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# APPLICATION OF *Dalbergia sissoo* BIOCHAR ENHANCED WHEAT GROWTH, YIELD AND NUTRIENT RECOVERY UNDER REDUCED FERTILIZER DOSES IN CALCAREOUS SOIL

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In a field trial, *Dalbergia sissoo* biochar was used to investigate its potential for improving growth, yield and nutrient recovery of wheat (*Triticum aestivum* L.), at varying fertilizer rates under calcareous soil. Two biochar levels (0.0 and 1.0% of soil weight) were used along with five fertilizer rates i.e. 0, 25, 50, 75 and 100% of recommended inorganic fertilizer dose (RFD). Seeds of wheat cultivar Faisalabad-2008 were sown in the field using 2 factorial-randomized complete block design. At reduced fertilizer rates, biochar application improved plant growth parameters i.e. plant height, spike length, number of tillers hill$^{-1}$ and grain yield over the respective treatments having inorganic fertilizer without biochar. Regarding nitrogen (N), phosphorus (P) and potassium (K) content, the highest statistical results were achieved at reduced fertilizer doses along with biochar application i.e. N and P content in wheat straw and grain at 50% RFD, straw N and P uptake at 75% RFD, grain N and K uptake at 50% RFD and grain P uptake at 75% RFD. The highest N, P and K recovery was calculated in the treatments having 50% RFD + biochar with 95%, 25% RFD + biochar with 38% and 25% RFD with 117%, respectively. In comparison with control treatment (without fertilizer and biochar), biochar application improved soil CEC up to 40%. With biochar application, no any significant change was observed in other soil chemical properties i.e. pH and EC. The results suggested that 1.0% biochar along with reduced fertilizer doses, could be effectively used to improve wheat growth, yield, nutrient content and nutrient uptake under field condition. Moreover, 1.0% biochar along with 75% of RFD can be effectively used in place of 100% RFD to get the highest yield.
**Keywords:** Wheat, calcareous soil, nitrogen, phosphorus, potassium.

## INTRODUCTION

In arid to semi-arid regions, soils are often low in organic matter (<1%) and poor in plant available nutrients. In prevailing soil and climatic conditions, crop plants use 50% or even less nitrogen (N) of the applied fertilizer and remaining is lost through denitrification and volatilization from the soil system (Khan *et al*., 2014). Despite of having high total phosphorus (P) contents (Muhammad *et al.*, 2008), due to the formation of insoluble salts with calcium (Ca), phosphatic fertilizers do not satisfy nutrient requirements of crops (Khan and Joergensen, 2006). Pakistani soils have potassium (K) bearing minerals i.e. mica and feldspar (Bajwa and Rehman, 1996), however the increase in cropping intensity and introduction of high yielding varieties have also resulted in the depletion of plant available soil K reserves (Laghari *et al*., 2010).

For the success of any soil management, it is crucial to maintain an appropriate level of soil organic matter and biological cycling of essential nutrients. Manure, mulches, cover crops and composts have been used effectively for supporting rapid cycling of soil nutrients through microbial activity and supplying nutrients to different crops (Trujillo, 2002). However, nutrient availability from these organic amendments depends on their decomposition rate and nutrient concentration (Reddy *et al*., 2005). The benefits of these organic soil amendments are, however, often short-lived, since decomposition rates are very high and the added organic amendment is usually mineralized to carbon dioxide (Mekuria and Noble, 2013). Organic amendments therefore have to be applied repeatedly to sustain soil quality.

Agricultural wastes are important in soil agro-ecosystems as they add organic matter and ultimately provide essential plant nutrients i.e. N, P and K. When these wastes are used to produce biochar, they bring about an opportunity to be used as a sustainable soil amendment. It may help to avoid further reduction of soil organic carbon (Gaskin *et al*., 2008) and prevent increased fertilizer-use (Widowati and Asnah, 2014). Pyrolysis is the combustion of organic waste materials in complete absence or partial presence of oxygen, leading to the formation of carbon-rich char (biochar) (Thies and Rillig, 2009). Due to its highly aromatic structure, resultant product biochar is highly resistant to decomposition (Cheng *et al*., 2008) and it is reported that biochar may improve the carbon content of alkaline soil (Qayyum *et al*., 2015). Comparing biochar with other organic soil amendments, very high porosity and surface area enable it to retain more water and nutrients and also provide a best habitat for soil microorganisms (Warnock *et al*., 2007). Provision of organic matter, sequestration of carbon, modification of soil water retention and soil physical characteristics, enhancement of cation exchange capacity (CEC), supply of plant available nutrients, modification of soil pH and microbial activity, and influence on green-house gases emissions are all potential key functions of biochar. Greater nutrient retention and direct nutrient addition by the biochar results higher nutrient availability for plants (Lehmann *et al*., 2003). Biochar can persist in soils and sediments for many centuries (Glaser, 2007), and has great potential to improve crop production when applied into the soil (Laird *et al*., 2009). In all over the world, effect of biochar regarding soil quality and nutrient availability is least explored under calcareous soils, similar in case of Pakistan. For investigating the potential of biochar as an organic soil amendment in calcareous soil, our study objectives were to produce biochar through brick-batch process, characterize biochar for its various physical, chemical, nutritional/elemental properties, and check the effect of biochar on wheat growth, yield and nutrition at varying fertilizer rates.

## MATERIALS AND METHODS

***Biochar production and analysis*:** Waste wood material of *Dalbergia sissoo* was collected from furniture market (Faisalabad) for biochar production. After removing soil and dust particles, tree cuttings were sun-dried, until 10-15% moisture content were remained. Crushed feedstock was pyrolyzed in an especially designed laboratory scale stainless-steel furnace of 15 kg feedstock capacity, at 350-400°C temperature with 2 hours residence time. After the completion of residence time, biochar was collected and ground into ≤2mm particle size.

***Chemical and physical analysis of biochar*:** The pH and EC of biochar was measured by using 1:20 solid:solution ratio after shaking the suspension on a mechanical-shaker for 90 min in deionized water (Rajkovich *et al*., 2012). The CEC of biochar was measured by using ammonium acetate compulsory displacement method proposed by Gaskin *et al*. (2008). Ash contents were determined by using method proposed by Slattery *et al*. (1991). For this purpose biochar samples were heated at 200°C for 1 hour and then at 500°C for an additional 4 hours in the muffle furnace. After heating biochar samples in muffle furnace, ash content was calculated through following equation:

$$\text{Ash content (\%)} = \frac{\text{Weight of biochar ash (g)}}{\text{Weight of biochar used for heating (g)}} \times 100$$

Conversion efficiency of biochar was calculated by the following equation:

$$\text{Conversion efficiency (\%)} = \frac{\text{Weight of biochar collected after pyrolysis (kg)}}{\text{Weight of feedstock used for pyrolysis (kg)}} \times 100$$

Moisture content in biochar were determined by calculating the difference between fresh weight and weight after being dried for 24 h in a forced air oven (Eyela WFO-600ND, Tokyo Rikakikai, Tokyo, Japan) at 65°C.

$$\text{Moisture content (\%)} = \frac{\text{Biochar weight after oven drying (g)}}{\text{Biochar weight before oven drying (g)}} \times 100$$

Physical and chemical characteristics of biochar are given in Table 1.

***Nutrient/elemental characteristics of biochar*:** Known weight of ground samples (about 0.1 g) were digested with sulfuric acid and hydrogen peroxide (2.5:1 ratio) (Wolf, 1982). Phosphorus concentration in the biochar samples was determined on UV–visible spectrophotometer (UV-1201, Shimadzu, Tokyo, Japan) at 410 nm after developing yellow color by vanadate-molybdate method (Chapman and Pratt, 1961). Potassium was directly determined on flame photometer (PFP7, Jenway, Essex, UK) using standard curve.The C, hydrogen (H), N and sulfur (S) content in biochar were analyzed on Vario Micro CHNS-O Analyzer (Elementar Analysensysteme GmbH, Hanau, Germany), while oxygen percentage was determined by difference method using following equation:

Oxygen (%) = 100 – (Carbon+Hydrogen+Nitrogen+Ash)%

The results obtained from Vario Micro CHNS-O analyzer were also used to calculate C:N, C:P and C:S elemental ratios, and H:C, O:C and (O+N):C molar ratios. Nutritional and elemental characteristics of biochar are given in the Table 1.

***Field experiment:*** A field experiment was conducted at Research area, Institute of soil and Environmental Sciences, University of Agriculture, Faisalabad to evaluate the effect of biochar along with different fertilizer rates on wheat growth, yield, nutrient uptake and chemical properties of the soil. In a two-factorial, randomized complete block design, five fertilizer rates i.e. 0, 25, 50, 75 and 100% of recommended fertilizer dose (RFD) were used along with 2 biochar levels (0.0 and 1.0% of soil weight). Field was ploughed and prepared before the application of treatments. Dimension of each experimental unit was 3 × 4 m with an area of 12 $m^2$. Biochar was manually applied and mixed into the soil by using spade. Recommended N:P:K dose (120:90:60 kg $ha^{-1}$) was applied as urea, single super phosphate (SSP) and sulfate of potash (SOP) respectively. After mixing biochar into the soil, calculated amount of N, P and K fertilizers were broadcasted into their respective plots according to the treatment plan. Before sowing, a composite soil sample (0-15 cm depth) was collected from the field and analyzed for its various physicochemical properties. Soil had loamy texture (sand 40.0%, silt 37.5%, clay 22.5%) with CEC 05.77 $cmol_c$

$kg^{-1}$, pH 8.21, $EC_e$ 0.42 dS $m^{-1}$, organic matter 0.69%, total N 0.23%, Olsen P 16.9 mg $kg^{-1}$, extractable K 151 mg $kg^{-1}$ and calcium carbonate ($CaCO_3$) 3.21%. Wheat variety "Faisalabad-2008" was sown by using seed at the rate of 120 kg $ha^{-1}$,with manual hand drill. During whole cropping duration, recommended cultural and plant protection measures were adopted. During the cropping period, all the experimental units were irrigated four times at recommended stages i.e. crown root initiation stage, tillering stage, booting stage and milking stage.

**Table 1. Characterization of *Dalbergia sissoo* biochar.**

| Property | Unit | Value* |
|---|---|---|
| **Chemical characteristics** | | |
| $pH_{1:10}$ | - | 6.58 |
| $EC_{1:10}$ | dS $m^{-1}$ | 0.74 |
| Cation exchange capacity | $cmol_c$ $kg^{-1}$ | 133 |
| Ash contents | % | 17.2 |
| **Physical characteristics** | | |
| Moisture | % | 1.03 |
| Bulk density ($\rho_b$) | Mg $m^{-3}$ | 0.38 |
| Particle density ($\rho_p$) | Mg $m^{-3}$ | 1.58 |
| Porosity | % | 76.0 |
| **Elemental/nutritional characteristics** | | |
| Total carbon | % | 55.7 |
| Total hydrogen | % | 2.05 |
| Total nitrogen | % | 1.03 |
| Total phosphorus | % | 0.21 |
| Total potassium | % | 0.92 |
| Total sulfur | % | 0.43 |
| Total oxygen | % | 24.0 |
| **Atomic/molar ratios** | | |
| C:N ratio | --- | 54.1 |
| C:P ratio | --- | 265 |
| C:S ratio | --- | 130 |
| H:C (molar ratio) | --- | 0.44 |
| O:C (molar ratio) | --- | 0.32 |
| (O+N):C (molar ratio) | --- | 0.34 |

* All values are mean of three replicates

***Plant and soil measurements***

***Agronomical and yield measurements*:** At harvesting stage parameters i.e. plant height, number of tillers and spike length were taken from all experimental units by randomly selected area of meter square ($m^2$). After harvesting, straw and grain weight was recorded by using weighing balance. Harvest index was calculated through following formula:

$$\text{Harvest index} = \frac{\text{Grain yield}}{\text{Straw yield}} \times 100$$

***Nutrient measurements*:** Straw and grain samples were oven-dried at 65 °C in a forced air oven (Eyela WFO─600ND, Tokyo Rikakikai, Tokyo, Japan), until the constant samples weight were achieved. After oven-drying, plant samples were ground (≤0.5 mm size) with a wiley grinding mill fitted with stainless steel blades. Ground samples (0.1 g) were digested with sulfuric acid and hydrogen peroxide (2.5:1 ratio) following wet digestion method (Wolf, 1982). The effect of treatments was evaluated for N, P and K content in wheat straw and grain samples. Nitrogen content were determined by following Kjeldhal method (Jackson, 1962). Phosphorus was determined on UV-visible spectrophotometer at 410 nm using standard curve, after developing yellow color by vanadate-molybdate method (Chapman and Pratt, 1961). Potassium was directly determined on flame photometer using standard curve.

***Secondary calculations*:** Nitrogen, P and K uptake in straw and grain samples was calculated separately for each nutrient by using following formula:

$$\text{Nutrient uptake} = \frac{\text{content in straw or grain} \times \text{straw or grain yield}}{100}$$

At different fertilizer doses, nutrient (N, P and K) recovery was calculated by using formula proposed by Mengel and Kirkby (2001):

$$\text{NR (\%)} = \frac{\text{NUF} - \text{NUC}}{\text{NAF}}$$

NR = Nutrient (N/P/K) recovery, NUF = Nutrient (N/P/K) uptake (straw + grain) in treatment having fertilizer, NUC = Nutrient (N/P/K) uptake (straw + grain) in treatment without fertilizer, NAF = Nutrient (N/P/K) added through fertilizer.

***Post-harvest soil analysis*:** After harvesting, soil samples were collected from each plot by using sampling auger.After sun-drying, soil samples were passed through a 2 mm sieve. A sub sample of the sieved soil was analyzed for various soil chemical properties i.e. EC, pH and CEC. Electrical conductivity of the saturated soil paste extract was measured by using EC meter (Cond 315i/SET, Weilheim, Germany). The pH of saturated soil paste was measured by Calomel glass electrode assembly. The CEC of soil samples was measured by using ammonium acetate compulsory displacement method proposed by Gaskin *et al*. (2008).

***Statistical analysis*:** Data was statistically analyzed by using software statistix 8.1® (Analytical Software, Tallahassee, USA). Standard error was calculated by using Microsoft Excel 2013® (Microsoft Corporation, Redmond, USA). Significantly different treatment means were separated by using least significant difference test (Steel *et al*., 1997).

## RESULTS

***Field Experiment***

***Growth parameters*:** Data in Table 2 reveals that in comparison with the treatment without biochar and fertilizer (control), the maximum increase in plant height (33%) was recorded when 75% of recommended fertilizer dose (RFD) was used along with biochar. The highest increase in spike length (38%) was calculated as a result of 50% of RFD along with biochar, as compared to the controlled one. These results

**Table 2. Effect of biochar and fertilizer application rates on plant height, spike length and number of tillers.**

| Fertilizer dose (%) | Plant height (cm) | | Spike length (cm) | | Number of tillers $m^{-2}$ | |
|---|---|---|---|---|---|---|
| | Control | Biochar | Control | Biochar | Control | Biochar |
| 0 | 081±5.57e | 087±5.46de | 6.82±0.21e | 8.11±0.35cd | 417±21.6e | 496±53.7cd |
| 25 | 090±5.23cd | 098±2.65bc | 7.93±0.13d | 8.38±0.37c | 484±25.5d | 540±31.6a-d |
| 50 | 102±4.58ab | 107±3.46a | 8.04±0.29cd | 9.42±0.33a | 512±47.3b-d | 592±58.3a |
| 75 | 106±4.36ab | 108±5.51a | 9.17±0.30ab | 9.30±0.21a | 550±33.3a-c | 583±63.5a |
| 100 | 105±9.54ab | 104±8.89ab | 9.23±0.55ab | 8.94±0.45b | 571±32.2ab | 560±37.0ab |

Means sharing similar letter(s) in the various treatments of each parameter do not differ significantly at P≤0.05. Data are average of three replicates ± standard deviation (SD).

**Table 3. Effect of biochar and fertilizer application rates on harvesting index, straw and grain yield.**

| Fertilizer dose (%) | Straw yield (ton $ha^{-1}$) | | Grain yield (ton $ha^{-1}$) | | Harvest index (%) | |
|---|---|---|---|---|---|---|
| | Control | 1% biochar | Control | 1% biochar | Control | 1% biochar |
| 0 | 3.49±0.32d | 4.16±0.40cd | 2.22±0.22f | 2.63±0.29e | $38.8^{NS}$ | 38.8 |
| 25 | 5.09±0.38bc | 5.02±0.55bc | 2.56±0.30e | 3.23±0.31d | 33.5 | 39.2 |
| 50 | 5.58±0.82ab | 5.75±0.60ab | 3.26±0.21d | 3.66±0.36bc | 37.1 | 38.9 |
| 75 | 5.99±0.37ab | 6.55±0.75a | 3.59±0.22c | 3.90±0.18ab | 37.5 | 37.4 |
| 100 | 6.26±0.72a | 6.37±0.92a | 3.68±0.25a-c | 3.95±0.13a | 37.1 | 38.5 |

Means sharing similar letter(s) in the various treatments of each parameter do not differ significantly at P≤0.05. Data are average of three replicates ± standard deviation (SD).

**Table 4. Effect of biochar and fertilizer application rates on straw nitrogen (N), phosphorus (P) and potassium (K) content.**

| Fertilizer dose (%) | Straw nitrogen content (%) | | Straw phosphorus content (%) | | Straw potassium content (%) | |
|---|---|---|---|---|---|---|
| | Control | 1% biochar | Control | 1% biochar | Control | 1% biochar |
| 0 | 0.83±0.09d | 1.04±0.12b-d | 0.144±0.022f | 0.231±0.017e | 0.817±0.081c | 0.857±0.088bc |
| 25 | 0.89±0.11cd | 1.07±0.18bc | 0.182±0.013f | 0.288±0.029cd | 0.857±0.059bc | 0.887±0.086a-c |
| 50 | 1.03±0.14cd | 1.11±0.17a-c | 0.257±0.019d | 0.344±0.036ab | 0.940±0.091ab | 0.987±0.071a |
| 75 | 1.02±0.10cd | 1.32±0.18a | 0.318±0.028bc | 0.343±0.027ab | 0.967±0.111a | 0.927±0.071ab |
| 100 | 1.07±0.13bc | 1.25±0.07ab | 0.341±0.026ab | 0.369±0.027a | 0.927±0.078ab | 0.980±0.071a |

Means sharing similar letter(s) in the various treatments of each parameter do not differ significantly at P≤0.05. Data are average of three replicates ± standard deviation (SD).

were statistically at par with the treatment having 100% of RFD. Biochar application along with 50% of RFD, resulted 42% increase in number of tillers $m^{-2}$, than control treatment. At 50% of RFD, biochar application resulted 16% more number of tillers $m^{-2}$, than the treatment having same fertilizer dose without biochar.

***Yield parameters:*** At 0 and 75% RFD, addition of biochar resulted 19 and 9% more straw yield, than their respective fertilizer treatments without biochar. As compared to control treatment, there was 76 and 78% improvement in grain yield as a result of 75 and 100% RFD along with biochar application, respectively. Up to 75% RFD, biochar application significantly increased grain yield, than their respective treatments without biochar addition. Results regarding harvest index were statistically non-significant, however the highest percentage of harvest index (39.2%) was calculated from the treatment having 25% RFD along with biochar (Table 3).

***Straw and grain nutrient content:*** Data presented in Table 4 clearly showed that the highest N content (1.32%) in wheat straw were obtained as a result of 75% RFD, followed by 1.25% as a result of 100% RFD along with biochar. As compared to control, there was 59 and 51% increase in straw N content as a result of 75 and 100% RFD along with biochar, respectively. At the highest fertilizer rate (100% RFD), in comparison to biochar control treatment, 17% increase in straw N content was observed after biochar addition. Regarding straw P content, the maximum statistical results were achieved at 50% RFD with 0.34% straw P content in biochar amended treatment. The highest value of P content (0.37%) was observed as a result of 100% RFD along with biochar, however this value was statistically similar to the P content obtain at 50% RFD along with biochar. In comparison with control treatment, maximum increase in straw K content (21%) was obtained as a result of 50% RFD along with biochar application.It is evident from the data given in Table 5 that maximum statistical results regarding grain N content were achieved from the treatments having 50% RFD along with or without biochar. As compared to control treatment, the highest increase (60%) in N content was achieved when 100% RFD was used along with biochar addition. The treatment having 100% RFD along with biochar resulted 73% more grain P content than controlled one. Regarding grain K content, no any statistical difference was observed between all the treatments, however, the highest grain K contents (0.78%) were observed in the treatment having 100% RDF along with biochar.

***Straw and grain nutrient uptake:*** Data presented in Table 6 is showing that there was nearly 2-fold increase in straw N uptake as a result of 75% RFD along with biochar addition. The treatments having 75 or 100% RFD without biochar could not compete for N uptake, than from the treatment having 75% RFD along with biochar. In comparison with control, 100% RFD along with biochar resulted 3.7 fold increase in straw P uptake, followed by 3.5 fold increase as a result of 75% RFD along with biochar. As compared to control treatment, the highest increase in straw K uptake was 0.8 fold, as a result of 50% RFD without biochar. Further incremental doses in fertilizer (75 and 100% RFD) with or without biochar addition, could not show any further statistical improvement in K uptake.Along with biochar addition, the highest statistical results regarding grain N uptake were achieved at 50% RFD with 53.5 kg N uptake $ha^{-1}$. Further increase in fertilizer rates (75 and 100% RFD) along with biochar application, showed non-statistical increase in N uptake up to 4 and 14%, respectively. At 100% RFD, the highest value of grain P uptake (16 kg $ha^{-1}$) was achieved as a result of biochar addition. In the absence of biochar, the highest grain P uptake was calculated at 100% RFD with 2.6 fold more P uptake, than control. Biochar addition at 50, 75 and 100% RFD, resulted 86, 93 and 106% better grain K uptake, respectively, than controlled one (Table 7).

**Table 5. Effect of biochar and fertilizer application rates on grain nitrogen (N), phosphorus (P) and potassium (K) content.**

| Fertilizer dose (%) | Grain nitrogen content (%) | | Grain phosphorus content (%) | | Grain potassium content (%) | |
|---|---|---|---|---|---|---|
| | Control | 1% biochar | Control | 1% biochar | Control | 1% biochar |
| 0 | 0.96±0.10e | 1.17±0.11d | 0.235±0.025f | 0.274±0.260ef | 0.673$^{NS}$ | 0.710 |
| 25 | 1.31±0.09b-d | 1.36±0.08bc | 0.305±0.036de | 0.336±0.022cd | 0.683 | 0.703 |
| 50 | 1.38±0.07a-c | 1.46±0.12ab | 0.343±0.042b-d | 0.378±0.026a-c | 0.713 | 0.769 |
| 75 | 1.22±0.05cd | 1.43±0.07ab | 0.348±0.033bc | 0.382±0.023ab | 0.717 | 0.740 |
| 100 | 1.47±0.12ab | 1.54±0.10a | 0.382±0.015ab | 0.407±0.045a | 0.743 | 0.783 |

Means sharing similar letter(s) in the various treatments of each parameter do not differ significantly at P≤0.05. Data are average of three replicates ± standard deviation (SD).

**Table 6. Effect of biochar and fertilizer application rates on uptake of nitrogen (N), phosphorus (P) and potassium (K) in straw.**

| Fertilizer dose (%) | Straw nitrogen uptake (kg $ha^{-1}$) | | Straw phosphorus uptake (kg $ha^{-1}$) | | Straw potassium uptake (kg $ha^{-1}$) | |
|---|---|---|---|---|---|---|
| | Control | 1% biochar | Control | 1% biochar | Control | 1% biochar |
| 0 | 29.3±5.00f | 43.2±4.41ef | 5.01±0.73e | 09.6±0.55d | 28.4±02.5d | 35.7±05.8cd |
| 25 | 45.3±5.60d-f | 53.8±13.1c-e | 9.24±0.64d | 14.5±2.77c | 43.4±01.0bc | 44.3±04.6bc |
| 50 | 57.8±13.5c-e | 63.9±12.5b-d | 14.3±1.92c | 19.7±1.20b | 52.0±03.5ab | 56.4±05.0a |
| 75 | 61.3±09.1b-e | 87.0±20.6a | 19.1±2.71b | 22.5±3.41ab | 58.0±07.7a | 60.9±10.5a |
| 100 | 66.2±3.00bc | 79.4±7.55ab | 21.3±2.22ab | 23.4±1.80a | 57.7±05.6a | 62.4±10.7a |

Means sharing similar letter(s) in the various treatments of each parameter do not differ significantly at P≤0.05. Data are average of three replicates ± standard deviation (SD).

**Table 7. Effect of biochar and fertilizer application rates on grain nitrogen (N), Phosphorus (P) and potassium (K) uptake.**

| Fertilizer dose (%) | Grain nitrogen uptake (kg $ha^{-1}$) | | Grain phosphorus uptake (kg $ha^{-1}$) | | Grain potassium uptake (kg $ha^{-1}$) | |
|---|---|---|---|---|---|---|
| | Control | 1% biochar | Control | 1% biochar | Control | 1% biochar |
| 0 | 21.5±4.29d | 31.0±6.41c | 05.3±1.06g | 07.3±1.46f | 15.0±2.86f | 18.6±1.38ef |
| 25 | 33.6±5.74c | 43.8±6.78b | 07.9±1.78f | 10.9±1.70e | 17.6±4.04f | 22.7±3.41de |
| 50 | 45.1±4.65b | 53.5±9.19a | 11.2±1.86de | 13.8±0.92bc | 23.2±2.16cd | 27.9±0.83ab |
| 75 | 43.9±1.43b | 55.7±0.17a | 12.5±1.95cd | 14.9±1.56ab | 25.7±2.67b-d | 28.9±2.45ab |
| 100 | 53.9±5.26a | 60.8±3.90a | 14.0±0.87bc | 16.0±1.23a | 27.3±1.88a-c | 30.9±3.19a |

Means sharing similar letter(s) in the various treatments of each parameter do not differ significantly at P≤0.05. Data are average of three replicates ± standard deviation (SD).

**Table 8. Effect of biochar and fertilizer application rates on cation exchange capacity (CEC), electrical conductivity (EC) and pH of the soil.**

| Fertilizer dose (%) | pH | | EC (dS $m^{-1}$) | | CEC ($cmol_c$ $kg^{-1}$) | |
|---|---|---|---|---|---|---|
| | Control | 1% biochar | Control | 1% biochar | Control | 1% biochar |
| 0 | 8.06±0.12a | 8.01±0.14ab | 0.409±0.032ab | 0.447±0.041a | 5.77±1.71b | 8.10±3.12a |
| 25 | 8.05±0.14a | 7.98±0.21ab | 0.392±0.039b | 0.392±0.018b | 5.75±1.80b | 7.97±3.58a |
| 50 | 7.94±0.23ab | 7.93±0.12ab | 0.377±0.019b | 0.415±0.023ab | 5.70±1.08b | 7.83±1.74a |
| 75 | 7.96±0.22ab | 7.84±0.12b | 0.367±0.002b | 0.394±0.028b | 5.74±1.65b | 8.02±2.17a |
| 100 | 7.90±0.12ab | 7.83±0.17b | 0.375±0.028b | 0.410±0.032ab | 5.75±1.60b | 7.96±2.45a |

Means sharing similar letter(s) in the various treatments of each parameter do not differ significantly at P≤0.05. Data are average of three replicates ± standard deviation (SD).

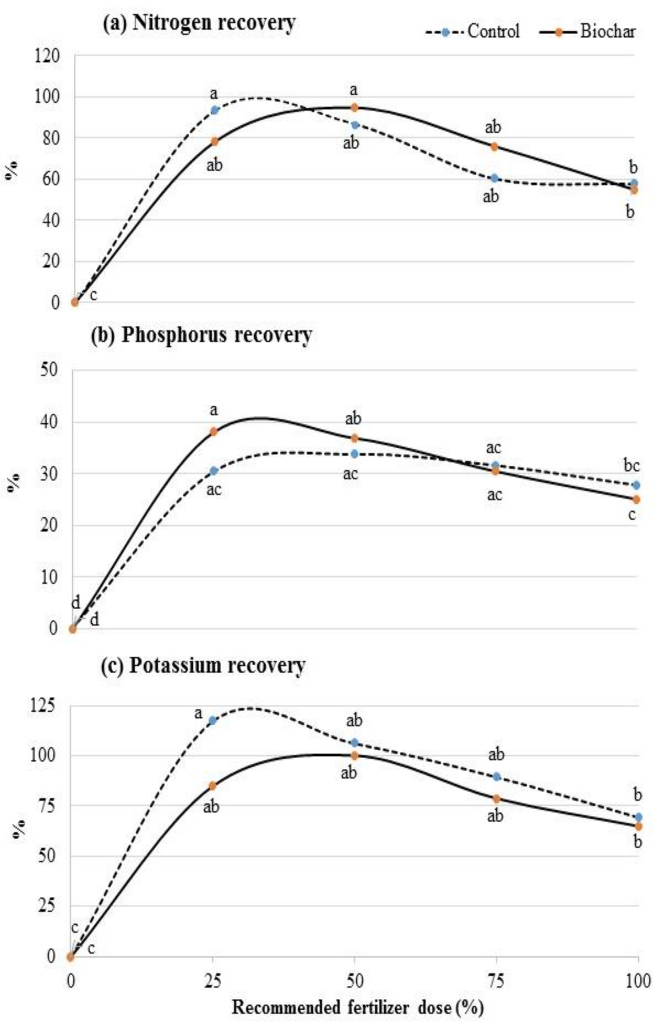


**Figure 1. Effect of biochar on nutrient recovery of applied fertilizer.**

***Nutrient recovery parameters:*** It is cleared from Figure 1a that treatments i.e. 50% RFD with biochar and 75% RFD with biochar resulted 9 and 27% more N recovery, as compared to their respective fertilizer treatments without biochar.It is evident from Figure 1b that treatment having 25% RFD along with biochar, resulted 27% more P recovery, than the treatment having same dose of fertilizer without biochar. In the same way, at 50% RFD along with biochar, there was 9% more P recovery than the treatment having same rate of fertilizer without biochar. Figure 1c showed that the highest K recovery was 117%, as a result of 25% RFD with biochar, followed by 106% when 50% RFD was used along with biochar.

***Po st-harvest soil analysis:*** Data presented in Table 8 is clearly showing a decreasing trend in soil pH with increasing fertilizer rates; however, this decrease was statistically non-significant. The lowest pH value (7.83) and 7.84 were measured as a result of 100 and 75% RFD along with biochar, respectively. The highest EC (0.45 dS $m^{-1}$) was measured from the soil of treatment having biochar without fertilizer, followed by 0.42 dS $m^{-1}$ as a result of treatment with 50% RFD with biochar addition. At all fertilizer doses, biochar addition significantly improved soil CEC. As compared to control, regarding soil CEC, the highest increase of 40% was obtained from the treatment where biochar was applied without fertilizer.

## DISCUSSION

In the present study, at different fertilizer rates, efficacy of Dalbergia sissoo biochar was tested to improve wheat growth, yield and nutrient recovery, in alkaline calcareous soil under field conditions. Biochar, a highly aromatic form of organic matter can persist in soils for many centuries (Schmidt and Noack, 2000; Glaser, 2007), and has great potential to improve agronomic production when applied as a soil amendment (Laird et al., 2009). Comparing with other organic soil amendments, very high porosity and surface area of biochar enable it to retain more water and nutrients, and also provide a best habitat for soil microorganisms (Lehmann and Rondon, 2006, Warnock et al., 2007). In addition to this, biochar may supply more plants available nutrients by adding organic matter, enhance physical and chemical properties of the soil and improve water status of the soil. In our experiment combined use of biochar with different fertilizer rates, significantly improved growth and yield of wheat. Plant growth parameters i.e. plant height, number of tillers and spike length (Table 1) were improved with increasing fertilizer rates, which might be due to better nutrient supply from applied fertilizer. With biochar addition, further improvement in wheat growth was observed especially up to 50% RFD (Table 2). As a result of biochar application, improvement in plant growth parameters was an indication for better grain yield outcome. It is clear from our results that up to 75% RFD, further biochar addition into the soil, significantly enhanced grain yield (Table 3). Abdullah *et al*. (2008) have also reported an improved plant growth as a result of soil biochar application.

From our results, it was clarified that with respect to the treatments having reduced fertilizer doses, further biochar addition improved straw and grain N content as well as N uptake up to 75% RFD (Table 4, 5, 6 and 7) and N recovery at 50 and 75% RFD (Figure c). Direct N additions by biochar resulted better nutrient availability for plants (Lehmann *et al*., 2003) and ultimately due to increased N availability in biochar amended soil (Sohi *et al*., 2010), an improvement in N uptake was observed. Our outcomes were resembled with the results of Yeboah *et al*. (2009) who documented that biochar increases the uptake of nitrogen in corn plants. The reason for better N content, uptake and N recovery was also might be the higher nutrient retention capacity of biochar amended soil. As a result of biochar application, soil CEC improved up to 40%. Due to this increase in soil CEC, ammonium ($NH_4^+$) retention might also be improved and during cropping period and penalty of nutrients were available for plant uptake. As a result of biochar application, significant increase in soil CEC has also been observed by some other scientists (Laird *et al*., 2010; Peng *et al*., 2011; Zwieten *et al*., 2010). Our results were in accordance with Blackwell *et al*. (2010) who concluded that biochar along with lower rates of fertilizer increased wheat yield. As a result of fertilizer application along with biochar, crop yields were improved due to better N utilization (Steiner *et al*., 2007; Widowati *et al*., 2011). Reason behind better nutrient utilization was an increase in soil CEC and decrease in N losses due to more $NH_4^+$ adsorption on biochar surfaces (Chan *et al*., 2008; Masulili *et al*., 2010) or because of its ability to inhibit N transformation as more N adsorbed on biochar surfaces so net nitrification process was slowed down (Widowati *et al*., 2011). Similar results were shown by Zwieten *et al*. (2010), who documented that biochar improve N use efficiency in wheat crop. Where Chan *et al*. (2007) documented that biochar application improved soil physical properties and increased the N use efficiency.

Along with biochar addition, the highest statistical improvement in straw P content and uptake was observed with 50 and 75% RFD, respectively (Table 4 and 6). In biochar amended treatments, significant increase in grain P uptake was calculated up to 75% RFD (Table 7). The possible reason behind the achievement of the highest statistical results at reduced doses, was might be the direct release of P soluble salts from biochar. Biochar can have also a considerable capacity of ion exchange (Atkinson *et al*., 2010; Liang *et al*., 2006), so it may enhance P availability due to more anion exchange capacity (AEC) or by affecting the activity of various cations (especially $Ca^{2+}$ in case of calcareous soils) that interact with P (Wang *et al*., 2012). In our case, biochar addition into soil enhanced P bioavailability and plant growth (Lehmann *et al*., 2003; DeLuca *et al*., 2009). In this field trial, biochar application resulted the highest P recovery at 25% RFD and then at 50% RFD (Figure b). Blackwell *et al*. (2010) also observed that P use efficiency was better when biochar was applied along with lower rates of fertilizer. Under calcareous soil condition, a significant increase in P uptake is also reported as a result of biochar addition (Aon *et al*., 2015). In our experiment, with biochar addition, overall no any significant improvement was observed regarding straw and grain K content (Table 4 and 5), and wheat straw K uptake (Table 6). However, along with biochar application, grain K uptake was improved at 25 and 50% RFD (Table 7). This might be due the reason that K content in soil were already enough (151 mg $kg^{-1}$) to fulfill plant nutrient requirement, while improvement in grain K uptake was ultimately due to increased availability of N and P through fertilizer and biochar application.

After the post-harvest soil analysis, it was cleared that despite of having slightly acidic pH (Table 1), after biochar application no any significant change in soil pH was observed (Table 8). It was might be due to the buffering capacity of the soil. Electrical conductivity of biochar was slightly higher (0.74 dS $m^{-1}$) than soil EC (0.42 dS $m^{-1}$). However, it is cleared from the post-harvest soil chemical analysis (Table 8), that soil biochar application did not enhance soil EC, significantly. Biochar used in this field study had CEC, 133 $cmol_c$ $kg^{-1}$ and its application improved soil CEC up to 40% (Table 8). High surface area of biochar has great influence on its CEC. As a result of biochar application, significant increase in soil CEC has also been observed by some other scientists (Laird *et al*., 2010; Peng *et al*., 2011; Zwieten *et al*., 2010). One more reason of increased soil CEC was might be due to the oxidation of biochar edges which ultimately provided more exchange sites and increased soil CEC (Cheng *et al*., 2006).

***Conclusion*:** The results of this field experiment strongly advocated soil biochar application for improving wheat growth, yield, and N and P uptake. At reduced fertilizer rates (i.e. 50 and 75% of RFD) along with biochar application, most of the studied plant growth and nutrient accumulation responses were statistically at par with the treatment having full (100%) RFD without biochar. It can be concluded that 1% *Dalbergia sissoo* biochar application can partly supplement N and P demand of wheat and can produce maximum outcome at 75% RFD in calcareous soil.

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