# Utilization of biochar in improving yield of wheat in Bangladesh

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**Abstract**

Biochar is a carbon-rich co-product resulting from pyrolysis process. Biochar amendment to soil can improve productivity of wheat plant. Therefore, the utilization of biochar in improving yield of wheat in Bangladesh was investigated in this study. Soil pH decreased 0.8 units and organic matter increased 0.67% after 159 days of incubation for the biochar amendment. Several yield parameters was similar between Bangladesh Agricultural Research Council (BARC) recommended fertilizer and half of BARC recommended fertilizer plus rice straw added treatment. This study also found that the combination of rice straw biochar with half of BARC recommended fertilizer gave better effect than single application rice straw biochar as well as gave the highest yield of wheat in the same treatment. Rice straw biochar can have the potential to decrease dependence on chemical fertilizer for wheat production. Therefore, utilization of biochar is a viable option to improve yield of wheat in Bangladesh.

**Key words:** Rice straw biochar, Pyrolysis, charcoal, BARI Gom 28

## Introduction

"Biochar" is a relatively new term, yet it is not a new substance (Skjemstad *et. al*., 2002). Historical use of biochar dates back at least 2000 years (O'Neill *et. al.*, 2009). Biochar is created by heating organic material under conditions of limited or no oxygen (Lehmann 2007). The relatively long residence times (usually hours) promotes extensive secondary reactions within biochar particles and in the gas and vapour phases, leading to condensation (Sohi *et. al*,. 2010). Several researches showed that biochar has contents of carbon (C), nitrogen (N), phosphorus (P) potassium (K) and other essential macro and micronutrients depending on types of biochar (Chan and Xu 2009).

Biochar can increase microbial activity and reduce nutrient losses during composting (Dias *et. al.*, 2010). Biochar can help to supply P to many agricultural crops (Solaiman *et. al.*, 2010). The application of biochar may contribute to the nutrient uptake but the effect of biochar could be either positive or negative depending on soil characteristics and other soil microorganisms (Hammer *et. al*., 2014). Compared to other soil amendments, the high surface area and porosity of biochar enable it to adsorb or retain nutrients and water and also provide a habitat for beneficial microorganisms to flourish (Glaser *et. al.*, 2002, Lehmann and Rondon 2006, Warnock *et. al.*, 2007).

A field study showed that biochar amendment improves soil fertility and productivity of mulberry plant in Bangladesh (Ahmed *et. al.*, 2017). However, the utilization of biochar in improving yield of wheat in Bangladesh was not investigated under pot experiment. This study aims at the following objectives: (i) To quantify changes in soil physical and chemical properties on biochar amended incubated soil (ii) To investigate growth and yield of wheat grown on biochar amended incubated soil. It was hypothesized that growth and yield of wheat will be better in biochar amended incubated soil than other treatments. Likewise, soil nutrient availability will be increased due to biochar amendment.

## Materials and Methods

### 2.1 Soil

The soil was collected from the Rajshahi region which is located at 26th AEZs (Agro-ecological Zone) of Bangladesh named High Barind Tract. The texture of the soil was clayey. The organic matter status and soil fertility was low and the pH of the soil was in between 6.8-7.9 (Bhuiya *et. al.*, 2008). The experimental soil was collected from the Agronomy Farm, University of Rajshahi, Bangladesh. The soil was collected from cultivable plot in which tomato was grown before soil collection. The collected soil initial basic physical and chemical properties shown in Table 1.

**Table 1.** *Initial soil basic physical properties and nutrient contents*

| Soil pH | OM (%) | TN (%) | P (ppm) | K (me/100g) | S (ppm) | Zn (ppm) | Ca (me/100g) | Mg (me/100g) | Cu (ppm) | Fe (ppm) | B (ppm) | Mn (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

### 2.2 Chemical properties of biochar used in this study

Chemical properties of biochar vary widely, depending on the source of biomass used and the conditions of production of biochar (Lehman and Joseph, 2009). In this experiment two types of biochar like rice straw and compound biochar were used (Fig. 1 and Fig. 2). The chemical properties of biochar are given Table 2.

**Table 2.** *Chemical properties or ingredients or composition of biochar used in this experiment*

| Element evaluated | Rice straw biochar | Compound biochar |
|---|---|---|
| pH | 8.02 | 8.87 |
| Total N (%) | 1.73 | 2.05 |
| Olsen-P (mg/kg) | 33 | 49 |
| Total K (%) | 0.2 | 1.1 |
| OC (g/kg) | 54 | 67 |
| Total Na (%) | 0.22 | 0.63 |
| S (mg/kg) | 0.18 | 0.35 |
| Fe (mg/kg) | 7.79 | 8.71 |
| Ca (mg/kg) | 213 | 273 |
| Cu (mg/kg) | 0.06 | 0.09 |
| Al (mg/kg) | 0.88 | 0.99 |
| Mn (mg/kg) | 4.37 | 5.13 |
| Si (%) | 0.01 | 0.13 |
| Ash (%) | 50.35 | 39.67 |


**Figure 1**. *Pictorial view of compound biochar used in this experiment*


**Figure 2**. *Pictorial view of rice straw biochar used in this experiment*

### 2.3 Plant and seed germination technique

The recently released Bangladesh Agricultural Research Institute (BARI) wheat variety BARI Gom 28 was used as a testing plant. The pedigree of BARI Gom 28 is shown in Table 3. The yield performance of BARI Gom 28 is best among all recently BARI released wheat varieties in Rajshahi region of Bangladesh. For that reason, the BARI Gom 28 has been selected in this study. Seeds were soaked for 30 h in de-ionized water. After that it was covered with cloth for sprouting that helps to maintain optimum temperature. Seed was sprouted after 48 h.

### 2.4 Experimental design

The basic objectives of this study were twofold: (a) To quantify changes in soil chemical properties due to addition of biochar within soil. (b) Growth and yield of wheat was investigated on the biochar added incubated soil as a pot experiment. Two types of biochar like rice straw and compound biochar were used. The chemical properties or nutrient compositions or ingredients of both biochar was already shown in Table 2. The treatments were replicated three times and laid out in Randomized Complete Block Design (RCBD) for the pot experiment.

### 2.5 Soil incubation experiment

Both rice straw and compound biochar was mixed with collected soil samples. Both biochar was grinded separately before mixing with collected soil samples. The amount of rice straw biochar was incorporated 16.67 g/kg soil. Likewise, the amount of compound biochar was incorporated 66.67 g/kg soil. After biochar incorporation, soil incubation study was conducted in the laboratory to study the changes in soil physical and chemical properties due to biochar amendment within soil. Biochar amended soils were kept in six separate transparent plastic containers for two containers each like control, rich husk biochar and mineral enriched biochar during incubation experiment. Soil and biochar were mixed by agitating each container every alternative day during whole incubation period. The unamended control was also subject to disruption of mixing. Water was maintained to field capacity. Soil water was monitored by a soil moisture meter (PMS-714; Made in Taiwan) during incubation period. Maximum and minimum temperature as well as relative humidity was recorded during soil incubation experiment by a temperature humidity meter. The incubation time was 159 d in total, and soils were analyzed at 0 d, 62 d and 159 d to determine their changes in physical and chemical properties due to biochar amendment.

**Table 3.** *Pedigree of BARI Gom 28*

| Variety | Accession No. | Pedigree/ Cross | Year of Release |
|---|---|---|---|
| BARI Gom 28 | BAW 1141 | CHIL/2*STAR/4/BOW/CROW//BUC/PVN/3/2*VEE#10 CMSS95Y00624S-0100Y-0200M-17Y-010M-5Y-0M | 2012 |

**Source**: Raj et. al. (2012)

### 2.6 Fertilizer additions

Incubated soils were divided in separate plastic bags for 1 kg soils each. Several small fertilizer doses were added in separate plastic bags that contains 1 kg soil each for treatments $T_2$, $T_5$ and $T_6$ respectively according to BARC recommended fertilizer doses for wheat production in Bangladesh. Fertilizer was added according to initial soil basic physical and chemical properties. Magnesium was not added to the incubated soil due to its availability to the initial soil. Amount of fertilizer reduced to half for the half BARC recommended fertilizer treatment. The amount of fertilizer mixed within incubated soil is shown in Table 4.

**Table 4.** *Amount of BARC recommended fertilizer 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 ($MgSO_4$) | -* |
| Organic matter (Cowdung) | 2.47 g/kg soil |

*No Mg was added due to BARC recommended available Mg was found in the collected soil.

### 2.7 Treatments for pot experiment

The pot experiment was conducted in seven treatments with three replications. These are $T_0$: Control (nothing was added) $T_1$: Half of BARC recommended fertilizer for wheat production $T_2$: BARC recommended fertilizer for wheat production $T_3$: Rice straw biochar only $T_4$: Compound biochar only $T_5$: Half BARC recommended fertilizer for wheat production plus rice straw biochar $T_6$: Half BARC recommended fertilizer for wheat production plus compound biochar.

### 2.8 Pot experiment procedure

Pot was selected that contained about 1.25 kg soils each. The size of the pot was 17 cm × 17 cm × 8.5 cm. No opening was kept at the bottom of the each pot to protect leaching of nutrients from the pot. Soils were compacted properly in each pot during filling of biochar amended incubated soils and other treated incubated soils into several pots. To avoid contamination within the soil, different plastic jars and separate snap polythene bag were used for different treatments and replicated samples.  Water was maintained to the field capacity for all soils through monitoring soil moisture by soil moisture meter (PMS-714; Made in Taiwan). Twelve uniform pre-germinated seeds were placed in each pot and covered by 0.5 cm of same treated soil from the top of pots. The pots were completely randomized and re-positioned regularly during spraying or watering to minimize any effect of uneven environmental factors during plant growth period.  Plants were grown in a net house at the Department of Agronomy and Agricultural Extension, University of Rajshahi, Bangladesh.

### 2.9 Leaf area

The leaf area was measured with the help of Green Leaf Area Meter at 35 days after sowing (DAS). The specification of the green leaf area meter is Model: GA-5; Tokyo Photo electric Company Limited; Made in Japan. Two to five number of wheat plants was cut from the ground of the plant. Remaining seven numbers of plants were kept in each pot for other measurement. Harvested plants were cut into two pieces to set within the green leaf area meter. Leaf area of wheat plant was measured immediate after harvesting. After measurement of leaf area shoot were dried in air for two days and then put in an oven for shoot dry weight measurement.

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

### 2.11 Measurements of soil chemical 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 and 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 and 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, 1996). The soil available K was extracted with 1N $NH_4OAC$ 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 $NaHCO_3$ as outlined by Huq and Alam (2005). The Zn in the bulk soil sample was measured by an atomic absorption spectrophotometer (AAS) after extracting with DTPA (Soltanpour and Schwab, 1997).

### 2.12 Data Collection

In the incubation experiment, changes in soil basic physical and chemical properties due to addition of two types of biochar for 0 d, 62 d and 159 d after biochar application were analyzed. The plant growth and yield data were collected during the pot experiment. Plant growth parameters like plant height, leaf area, tiller number, panicle length, spike length, spikelet per spike, shoot dry weight were recorded. Yield parameters like thousand grain weight, grain yield, straw yield and biological yield were recorded.

### 2.13 Statistical analysis

Results were analyzed by a one-way or two-way analysis of variance (ANOVA) using Genstat 12$^{th}$ ed$^{n}$ for Windows (Lawes Agricultural Trust, UK).

## Results

### 3.1 Changes in soil pH and organic matter due to incubation after biochar amendment

Initial soil properties were changed with time during incubation (Table 5). Interestingly, soil pH declined due to biochar amendment in soil. In contrast, soil organic matter status was increased during incubation due to application of both compound and rice straw biochar . Thus, soil organic matter was significantly affected by biochar amendments.

**Table 5.** *Changes in soil pH and organic matter due to incubation*

| Days of sampling | Soil pH in water | | Soil organic matter (%) | |
|---|---|---|---|---|
| | Rice straw | Compound | Rice straw | Compound |
| 0 days | 8.3 | 8.3 | 1.4 | 1.4 |
| 62 days | 8.2 | 7.4 | 1.62 | 1.79 |
| 159 days | 8.0 | 7.5 | 1.89 | 2.07 |

### 3.2 Changes in soil macronutrients due to incubation after biochar amendment

Changes in soil macro nutrients status for the incubation experiment under biochar amendment is shown in Table 6. Interestingly, the nitrogen percentage increase with incubation time due to biochar amendment. In contrast, P content declined with incubation due to rice straw biochar amendment. However, P content initially reaches 335.10 ppm and then drop to 198.90 ppm in the compound biochar amended treatment. The potassium content of both rice husk and compound biochar was same and it increases with time. The magnesium content in both biochar increased with the increase of incubation time. The magnesium content increased about 2.5 times in rice straw and compound biochar after 159 days of incubation. On average, the calcium content did not change with incubation in both rice straw and compound biochar. The sulphar content dramatically increased in both type of biochar amendment due to incubation. This increasing trend was triple for rice straw biochar and twenty five times for compound biochar after 159 days of incubation.

**Table 6.** *Changes in soil macro nutrient status due to biochar amendment in incubation experiment*

| Days of sampling | N in percent | | P in ppm | | K in me/100g | | Ca in me/100g | | Mg in me/100g | | S in ppm | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound |
| 0 days | 0.08 | 0.08 | 29.80 | 29.80 | 0.31 | 0.31 | 15.53 | 15.53 | 2.43 | 2.43 | 36.1 | 36.1 |
| 62 days | 0.09 | 0.10 | 23.17 | 335.10 | 1.10 | 1.10 | 15.72 | 12.97 | 5.01 | 5.93 | 54.9 | 780.1 |
| 159 days | 0.10 | 0.12 | 7.90 | 198.90 | 1.11 | 1.11 | 15.89 | 13.73 | 8.13 | 8.76 | 94.3 | 907.3 |

### 3.3 Changes in soil micro nutrients due to incubation after biochar amendment

A change in soil micro nutrient status for biochar amendments due to incubation is shown in Table 7. On average, the zinc content within rice straw biochar amendment declined due to incubation. In contrast, zinc content reached double due to 159 days of incubation in compound biochar added treatment. Similarly, iron content declined due to incubation in rice straw biochar amendment. In contrast, iron content increased in compound biochar due to incubation of compound biochar. However, cupper and manganese content in both rice straw and compound biochar did not change remarkably due to incubation. But, sulphar content increased in both rice straw and compound biochar due to incubation.

**Table 7**. *Changes in soil micro nutrient status due to biochar amendment in incubation experiment.*

| Days of sampling | Zn in ppm | | B in ppm | | Fe in µg/g | | Cu in µg/g | | Mn in µg/g | | S in µg/g | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound |
| 0 days | 0.51 | 0.51 | 0.62 | 0.62 | 12.9 | 21.1 | 0.79 | 0.75 | 8.8 | 72.7 | 34.9 | 780.1 |
| 62 days | 0.31 | 0.74 | 0.40 | 4.94 | 7.4 | 22.3 | 0.76 | 0.78 | 10.2 | 75.7 | 35.9 | 785 |
| 159 days | 0.40 | 1.09 | 0.81 | 3.03 | 6.2 | 24 | 0.72 | 0.79 | 10.5 | 79.4 | 40.2 | 790 |

### 3.4 Bulk soil nutrient contents, pH and organic matter

In general, nutrient contents did not change remarkably within bulk soil due to BARC recommended fertilizer and rice straw biochar application (Table 8). Interestingly, potassium content was found three times higher in rice straw biochar added treatment than control. Like as incubation, bulk soil pH declined in rice straw biochar added treatment. In contrast, bulk soil organic matter increased in rice straw biochar added treatment.

**Table 8.** *Bulk soil chemical properties and macro nutrient contents*

| Treatments | Soil pH | Organic matter (%) | TN (%) | P (µg/g) | K ($cmol^+$/kg) | Ca ($cmol^+$/kg) | Mg ($cmol^+$/kg) | S (µg/g) |
|---|---|---|---|---|---|---|---|---|
| Control | 8.7 | 1.34 | 0.08 | 13.7 | 0.27 | 14.37 | 2.67 | 28.2 |
| ½ BARC | 8.7 | 1.39 | 0.09 | 14.2 | 0.26 | 14.13 | 2.66 | 31.6 |
| BARC | 8.6 | 1.31 | 0.08 | 13.2 | 0.26 | 14.05 | 2.74 | 27.9 |
| Rice straw | 8.3 | 1.57 | 0.09 | 13.1 | 0.96 | 13.34 | 2.67 | 40.2 |
| ½ BARC + Rice straw | 8.4 | 1.69 | 0.10 | 13.8 | 0.95 | 12.79 | 2.69 | 35.3 |

Bulk soil micro nutrient contents were shown in Table 9. Interestingly, iron and copper content declined in rice straw biochar added treatment than control. Other micro nutrient content like boron, zinc and manganese did not changed due to BARC recommended fertilizer and biochar application.

**Table 9.** *Bulk soil micro nutrient contents*

| Treatments | B (µg/g) | Zn (µg/g) | Fe (µg/g) | Cu (µg/g) | Mn (µg/g) |
|---|---|---|---|---|---|
| Control | 1.16 | 0.64 | 11.9 | 0.78 | 10.0 |
| ½ BARC | 1.63 | 0.75 | 12.2 | 0.79 | 9.0 |
| BARC | 1.82 | 0.91 | 7.4 | 0.80 | 7.7 |
| Rice straw | 0.81 | 0.60 | 5.8 | 0.76 | 10.2 |
| ½ BARC + Rice straw | 1.33 | 0.72 | 3.1 | 0.72 | 10.5 |

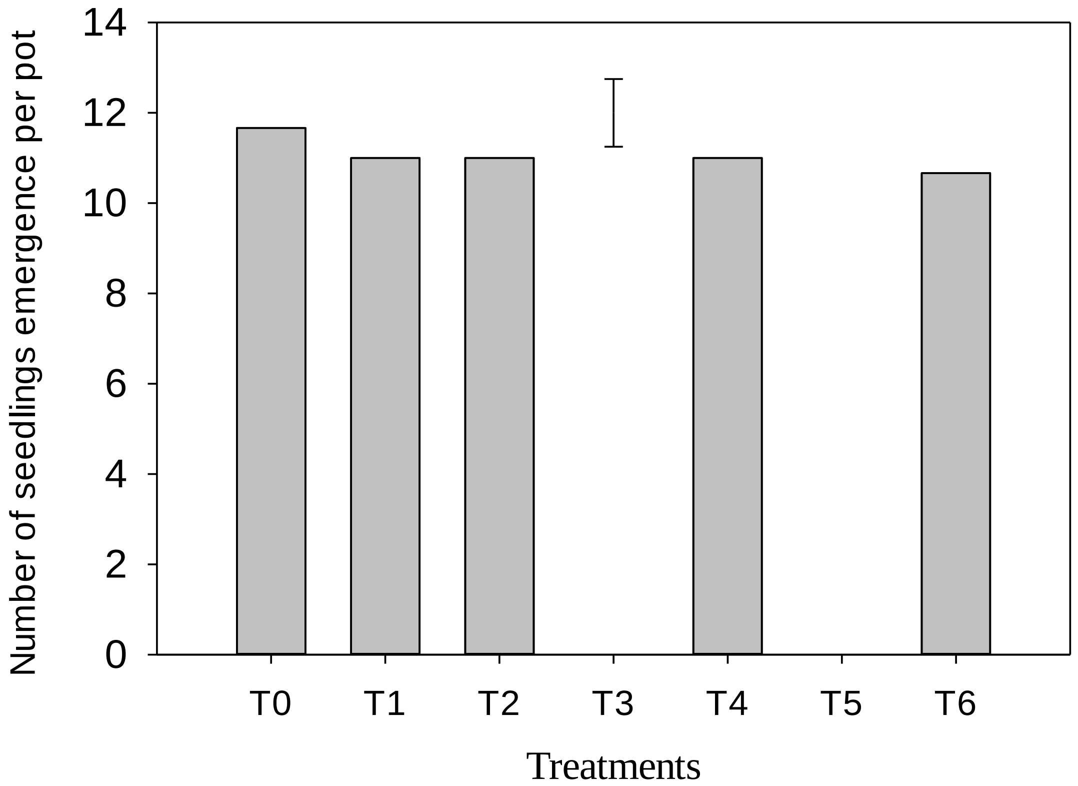


**Figure.3.** *Number of seedlings emergence in several treatments. Vertical bar indicates LSD ($P \geq 0.05$) for treatment interaction. $T_0$ = Control, $T_1$= Half of BARC recommended fertilizer, $T_2$= BARC recommended fertilizer, $T_3$= compound biochar only, $T_4$ = rice straw biochar only, $T_5$=half of BARC recommended fertilizer plus compound biochar and $T_6$ = half of BARC recommended fertilizer plus rice straw biochar.*

### 3.5 Biochar effect on wheat plant growth response

The number of seedlings emerged did not significantly differ among several treatments at 6 days after sowing (DAS). However, seedlings did not come out compound biochar and half BARC plus compound biochar treatments (Fig. 3).

Increase in plant height with respect to Days after Sowing (DAS) is shown in Fig. 4(a-d). Initially, plant height of rice straw biochar and ½ BARC plus rice straw biochar was lower compared to control, ½ BARC and BARC treatment. However, this difference became closer with DAS. The plant height at 21 DAS for control, ½ BARC, BARC, rice husk biochar and ½ BARC plus rice husk biochar were 29.63, 30.13, 31.03, 27.27 and 28.12 cm respectively. Similarly, the plant height at 43 DAS for control, ½ BARC, BARC, rice husk biochar and ½ BARC plus rice husk biochar were 38.10, 39.67, 42.61, 40.72 and 42.47 cm respectively. Likewise, the plant height at 60 DAS for control, ½ BARC, BARC, rice husk biochar and ½ BARC plus rice husk biochar were 51.53, 53.40, 55.90, 53.15 and 54.67 cm respectively.

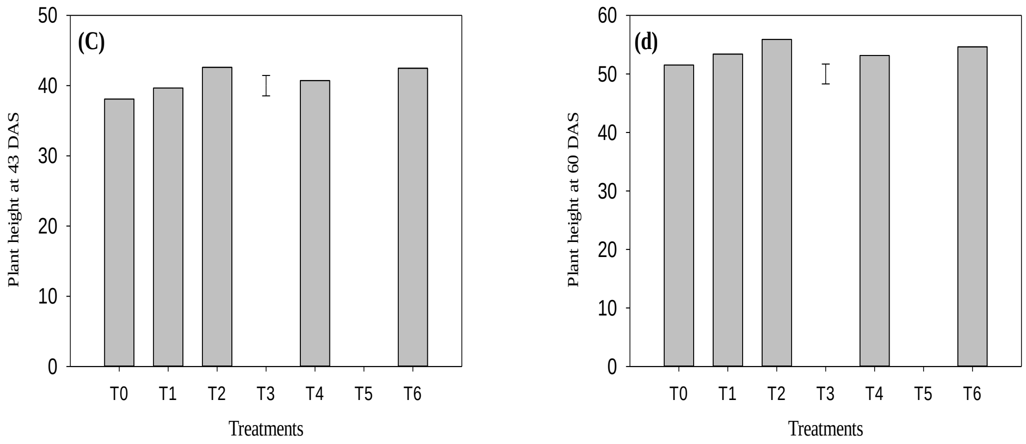


**Figure 4(a-d):** Plant height at 8 DAS in several treatments. Vertical bar indicates LSD ($P \geq 0.05$) for treatment interaction. $T_0$ = Control, $T_1$= Half of BARC recommended fertilizer, $T_2$= BARC recommended fertilizer, $T_3$= compound biochar only, $T_4$ = rice straw biochar only, $T_5$=half of BARC recommended fertilizer plus compound biochar and $T_6$ = half of BARC recommended fertilizer plus rice straw biochar.

The wheat plant height at harvest for several treatments was shown in Fig. 5. The plant height at harvest for control, ½ BARC, BARC, rice husk biochar and ½ BARC plus rice husk biochar were 60.40, 62.50, 64.88, 62.58 and 63.23 cm respectively. Statistical result showed that plant height at 60 DAS and harvest did not differ significantly between BARC and ½ BARC plus rice straw biochar treatments (Table 10). This indicates that biochar can be utilized with the reduction rate of inorganic chemical fertilizer. It will help to minimize chemical fertilizer application in Bangladesh agriculture which will improve soil fertility and wheat productivity.

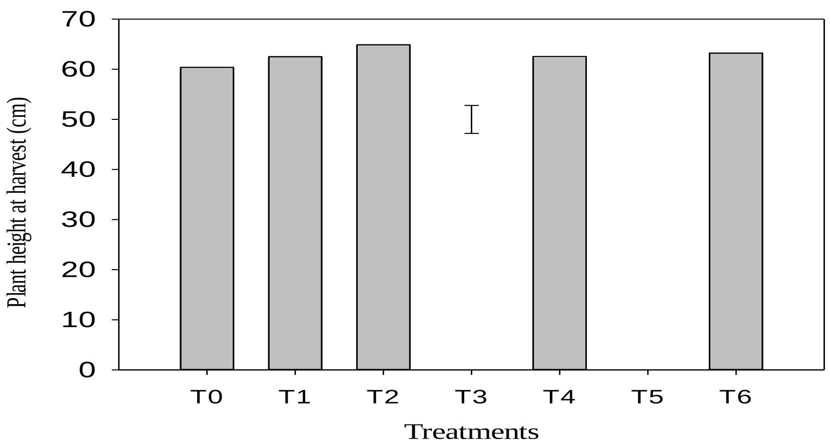


**Figure 5.** *Wheat plant height at harvest for several treatments. Vertical bar indicates LSD ($P \geq 0.05$) for treatment interaction. $T_0$ = Control, $T_1$= Half of BARC recommended fertilizer, $T_2$= BARC recommended fertilizer, $T_3$= compound biochar only, $T_4$ = rice straw biochar only, $T_5$=half of BARC recommended fertilizer plus compound biochar and $T_6$ = half of BARC recommended fertilizer plus rice straw biochar.*

Interestingly, the leaf area per plant was significantly ($P \geq 0.05$) highest in half BARC plus rice straw biochar treatment as compared to other treatments (Fig. 6). The lowest leaf area was found in the control treatment where nothing was added within soil. Half BARC, BARC and rice straw treatment did not differ significantly ($P \geq 0.05$) irrespective to leaf area. However, these treatments tended to be higher than control treatment.

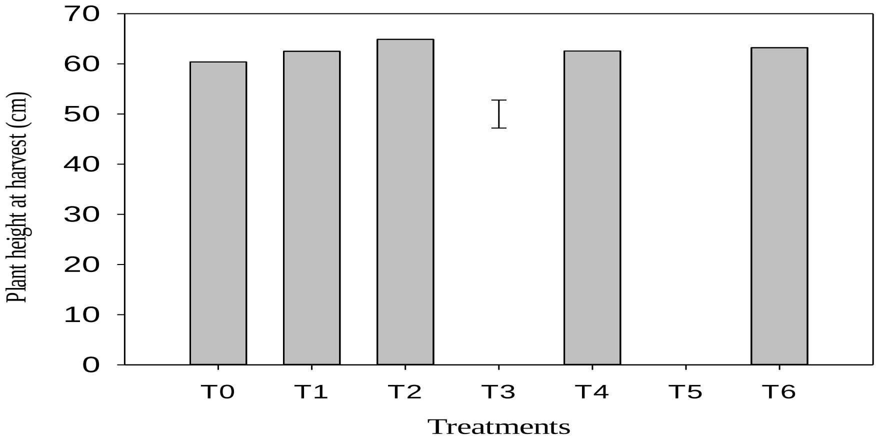


**Figure 6.** *Wheat plant height at harvest for several treatments. Vertical bar indicates LSD ($P \geq 0.05$) for treatment interaction. $T_0$ = Control, $T_1$= Half of BARC recommended fertilizer, $T_2$= BARC recommended fertilizer, $T_3$= compound biochar only, $T_4$ = rice straw biochar only, $T_5$=half of BARC recommended fertilizer plus compound biochar and $T_6$ = half of BARC recommended fertilizer plus rice straw biochar.*

The shoot dry weight at 35 DAS for ½ BARC and BARC treatment was highest followed by the rice straw biochar treatments (Fig. 6). This could be due to the reason that rice straw biochar release slow nutrients that resulted less nutrient uptake by the wheat plant. However, all treatments had significantly ($P \geq 0.05$) higher shoot dry weight at 35 DAS than the control i.e nothing added treatment (Table 10).

**Table 6**. *Changes in soil macro nutrient status due to biochar amendment in incubation experiment*

| Days of sampling | N in percent | | P in ppm | | K in me/100g | | Ca in me/100g | | Mg in me/100g | | S in ppm | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound |
| 0 days | 0.08 | 0.08 | 29.80 | 29.80 | 0.31 | 0.31 | 15.53 | 15.53 | 2.43 | 2.43 | 36.1 | 36.1 |
| 62 days | 0.09 | 0.10 | 23.17 | 335.10 | 1.10 | 1.10 | 15.72 | 12.97 | 5.01 | 5.93 | 54.9 | 780.1 |
| 159 days | 0.10 | 0.12 | 7.90 | 198.90 | 1.11 | 1.11 | 15.89 | 13.73 | 8.13 | 8.76 | 94.3 | 907.3 |

Rice straw biochar had remarkable effect on root proliferation. The root proliferation after harvest was similar between ½ BARC and rice straw treatment. Similarly, root proliferation was same between BARC and ½ BARC plus rice straw treatment. Rice straw biochar treatments noticeably facilitate root proliferation in this experiment (Fig. 9). This may help to more nutrient uptake by wheat plant in the rice straw added treatments.

### 3.6 Effect of rice straw biochar on yield of wheat

The spike length was highest in BARC treatment followed by ½ BARC in combination with rice straw biochar, rice straw biochar only, ½ BARC only and nothing added treatments (Fig. 10). The spike length pot for control, ½ BARC, BARC, rice husk biochar and ½ BARC plus rice husk biochar were 8.93, 9.92, 10.61, 9.48 and 10.1 cm respectively.

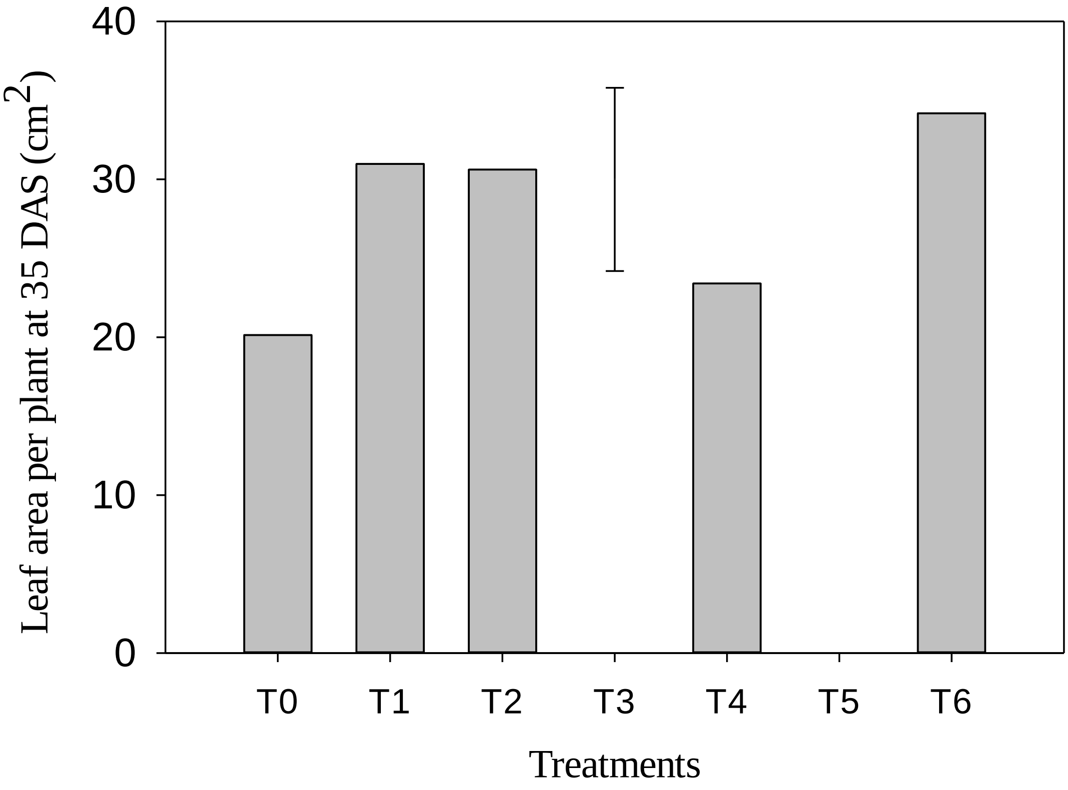


**Figure 7.** *Leaf area at 35 DAS in several treatments. Vertical bar indicates LSD ($P \geq 0.05$) for treatment interaction. $T_0$ = Control, $T_1$= Half of BARC recommended fertilizer, $T_2$= BARC recommended fertilizer, $T_3$= compound biochar only, $T_4$ = rice straw biochar only, $T_5$=half of BARC recommended fertilizer plus compound biochar and $T_6$ = half of BARC recommended fertilizer plus rice straw biochar.*

The thousand grain weight was similar between BARC and combined ½ BARC with rice straw biochar amended treatment (Fig. 11). The thousand grain weight per pot for control, ½ BARC, BARC, rice husk biochar and ½ BARC plus rice husk biochar were 44.53, 46.33, 47.93, 46.13 and 47.53 g/pot respectively.

The grain yield was similar between BARC and ½ BARC plus rice straw biochar treatment (Fig. 12). However, grain yield significantly ($P \geq 0.05$) increased all inorganic fertilizer and rice straw biochar amended treatments as compared to control i.e nothing added treatment.

Like as grain yield the straw yield was similar between BARC and ½ BARC plus rice straw biochar treatment (Fig. 13). Straw yield significantly ($P \geq 0.05$) increased among all treatments from the nothing added treatment (Table 11). The straw yield for control, ½ BARC, BARC, rice husk biochar and ½ BARC plus rice husk biochar were 4.79, 5.02, 5.92, 5.20 and 5.86 g/pot respectively.

**Table 7.** Changes in soil micro nutrient status due to biochar amendment in incubation experiment.

| Days of sampling | Zn in ppm | | B in ppm | | Fe in µg/g | | Cu in µg/g | | Mn in µg/g | | S in µg/g | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound | Rice straw | Compound |
| 0 days | 0.51 | 0.51 | 0.62 | 0.62 | 12.9 | 21.1 | 0.79 | 0.75 | 8.8 | 72.7 | 34.9 | 780.1 |
| 62 days | 0.31 | 0.74 | 0.40 | 4.94 | 7.4 | 22.3 | 0.76 | 0.78 | 10.2 | 75.7 | 35.9 | 785 |
| 159 days | 0.40 | 1.09 | 0.81 | 3.03 | 6.2 | 24 | 0.72 | 0.79 | 10.5 | 79.4 | 40.2 | 790 |

## Discussion

**4.1 Incubation effect**Both rice straw and compound biochar has potentiality to increase soil organic matter and reduce soil pH due to incubation (Table 5). Biochar amendment decreased soil pH by 0.3 units for rice straw biochar and 0.9 for compound biochar. A similar type of incubation study found that biochar incorporation declined soil pH with time (Liu and Zhang, 2012). They speculated that acidic materials produced by the oxidation of biochar and organic matters may have caused the pH decrease. Because, the formation of the acidic functional groups can neutralize alkalinity and eventually decrease soil pH. Similarly, the dilution of the cations in the biochar may decrease soil pH at the initial phase when biochar is mixed with soils. Findings also indicated that soil organic matter status dramatically increased in biochar amended soil. This increasing trend also rapidly rises with incubation time (Table 5). Increases in soil organic matter by biochar amendment were also observed by a number of researchers (McHenry, 2011). Likewise, Ming *et. al.* (2015) found that the biochar-amended soils had 37.7, 7.3 and 227.6% more soil organic carbon (SOC) than the control soil. It may be due to the reason that concerning possible priming effect whereby accelerated decomposition of soil organic matter occurs upon biochar addition to soil (Verheijen *et. al.*, 2009). Other short term (59 d) incubation study found that biochar amendment reduced soil pH and increased soil organic matter (Wu *et. al.,* 2014). They speculated that soil pH reduction in biochar amended soil due to loss of acidity in pyrolysis process. Lower pH is beneficial for the dissolution and activation of some difficult soluble elements thus increasing the ionic concentration of soil solution (Yuan and Xu’2011). However, many reports have showed soil pH increases due to biochar application (Yuan *et. al.,* 2011). Most of these studies have been performed on acidic soils with low pH in comparison to the biochar pH. This study was conducted in alkaline soil with an initial soil pH was 8.3 as well as rice straw biochar pH was 8.02 and compound biochar pH was 8.87 (Table 5 and Table 2). Liu and Zhang (2012) reported that alkaline 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 also pH of 8.3, which could have prevented any biochar liming effect. High pH soil could result in lowering pH in the high pH biochar amended soils. Because, biochar is not at all inert and can be oxidized in soil, especially at its surface (Cheng *et. al.*, 2006). This clearly indicated that biochar amended incubated soil has the potential to increase soil organic matter and reduce soil pH.

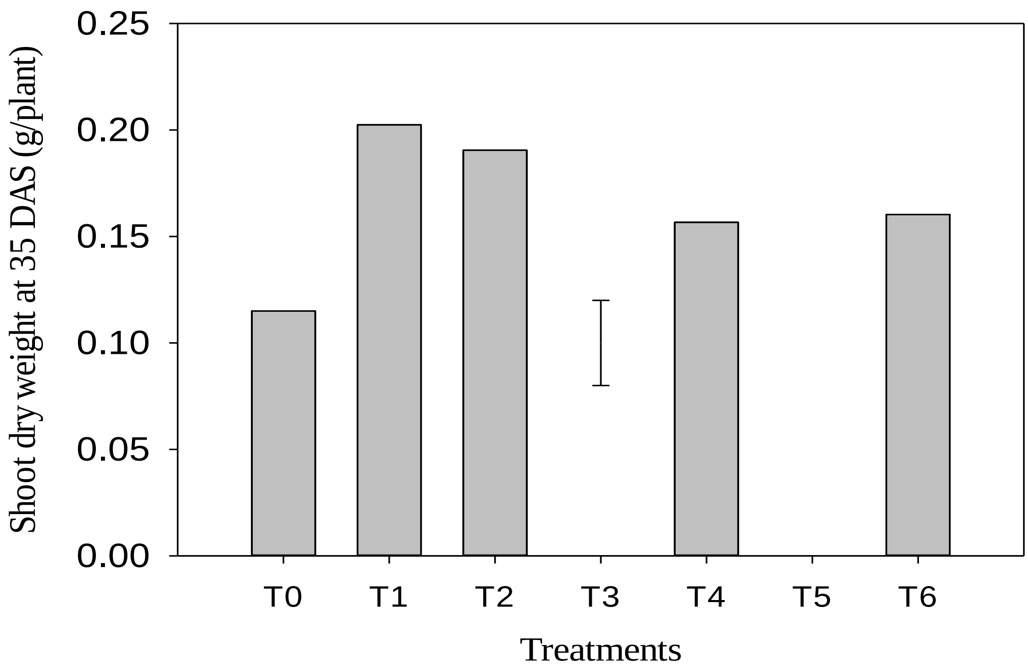


**Figure 8.** *Shoot dry weight at 35 DAS in several treatments. Vertical bar indicates LSD (P > 0.05) for treatment interaction.* $T_0$ *= Control,* $T_1$*= Half of BARC recommended fertilizer,* $T_2$*= BARC recommended fertilizer,* $T_3$*= compound biochar only,* $T_4$ *= rice straw biochar only,* $T_5$*=half of BARC recommended fertilizer plus compound biochar and* $T_6$ *= half of BARC recommended fertilizer plus rice straw biochar.*

### 4.2 Effect of compound biochar on wheat germination

Compound biochar has negative effect on wheat germination. The coleoptile was not able to come out in the compound biochar added treatment (Fig. 3). It was tried two times to survive wheat seedlings through transplantation. But, it was not succeeded. This could be due to the reason that the rate of compound biochar application was high. It is necessary to judge the compound biochar effect on germination of wheat plant. Because, applied compound biochar amendment rate was high (66.67 g/kg soil) in this experiment. Several study also viewed similar opinion. Rondon *et. al.*, (2007) found that instances of decreasing yield due to a high biochar application rate were reported when the equivalent of 165 t of compound biochar/ha was added to a poor soil in a pot experiment. It was hypothesized that germination, growth and yield of wheat plant will be highest in compound biochar treatment among other treatments. However, it could not be happen due to application of high rate compound biochar. Further, experiment will be conducted in the following year with the reduction of compound biochar application rate for wheat production.

**Table 8.** *Bulk soil chemical properties and macro nutrient contents*

| Treatments | Soil pH | Organic matter (%) | TN (%) | P (μg/g) | K ($cmol^+/kg$) | Ca ($cmol^+/kg$) | Mg ($cmol^+/kg$) | S (μg/g) |
|---|---|---|---|---|---|---|---|---|
| Control | 8.7 | 1.34 | 0.08 | 13.7 | 0.27 | 14.37 | 2.67 | 28.2 |
| ½ BARC | 8.7 | 1.39 | 0.09 | 14.2 | 0.26 | 14.13 | 2.66 | 31.6 |
| BARC | 8.6 | 1.31 | 0.08 | 13.2 | 0.26 | 14.05 | 2.74 | 27.9 |
| Rice straw | 8.3 | 1.57 | 0.09 | 13.1 | 0.96 | 13.34 | 2.67 | 40.2 |
| ½ BARC + Rice straw | 8.4 | 1.69 | 0.10 | 13.8 | 0.95 | 12.79 | 2.69 | 35.3 |

### 4.3 Biochar amendments improves nutrient availability in soil

Biochar amendments are potential to improve nutrient availability in soil. Application of biochar increase N and K availability in soil (Table 6). Other study also found similar result. Tammeorg *et. al.,* (2014) evaluated 0, 5, 10, 20 and 30 t/ ha of biochar without inorganic fertilizer and found that biochar improved N and K content in soil. Similarly, Mg content increased with incubation in both rice straw and compound biochar (Table 6). Nigusse *et. al.,* (2012) evaluated 0, 5 and 10 t/ha of biochar in a field experiment. They found that Mg content increased 6.91 to 7.12 ppm due to this biochar amendment.

**Table 9.** *Bulk soil micro nutrient contents*

| Treatments | B (μg/g) | Zn (μg/g) | Fe (μg/g) | Cu (μg/g) | Mn (μg/g) |
|---|---|---|---|---|---|
| Control | 1.16 | 0.64 | 11.9 | 0.78 | 10.0 |
| ½ BARC | 1.63 | 0.75 | 12.2 | 0.79 | 9.0 |
| BARC | 1.82 | 0.91 | 7.4 | 0.80 | 7.7 |
| Rice straw | 0.81 | 0.60 | 5.8 | 0.76 | 10.2 |
| ½ BARC + Rice straw | 1.33 | 0.72 | 3.1 | 0.72 | 10.5 |

A study showed that K, Mg and Ca content was 0.09, 0.21 and 0.31 $cmol^+/kg$ soil in a fine sandy loam soil. However, K, Mg and Ca content reached to 0.23, 0.34 and 0.31 $cmol^+/kg$ soil due to rice straw biochar amendment. Similarly, Major *et. al.*, (2010) attributed the greater crop yield and nutrient uptake in their 4 year field trial to 77-320% more Ca and Mg in soil where biochar was applied. The increased N content in biochar amended soil may be due to the biochar efficiency to adsorbs ammonia ($NH_3$) and acts as a binder for ammonia in soil, therefore, having the potential to decrease ammonia volatilization losses from soil (Oya and Iu, 2002). Regardless of that bulk soil N,P and K status increased with combining biochar with ½ BARC recommended treatment (Table 8). Likewise, Gandahi *et. al.,* (2015) residual N, P and K status in soil increased in the integrating rice straw biochar with N, P and K fertilizers on a low fertility soil. They speculated that although residual N, P and K status in soil increased but increase in soil pH was not good sign for calcareous soils and it was may be due to alkali nature of rice husk biochar.

**Table 10**. *Significance levels from the analysis of variance for the main effects on growth response of wheat seedlings.*

| Source of variation | Seedling emergence | Plant height at 8 DAS | Plant height at 21 DAS | Plant height at 43 DAS | Plant height at 60 DAS | Plant height at harvest | Leaf area at 35 DAS | Shoot dry weight at 35 DAS |
|---|---|---|---|---|---|---|---|---|
| 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.

**Table 11**. *Significance levels from the analysis of variance for the main effects on yield response of wheat plant.*

| Source of variation | Spike length | Thousand grain weight | Grain yield | Straw yield |
|---|---|---|---|---|
| Treatments | *** | * | *** | ** |

### 4.4 Effect of rice straw biochar on wheat production

Rice straw biochar has positive response on growth and yield of wheat. Result showed that several growth parameters like plant height, leaf area and shoot dry weight of wheat plant tended to be greater in rice straw biochar only compared to control (Fig. 2 to Figure 8). Similarly, several yield parameters like spike length, thousand grain weight, grain yield and straw yield were higher in rice straw biochar only compared to control (Fig. 9 to Fig. 12). These both growth and yield parameters were also more in combined half BARC plus rice straw biochar than only rice straw biochar treatment. These indicate 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 effect of biochar on wheat productivity and soil properties. They also have used combination of biochar and chemical fertilizer.

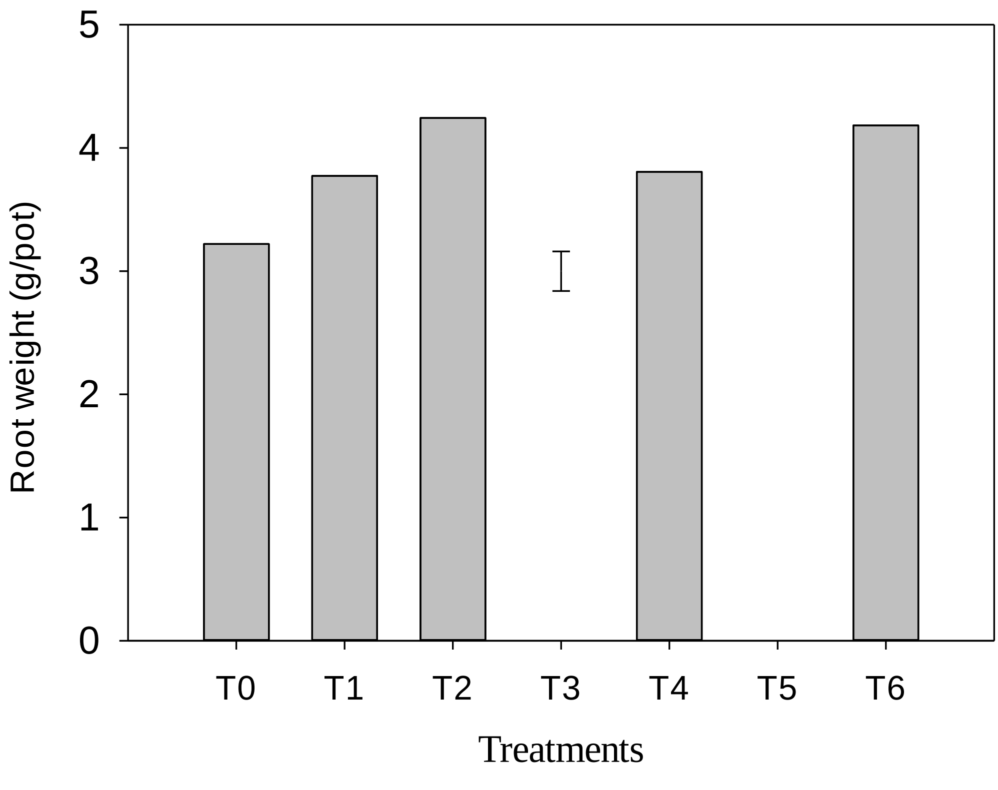


**Figure 9**. *Root dry weight after harvest in several treatments. Vertical bar indicates LSD (P > 0.05) for treatment interaction.* $T_0$ *= Control,* $T_1$*= Half of BARC recommended fertilizer,* $T_2$*= BARC recommended fertilizer,* $T_3$*= compound biochar only,* $T_4$ *= rice straw biochar only,* $T_5$*=half of BARC recommended fertilizer plus compound biochar and* $T_6$ *= half of BARC recommended fertilizer plus rice straw biochar.*

They found that plant height at maturity for chemical fertilizer was 64.53 cm and increased to 66.8 cm due to combined biochar and chemical fertilizer application. This study also showed that plant height at maturity for chemical fertilizer (half of BARC recommendation) was 62.50 cm and it reached to 63.23 cm due to addition of rice straw biochar with half of BARC recommended chemical fertilizer for wheat production (Fig. 5). Other growth and yield parameters also increase in combined chemical fertilizer and rice straw biochar added treatment. Similarly, in this experiment other growth and yield parameters also increased in combined chemical fertilizer and rice straw biochar added treatment (Fig. 6 to Fig. 12). It was speculated that biochar retains nutrients and water to improve wheat productivity. Likewise, Lehman *et. al.*, (2003) speculated that biochar serves as a direct source of nutrients for plant uptake that results increased wheat production. Similarly, Vaccari *et. al.*, (2011) found that biochar application increased wheat yield by 30%.

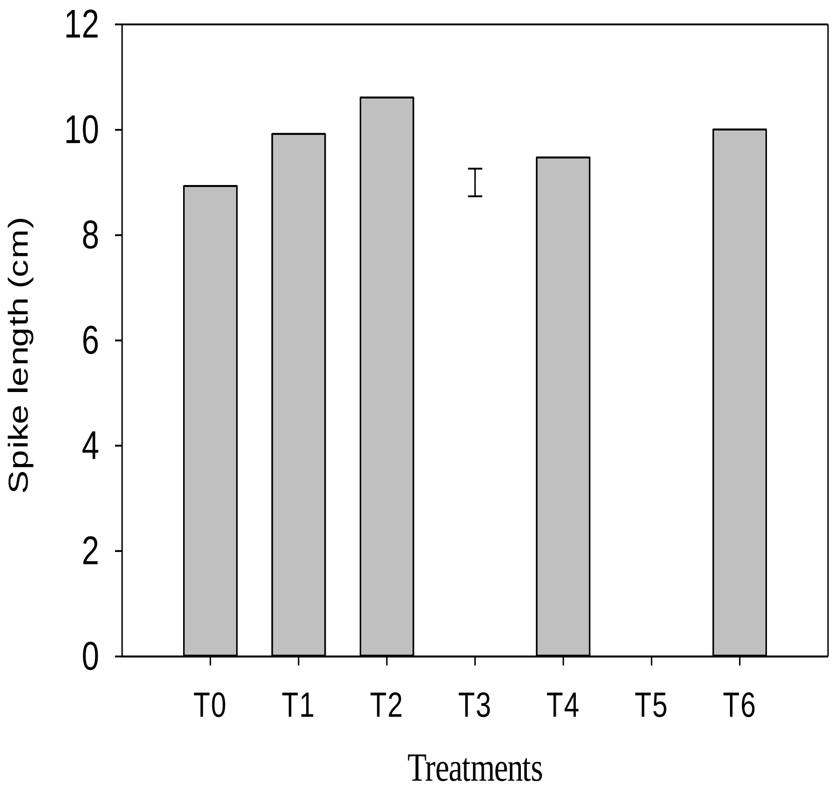


**Figure 10.** *Spike length of wheat plant in several treatments. Vertical bar represents LSD (P > 0.05) for treatment interaction.* $T_0$ *= Control,* $T_1$*= Half of BARC recommended fertilizer,* $T_2$*= BARC recommended fertilizer,* $T_3$*= compound biochar only,* $T_4$ *= rice straw biochar only,* $T_5$*=half of BARC recommended fertilizer plus compound biochar and* $T_6$ *= half of BARC recommended fertilizer plus rice straw biochar.*

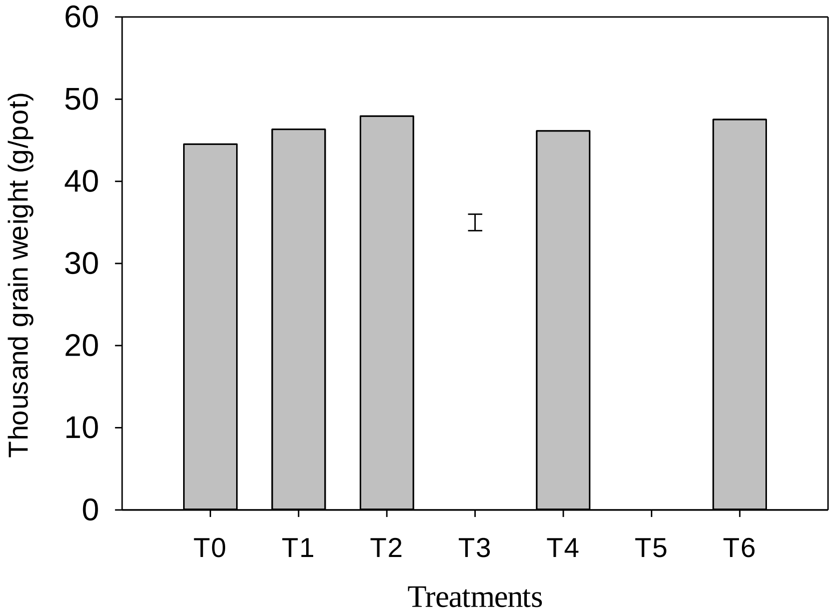


**Figure 11.** *Thousand grain weight in several treatments. Vertical bar indicates LSD (P > 0.05) for treatment interaction.* $T_0$ *= Control,* $T_1$*= Half of BARC recommended fertilizer,* $T_2$*= BARC recommended fertilizer,* $T_3$*= compound biochar only,* $T_4$ *= rice straw biochar only,* $T_5$*=half of BARC recommended fertilizer plus compound biochar and* $T_6$ *= half of BARC recommended fertilizer plus rice straw biochar.*

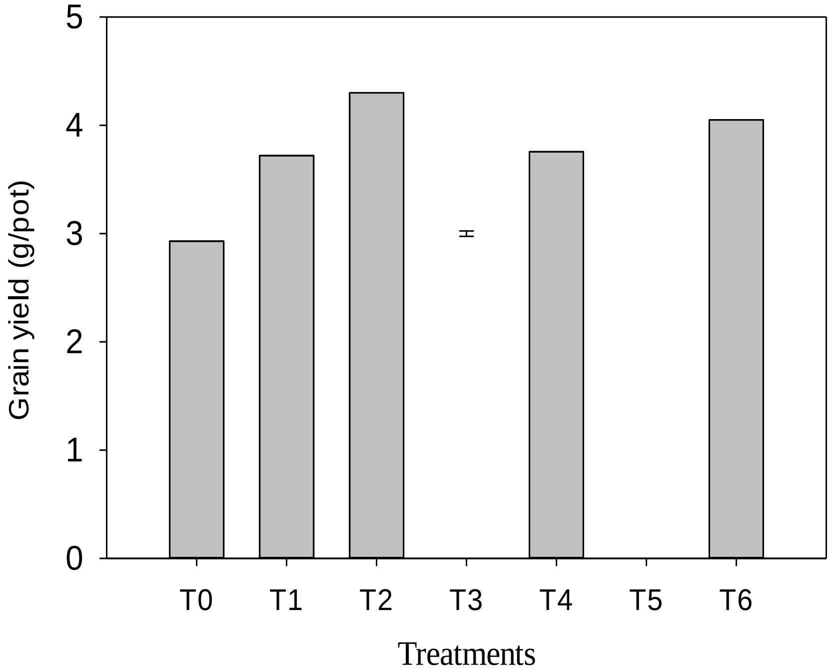


**Figure 12.** *Wheat yield for several treatments. Vertical bar indicates LSD (P > 0.05) for treatment interaction.* $T_0$ *= Control,* $T_1$*= Half of BARC recommended fertilizer,* $T_2$*= BARC recommended fertilizer,* $T_3$*= compound biochar only,* $T_4$ *= rice straw biochar only,* $T_5$*=half of BARC recommended fertilizer plus compound biochar and* $T_6$ *= half of BARC recommended fertilizer plus rice straw biochar.*

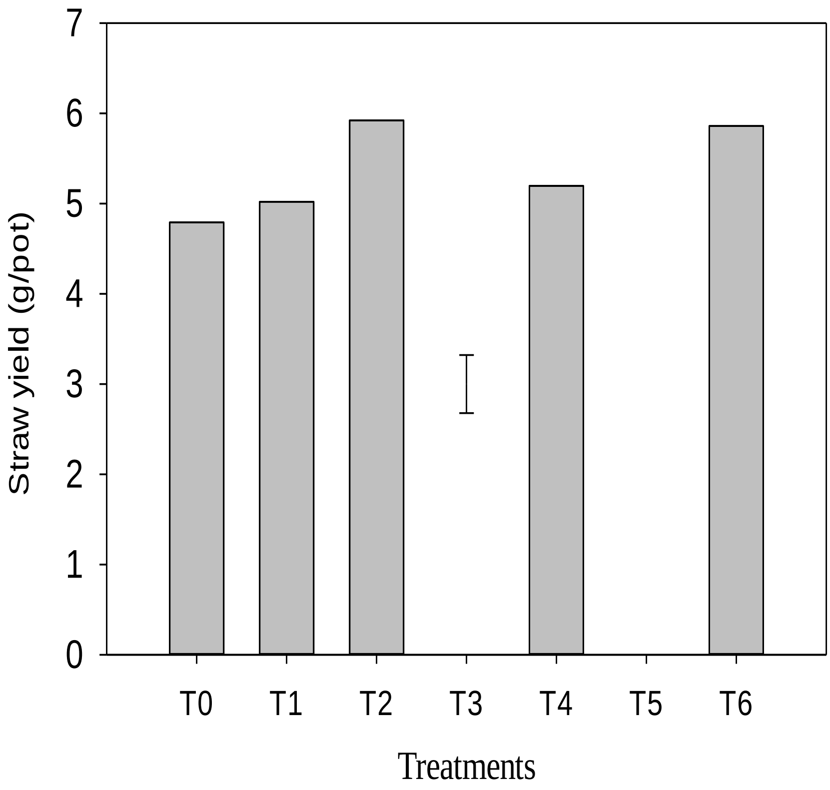


**Figure 13.** *Straw yield for several treatments. Vertical bar indicates LSD (P > 0.05) for treatment interaction. $T_0$ = Control, $T_1$= Half of BARC recommended fertilizer, $T_2$= BARC recommended fertilizer, $T_3$= compound biochar only, $T_4$ = rice straw biochar only, $T_5$=half of BARC recommended fertilizer plus compound biochar and $T_6$ = half of BARC recommended fertilizer plus rice straw biochar.*

## Conclusion

This study demonstrated that both rice straw and compound biochar amendment increases soil fertility within incubated soils after 159 days of incubation. This study revealed that both rice straw and compound biochar amendment increases soil organic matter status within incubated soils after 159 days of incubation. In contrast, soil pH declined in both biochar amended incubated soil. The combination of rice straw biochar and ½ BARC fertilizer dose gave better effect than single application rice straw biochar and gave second highest yield of wheat. However, highest yield was observed in BARC recommended fertilizer applied treatment. It indicates that biochar could be used as nutrients to achieve comparable yields to that obtained with inorganic fertilizers. This study recommended that utilization of rice straw derived biochar is authoritative in order to increase soil fertility status and wheat productivity in Bangladesh. Further study will be conducted with the reduction of compound biochar amendment to soil for wheat production.

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