Chittagong Univ. J. B. Sci. Vol. 12 (1 & 2): 56-71, 2024

A Comparative Study of Biochar Derived from Two Different Sources and Inorganic NPK Fertilizer on the Growth and Biomass Yield of Wheat (*Triticum aestivum* L.)

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DOI: https://doi.org/10.3329/cujbs.v12i1.78243

Received: 27 August, 2024; Accepted: 29 September, 2024; Published: 12 December, 2024

Abstract

Biochar has been regarding as a potential soil amendment for sustainable soil health, crop growth and mitigating climate change. Thus, the present study was performed to assess the effects of different rates of two biochar amendments and inorganic NPK fertilizer on the growth and biomass yield of wheat under pot condition at Chittagong University, Bangladesh. The two biochars prepared from mustard oil cake and rice straw by slow pyrolysis technique at 350-450 ºC were applied separately to the pot soil at the rate of 0, 1, 2, 3, 4 and 5% (w/w) and inorganic NPK fertilizer were also separately applied to the soil at the rate of 0, ¼, ½, ¾ and 1 of the recommended rate. The amended pot soil was incubated for 2 weeks before sowing of wheat seeds and observed the initial changes of soil properties. After 2 weeks of equilibration, soil organic carbon (OC) and Olsen P were relatively higher increased with oil cake biochar (OCB) whereas soil pH, electrical conductivity (EC) and available K were shown relatively higher value with rice straw biochar (RSB). The growth parameters at different growth periods and biomass yield after harvest were recorded. The growth parameters such as plant height, leaf number, spike growth, root length, total fresh and dry biomass were increased significantly ($p < 0.05$) with different rates of biochar and fertilizer amendments. In biochar amendment, the highest total fresh biomass (50.77 $g.pot^{-1}$), total dry biomass (32.27 $g.pot^{-1}$) and above ground dry biomass (27.14 $g.pot^{-1}$) were found with 5% OCB rate which were statistically identical with 1 NPK rate ($p < 0.05$). Overall, the growth performance and biomass yield with OCB amendment was relatively better than RSB amendment. Our results suggest that both biochar (OCB or RSB) could be used to improve soils properties and hence productivity.

Keywords: Biochar, wheat growth, soil health, climate change, sustainable production.

Introduction

Sustainable agricultural practices is important for global food security, soil health and climate change mitigation. Climate change is one of the most severe environmental challenges facing the world today which closely linked to the accumulation of greenhouse gases (GHGs) in the Earth's atmosphere. The agriculture is a significant contributor to global greenhouse gas emissions (10-12%), primarily through the release of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The majority of CO_2 from agriculture is produced by excessive fertilizer use and burning fossil fuels[1]. The increase in greenhouse gas emissions leads to rise in air temperatures and global warming, resulting in ecological degradation[2]. The careful management of natural resources and the adoption of agricultural practices that reduces greenhouse gas emissions and promote long-term soil carbon sequestration and agricultural production will be crucial in mitigating the adverse effects of climate change on agriculture[3]. Therefore, searching for cost-effective usable sustainable soil amendment that has benefits to both environment and agriculture is important. Biochar has been regarding as a sustainable amendment for soil health and plant growth because it can remain stable in soil over relatively long timescales[4]. Furthermore, applying biochar aids in climate change mitigation by reducing greenhouse gas emissions and sequestering carbon[5].

The gradual increase in the world's population and agricultural actions generates a huge amounts of solid organic waste such as crop straw, food waste and animal manure[6]. Traditionally, these organic wastes are used as natural fertilizers for enhancing soil quality and promoting crop growth. However, direct application of these materials may introduce pathogens and heavy metals, resulting in nutrient loss[7]. Using agricultural wastes as fuel also results in global warming due to greenhouse gas emissions, increasing particulate material in the air, and decreasing soil fertility[8]. Conversely, utilizing organic waste materials for the production of biochar offers potential benefits such as waste volume reduction, reduced harmful substances, decreased waste pollution and keep the environment clean[7]. In addition, the biochar applied as a soil amendment can reduce the demands for chemicals and fertilizer inputs[9]. Thus, conversion of organic solid wastes into biochar could be a reasonable alternative of economic waste management and promoting sustainable agriculture[10].

Biochar is a carbon-rich solid organic material prepared from the pyrolysis of organic matter such as plant residues, food wastes, and animal waste at relatively high temperatures (< 700 °C) and under an oxygen-limited environment[11, 12]. In recent years, biochar has attracted considerable attention for carbon sequestration, soil quality improvement and crop production enhancement due to its excellent physical and chemical properties[13]. The pyrolysis process increase the stability of organic materials as C-rich biochar product. The condensed aromatic rings in biochar has a strong ability to resist microbial degradation, and is generally considered to have high chemical and biochemical stability, which is conducive to C sequestration[14]. Biochar has large specific surface area, various functional groups (e.g. carboxyl and hydroxyl groups), high porosity, and rich nutrients[15].

The biochar application can change the soil properties to those supporting plant growth as well. It can improve soil nutrient contents and availability, soil organic matter (OM) content, soil pH, soil EC and, soil cation exchange capacity (CEC), reduce soil bulk density, enhance soil aggregate stability, soil porosity and water holding capacity (WHC)[16,17]. The high oxygen-containing functional group structures and cation exchange capacity (CEC) of biochar may improve nutrient retention and soil aggregation through the formation of clay-like complexes between organic matter and minerals[7, 18]. Biochar can also reduce leaching and heavy metal mobility and bioavailability in soil[7]. Additionally, biochar helps in increasing soil microbial diversity and provides a habitat for beneficial soil microorganisms due to its porous nature and nutrient content which further enhance nutrient availability to plants[19].

In recent years, studies have demonstrated the positive impacts of biochar application on plant growth, particularly under adverse weather conditions[20]. Some adverse impacts of biochar application have also been reported in recent years[13]. Numerous studies have shown that the promotion of crop growth and nutrient uptake did not occur until many years following the application of biochar[21]. Nutrient content of biochar might not be sufficient to significantly enhance plant growth and crop yield in large quantities, and using vast amounts of biochar may not be practical from both an economic and agronomic perspective[22]. However, the success will be acquired when the biochar can be used profitably like as chemical fertilizer in the crop production. Therefore, it is important to identify the usable profitable biochar for farmers especially in Bangladesh which will increase the uses of biochar as a soil amendment and also will contribute to the sustainable soil fertility, C-sequestration and environmental improvement.

The effects of biochar as a soil amendment depends on biochar properties, soil type and climatic conditions[23]. The properties of biochar largely depends on the properties of original raw biomaterials from which biochar is produced[24]. In the present study, rice straw and mustard oil cake were used as a raw biomaterials of biochar production. Hence the choice of these residues for biochar preparation were based on the richness, availability and nutrient composition of these materials. The rice straw and oil cake has different nutrient composition. The mustard oil cake contains relatively higher amounts of N and P but lower K content than rice straw[25, 26]. Mustard oil cake contains 4.5% N, 0.87% P and 1.24% K[25]. In contrast, rice straw contains 0.65% N, 0.10% P and 1.40% K[26].

Rice straw is a residual byproduct of rice production at harvest and usually considered a waste material. In Asia, rice straw is a major agricultural residue which is generated in large amount. Globally, it is the third-largest residue from agriculture after sugarcane bagasse and maize straw[27]. In Bangladesh, rice is the main staple crop that produces a large quantity of rice straw as a by-product every year. Thus, there is an enormous potential of using these residues in the biochar production systems. Mustard oil cake is the residue obtained as a byproduct after oil extraction from the seeds of mustard and is considered as agricultural wastes. Mustard is one of the most important oilseed crops throughout the world after soybean and groundnut[28]. It is also an important crop in Bangladesh that has been grown in a large extent for centuries. In oil processing industry, a large amount of oil cakes generate after the extraction of oil from oilseeds. Among the different crop residues available in Bangladesh, mustard oil cake (MOC) is a highly valued one as it contains high amount of essential nutrient elements for plant growth. Thus, mustard oil cake may will become an excellent raw biomaterial of biochar production.

In the present study, wheat (*Triticum aestivum* L.) was used as a test crop because of its economic importance, and vital role in global food security. Wheat is the most widely cultivated cereal crop as a staple food for the majority of the world's population. It contains high carbohydrates (55%) and proteins (8-12%), and also contains various essential vitamins and nutrients (Zn, Fe, Cu, and Se) which providing 20% of dietary calories and proteins[29, 30]. Based on the above information, the present study was planned to investigate the effect of biochar and inorganic NPK fertilizers on the growth parameters and to find out the optimum biochar rate for the growth of wheat.

Materials and Methods

Preparation of amendments and soil

Biochar used in the study was prepared at the experimental crop field of the Department of Soil Science, University of Chittagong, Bangladesh. Rice straw and mustard oil cake were collected from local sources of Chittagong, Bangladesh (22°30‘N, 91°48‘E) for preparing biochar. The mustard oil cake was procured from local market, Hathazari and rice straw was collected from local farmers of Jobra village near Chittagong University campus. They were then dried in air for several days to remove excess moisture before pyrolysis. Biochar was then made via slow pyrolysis by using a two-barrel stacked retort system, as described by Jonathan Pollnow[31]. The pyrolysis temperature for biochar production was in the range of 350-450 ºC. A simple low-cost pyrolysis retort was designed using two steel barrels (200L and 100L capacity) for biochar preparation. The smaller 100 L barrel maintained with a well tight lid was placed inside a larger 200 L barrel. The smaller inner barrel used as a biochar chamber loaded with dried rice straw or oil cake biomaterials from which biochar were prepared. The larger outer barrel acted as a burning barrel that heated the inner biochar chamber. The gap between the outer and inner barrel was filled with fuel wood which was burnt for heating the inner barrel. During burnig process, the temperature of the inner biochar chamber was measured by placing the thermocouple probes of a K-type thermometer. The burning process was completed after all the outer barrel fuel wood had burnt up. After completed the burning process, the inner barrel was left to cool and then removed for collecting the produced biochar. The produced biochar was ground and passed through a 2 mm sieve for using in the pot experiment. Chemical fertilizers urea, triple super phosphate (TSP) and murate of potash (MoP) were bought from the Regional Seed Sale Center, Bangladesh Agricultural Development Corporation (BADC), Solashohor, Muradpur, Chittagong, Bangladesh. A surface soil (Aquept) of the Pahartali series (0-20 cm) was collected from a fallow area of Chittagong University campus (22°47‘N, 91°88‘E) to avoid the influence of other residual fertilizers on the outcome of this study. After removing visible roots, weeds and other plant residues, the collected soils was ground, homogenized and passed through a 4 mm sieve for using in the pot experiment. For laboratory analysis, a sub samples were air dried and passed through a 2 mm sieve and stored. The experimental soil was sandy loam in texture with 75.75 % sand, 10.0 % silt, and 14.25 % clay. The soil was also acidic in nature with low organic carbon content, electrical conductivity, cation exchange capacity (CEC) and poor in available nutrient such as Olsen P and K (Table 2).

Experimental setup

A pot experiment was conducted using the collected sandy loam surface soil in the crop field of the Department of Soil Science, University of Chittagong. This location experiences a tropical monsoon climate with a hot humid summer and cool dry winter. The pot trial was conducted in the winter season (November-March). Each earthen pot had a capacity to accommodate 5 kg soil (+amendments) and the same amount of soil was used in the experiment. Moist soil equivalent to 5 kg (oven dry weight basis) were separately 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) for filling the earthen pots. The rate of 1 NPK was considered as recommended dose (i.e. N: P: K= 140: 60: 100 Kg ha^{-1}) for wheat (*Triticum aestivum*)[32]. The NPK were applied in the form of urea, triple super phosphate (TSP) and murate of potash (MoP). Therefore, the fifteen treatments were control (T0), 1% OCB (T1), 2% OCB (T2), 3% OCB (T3), 4% OCB (T4), 5% OCB (T5), 1% RSB (T6), 2% RSB (T7), 3% RSB (T8), 4% RSB (T9), 5% RSB (10), ¼ NPK (T11), ½ NPK (T12), ¾ NPK (T13) and 1 NPK (T14). A completely randomized experimental design (CRD) was used in the arrangement of these treatments with three replications. Each of the total 45 earthen pots had a small bottom hole of an equal diameter covered with nylon gauge for draining excessive water. After preparing pot with soil plus amendment mixture, the pots were watered up to the field capacity and were kept for two weeks to be in an equilibrium. After two weeks equilibrium with different amendments, pot soils were homogenously tilled with small hand tool and 10 seeds of wheat (variety: BARI Gom-25) were sown in each pot and then water was applied to field capacity. At this time before sowing of seeds, an initial sub soil sample was also taken from each prepared pot and air dried for laboratory analysis. Initial soil samples were used for determination of chemical (pH, EC, OC and CEC) and nutritional properties (Olsen P and available K). After 10 days of emergence, 5 healthy seedlings of wheat were kept in each earthen pot and plants were grown up to maturity. Water was added periodically roughly up to 60% of the water holding capacity by weighing each pot. Weeds were removed manually from each earthen pot, and during the entire growth period no insect, pest and diseases attack was observed.

Soil analysis

Soil particle size analysis was made by the hydrometer method as described by Day[33]. Soil textural class was determined by Marshall’s Triangular coordinates as designed by the USDA[34]. After the equilibrium with different amendments, the pH of the initial pot soils were measured in deionized water at a ratio of 1: 2.5 (w/v) by using glass electrode pH meter. EC of the soils were measured in deionized water at a ratio of 1: 5 (w/v) by using a standard EC meter. Organic carbon (OC) was determined by Walkley and Black’s wet oxidation method[35]. Cation exchange capacity (CEC) of the soils was determined by using 1N NH_4OAc solution at pH 7.0[36]. The soil available phosphorus (P) was extracted with 0.5 M $NaHCO_3$ (pH 8.5) (soil/solution ratio, 1:20 w/v) for 30 min on a reciprocating shaker[37]. Soil available potassium (K) was extracted with 1 N ammonium acetate (NH_4OAc) buffered at pH 7[38]. Phosphorus in the soil extract were determined colorimetrically using the ascorbic acid blue color method[39]. A scanning spectrophotometer (UV-1800, Shimadzu, Japan) was used to measure absorbance at wave length of 882 nm. Potassium concentration in the solution was determined by using atomic absorption spectrophotometer (AAS; Agilent 200 Series AA).

Plant growth and biomass measurement

Growth parameters including height of plants, number of leaves, number of spikes, spike length and length of roots were recorded at certain days interval or at harvest. Fresh weight and dry weight of plant parts ($g.pot^{-1}$) were recorded after plant harvest. Plant height was measured from the surface of the soil to the highest leaf tip using a measuring scale in each pot at 20, 35 and 50 days of growth after germination and at plant harvest. The leaf number per plant was counted manually at 20, 35 and 50 days of growth after germination. The number of spikes per pot were manually counted at the time of plant harvest and the length of spike with awn (cm) was measured with the help of a measuring scale. At the end of the pot experiment, the aboveground part of wheat plants from each pot was cut from the base of the stem, close to the soil surface, and immediately weighed to obtain aboveground fresh biomass. The harvested roots were then carefully removed from the pot soil and thoroughly washed with tap water before rinsing with deionized water to remove the attached soil particles and biochar. The fresh weight of root was then taken after removing the excess moisture with tissue papers. Root length was also measured with the help of a measuring scale from end of the root to the tip of the root. Total fresh biomass was obtained from the addition of aboveground and root biomass of wheat. After measurement of fresh weight, the aboveground plant part were separated into straw and grain biomass of wheat. The dry weight of plant parts were taken after drying in air for few days and then an oven at 65°C for 48 hours. Total dry biomass was obtained from the dry weight of all plant parts of wheat. Aboveground dry biomass was obtained by subtracting dry root weight from the total dry biomass. The dry grain-straw ratio (harvest index) was calculated from the dry weight of grain and straw.

Data analyses

All statistical analyses were done using the SPSS software (IBM SPSS Statistics 26). One-way analysis of variance (ANOVA) was used to determine statistically significant differences between means. Duncan's Multiple Range Test (DMRT) was performed at $p \leq 0.05$ level of significance to compare treatment mean within each measured parameter. Figures were processed using Microsoft Excel 2013 software.

Results and Discussion

Initial changes in amended pot soil properties

The initial changes in amended pot soil properties after two weeks equilibration with mixing different rates of biochar and NPK fertilizer before sowing of wheat seeds in the experiment are given in Table 1. The initial soil pH was increased significantly with increasing the rates of both biochars (OCB & RSB) but no such changes in soil pH was observed with NPK fertilizer rates. Between two biochar, soil pH values with RSB rates were significantly higher than OCB rates. The initial soil pH value in the control pot was 6.05, while it increased from 6.33 to 7.05 in OCB and 6.66 to 7.80 in RSB amended soil pots. The increase in soil pH with increasing rates of biochar may be related to the biochar’s alkalinity, base cation content and its ability to reduce exchangeable acidity ($H^+ + Al^{3+}$)[40]. The initial changes of soil EC in amended soil before sowing of seeds was found similar as was observed for soil pH. Soil EC in the control pot was 94 $\mu S.cm^{-1}$, while it increased from 114 to 213 $\mu S.cm^{-1}$ in OCB and 135 to

263 µS.cm^{-1} in RSB amended soil pots but in the cases of NPK fertilizer, no significant changes was observed in the soil EC (Table 1). Soil EC value could be attributed to the amount of water-soluble nutrient ions which released from the biochars[41].

Biochar additions to soil also increased initial soil organic carbon (OC) significantly with increasing the rates but with NPK fertilizer no such changes were found. Soil OC values with OCB rates were significantly higher than RSB rates. The OC value in the control pot was 0.79%, while it increased from 1.08 to 2.49% in OCB and 0.92 to 1.74% in RSB amended pot soils (Table 1). Laird et al.[42] reported that applying biochar to soils can increase soil organic carbon (OC) content and resolve certain problems associated with soil quality. Similarly, initial soil CEC value increased significantly with increasing the rates of biochar where it slightly changed with NPK fertilizer. The increasing trends of CEC were similar in both OCB and RSB amended pot soils. Soil CEC value in the control pot was 16.81 cmol.Kg^{-1} while it increased from 19.10 to 26.12 cmol.Kg^{-1} in OCB and 18.71 to 26.46 cmol.Kg^{-1} in RSB amended pot soils (Table 1). Soil CEC as an important indicator of soil fertility could be related to the availability of essential nutrients to plant. Gul and Whalen[43] reported that K availability in biochar amended soils increased through the improved CEC.

Soil available Olsen P was increased with the increasing rates of both biochars where OCB amended soils showed relatively higher Olsen P than RSB. Soil Olsen P was also increased with the increasing rates of NPK fertilizer but this value was significantly lower than biochar amended soils. Olsen P value in the control pot was 4.75 mg.Kg^{-1}, while it increased from 10.49 to 30.52 mg.Kg^{-1} in OCB, and 9.07 to 24.00 mg.Kg^{-1} in RSB amended soil pots (Table 1). The effects of biochar on soil available P may depends on the P level, sorption and desorption of both soil and biochar[44]. Soil available K was also increased with the increasing rates of both biochars where RSB amended soils showed relatively higher K value than OCB amended soils. The soil available K was also increased with the increasing rates of NPK fertilizer but this value was significantly lower than biochar amended soils. Soil available K value in the control pot was 40.18 mg.Kg^{-1}, while it increased from 62.37 to 88.17 mg.Kg^{-1} in OCB, and 65.92 to 93.02 mg.Kg^{-1} in RSB amended soil pots (Table 1). As a source, biochar can supply nutrients such as nitrogen (N), phosphorus (P), potassium (K), and other trace elements inherently present in the original raw biomaterial used for biochar production[45].

Table 1: Effect of two different biochars and NPK fertilizer on soil properties after two weeks equilibration before sowing of wheat seeds.

Treatment	pH	EC (µS.cm^{-1})	OC (%)	CEC (cmol.Kg^{-1})	Olsen P (mg.Kg^{-1})	Av. K (mg.Kg^{-1})
Control	6.05k	94i	0.79f	16.81fg	4.75k	40.18m
1% OCB	6.33i	114h	1.08e	19.10e	10.49h	62.37h
2% OCB	6.55h	135g	1.41d	21.76d	14.71f	69.69f
3% OCB	6.76f	159f	1.75c	23.33c	21.20d	74.49e
4% OCB	6.97e	181d	2.02b	24.39bc	27.83b	83.58c
5% OCB	7.05d	213c	2.49a	26.12a	30.52a	88.17b
1% RSB	6.66g	135g	0.92f	18.71e	9.07hi	65.92g
2% RSB	7.10d	169e	1.05e	20.53d	12.83g	72.06ef
3% RSB	7.32c	205c	1.38d	23.36c	18.98e	78.78d
4% RSB	7.59b	245b	1.65c	25.04ab	20.24de	86.21bc
5% RSB	7.80a	263a	1.74c	26.46a	24.00c	93.02a
¼ NPK	6.15j	94i	0.83f	16.72g	6.26jk	44.20l
½ NPK	6.13jk	96i	0.83f	17.90efg	6.78j	48.02k
¾ NPK	6.13jk	95i	0.81f	18.50e	7.37ij	52.45j
1 NPK	6.15j	99i	0.84f	18.30ef	7.69ij	56.30i

OCB – Oil cake biochar, RSB – Rice straw biochar, NPK – Recommended inorganic NPK fertilizers; Values are the means of three 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 the plant height

In the present study, plant height at all growth periods increased with increasing the rates of biochar (OCB & RSB) and NPK fertilizer, which were significantly higher than control (Table 2).

At 20 days of growth, plant height in the control pot was 20.22 cm, while it increased from 26.86-31.43 cm in OCB, 23.56–31.28 cm in RSB and 25.64–27.43 cm in NPK fertilizer amended soil pots. At 35 days, plant height in the control pot was 22.77 cm, while it increased from 33.69–37.98 cm in OCB, 32.29–37.55 cm in RSB and 28.80–36.96 cm in NPK fertilizer amended soil pots. At 50 days, plant height in the control pot was 31.50 cm, while it increased from 49.05–54.13 cm in OCB, 47.11–52.28 cm in RSB and 42.37–52.17 cm in NPK fertilizer amended soil pots. At harvest, plant height in the control pot was 65.19 cm, while it increased from 74.66–79.84 cm in OCB, 72.40–77.36 cm in RSB and 75.29–80.73 cm in NPK fertilizer amended soil pots.

The highest plant height at 20, 35 and 50 days of growth were 31.43, 37.98 and 54.13 cm, respectively which were observed with 5% OCB rate. At harvest, the highest plant height (80.73 cm) was observed with ¾ NPK rate. Plant height with OCB amendment were somewhat higher than RSB amendment at all growth periods. At higher biochar rates (4-5%), the plant height with OCB were statistically similar to plant height with RSB amendment. At 20 days of growth, plant height values with 4-5% biochar rates were significantly higher than values with 1 NPK rate but at other growth periods these values were statistically similar to values with 1 NPK rate (Table 2). These increase in plant height with different biochar amendments are supported by the other previous studies. Liu *et al.*[46] found a significant positive effect of corn straw biochar on soybean growth in alkaline soil under pot experiment where the highest plant height was observed with 5% biochar level. Pratiwi and Shinogi[47] observed a significantly higher shoot height of rice plants in soil

Table 2: Effect of two different biochars and inorganic NPK fertilizers on the plant height of wheat at different growth periods.

Treatment	Plant height (cm)			
	20 days	**35 days**	**50 days**	**At harvest**
Control	20.22g	22.77f	31.50e	65.19h
1% OCB	26.86cde	33.69bcd	49.05bc	74.66fg
2% OCB	28.06cd	34.58abcd	49.53bc	75.66efg
3% OCB	30.34ab	36.24abc	51.24abc	76.97cdef
4% OCB	31.33a	37.15abc	52.95ab	78.76abcde
5% OCB	31.43a	37.98a	54.13a	79.84abc
1% RSB	23.56f	32.29d	47.11c	72.40g
2% RSB	27.39cde	33.46cd	48.81bc	74.48fg
3% RSB	28.94bc	36.03abcd	50.59abc	76.05def
4% RSB	31.17a	36.91abc	51.80ab	77.15bcdef
5% RSB	31.28a	37.55ab	52.28ab	77.36abcdef
¼ NPK	25.64e	28.80e	42.37d	75.29efg
½ NPK	26.50de	34.86abcd	49.28bc	79.35abcd
¾ NPK	27.25cde	36.83abc	51.86ab	80.73a
1 NPK	27.43cde	36.96abc	52.17ab	80.61ab

OCB – Oil cake biochar, RSB – Rice straw biochar, NPK – Recommended inorganic NPK fertilizers; Values are the means of three 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 $p < 0.05$.

amended with 4 % rice husk biochar than control soil under a pot experiment. Syuhada *et al.*[48] also observed an increases in plant height of maize after applications of biochar in a sandy podzol soil.

Effect on leaf, spike and root growth of wheat

In this study, number of leaf (plant^{-1}) at all growth periods were increased with increasing the rates of different biochar and NPK fertilizer amendment. Leaf number at 20, 35 and 50 days of growth in the control pot were 3.87, 4.87 and 4.53, respectively (Table 3). At 20 days of growth, leaf number with different biochar rates (except 1% RSB) were significantly higher than control but in the cases of NPK fertilizer it was only significantly higher with 1NPK rate than control. Leaf number at 20 days with RSB amendment was relatively higher than OCB amendment and the highest leaf number (8.63) among the treatments was also observed with 5% RSB rate. At 35 and 50 days of growth, leaf number with different rates of biochar and NPK fertilizer were significantly higher than control. The highest leaf number at 35 and 50 days of growth were 20.13 and 17.00, respectively which observed with 5% OCB rate. In OCB amended pots, leaf number with 5% rate was significantly higher than 4% rate at all growth periods whereas in RSB amended pots, leaf number with 4% and 5% rates were significantly the same value. However, at 35 and 50 days of growth, leaf number with 4% and 5% rates of both biochar amendments (OCB and RSB) were significantly the similar value with 1 NPK fertilizer rate (Table 3). The present increase in leaf number with different biochar amendments are supported by the other previous studies. Obadi *et al.*[49] found that application of 2% biochar with 2% compost in a sandy soil showed a positive effects on the number of leaves of sweet pepper. Carter *et al.*[50] applied rice-husk biochar at a rates of 50-150 g Kg^{-1} with and without local organic fertilizers for lettuce and cabbage growth in a sandy

Table 3: Effect of two different biochars and inorganic NPK fertilizers on the leaf number and spike growth of wheat at different growth periods.

Treatment	**Leaf number (plant^{-1})**			**Spike growth at harvest**	
	20 days	**35 days**	**50 days**	**Spike number (pot^{-1})**	**Awned spike length (cm)**
Control	3.87f	4.87f	4.53h	5.33f	12.80f
1% OCB	4.87cde	11.33e	10.80fg	8.00cde	14.00e
2% OCB	5.53c	12.60de	11.47efg	8.67cde	14.56bcde
3% OCB	6.87b	13.73cde	12.77def	9.33bc	15.28ab
4% OCB	7.27b	15.73bcd	14.40bcd	11.33a	15.28ab
5% OCB	8.20a	20.13a	17.00a	12.00a	15.42a
1% RSB	4.20ef	12.47de	12.93def	7.67de	13.84e
2% RSB	5.60c	12.93de	13.43cde	8.33cde	14.27de
3% RSB	7.33b	14.47cde	13.87cd	9.00cd	14.52cde
4% RSB	8.60a	18.20ab	14.70bcd	10.67ab	14.86abcd
5% RSB	8.63a	18.53ab	15.47abc	11.33a	14.90abcd
¼ NPK	4.03f	10.90e	9.53g	7.33e	14.46cde
½ NPK	4.27def	14.30cde	12.35def	9.00cd	14.83abcd
¾ NPK	4.53def	17.25abc	14.35bcd	10.67ab	15.11abc
1 NPK	5.00cd	17.93ab	16.40ab	11.67a	15.31ab

OCB – Oil cake biochar, RSB – Rice straw biochar, NPK – Recommended inorganic NPK fertilizers; Values are the means of three 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 $p < 0.05$.

acidic soil under pot trials and also found that plant height and number of leaves of crops increased with biochar treatments compared to the no biochar treatments. Shepherd *et al*.[51] also found that applying some biochars at 5% rate gives more than 50% higher leaf yield in barley than sand without any biochar.

The spike number (pot^{-1}) increased with increasing the rates of biochar and NPK fertilizer which were significantly higher than control. Number of spikes in the control pot was 5.33 (Table 3).

The spike number with OCB amendment was relatively a little higher than spike number with RSB amendment. The highest spike number observed with different amendments were 12 in 5% OCB, 11.33 in 5% RSB and 11.67 in 1 NPK rate which were statistically similar in value. The spike number with 4% biochar (OCB & RSB) were also statistically similar to value with 5% biochar and 1 NPK rate. The length of spike with awn (cm) also increased with increasing the rates of biochar and NPK fertilizer which were significantly higher than control. The awned spike length in the control pot was 12.80 cm. Spike length was relatively higher in OCB amended pots than RSB amendment. The highest spike length with different amendments were 15.42 cm in 5% OCB, 14.90 cm in 5% RSB and 15.31 cm in 1 NPK rate. At 4 to 5% biochar rates (OCB & RSB), the length of spike was statistically similar and also comparable with 1 NPK fertilizer rate (Table 3). The present study results are also consistent with the findings of other previous studies. Haider *et al*.[52] reported that application of wheat straw biochar in a fine loam soil under a pot experiment increased spike length and spikelet number per spike of wheat compared to control pot with no biochar amendment under semi-arid climatic conditions. Gu *et al*.[53] also reported that co-application of rice straw biochar produced at 450°C temperature and chemical fertilizers in a paddy soil under field experiment could increase the effective panicle number and grains per panicle of rice.

The root length was also increased with increasing the rates of biochar and NPK fertilizer which were significantly higher than control (T0) treatment (Figure 1). Root length in the control (T0) pot was 12.94 cm and the highest root length (23.98 cm) was observed with 1 NPK fertilizer rate (T14) among the treatments. The highest root length value in biochar amended pots was 23.22 cm which observed with 5% OCB rate (T5). Root length values in the OCB amendments (T1-T5) were

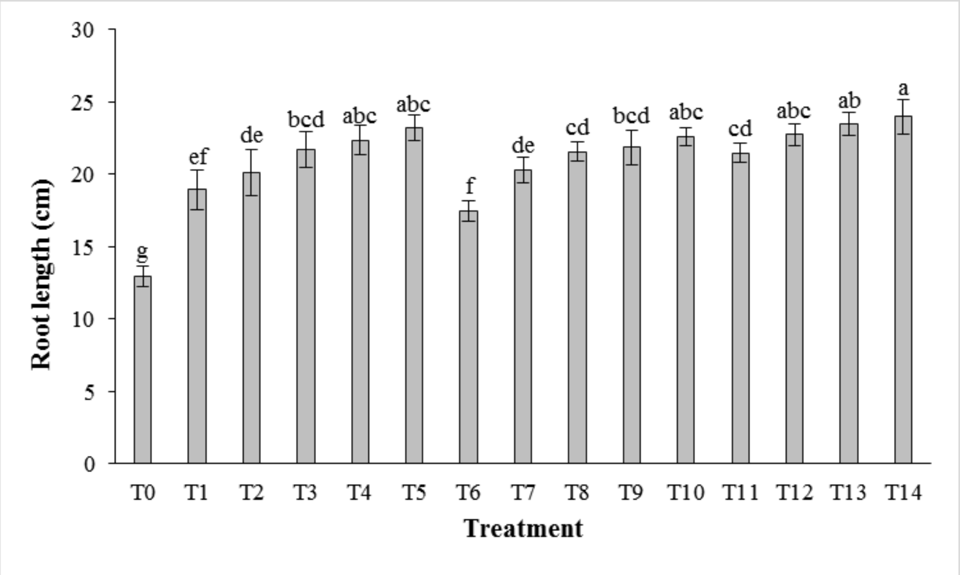

Figure 1. Effect of biochar (OCB & RSB) and inorganic NPK fertilizer on the root length of wheat. Mean values in bars followed by a common letter are not significantly different at $p < 0.05$ by DMRT. Error bars represent ± standard deviation (SD) of means ($n = 3$). T0 = control, T1 = 1% OCB, T2 = 2% OCB, T3 = 3% OCB, T4 = 4% OCB, T5 = 5% OCB, T6 = 1% RSB, T7 = 2% RSB, T8 = 3% RSB, T9 = 4% RSB, T10 = 5% RSB, T11 = ¼ NPK, T12 = ½ NPK, T13 = ¾ NPK and T14 = 1 NPK; OCB- Oil cake biochar; RSB- Rice straw biochar.

relatively a little higher than values with RSB amendment (T6-T14) but these values across the same rate in both biochars were significantly the similar in value. In biochar amendment, root length with 4-5% OCB (T4 and T5) and 5% RSB (T10) rates were significantly the similar value to root length with 1NPK rate (T14) (Figure1). In a previous study, Majeed *et al.*[54] found that biochar application in soil increases root dry matter of maize plant. The root growth may be increased by the improved soil physicochemical properties after biochar application[55]. Applying biochar may also lowered the bulk density of the soil, which in turn promoted the growth of plant roots[56].

Effect on the biomass yield of wheat

Total fresh biomass (g.pot^{-1}) of wheat was increased with increasing the rates of different amendments and these values were significantly higher than control (T0) (Figure 2). In the control pot, total fresh biomass value was 13.11 g.pot^{-1}. The highest total fresh biomass (53 g.pot^{-1}) was observed with 1 NPK fertilizer rate (T14). The second highest value (50.77 g.pot^{-1}) was found with 5% OCB rate (T5) which was statistically identical with 1NPK rate (T14). In biochar amendment, total fresh biomass value with OCB amendment (T1-T5) was relatively a little higher than value with RSB amendment (T6-T10) but these values across the same rate of both biochar were significantly the similar in value (Figure 2).

Total dry biomass (g.pot^{-1}) and above-ground dry biomass (g.pot^{-1}) were also increased with increasing the rates of different amendments and these values were significantly higher than control (T0) (Figure 3) as was observed in the case of total fresh biomass. The highest total dry biomass (35.36 g.pot^{-1}) and above-ground dry biomass (27.70 g.pot^{-1}) were observed with 1 NPK fertilizer rate (T14) among the treatment. In biochar amendment, the highest total dry biomass (32.27 g.pot^{-1}) and above-ground dry biomass (27.14 g.pot^{-1}) were observed with 5% OCB rate (T5) which were significantly similar in value with 1NPK rate (T14). At 4-5% biochar rate (T4-T5; T6-T10), the total dry biomass and above-ground dry biomass values were relatively higher with OCB amendment than values with RSB amendment but these values were also

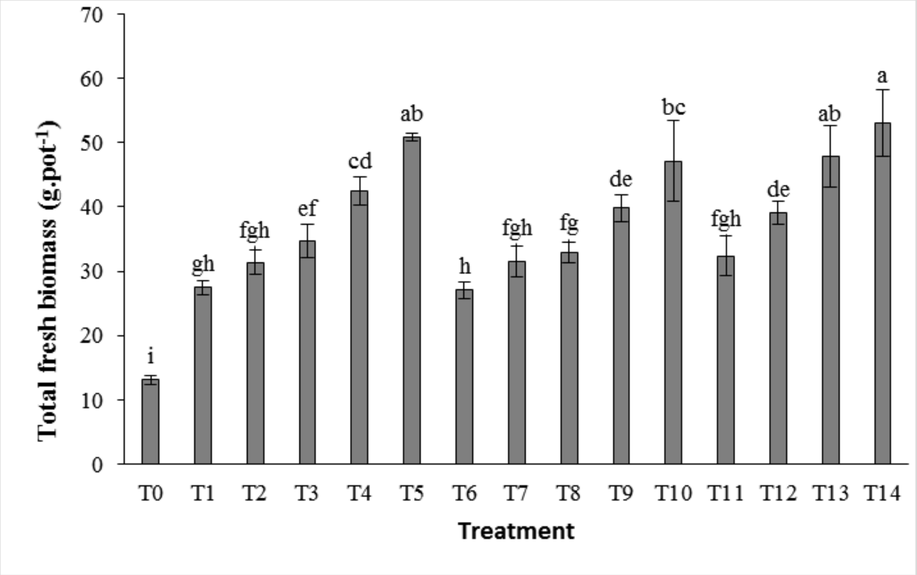

Figure 2. Effect of biochar (OCB & RSB) and inorganic NPK fertilizer on the total fresh biomass of wheat. Mean values in bars followed by a common letter are not significantly different at $p < 0.05$ by DMRT. Error bars represent ± standard deviation (SD) of means ($n = 3$). T0 = control, T1 = 1% OCB, T2 = 2% OCB, T3 = 3% OCB, T4 = 4% OCB, T5 = 5% OCB, T6 = 1% RSB, T7 = 2% RSB, T8 = 3% RSB, T9 = 4% RSB, T10 = 5% RSB, T11 = ¼ NPK, T12 = ½ NPK, T13 = ¾ NPK and T14 = 1 NPK; OCB- Oil cake biochar; RSB- Rice straw biochar.

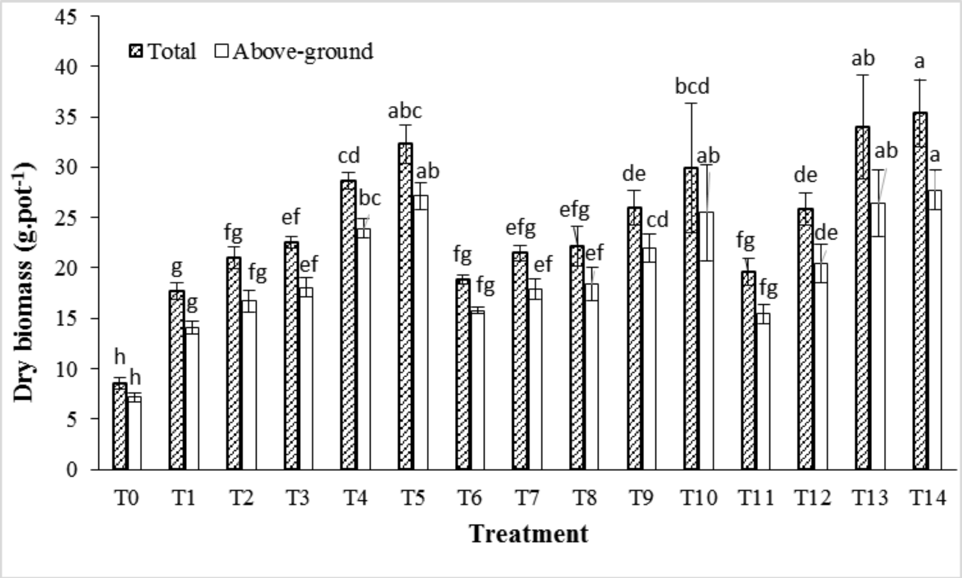

Figure 3. Effect of biochar (OCB & RSB) and inorganic NPK fertilizer on the total dry biomass and above-ground dry biomass of wheat. Mean values in bars of the same category followed by a common letter are not significantly different at $p < 0.05$ by DMRT. Error bars represent ± standard deviation (SD) of means ($n = 3$). T0 = control, T1 = 1% OCB, T2 = 2% OCB, T3 = 3% OCB, T4 = 4% OCB, T5 = 5% OCB, T6 = 1% RSB, T7 = 2% RSB, T8 = 3% RSB, T9 = 4% RSB, T10 = 5% RSB, T11 = ¼ NPK, T12 = ½ NPK, T13 = ¾ NPK and T14 = 1 NPK; OCB- Oil cake biochar; RSB- Rice straw biochar.

statistically similar in value (Figure 3). In the control, total dry biomass and above-ground dry biomass (pot^{-1}) were 8.58 g and 7.16 g, respectively, while the corresponding mean values across rates with different amendments were 24.41 g and 19.98 g in the OCB, 23.69 g and 19.89 g in the RSB amendment and 28.72 g and 22.49 g, respectively, per pot in the NPK fertilizer treatment (Figure 4). The highest mean value of total dry biomass and above-ground dry biomass (g.pot^{-1}) across rates of different amendments observed with NPK fertilizer amendment but these value were not significantly different from both biochar (OCB and RSB) amendments (Figure 4).

The present study results are consistent with the findings of several other previous studies. Choudhary *et al.*[57] observed that biochars prepared at 350 °C

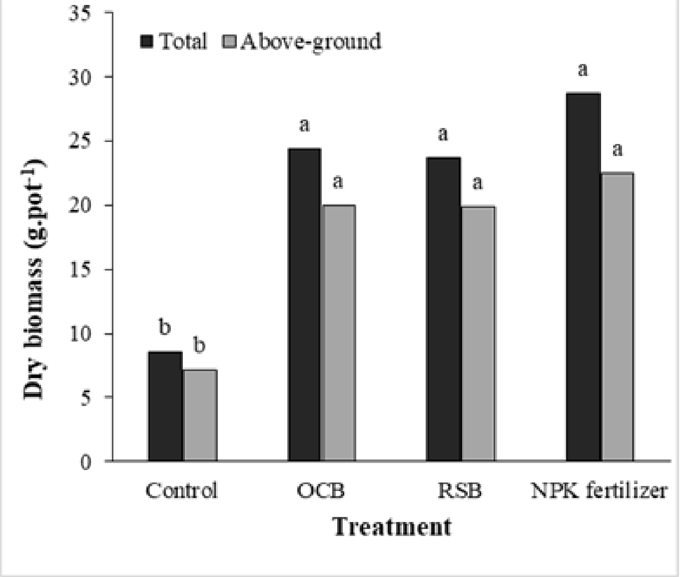

Figure 4. Mean effects of different biochar (OCB & RSB) and inorganic NPK fertilizer across the rates on the total dry biomass and above-ground dry biomass (g.pot^{-1}) of wheat. Means in bars followed by a common letter are not significantly different at $p < 0.05$ by DMRT. OCB- Oil cake biochar; RSB- Rice straw biochar.

temperature from sugarcane filter cake, farmyard manure, and rice husk significantly improved fresh biomass and dry biomass of maize in a pot experiment. Kim *et al*.[58] observed a maximum maize dry weight at 5% rate of rice hull biochar in a reclaimed tidal land soil and this value was 101% higher than control soil. Similarly, Prapagdee and Tawinteung[59] reported that cassava stem biochar produced at 350 °C temperature applied in the soil at 5 and 10% rate under a pot trial significantly increased the green bean plant fresh weight and dry weight. Olmo *et al*.[60] also reported that olive-tree pruning biochar addition to vertisol soil in a field experiment significantly increased aboveground plant biomass at reproductive stage of wheat (*Triticum durum* L.). The increased biomass with biochars application may be due to the increase in available nutrients in soil and subsequent uptake by plant, and also the enhancement of soil physio-chemical properties[61, 62].

Effect on the dry grain-straw ratio (harvest index) of wheat

The dry grain-straw ratio with different rates of OCB amendments (T1-T5) were relatively higher than RSB

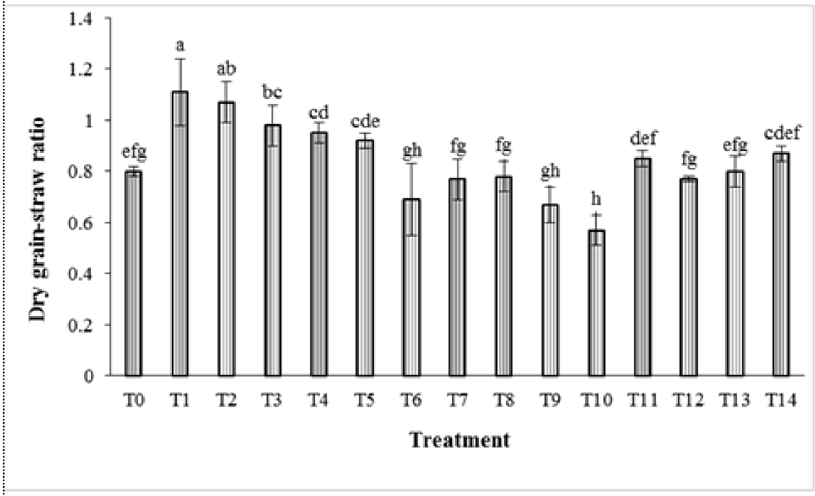

Figure 5. Effect of biochar (OCB & RSB) and inorganic NPK fertilizer on the dry grain-straw ratio of wheat. Mean values in bars followed by a common letter are not significantly different at $p < 0.05$ by DMRT. Error bars represent ± standard deviation (SD) of means ($n = 3$). T0 = control, T1 = 1% OCB, T2 = 2% OCB, T3 = 3% OCB, T4 = 4% OCB, T5 = 5% OCB, T6 = 1% RSB, T7 = 2% RSB, T8 = 3% RSB, T9 = 4% RSB, T10 = 5% RSB, T11 = ¼ NPK, T12 = ½ NPK, T13 = ¾ NPK and T14 = 1 NPK; OCB- Oil cake biochar; RSB- Rice straw biochar.

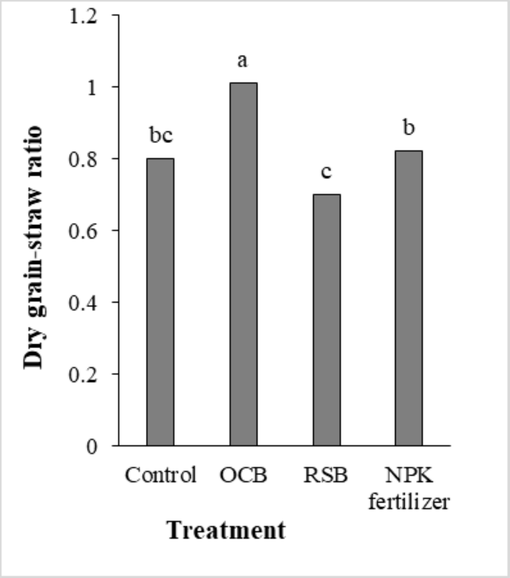

Figure 6. Mean effects of different biochar (OCB & RSB) and inorganic NPK fertilizer across the rates on the dry grain-straw ratio of wheat. Means in bars followed by a common letter are not significantly different at $p < 0.05$ by DMRT. OCB- Oil cake biochar; RSB- Rice straw biochar.

(T6-T10) and NPK fertilizer (T11-T14) amendments (Figure 5). In the biochar and NPK fertilizer amendments, only grain-straw ratio with the rates of OCB amendment (T1-T4) were significantly higher than control (T0). The minimum dry grain-straw ratio was observed with RSB biochar amendment among the treatments. The dry grain-straw ratio in the control pot was 0.80, while with different amendments across the rates it was 0.92-1.11 with a mean 1.01 in OCB, 0.57-0.78 with a mean 0.70 in RSB and 0.77-0.87 with a mean 0.82 in NPK fertilizer amended pots. The mean dry grain-straw ratio across rates with OCB amendment (1.01) was significantly higher than other amendments and control pot (Figure 6). The higher grain-straw ratio (harvest index) indicated the higher economic grain yield of wheat relative to straw biomass. The present results are also supported by the other previous studies. Minhas *et al.*[63] found that application of sugarcane bagasse biochar with half dose of nitrogen (N) and phosphorus (P) resulted in a better grain yield of maize than full dose of N and P without biochar in alkaline loamy soil. Bhattacharjya *et al.*[64] found that pine needle and lantana biochar application in a loam soil under a pot culture increased wheat grain yield significantly by 6.2%–24.2% over the control. Yao *et al.*[65] also reported that peanut shell biochar application significantly increased the grain yield and harvest index of rice in a saline sodic paddy field where the highest performance was observed with 67.5 t ha^{-1} biochar rate.

Conclusion

The findings from this pot study have indicated that both biochars (OCB and RSB) addition had positive effect on the growth and biomass yield of wheat grown in sandy loam soil. Biochar application was also provided an immediate changes and improvement of some soil properties such as pH, EC, OC, CEC, available P and K which were may allowed to the positive growth and biomass yields of wheat. Between two biochars, the performance of OCB was found better than the RSB. From this study, we recommend 4-5% biochar rate (OCB or RSB) as a soil amendment for maximum growth which are comparable to the 1 NPK fertilizer rate. To improve soil quality and productivity, we also suggest to use biochar as a soil amendment to reduce the dependency on inorganic fertilizer. Future investigation is needed with the combination of varying rates of biochar and NPK fertilizer in both green house and field conditions.

Acknowledgement

This work was supported by the Research & Publication Cell of the University of Chittagong, Bangladesh (No. 6582).

Conflict of Interest

Authors do not have any conflict of interests to declare.

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