Integration of biochar and chemical fertilizer to enhance quality of soil and wheat crop (*Triticum aestivum* L.)

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**Abstract**

A wide variety of soil amendments like manures, compost, humic acid and bio-sorbents have been used to make nutrients available to crops as well as to protect them from toxic elements. Among soil amendments, biochar has been known to improve soil health, soil nutrients’ availability to plants and ultimately the yield of crops. A field experiment was conducted by using biochar prepared from *Dalbergia sissoo* Roxb. wood by brick batch process. Two doses of biochar were applied to soil 0 and 12 t ha⁻¹. Fertilizer rates used in the experiments were 25% recommended doses of fertilizers (RDF), 50% RDF, 75% RDF and 100% RDF alone and with biochar applied under two factorial randomized complete block design in natural field conditions (RDF of NPK fertilizer is 120-60-60 kg ha⁻¹). Soil physico-chemical properties viz., bulk density, particle density, porosity, pH, electrical conductivity, organic matter, soil organic carbon, total nitrogen, available phosphorus, available potassium, soil organic carbon, soil microbial biomass carbon and soil microbial biomass nitrogen were measured from the soil samples collected from 0-30 cm depth. All these parameters varied significantly among the treatments. A combined treatment of biochar and 50% of the recommended dose of NPK was most effective for soil conditioning. Agronomic parameters were also measured by standard methods. Due to chelation of heavy metal ions and availability of nutrients to the soil, yield of the crop may significantly increase due to cumulative treatment of fertilizer and biochar but up to a certain limit.

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Introduction

Wheat (Triticum aestivum L.) is the principal cereal crop of Pakistan. Wheat has supreme importance in agricultural policies of our country. Its contribution is about 10.1% in agriculture having 2.2% share in GDP of the country. The area under wheat cultivation is 9180 thousand ha with yield per hectare was 2775 kg per hectare in 2014-15 (Pakistan Economic Survey, 2015). The production of wheat is low in Pakistan due to the imbalance application of fertilizers and organic matter decomposition at rapid rate due to severe hot climatic conditions (FAO, 2007; Khaskheli, 2013).

Soil organic matter (SOM) have significant effect on soil physico-chemical health, sequestration of carbon, controlling land erosion and protecting land from degradation (Galantini and Rosell, 2005). Soil microbial biomass carbon (SMBC), microbial activity and mineral transport are significantly affected by SOM (Carter, 1999). Organic matter decompositions are certainly rapid in tropic and arid to semiarid regions because of high decomposition rates and mineralization of SOM (Haron et al., 1997).

Addition of soil amendments helps to retain nutrients in soil. Biochar is more effective than other organic amendments in retaining and making nutrients available to plants for a long time. Among soil organic amendments, biochar is considered more stable nutrient source than others (Chen et al., 2007). Biochar is the product of thermal decomposition of organic materials under oxygen stress conditions and high temperature. It is applied to soil to achieve environmental benefits, like decreasing CO$_2$ gas emissions (Lehmann and Joseph, 2009). Its application to soil is an approach to decrease CO$_2$ emissions and to mitigate global climate change (Woolf et al., 2010). Its surface area and complex pore structure are hospitable to bacteria and fungi that plants need to absorb nutrients from the soil. Moreover, biochar is a more stable nutrient source than compost and manure (Cheng et al., 2006). Properties of biochar depend upon the selection of biomass for biochar production which in turn decides the carbon (C) inputs in soil (Jeffery et al., 2013).

Biochar produced at low temperature are more prone to rapid degradation in soil than those that produced at higher temperature and generally biochar produced from grasses are more degradable than that produced from hard wood (Zimmerman et al., 2011). Organic carbon contents in biochar have been reported up to 90%, depending upon its feedstock which enhances carbon sequestration in soil (Yin et al., 2009).

Biochar application to soil and crop as well as its effect on the nitrogen (N) cycle also proved helpful (Anderson et al., 2011). Biochar have potential to improve the growth and action of microorganisms which are directly or indirectly involved in soil N cycling. So, due to the activation of microorganisms it can mineralize complex soil organic carbon (SOC), and can enhance the effect of biochar application on native SOC (Belay-Tedla et al., 2009). Biochar application could also increase net microbial immobilization of inorganic N because biochar comprise by small labile C fractions with high C:N ratio (Deluca et al., 2009).

Based upon the significance of wheat and biochar this experiment was conducted to find out the cumulative effect of biochar along with different rates of fertilizer improves on SOM pools by improving microbial biomass accumulation, its effect on soil physico-chemical properties and yield of wheat crop.

Materials and methods

Experimental site and climate

A field experiment was conducted to study the influence of biochar and chemical fertilizer on soil physical and chemical parameters. Its effect on growth and yield of wheat crop (Triticum aestivum L.) was also studied at the farm of Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan (31.25° N, 73.09° E). Two factorial randomized complete block design was used for this study. Soil of the experimental area was classified as a well-drained hafizabad loam, mixed, semi-active, iso-hyperthermic typic calciargids.
The soil bulk density of the top 30 cm of soil before the biochar amendment was 1.42 Mg m$^{-3}$, while the particle density and porosity were 2.61 Mg m$^{-3}$ and 45.50% respectively. Soil organic matter (SOM) content was 0.69% of soil. The soil pH was 7.87, electrical conductivity (EC) was 1.25 dS m$^{-1}$ and cation exchange capacity (CEC) was 17.30 Cmol kg$^{-1}$. Measured soil microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN) were 136.6 and 44.13 per kg of soil, respectively.

**Biochar preparation**

Wood of *Dalbergia sissoo* was selected as feedstock. Feedstock was pyrolyzed using brick batch process (Brown, 2009) with estimated pyrolysis temperature of 500°C and residence time of 6 hours. After that biochar was ground and sieved through a 2mm sieve and stored in plastic bags.

The biochar contained 49.71% carbon and 1.03 N g/Kg measured by elemental analysis apparatus (ASTM, 2006). Available phosphorus content was 2.06 g/Kg (extracted at 410 nm wavelength using spectrophotometer, measured by colorimetric method), and available potassium content was 9.21 g/Kg (extracted with 2.0 M solution of HNO$_3$ determined by the use of flare photometer, FP640, Cany, China). Ash contents of the biochar were 4.98% (analyzed by D-3173 method i.e. in a muffle furnace at 550°C for 2 h). Bulk density was 0.38 Mg m$^{-3}$ (oven dried at 105°C using core sampler technique). However, recorded particle density was 1.58 Mg m$^{-3}$ (Pycnometer method, Blake 1965). The pH of the biochar was 8.85, while the EC was 1.74 dS m$^{-1}$ and CEC was 17.30 cmol kg$^{-1}$.

**Field experiment**

Field was ploughed and prepared before application of biochar and fertilizer. Soil composite samples were taken at random with auger before sowing and at harvest from (0–30 cm depth) from each experimental unit. The soil samples were air dried, ground, well mixed and passed through a 2 mm sieve and analyzed for different characteristics.

All macro-nutrients i.e. nitrogen, phosphorus and potassium (NPK) and biochar amendments were applied in respective experimental unit plots at different doses and mixed thoroughly. Recommended dose for nitrogen, phosphorus and potassium is 120 kg/ha, 60 kg/ha and 60 kg/ha, respectively which was referred as F$_4$. Urea was used as a nitrogen source, while SSP was used as phosphorus and SOP was used as potassium sources. Five different levels viz., 0%, 25%, 50% and 75% of the recommended dose of NPK, and the original recommended dose of NPK were used in the experiment. Different doses applied in each plot were: no NPK at 0% level referred as F$_0$, nitrogen (30 kg/ha), phosphorus (15 kg/ha) and potassium (15 kg/ha) were used at 25% level of the recommended dose referred as F$_i$. Similarly nitrogen (30 kg/ha), phosphorus (30 kg/ha) and potassium (30 kg/ha) were used at 50% level of the recommended dose referred as F$_j$. Recommended dose for nitrogen, phosphorus and potassium was referred as F$_k$. Recommended rate of biochar was 12 t ha$^{-1}$ so two levels of biochar were used in the experiment which were referred as B$_0$ (0%) and B$_1$ (recommended dose). All the possible combinations of fertilizer and biochar gave rise to ten treatments i.e. B$_0$F$_0$, B$_0$F$_1$, B$_0$F$_2$, B$_0$F$_3$, B$_0$F$_4$, B$_1$F$_0$, B$_1$F$_1$, B$_1$F$_2$, B$_1$F$_3$, and B$_1$F$_4$. Each treatment was replicated four times. Size of each experimental unit was 3.66×2.44 m$^2$. Wheat crop (cultivar “Faisalabad–2008”) was sown using manual hand drill at the rate of 123.5 kg per hectare in each experimental unit. Recommended cultural and plant protection measures were adopted. The crop was grown up to maturity and different parameters were recorded.

**Soil sampling**

A composite soil sample at the depth of 0–30 cm was obtained from 3 sub samples collected using a core sampler from each treatment plot. Soil samples were collected after the harvesting of crop at three points from each treatment plot. Samples for each depth were composited, placed in tagged plastic bags and dried at room temperature. These samples were air dried grinded and sieved through a 2 mm sieve and analyzed for physio–chemical analysis.
**Soil analysis**

Soil bulk density was determined by core sampler’s method as described by (Blake and Hartage, 1986). Soil particle density was determined by using pycnometer method (Blake, 1965). Soil porosity (%) was calculated by using the following formula (Blake and Hartage, 1986):

\[
\text{Porosity (}\phi\text{)} = \left[1 - \frac{(\text{Bulk density})}{(\text{Particle density})}\right] \times 100
\]

Soil pH was measured by using a pH meter HM – 12 and EC was determined and EC (dS m\(^{-1}\)) was measured by using Jenway Conductivity meter Model-4070 (Mckeepage, 1978; Mclean, 1982)

\[
K = \frac{1.4118 \times dSm^{-1}}{EC \text{ of } 0.01 \text{ N KCl (dSm}^{-1})}
\]

For CEC measurements four gram of soil was saturated with 1 N CH\(_3\)COONa (pH 8.2), then it was washed thrice with ethanol and finally extracted with 1 N CH\(_3\)COONH\(_4\) (pH 7.0). Sodium in the extract was determined with the help of PFP-7 flame photometer using Na\(^+\) filter. CEC was calculated from following formula (Richards, 1954; Rhoades, 1982)

\[
\text{CEC (cmol, kg}^{-1}\text{)} = \frac{\text{Na (mmol, L}^{-1}\text{)}}{100} \times \frac{100}{\text{Weight of Soil}} \times 100
\]

Soil organic matter was determined at up to 30 cm depths by titration method following the method described by (Ryan et al., 2001). Total nitrogen was measured using the Kjeldhal digestion method (Richards, 1954). The SMBC and SMBN were determined by fumigation–extraction method (Brookes et al., 1985; Vance et al., 1987). Briefly, soil samples were fumigated with chloroform to the extent to kill all microbes present in the soil sample. The fumigated samples were inoculated with 1.0 g of unfumigated same soil sample. Both fumigated and unfumigated soil samples were incubated in the presence of NaOH solution. The amount of CO\(_2\) evolved was measured by titration the NaOH solution against standard HCl solution.

The amount of mineral N was also measured both in fumigated and unfumigated samples. The amount of SMBC and SMBN were calculated as described by (Shah et al., 2010).

**Plant sampling and analysis**

Plant height, spike length, number of tillers, biomass yield, grain weight and harvest index were measured from an area of 1 × 1 m\(^2\). At maturity, wheat was harvested from an area of 1 × 1 m\(^2\) per plot. The fresh weight was determined in the field. The samples of grains and straws were kept at 65 °C for 48 h, and then their dry weight was obtained.

**Statistical analysis**

Statistical analysis of the data was carried out using two factorial RCBD. Analysis of variance and post ANOVA analysis was carried out on Statistix 8.1. (Analytical Software, 2005).

**Results**

Bulk Density is an important physical property of soil. The soil having lower bulk density enables root proliferation ultimately that will affect growth and yields of whole crop as a whole so applied biochar assist in significantly lowering the bulk density of soil alone and with fertilizer application than the fertilizer alone amended plots. The maximum decreased bulk density was calculated from B\(_1\)F\(_0\) i.e. 1.15±0.01 Mg m\(^{-3}\) and highest was with B\(_0\)F\(_1\) 1.45±0.01 Mg m\(^{-3}\) (Table 1).

In biochar amended soil an increasing trend in pH was observed due to the liming effect of Soil and may be due to the intrinsic basic nature pH used in our experiment. On the other hand the plots amended with fertilizer and biochar showed significantly the lower pH than the biochar alone amended plots. Highest soil pH (8.15±0.01) was found in the experimental unit having B\(_1\)F\(_0\) treatment while the lowest was found in B\(_0\)F\(_4\) i.e. 7.59±0.02 (P=0.004, F=7.73, DF=24) (Table 1). Similarly, soil EC also varied significantly in soil samples obtained from different treatments block. EC value represents the health of soil which directly affects the different physical properties of soil.
In our studies biochar also assist in the lowering of EC. Highest EC i.e. 1.25±0.02 dSm⁻¹ was found in B₀F₀ and the lowest was in B₁F₂ viz. 0.88±0.01 dSm⁻¹ (P=0.00, F=47.79, DF=24) (Table 1).

Regarding cation exchange capacity (CEC), a bell shaped trend was observed i.e. increase in value to optimum and then decline. The CEC also increases due to the large surface area and having high porosity biochar these factors help influence the CEC of the soil. It may be due to the fact upon biochar addition spontaneous oxidation reactions occur, resulting in an increase in the net negative charge and hence an increase in CEC. Highest soil CEC viz. 24.26±0.04 cmol kg⁻¹ was observed in B₁F₂ and the lowest was in B₀F₁ i.e. 17.27±0.01 cmol kg⁻¹ (P=0.04, F=1.02, DF=24) (Table 1).

Organic matter contents were directly proportional with the amount of biochar while inversely proportional to the amount of fertilizer. The cause of the increase in O.M was biochar has greater retention capacity and it facilitate slow release of nutrients and favors stabilization of organic matter. Highest organic matter contents (1.07±0.02%) were calculated from the treatment receiving biochar amendments alone i.e. B₀F₁ and lowest organic matter contents (0.58±0.01%) were found in B₀F₄ (P=0.00, F=155.34, DF=24) (Table 2).

The total nitrogen was found to be higher among the amended plots in comparison to the control. The highest contribution to total nitrogen was in soil having high fertilizer dose with biochar i.e. B₁F₄ 502.25±0.01 and lowest with B₀F₀ plot 315.00±0.02 mg kg⁻¹ (P=0.00, F=45.43, DF=24) (Table 2).

Soil microbial biomass carbon reflects the growth and mortality of microbes and organic matter decomposition.

Biochar influences soil microbial biomass nitrogen due to biochars labile fraction induces microbes population. It also provides favorable growth conditions to microbes in soil due to higher porosity and water holding capacity. The SMBN was directly proportional to the amount of biochar (only). Highest SMBN calculated was in treatment B₁F₂ i.e. 77.17±0.26 mg/kg and lowest SMBN was in B₀F₀ i.e. 44.13±0.42 mg/kg (P=0.00, F=96.19, DF=24) (Table 2).

Table 1. Soil chemical parameters recorded at different combined applications of chemical fertilizers and biochar.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Bulk Density (Mg m⁻³)</th>
<th>pH</th>
<th>EC (dSm⁻¹)</th>
<th>CEC (Cmol kg⁻¹)</th>
<th>Porosity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>B₀F₁</td>
<td>1.40±0.02ab</td>
<td>7.70±0.02c</td>
<td>1.32±0.04bc</td>
<td>17.35±0.01c</td>
<td>44.02±0.03e</td>
</tr>
<tr>
<td>B₀F₂</td>
<td>1.39±0.01b</td>
<td>7.67±0.02cd</td>
<td>1.39±0.04ab</td>
<td>17.34±0.00c</td>
<td>43.05±0.01f</td>
</tr>
<tr>
<td>B₀F₃</td>
<td>1.37±0.03c</td>
<td>7.61±0.02d</td>
<td>1.42±0.03a</td>
<td>17.27±0.01c</td>
<td>43.00±0.02f</td>
</tr>
<tr>
<td>B₀F₄</td>
<td>1.34±0.02d</td>
<td>7.59±0.02d</td>
<td>1.48±0.04a</td>
<td>19.03±0.01b</td>
<td>42.00±0.02g</td>
</tr>
<tr>
<td>B₁F₀</td>
<td>1.15±0.01g</td>
<td>8.15±0.01a</td>
<td>0.88±0.01f</td>
<td>24.20±0.01a</td>
<td>56.05±0.01a</td>
</tr>
<tr>
<td>B₁F₁</td>
<td>1.22±0.01e</td>
<td>7.99±0.02ab</td>
<td>0.95±0.03ef</td>
<td>24.02±0.01a</td>
<td>55.01±0.03ab</td>
</tr>
<tr>
<td>B₁F₂</td>
<td>1.25±0.02e</td>
<td>7.95±0.01bc</td>
<td>0.98±0.04ef</td>
<td>24.26±0.04a</td>
<td>54.00±0.01bc</td>
</tr>
<tr>
<td>B₁F₃</td>
<td>1.27±0.01f</td>
<td>7.92±0.02bc</td>
<td>1.02±0.03de</td>
<td>24.05±0.04a</td>
<td>52.00±0.01c</td>
</tr>
<tr>
<td>B₁F₄</td>
<td>1.28±0.03f</td>
<td>7.90±0.01bc</td>
<td>1.10±0.03d</td>
<td>24.08±0.03a</td>
<td>51.50±0.02c</td>
</tr>
<tr>
<td>B₀F₅</td>
<td>1.45±0.01a</td>
<td>7.87±0.04bc</td>
<td>1.25±0.01e</td>
<td>17.30±0.04c</td>
<td>45.50±0.01d</td>
</tr>
</tbody>
</table>

*Mean values followed by the different letter in the same column are statistically different (P ≤ 0.05).
Plant height increased with increase in biochar and fertilizer upto an extent after that they depicted less or even negative effect on plant height. Highest plant height was found in B\textsubscript{F2} viz. 107.75±1.44 cm\textsuperscript{2}, while lowest plant height was found in B\textsubscript{F1} i.e. 99.35±1.65 cm\textsuperscript{2} (P=0.00, F=2.79, DF=24). Like that of plant height, spike length also increased with increase in biochar and fertilizer upto an extent after that less or even negative effect was observed. Highest spike length was recorded in B\textsubscript{F2} i.e. 10.65±0.18 cm\textsuperscript{2} and lowest spike length viz. 8.10±0.42 cm\textsuperscript{2} was observed in B\textsubscript{F0} (P=0.00, F=3.30, DF=24). A fashion similar to plant height and spike length was observed in case of number of tillers. Highest numbers of tillers i.e. 592.13±0.45m\textsuperscript{2} were counted from the treatment plot B\textsubscript{F2} while lowest numbers of tillers viz. 419.95±0.51m\textsuperscript{2} were found in B\textsubscript{F1} (P=0.00, F=14.31, DF=24). (Table 3)

**Table 2.** Soil chemical parameters recorded at different combined applications of chemical fertilizers and biochar.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Organic matter (%)</th>
<th>Total Nitrogen mg kg\textsuperscript{-1}</th>
<th>Soil microbial biomass carbon mg kg\textsuperscript{-1}</th>
<th>Soil microbial biomass nitrogen mg kg\textsuperscript{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>B\textsubscript{0}</td>
<td>0.65±0.03fg</td>
<td>436.00±0.02b</td>
<td>138.85±0.61h</td>
<td>58.13±0.43e</td>
</tr>
<tr>
<td>B\textsubscript{F1}</td>
<td>0.64±0.02gh</td>
<td>440.38±0.01c</td>
<td>157.15±0.86g</td>
<td>63.12±0.44d</td>
</tr>
<tr>
<td>B\textsubscript{F2}</td>
<td>0.62±0.03h</td>
<td>465.00±0.3c</td>
<td>167.75±0.91l</td>
<td>49.14±0.40h</td>
</tr>
<tr>
<td>B\textsubscript{F3}</td>
<td>0.58±0.11h</td>
<td>487.75±0.11d</td>
<td>170.88±0.82e</td>
<td>51.12±0.46g</td>
</tr>
<tr>
<td>B\textsubscript{F4}</td>
<td>0.70±0.02a</td>
<td>430.75±0.01de</td>
<td>230.20±0.82d</td>
<td>53.75±0.32f</td>
</tr>
<tr>
<td>B\textsubscript{F5}</td>
<td>0.98±0.01b</td>
<td>437.88±0.03e</td>
<td>235.20±0.77e</td>
<td>75.05±0.21b</td>
</tr>
<tr>
<td>B\textsubscript{F6}</td>
<td>0.89±0.03c</td>
<td>450.25±0.01e</td>
<td>238.93±0.69g</td>
<td>77.17±0.26a</td>
</tr>
<tr>
<td>B\textsubscript{F7}</td>
<td>0.76±0.02d</td>
<td>469.88±0.02f</td>
<td>240.80±0.66b</td>
<td>68.07±0.22c</td>
</tr>
<tr>
<td>B\textsubscript{F8}</td>
<td>0.72±0.03e</td>
<td>502.25±0.01f</td>
<td>245.20±0.38a</td>
<td>64.08±0.22d</td>
</tr>
<tr>
<td>B\textsubscript{F9}</td>
<td>0.69±0.01f</td>
<td>315.00±0.02a</td>
<td>136.63±0.82i</td>
<td>44.13±0.42i</td>
</tr>
</tbody>
</table>

* Mean values followed by the different letter in the same column are statistically different (P ≤ 0.05).

An increasing trend was also found in biomass yield i.e. increased to an extent with increase in amount of combined treatment of biochar and fertilizer. Highest biomass yield i.e. 14.65±0.40 t ha\textsuperscript{-1} was calculated from the experimental plot treated with B\textsubscript{F3} and lowest was in B\textsubscript{F1} (9.80±0.42 t ha\textsuperscript{-1}) (P=0.00, F=789.16, DF=24). Grain weight, also, increased to an extent with increase in amount of combined treatment of biochar and fertilizer. Grain weight was highest i.e. 3.68±0.05 t ha\textsuperscript{-1} in plot treated with B\textsubscript{F3} treatment which gradually decreased to minimum in B\textsubscript{F0} (2.60±0.04 t ha\textsuperscript{-1}) (P=0.00, F=213.64, DF=24). (Table 4). Harvest index firstly increased up to certain limit i.e. B\textsubscript{F2} where 0.32±0.02% was observed which afterwards decreased to minimum i.e. 0.20±0.03% in plot treated with B\textsubscript{F1} (P=0.00, F=2051.00, DF=24) (Table 3).

**Table 3.** Different agronomic parameters recorded at different combined applications of chemical fertilizers and biochar.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant Height Cm</th>
<th>Spike Length cm</th>
<th>Number of Tillers m\textsuperscript{-2}</th>
<th>Biomass Yield t ha\textsuperscript{-1}</th>
<th>Grain Weight t ha\textsuperscript{-1}</th>
<th>Harvest Index %</th>
</tr>
</thead>
<tbody>
<tr>
<td>B\textsubscript{0}</td>
<td>99.35±1.65c*</td>
<td>8.12±0.42d</td>
<td>419.95±0.51h</td>
<td>9.80±0.42h</td>
<td>2.66±0.12gh</td>
<td>0.27±0.01b</td>
</tr>
<tr>
<td>B\textsubscript{F1}</td>
<td>101.18±0.06bc</td>
<td>9.22±0.41c</td>
<td>458.58±0.93g</td>
<td>10.65±0.41g</td>
<td>2.85±0.04f</td>
<td>0.27±0.02b</td>
</tr>
<tr>
<td>B\textsubscript{F2}</td>
<td>105.63±0.02am</td>
<td>9.01±0.41c</td>
<td>484.38±0.84f</td>
<td>11.37±0.39f</td>
<td>3.05±0.04e</td>
<td>0.26±0.03c</td>
</tr>
<tr>
<td>B\textsubscript{F3}</td>
<td>99.63±0.02c</td>
<td>9.03±0.41c</td>
<td>512.23±0.45d</td>
<td>13.27±0.40c</td>
<td>3.29±0.04d</td>
<td>0.25±0.02c</td>
</tr>
<tr>
<td>B\textsubscript{F4}</td>
<td>101.73±0.53bc</td>
<td>8.35±0.45bc</td>
<td>512.13±0.44d</td>
<td>13.72±0.41b</td>
<td>3.52±0.04c</td>
<td>0.26±0.02d</td>
</tr>
<tr>
<td>B\textsubscript{F5}</td>
<td>104.65±0.34ab</td>
<td>10.17±0.42b</td>
<td>496.50±0.45e</td>
<td>12.15±0.41e</td>
<td>3.28±0.04d</td>
<td>0.27±0.03bc</td>
</tr>
<tr>
<td>B\textsubscript{F6}</td>
<td>107.54±1.44a</td>
<td>10.65±0.18a</td>
<td>592.13±0.45a</td>
<td>13.13±0.41c</td>
<td>3.58±0.04d</td>
<td>0.32±0.02a</td>
</tr>
<tr>
<td>B\textsubscript{F7}</td>
<td>107.65±1.79a</td>
<td>10.54±0.45a</td>
<td>540.13±0.45c</td>
<td>14.65±0.40a</td>
<td>3.68±0.05a</td>
<td>0.32±0.04a</td>
</tr>
<tr>
<td>B\textsubscript{F8}</td>
<td>105.10±0.72ab</td>
<td>8.47±0.12d</td>
<td>516.23±0.45d</td>
<td>12.72±0.42d</td>
<td>2.77±0.04h</td>
<td>0.20±0.03g</td>
</tr>
<tr>
<td>B\textsubscript{F9}</td>
<td>100.68±1.26c</td>
<td>8.10±0.42d</td>
<td>550.13±0.46b</td>
<td>25.07±0.81bc</td>
<td>13.05±0.41e</td>
<td>2.60±0.04fg</td>
</tr>
</tbody>
</table>

* Mean values followed by the different letter in the same column are statistically different (P ≤ 0.05).
Discussion
Soil compaction can change the interactions between air–soil and water–soil which in turn influence the water retention, microbiological activity and nutrient uptake (Martinez and Zinck, 2004). Mixing of organic amendments with more dense mineral fractions of soils causes a decrease in bulk density majorly due to increase in total porosity and decreased soil bulk density (Bronick and Lal, 2005; Tejada and Gonzales, 2008).

Biochar significantly improves pH, total nitrogen, cation exchange capacity (CEC), organic carbon, exchangeable bases (Nigussie et al., 2012). Soil pH improved significantly with Biochar addition possibly due to higher concentration of metal ions in biochar (Kumar et al., 2013). It was observed that with the addition of biochar soil EC improves and it decreases with time (Renner, 2007).

The application of organic amendments may enhance the pH and CEC in highly weathered soils (Glaser et al., 2002). High surface area, abiotic oxidation and charge density of the biochar can attribute to increased CEC and pH increase (Cheng et al., 2006; Liang et al., 2006). Increase in pH increase not only improve soil health but also improve plant growth due to higher availability of nutrients (Brady and Weil, 2008).

Biochar can significantly enhance nutrient cycling, cation exchange capacity and the ability of soils to retain plant available water (Liang et al., 2006). Increase in soil meso-porosity or increased weathering at the expense of macro porosity strongly influences CEC of soil (Cheng et al., 2006; Yamato et al., 2006), but it is not a fact in all types of soil or conditions (Novak et al., 2009). Thus the use of biochar as a soil amendment is anticipated to increase both nutrient and water use efficiency and thereby crop productivity (Glaser et al., 2001; Liang et al., 2006).

Inorganic fertilization is necessary to obtain higher yields but it has very little positive impact on organic matter. It may increase mineralization rate which cause decline in soil organic matter (Lal, 2006).

It may also favor positive response to improve microbial populations and organic matter mineralization (Balesdent et al., 1998). However, biochar addition to soil is important for the C sequestration and soil fertility, and having residence time up to millennial in soil (Kumar et al., 2013). Biochar has a habitable pore area therefore biochar is considered favorable for microbial habitation (Strong et al., 1998). Accumulation of organic substances (biochar) at surface soil provides a substrate for microorganism that result in higher rates of SMBC (Balota et al., 2004). The readily metabolizable C and N in organic amendments are the most influential factors contributing to the biomass increase (Hao et al., 2008; Liu et al., 2010). A cumulative application of biochar and inorganic fertilizer is more effective for beneficial microbes in soil (Wardle et al., 2008; Brunn et al., 2012). Accumulation of organic amendment i.e. biochar at the soil surface enhances microbial activity which ultimately results in greater amount of SMBC (Balota et al., 2004).

Biochar addition increases pH which enhances N₂O reductase activity (Yanai et al., 2007) simultaneously inhibits nitrite conversion i.e. nitrate to nitrous oxide (Van-Zwieten et al., 2009). This phenomenon may improve the total nitrogen in our studies.

Biochar also has strong influence on plant growth by changing soil nutrient conditions (Chan et al., 2008; Taghizadeh et al., 2012). The decreased bulk density of soil by biochar amendment promotes root proliferation consequently the growth of plant (Atkinson et al., 2010; Laird et al., 2010). Therefore, a decreased bulk density has a positive influence on plant growth because of a lower resistance to root penetration. This effect may be due to the involvement of species, compaction of soil and environmental factors (Alameda et al., 2011). Plant height may increase due to more phosphorus availability, enhanced root growth and increased nutrient adsorption (Hussnain et al., 2006). It can also be attributed to improved phosphorus availability (Asai et al., 2009; Abdullah et al., 2008).
Biochar can increase crop growth and productivity (Spokas et al., 2010) Spike length, plant height and tillers also increase with increase of chemical fertilizers but up to a limit (Hussain et al., 2006; Asai et al., 2009). Biochar also can significantly increase crop growth and productivity (Spokas et al., 2010).

Maize grain yield was reported to be doubled when plots were amended with a combination of biochar and NPK fertilizer compared with NPK fertilizer alone (Steiner et al., 2007). Biochar addition may also increase biomass of crops (Van-Zwieten et al., 2007). Nitrogen fertilizer and biochar together can increase the wheat biomass and grain yield (Ayub et al., 2002; Blackwell et al., 2010; Solaiman et al., 2010). In a field study, biochar amended plots receiving NPK fertilizers sustained higher crop yield compared with control plots (Steiner et al., 2008). In another study in Australian semiarid soils, positive significant effect on plant growth was observed by the use of biochar and fertilizer (Chen et al., 2007). Biochar amendment increased grain yield up to 91% and biomass yield up to 44% than control (Oguntunde et al., 2004). The effects of biochar-amended soil on wheat production were also evaluated. Biochar applied at a rate of 6 t ha⁻¹ with half the recommended rate of soluble fertilizer increased yields of wheat by 18% over the control (Solaiman et al., 2010). Wheat grown with mineral fertilizer and 1.5 t ha⁻¹ biochar increased grain yield by 46% over the control (Blackwell et al., 2010).

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