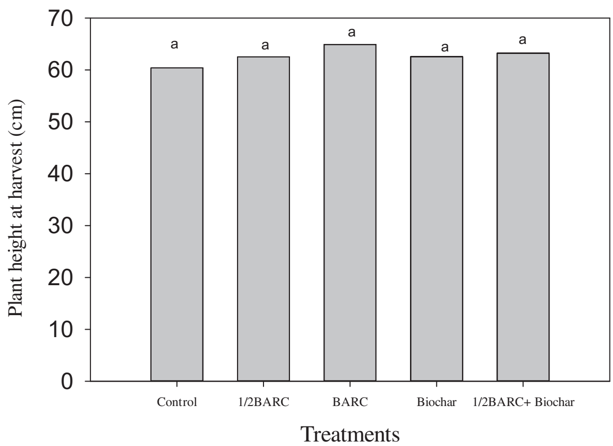

Figure 2. Plant height at harvest for wheat plant that grown in pot. Same letter are not significantly different. Data were means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

BARC plus rice straw biochar (1.72%) and lowest N% in grain was found in rice straw biochar only (1.45%). The maximum root N% was found in ½ BARC plus rice straw biochar (0.74%) and minimum root N% was found ½ BARC (0.54%) treatments.

3.6. Plant tissue carbon

Plant tissue C was highest in grain followed by shoot and root with the exceptions of rice straw biochar only treatment (Figure 9). Wheat grain C content for ½ BARC, control, BARC, ½BARC plus rice straw and rice straw biochar only treatment were 44.42%, 44.37%, 43.39%, 43.03%, and 41.86% respectively. Shoot C content for rice straw biochar, BARC, ½ BARC, control and ½ BARC plus rice straw were 50.10%, 41.39%, 41.22%, 40.89%, and 38.87%, respectively. Root C

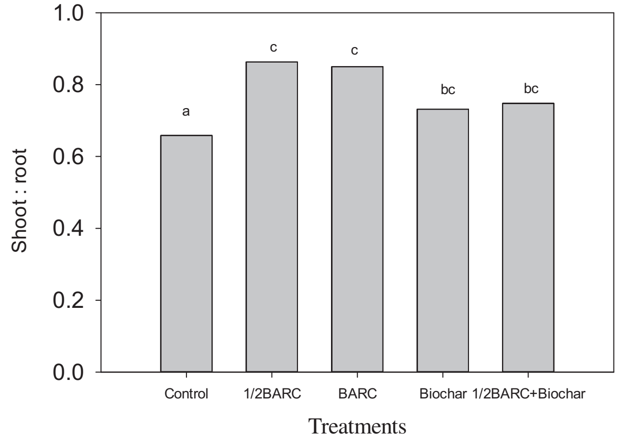

Figure 3. Shoot: root for wheat plant that grown in pot under several treatments. Same letter are not significantly different. Data were means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

Table 7. Significance levels from the analysis of variance (ANOVA) for the main effects on yield of wheat plant.

Source of variation	Spike length	Grain yield	Biological yield	Harvest index
Treatments	***	***	***	*

where n.s.,*, ** and *** represent probability of > 0.05, ≤ 0.05, ≤ 0.01 and ≤ 0.001. Values were means of three replicates.

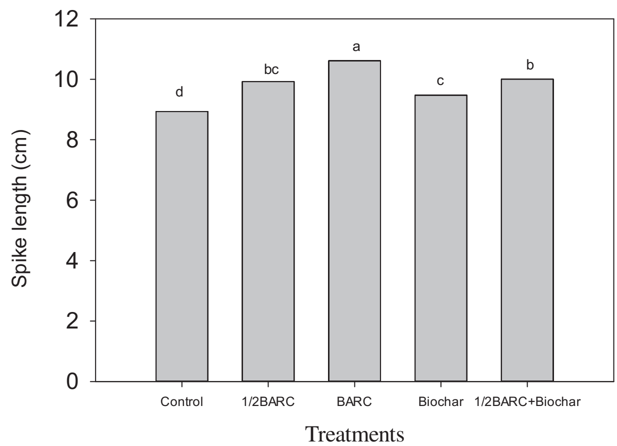

Figure 4. Spike length for wheat plant that grown in pot under several treatments. Same letter are not significantly different. Data were means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

content did not differ among treatments (Figure 9). Root C content for rice straw biochar only, control, ½ BARC, BARC, and ½ BARC plus rice straw biochar were 40.30%, 39.41%, 38.87%, 38.72%, and 38.35%, respectively.

3.7. Macro-nutrient content in root, shoot, and grain in various fertilizer management

Phosphorus (P) concentration was highest in grain followed by shoot and root (Figure 10). Wheat grain P concentration for rice straw biochar+½ BARC, BARC, control, ½ BARC, and rice straw biochar was 0.333%, 0.295%, 0.286%, 0.279%, and 0.254% respectively. Shoot and root P concentration was highest in rice straw biochar+½ BARC treatments among all treatments.

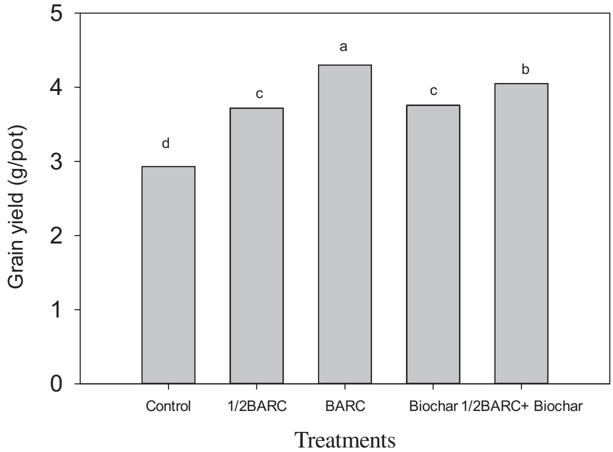

Figure 5. Grain yield for wheat plant that grown in pot under several treatments. Same letter are not significantly different. Data were means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

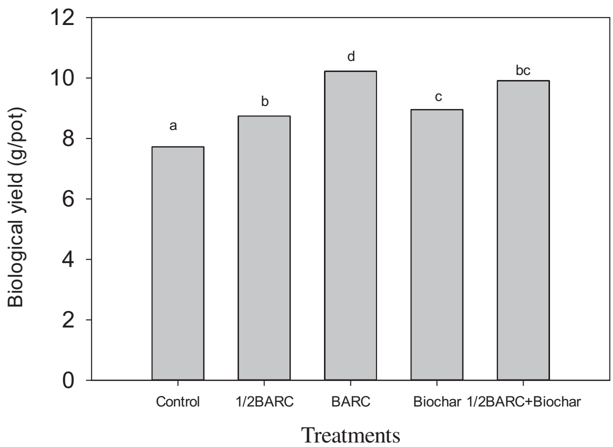

Figure 6. Biological yield for wheat plant that grown in pot under several treatments. Same letter are not significantly different. Data were means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

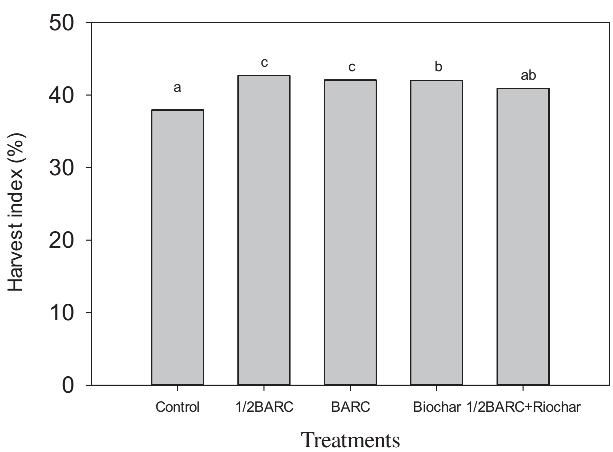

Figure 7. Harvest index for wheat plant that grown in pot under several treatments. Same letter are not significantly different. Data were means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

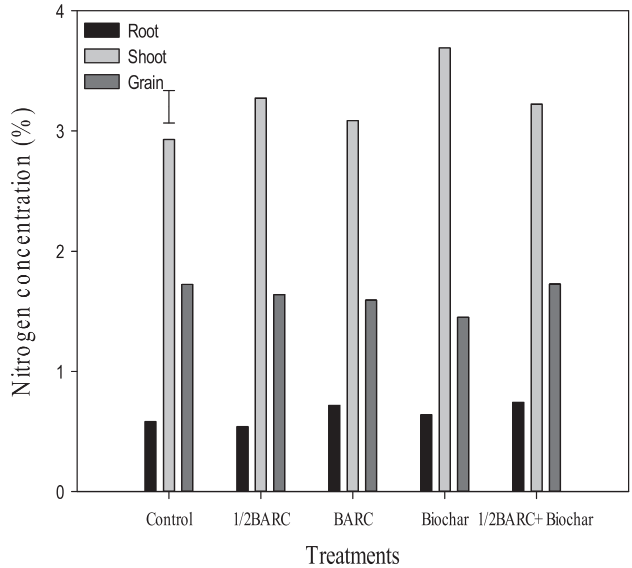

Figure 8. Nitrogen concentration in root, shoot and grain of wheat under several treatments. Vertical bar represent least significance difference ($p \geq 0.05$) for plant biomass × interaction. Data are means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

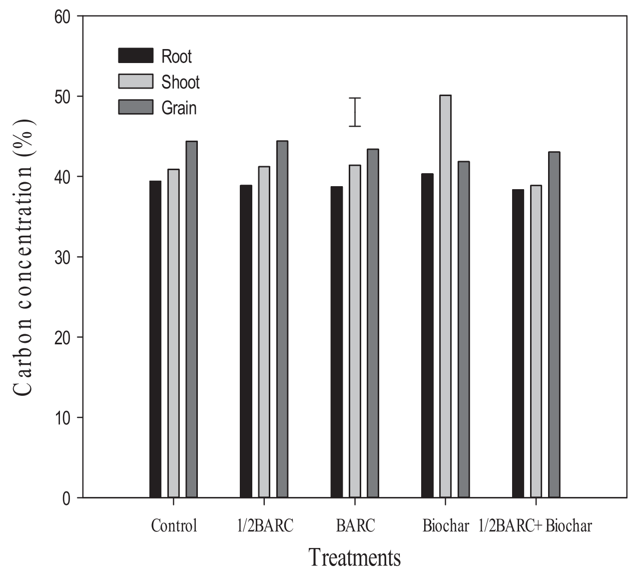

Figure 9. Carbon concentration in root, shoot and grain of wheat under several treatments. Vertical bar represent least significance difference ($p \geq 0.05$) for plant biomass × interaction. Data are means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

Potassium (K) concentration was highest in shoot followed by grain and root. The K concentration was highest in rice straw biochar+½ BARC for shoot and grain was 4.06% and 0.56%, respectively (Figure 11).

Calcium (Ca) concentration was highest in root followed by shoot and grain (Figure 12). Wheat plant root Ca concentration tended to be differed from treatment to treatment. However, wheat plant shoot and grain did not differ from treatment to treatment (Table 8).

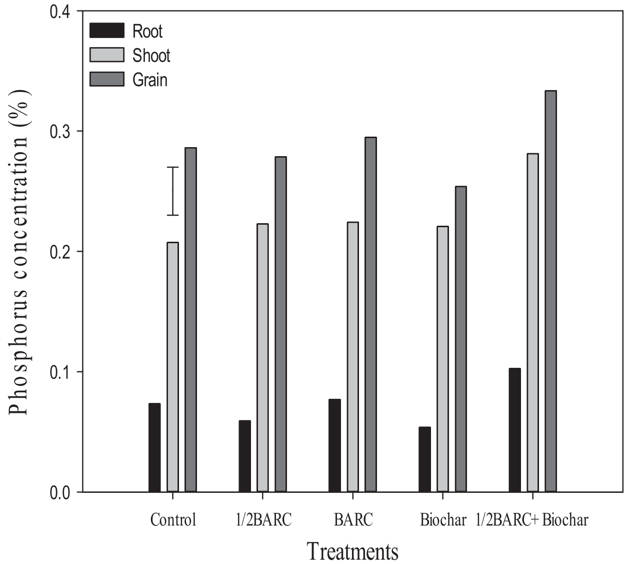

Figure 10. Phosphorus concentration in root, shoot and grain of wheat under several treatments. Vertical bar represent least significance difference ($p \geq 0.05$) for plant biomass × interaction. Data are means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

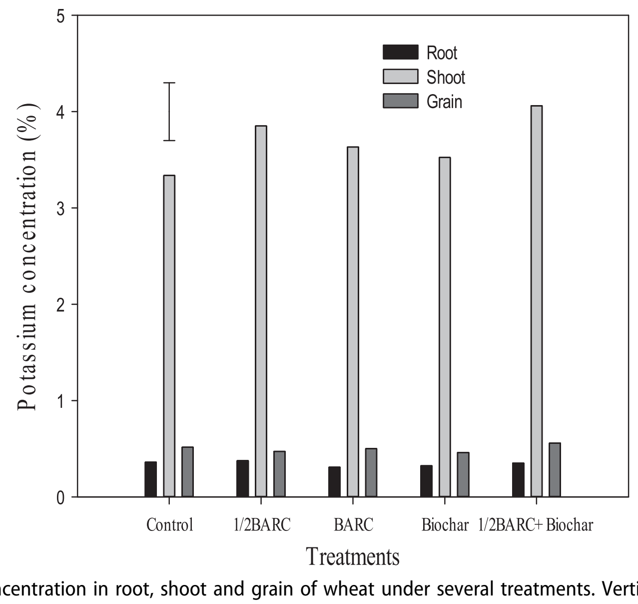

Figure 11. Potassium concentration in root, shoot and grain of wheat under several treatments. Vertical bar represent least significance difference ($p \geq 0.05$) for plant biomass × interaction. Data are means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

Magnesium (Mg) concentration was highest in shoot followed by grain and shoot (Figure 13). On average, the Mg concentration was highest in root, shoot and grain in the control treatment for the high availability of Mg in initial soil.

3.8. Micro-nutrient content in root, shoot and grain in various fertilizer management

The iron (Fe) content was highest in root followed by shoot and grain (Figure 14). The Fe content of several plant parts differs separately irrespective to fertilizer management.

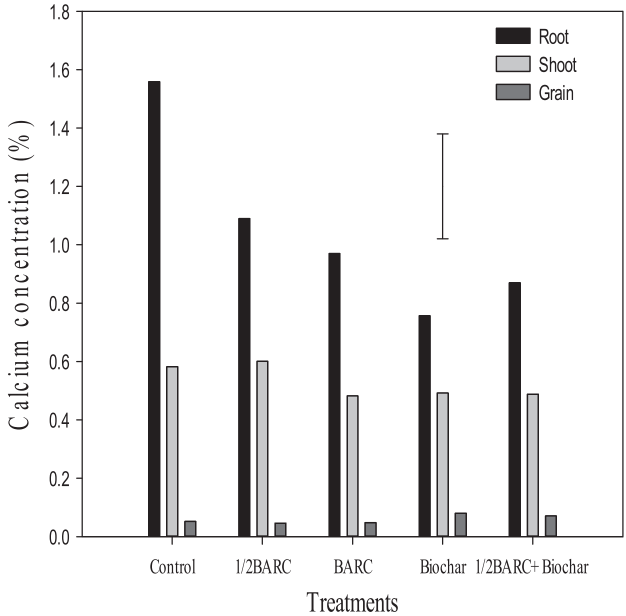

Figure 12. Calcium concentration in root, shoot and grain of wheat under several treatments. Vertical bar represent least significance difference ($p \geq 0.05$) for plant biomass × interaction. Data are means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

Table 8. Significance levels from the analysis of variance (ANOVA) for the main effects on wheat plant tissue nutrient content.

Source of variation	N%	C%	P%	Ca%	K%	Mg%	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)
Plant biomass	***	***	***	***	***	***	n.s.	***	***	***
Treatments	n.s.	**	***	n.s.	n.s.	n.s.	*	**	n.s.	n.s.
Plant biomass × treatments	***	***	n.s.	n.s.	n.s.	n.s.	n.s.	**	*	*

where n.s.,*, ** and *** represent probability of > 0.05, ≤ 0.05, ≤ 0.01 and ≤ 0.001. Values were means of three replicates.

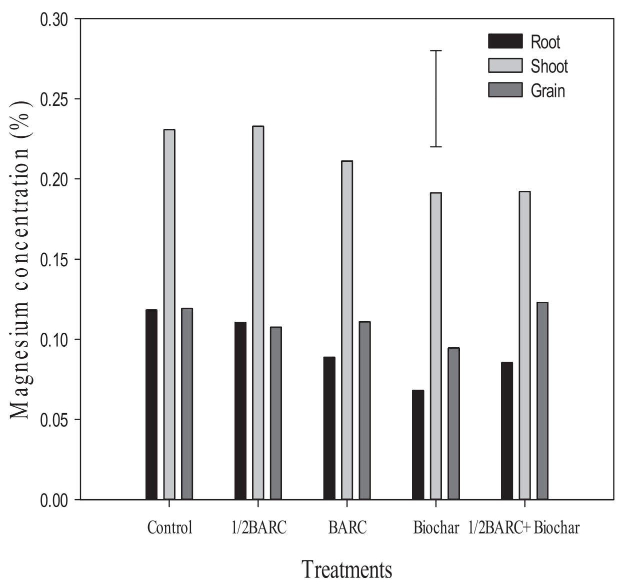

Figure 13. Magnesium concentration in root, shoot and grain of wheat under several treatments. Vertical bar represent least significance difference ($p \geq 0.05$) for plant biomass × interaction. Data are means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

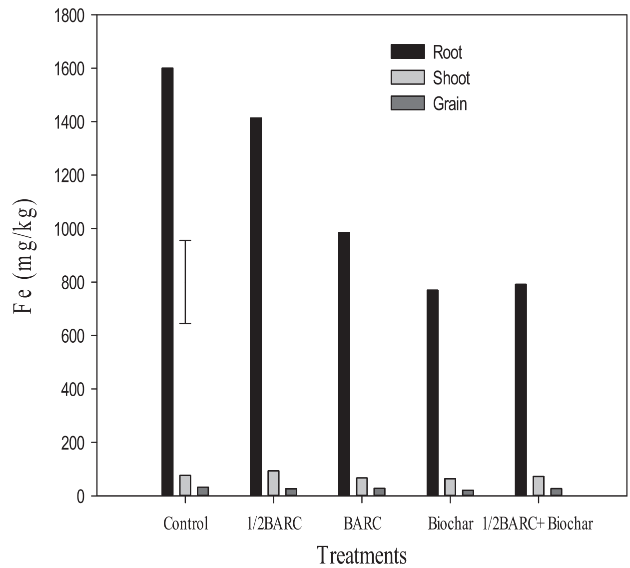

Figure 14. The Fe content in root, shoot and grain of wheat under several treatments. Vertical bar represent least significance difference ($p \geq 0.05$) for plant biomass × interaction. Data are means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

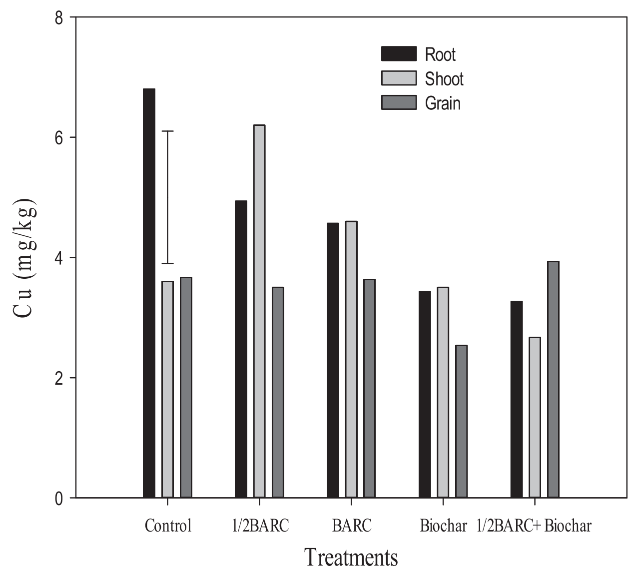

Figure 15. The Cu content in root, shoot and grain of wheat under several treatments. Vertical bar represent least significance difference ($p \geq 0.05$) for plant biomass × interaction. Data are means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

The cupper (Cu) content was highest in wheat grain at ½ BARC + biochar treatment among all treatments. The Cu content varied differently in root, shoot and grain in several treatments (Figure 15).

The manganese (Mn) content was highest in root followed by shoot and grain (Figure 16). Rice straw biochar+½ BARC treatment had highest Mn content in root, shoot, and grain.

The zinc (Zn) content was highest in shoot followed by grain and root (Figure 17). The shoot Zn content for rice straw+½ BARC, ½ BARC, rice straw biochar only, BARC, and control was 38, 30, 28, 27, and 24 mg/kg respectively. Root Zn content was highest in rice straw biochar only

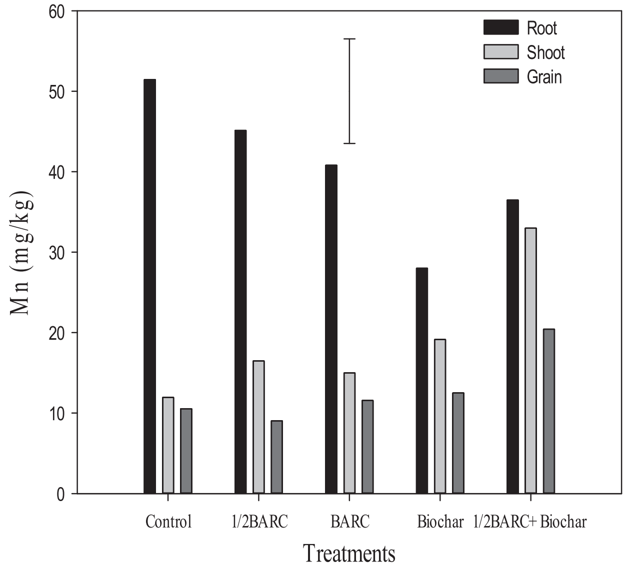

Figure 16. The Mn content in root, shoot and grain of wheat under several treatments. Vertical bar represent least significance difference ($p \geq 0.05$) for plant biomass × interaction. Data are means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

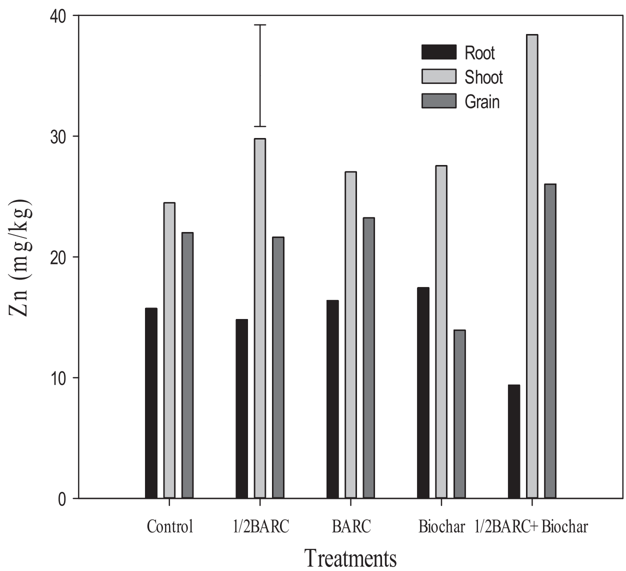

Figure 17. The Zn content in root, shoot and grain of wheat under several treatments. Vertical bar represent least significance difference ($p \geq 0.05$) for plant biomass × interaction. Data are means of three replicates. BARC, Bangladesh Agricultural Research Council; Biochar, rice straw biochar.

among other treatments. The grain Zn content was highest in rice straw biochar + ½ BARC among other treatments.

4. Discussion

4.1. Effect of rice straw biochar on soil properties

Rice straw biochar addition to soil improved soil physical and chemical properties as compared to soil without biochar amendment (Table 1). Soil pH of rice straw biochar amended soil declined 8.3–8.0 due to incubation (Table 1). Similarly, bulk soil pH declined 8.7–8.3 and 8.4 in the rice straw biochar only and ½ BARC plus rice straw biochar treatment to the control (Table 4). A study found that soil pH increased 4.8–5.4 due to 15 g kg^{-1} rice straw biochar mixing into perforated black polythene begs (Kamara, Kamara, & Kamara 2015). We mixed 16.6 g kg^{-1} rice straw biochar in plastic containers with an initial soil pH of 8.3. However, these two studies have differed initial soil pH that is one was highly acidic and other was highly alkaline soil. Acidic soil showed rice straw biochar amendment increase soil pH. In contrast, alkaline soil showed rice straw biochar amendment decreased soil pH. Likewise, Liu and Zhang (2012) found that rice straw biochar did not increase the pH of five types of alkaline soils, but instead produced a decreasing pH trend. The alkaline soil used for the study had pH of 8.3, which could have prevented any biochar liming effect. Similarly, decreasing trend in soil pH was related to lower temperature (300 °C). The slow oxidization of biochar in soils could produce carboxylic functional. This might be because of the formation of the acidic functional groups at lower temperature on surface of biochar that can neutralize alkalinity and eventually decrease soil pH (Cheng, Lehmann, & Engelhard 2008).

Soil organic matter reached 1.39%–1.89% in the rice straw biochar amended incubated soil. Likewise, soil organic increased from 1.34% to 1.69% in the rice straw biochar amended bulk soil (Tables 1 and 5). Similarly, other study also found that bulk soil organic matter increased 0.54%–4.09% from control to rice straw biochar amended treatment (Masulili, Utomo, & Syechfani 2010). As rice straw were partially decomposed during biochar preparation that results increase soil organic matter in bulk soil.

The P availability in rice straw amended incubated soil reduced to 12.5–7.90 ppm (Table 1). This may be reason that due to reduction in soil pH, P was fixed with Fe or Ca like as Fe-P and Ca-P. Bulk soil K and S content increased by 0.69 and 12 $cmol^{+}/kg$ due to rice straw biochar amendment (Table 4). Similarly, bulk soil B and Zn content increased by 0.17 and 0.08 µg/g at the 1/2BARC + rice straw biochar amendment (Table 5). Other study also speculated that biochar also directly adds some macronutrients (P, K, Na, Ca, and Mg) and micronutrients (Cu, Zn, Fe, and Mn) which are needed for sustainable agriculture to the soil (Glaser, Lehmann, & Zech 2002).

Bulk soil available K was found 0.27 $cmol^{+}kg^{-1}$ in control treatment. The bulk soil available K reached to 0.96 $cmol^{+}kg^{-1}$ in the rice straw biochar added treatment (Table 4). Other study also found that bulk soil available K was 0.20 $cmol^{+}kg^{-1}$ in control treatment and it reached to 0.51 $cmol^{+}kg^{-1}$ in the rice straw biochar amended treatment (Masulili, Utomo, & Syechfani 2010). They speculated that biochar significantly increased the K partial factor productivity only when the highest amounts of N and P fertilizer were mixed.

4.2. Effect of rice straw biochar on wheat plant productivity

Rice straw biochar has positive response on growth and yield of wheat. Result showed that several growth parameters like plant height, leaf area, shoot: root of wheat plant tended to be greater in rice straw plus ½ BARC as compared to other treatments (Figures 1–3). Similarly, yield parameters like spike length, grain yield, biological yield and harvest index were tended to be higher in rice straw biochar plus ½ BARC treatments compared to other treatments (Figures 4–7). These findings revealed that rice straw biochar amended soils increased growth and yield of wheat. It could be due to reason that some inorganic fertilizer can speed up growth and yield performance of the BARI Gom 28 when added with rice straw biochar. Gebremedhin et al. (2015) found similar results. They have conducted a pot experiment to evaluate the effect of biochar on wheat productivity and soil properties. They also have used combination of biochar and chemical fertilizer. They found that plant height at maturity for chemical fertilizer was 64.53 cm and increased to 66.8 cm due to biochar addition with chemical fertilizer. They speculated that biochar retains nutrients and water to improve wheat productivity. Other study also found that compared with chemical fertilizer application, biochar amendment to a typical Ultisol resulted in better crop growth (Peng et al., 2011). We speculated that the effect of rice straw biochar on wheat production were mainly ascribed to the properties of rice straw biochar, soil physiochemical properties and wheat variety used in this study.

4.3. Effect of rice straw biochar application on wheat plant tissue nutrient content

The average uptake of macro and micronutrient content in root, shoot and wheat grain varied remarkably with biochar treatment. Most of the macro and micronutrients were accumulated more in shoot as compared to root and wheat grain (Figures 8–17). The Ca, Mn, and Fe were accumulated more in root as compared to shoot and wheat grain (Figures 12–14). Only, P nutrition accumulated in wheat grain (Figure 10). We found that a higher P uptake into wheat was accompanied by an increased wheat yield when rice straw biochar was applied with half of recommended dose for wheat production. Other study also found that biochar incorporation with improved soil P availability enhanced P uptake and increased wheat and wheat yield by 157% and 150%, respectively (Zhao et al., 2014). Rice straw biochar enhanced P translocation within wheat plant tissue that resulted P accumulation within wheat grain. Regardless of that our soil used in this study was very low in P availability and therefore showed a significant response to the application of rice straw biochar which had a high content of P (Tables 1 and 3). On the whole, the observed increased in wheat plant growth and biomass production could be attributed to the incubated soil enhancing properties of rice straw biochar used in this study, particularly in the presence of chemical fertilizer application.

Biochar utilization tended to be decline Cu content in root, shoot and grain of wheat from without biochar amendment (Figure 15). The Cu availability in the biochar treatments may be reduced due to sorption, complexation and precipitation (Zhang et al., 2013).

The nitrogen (N) concentration in shoot significantly ($p \geq 0.05$) highest in biochar amended treatment (Figure 8). Similarly, rice straw biochar increased C concentration in shoot of wheat plant (Figure 9). This indicates that rice straw biochar helps to increase C and N concentration in the above ground biomass of wheat plant. The C and N concentration in the above ground biomass of wheat plant can be directly affected by biochar and/or fertilizer-induced changes in soil nutrient status. A study speculated that the superiority of biochar in increasing wheat plant shoot N and C concentration over chemical fertilizer according to the improvement in their availability through reduction in N leaching and soil C sequestration (Biederman & Harpole, 2013).

5. Conclusion

This study demonstrated that biochar has high potential in improving soil physio-chemical properties and nutrient availability. Findings also demonstrated that application of rice straw biochar alone is not able to supply enough nutrients for the healthy growth of wheat plant. The partial application of chemical fertilizer along with rice straw biochar resulted in an improvement of wheat production as shown by an increase in wheat plant biomass and wheat yield. Rice straw biochar also helps to increase C and N concentration in shoot and wheat grain. Rice straw biochar enhances P translocation within wheat plant tissue that resulted P accumulation in wheat grain in rice straw amended treatment. Therefore, it is clear that rice straw biochar has the potential to reduce chemical fertilizer utilization and can be act as a soil amendment.

Disclosure statement

No potential conflict of interest was reported by the authors.

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