Research Article

Residual effect of biochar and summer legumes on soil physical properties and wheat growth

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Abstract

Biochar, a carbon-rich solid material and legumes having numerous benefits to the soil-plant system gaining a keen interest as an innovative sustainable approach among the agriculture research community in many parts of the world especially in developing countries in order to enhance soil quality and ensure food security. Thus, with the same approach, we have carried out a field experiment to examine the residual effect of biochar application and summer legumes on soil physical properties and subsequent wheat crop growth at the Research Farm, The University of Agriculture Peshawar during winter 2016-2017. An experiment was designed in two-factor factorial randomized complete block design with three replications in summer 2016 in which three different summer legumes i.e. mungbean, sesbania, and cowpea were grown in the summer for the purpose of grain, green manuring and fodder, a fallow was also included with the purpose of control. Biochar was applied at the rate of 0, 5 and 10 tons ha⁻¹. After the harvesting of summer legumes, sesbania biomass was completely incorporated into the soil while the biomass of other two legumes were removed. The experiment on subsequent wheat was on the same field layout of summer legumes. Both the treatments i.e. previously applied biochar especially 10 tons ha⁻¹ and preceding summer legumes especially sesbania as well as their interaction showed a significant effect on the selected soil physical properties. Similarly, the response of wheat growth was also significant to both treatments but their interaction was non-significant. Thus, it was concluded that both the treatments had a significant effect on the soil physical properties and growth of wheat and should be included in the cropping system.

Keywords: Biochar; soil physical properties; summer legumes; wheat growth

Introduction

The growing global posterity is supposed to surely face the supreme challenge of food security; particularly, the advancing nations have greater threats for food security because

they lack natural resources or severe degradation specifically of fertile soil and water. Soil degradation and nutrient depletion are global concerns and soil restoration techniques are greatly needed to

increase soil organic matter (SOM), and stability of soil organic carbon (C) are required to increase productivity and minimize risks of soil degradation and environmental pollution. To this end, impacts of a range of agricultural, industrial by-products (waste materials) and composts have been studied as soil amendments to enhance soil physical properties [1, 2], availability of plant nutrients [3]. So keeping in consideration the importance of soil resources for the maximum crop yield and growth and management of environmental pollutions, the biochar is gaining a keen interest among the scientists as a sustainable technique to get the desired objectives.

Biochar is a carbon-rich, fine-grained, a porous substance produced under oxygen-limiting conditions [4] at temperatures between 350 and 700 °C. It can be defined as the solid residue obtained from the thermochemical decomposition or pyrolysis of plant and waste feedstock's, and can be specifically used for application to the soil as part of an agronomic or environmental management plan [5]. It can alter the physical properties of the soil such as structure, porosity, density, aeration, soil workability, water holding capacity and hence the growth of the plant [6].

Sustainable agricultural practices i.e. inclusion of biochar, legumes, compost, cover crops and other organic amendments are the ways of raising food that is healthy for consumers and animals without causing damage to ecosystem health. Low nutrient content and accelerated mineralization of soil organic matter (SOM) are the two major constraints currently encountered in sustainable agriculture renner [7]. Nutrients are retained in the soil and remain available to crops mainly by adsorption to minerals and soil organic matter. Usually, the addition of organic matter such as compost and manure into the soil can help retain nutrients. Biochar is considered much more effective than other

organic matter in retaining and making nutrients available to plants. 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 [8].

Materials and methods

A rotation experiment was conducted in summer 2016 in which three legumes crops i.e. mungbean, sesbania, and cowpea were grown in the summer for the purpose of grain, green manuring and fodder, a fallow was also adjusted for the purpose of control. Biochar was added at the rate of 0, 5 and 10 tons ha⁻¹. The details of the treatment combinations as applied to the soil is presented in (Table 1). After the harvesting of summer legumes, sesbania biomass was thoroughly incorporated into the soil while the biomass of mungbean and cowpea were removed. The field experiment on the subsequent wheat was carried out in winter 2017 on two-factor factorial randomized complete block design having three replications on the same field layout of previous summer legumes. The plot size was 13.5 x 4.2 m² and wheat variety Pir Sabaq-2013 was sown at the rate of 120 kg ha⁻¹. Soil samples were collected in proper moisture condition after subsequent wheat crop harvesting from each treatment plots and were analyzed for various soil physical properties such as organic matter, bulk density, saturation percentage and water holding capacity. The row to row distance for wheat was kept at 30 cm. Basel dose of N at the rate of 120 kg N ha⁻¹, P at the rate of 90 kg P₂O₅ ha⁻¹ and K at the rate of 60 kg K₂O ha⁻¹ were added in the form of Urea, DAP, and MOP, respectively, to each plot. N was added in two doses, half at the time of sowing and half at the vegetative stage of the crop, whereas all the P and K have been applied at sowing time.

Factors along their levels are presented below

Factor A: Legumes grown in summer

1. Mungbean were added for food grain
2. Cowpea for forage
3. Sesbania for green manuring
4. Fallow as a control

Factor B: Biochar

1. 0 tons ha⁻¹ (control)
2. 5 tons ha⁻¹
3. 10 tons ha⁻¹

Table 1. Details of the treatment combinations as applied to the soil

M0 = Mungbean + 0 tons ha ⁻¹ Biochar	S0 = Sesbania + 0 tons ha ⁻¹ Biochar
M1 = Mungbean+ 5 tons ha ⁻¹ Biochar	S1 = Sesbania + 5 tons ha ⁻¹ Biochar
M2 = Mungbean + 10 tons ha ⁻¹ Biochar	S2 = Sesbania + 10 tons ha ⁻¹ Biochar
C0 = Cowpea + 0 tons ha ⁻¹ Biochar	F0 = Fallow + 0 tons ha ⁻¹ Biochar
C1 = Cowpea+ 5 tons ha ⁻¹ Biochar	F1 = Fallow + 5 tons ha ⁻¹ Biochar
C2 = Cowpea+ 10 tons ha ⁻¹ Biochar	F2 = Fallow + 10 tons ha ⁻¹ Biochar

Data was recorded on the following parameters

Soil organic matter (%)

In soil samples, organic matter was determined by the method of Walkley-Black as expounded by Nelson and Sommers [9], by using the formula.

$$\text{SOM (\%)} = \frac{[(\text{mL of K}_2\text{Cr}_2\text{O}_7 \times \text{N}) - (\text{mL of FeSO}_4 \cdot 7\text{H}_2\text{O} \times \text{N})] \times 0.69}{\text{Weight of soil (g)}}$$

Weight of soil (g)

Soil bulk density (g cm⁻³)

Blake and Hartge [10] method was used for the measurement of bulk density by using the given formula.

$$\text{BD} = \frac{M}{V}$$

Soil Saturation percentage (%)

The saturation percentage was determined by the procedure as described by Gardner [11], with the help of formula.

$$\text{Saturation water percentage (sPw)} = \frac{M_t - M_s}{M_s} \times 100$$

Water holding capacity (%)

Available water holding capacity was determined in soil samples by the procedure as mentioned by Raza *et al.* [12]

$$\text{Formula: } \Psi = a\omega^b$$

Plant height (cm)

The plant height of wheat was recorded with the help of measuring tape on selected ten plants randomly in two central rows of each and every treatment plots.

Number of grains spike⁻¹

Data regarding the number of grains spike⁻¹ were recorded by counting the number of grains for five representative spikes in each subplot. Spikes of various sizes were randomly chosen and threshed separately. Number of the grains were counted and averaged.

Spikes m⁻²

Data regarding spikes m⁻² was recorded by counting the total number of spikes in one meter area in three central rows of each subplot and converted into the number of spikes m⁻² by using the following formula:

$$\text{Spike m}^{-2} = \frac{\text{No. of spikes counted}}{\text{R-R distance} \times \text{Row length} \times \text{No. of rows selected}}$$

Spike length (cm)

Five spikes in each subplot were randomly selected; spike length was measured with the help of measuring tape from the base of spike and to the tip of the awn. Average spike length was then calculated.

Results and discussion

Soil Organic Matter (%)

The data concerning soil organic matter content as affected by the residual application of biochar and summer legumes are given in (Table 2 & Figure 1). Mean Values of the data revealed that previously applied biochar and legumes sown in summer significantly affected ($p \leq 0.05$) soil organic matter. The legumes and biochar interaction was also significant for the organic matter. The soil organic matter was considerably affected by

preceding legumes. The maximum soil organic matter (0.85 %) was recorded in the plots incorporated with sesbania followed by cowpea (0.80 %) and mungbean (0.73 %). The lowest soil organic matter (0.47 %) was recorded in the plots previously kept fallow. Similarly, in the case of biochar, the maximum soil organic matter (0.96 %) was recorded in the plots previously received biochar at the rate of 10 tons ha⁻¹ followed by 5 tons ha⁻¹ (0.70 %), while the minimum soil organic matter (0.48 %) was recorded in the plots previously received biochar at the rate of 0 tons ha⁻¹. *Shah et al.* [13] reported that soil organic fertility after green manuring of summer legumes in summer of 2002 showed that the soil organic fertility was consistently higher in legumes than in fallow plot. Our results are also in accordance with *Jensen et al.* [14] who reported that legumes inclusion can increase humus, soil organic carbon content, improve structure and water holding capacity of the soil. *Chaudhry et al.* [15] reported that highest soil organic matter content was observed for the treatment having biochar application alone and the lowest organic matter content was noticed for the treatment receiving inorganic fertilizer without biochar amendment. Addition of biochar to the agricultural soil is important for the carbon sequestration and soil organic fertility, and having residence time for millions of years in the soil reported by *Kumar et al.* [16]. Our results are also in accordance with *Ali et al.* [17], *Pattanayak et al.* [18] and *Sarwar et al.* [19].

Soil bulk density (gcm⁻³)

The data concerning the bulk density of soil as influenced by the residual application of biochar and summer legumes are shown in (Table 2 & Figure 2). Mean values of the data revealed that both previously applied biochar and preceding legumes considerably affected the bulk density of soil. All the interactions were also significant ($p \leq 0.05$). The soil bulk density was considerably affected by

preceding legumes. The lowest soil bulk density (1.13 g cm⁻³) was noticed in the plot previously sown with sesbania followed by mungbean (1.19 g cm⁻³) and cowpea (1.21 g cm⁻³), while the highest bulk density (1.23 g cm⁻³) was observed in the fallow plots. Similarly, in case of biochar, the minimum bulk density of soil 1.14 g cm⁻³ has been observed for the treatment having biochar at the rate of 10 tons ha⁻¹ followed by 1.19 g cm⁻³ for the treatment received 5 tons ha⁻¹ biochar. The highest soil bulk density of 1.25 g cm⁻³ was noticed in the control plots. A reduce bulk density of soil having treatment of sesbania is probably associated with the greater amount of soil organic matter deposition and loosening of soil by root action, these results were reported by *Lampurlanes and Martinez* [20]. Similarly, *Chikowo et al.* [21] published that addition of woody legumes to the soil reduces bulk density and increases soil granulation and porosity. Alike results were also given by *Haynes*, [22]. *Quin et al.* [23] reported that biochar prepared from woody residues had a higher effect on bulk density in a coarse-textured soil than in soils having a higher amount of clay content. Our results are also in support of the *Laird et al.* [24] who reviewed that biochar-amended soil after 500 days even applied in lower amount have recorded large decrease in bulk density of soil. Same results have also been reported by *Chaudhry et al.* [15].

Soil saturation percentage (%)

Average values of the data stated that preceding legumes and previously applied biochar significantly affected ($p \leq 0.05$) saturation percentage as shown in (Table 2 & Figure 3). The legumes and biochar interaction were also significant for the saturation percentage. Maximum saturation percentage (52.3 %) was noticed in the plots incorporated with sesbania followed by cowpea (48.1 %) and mungbean (46.2 %), while the lowest soil saturation percentage

(42.6 %) was recorded in the fallow plots. In case of biochar, the maximum soil saturation percentage (51.0 %) was noticed in the treatments plots previously received biochar at the rate of 10 tons ha⁻¹ followed by 5 tons ha⁻¹ (47.4 %), while the minimum saturation percentage (43.5 %) was noticed in the plots previously received biochar at the rate of 0 tons ha⁻¹. Sultani *et al.* [25] reported that green manuring crops significantly reduced bulk density, enhanced total porosity, increased available water holding capacity, and also increase the water retention in the soil. Our results were also confirmed by the observation of (Carlson and Huss-Danell, [26]; Mayer *et al.* [27] who found that green manuring legumes as compared to non-legumes significantly increase aeration, porosity, and moisture retention capacity of the soil. Atkinson *et al.* [28]; Major *et al.* [29] reported that application of biochar to the soil improves a wide range of physical properties of the soil such as total porosity, moisture content, saturation percentage, water holding capacity or plant available water content and hydraulic conductivity. Our results are also in agreement with Sohi *et al.* [30]; Zwieten *et al.* [31].

Water holding capacity (%)

Preceding legumes and previously applied biochar significantly affected ($p \leq 0.05$) water holding capacity of the soil as shown in (Table 2 & Figure 4). The legumes and biochar interaction were also significant. The maximum water holding capacity (13.50 %) was noted in the plots incorporated with sesbania followed by cowpea (12.10 %) and mungbean (11.80 %), while the lowest soil water holding capacity (7.10 %) was recorded in the fallow plots. In case of biochar, the maximum soil water holding capacity (13.60 %) was noted in the treatments plots previously received biochar at the rate of 10 tons ha⁻¹ followed by 5 tons ha⁻¹ (10.70 %), while the minimum water holding capacity (9.10 %) was noticed in the

plots previously received biochar at the rate of 0 tons ha⁻¹. Sultani *et al.* [25] reported that green manuring crops significantly reduced bulk density, enhanced total porosity, increased available water holding capacity, and also increase the water retention in the soil. Our results were also confirmed by the observation of Carlson and Huss-Danell [26]; Mayer *et al.* [27] who found that green manuring legumes as compare to non-legumes significantly increase aeration, porosity, and moisture retention capacity of the soil. Atkinson *et al.* [28]; Major *et al.* [27] reported that application of biochar to the soil improves a wide range of physical properties of the soil such as total porosity, moisture content, saturation percentage, water holding capacity or plant available water content and hydraulic conductivity. Our results are also in agreement with Sohi *et al.* [30]; Zwieten *et al.* [31].

Plant height (cm)

Statistical analysis of the data revealed that previously applied biochar and preceding legumes significantly affected ($p \leq 0.05$) plant height of wheat as shown in (Table 3). The legumes and biochar interaction was non-significant. The plots incorporated with sesbania produced the tallest plants (101 cm), followed by mungbean (96.4 cm) and cowpea (96.1 cm), while the fallow plot produced the shortest plants (94.8 cm) which were statistically at par with each other. In case of biochar, the tallest plant height (98.3 cm) were recorded in the plots where biochar was applied previously at the rate of 10 tons ha⁻¹, which was statistically at par with 5 tons ha⁻¹ (97.9 cm), while the plots previously received biochar at the rate of 0 tons ha⁻¹ produced the shortest wheat plants (95.2 cm). Gerami *et al.* [32] reported that plant height of wheat is significantly affected by green manures as compare to no-green manures. This is due to the release of different macro and micronutrients specifically nitrogen from the residues of these green manures which

have a positive effect on the stem elongation of subsequent crop. Similarly, Ali *et al.* [33] reported that plots previously sown with legumes (sesbania, cowpea, mungbean and fallow) have a significant effect on plant height which may be due to the residual soil

fertility improved by the previous legumes. Olmo *et al.* [34] reported that plots treated with biochar improved soil characteristics, nutrients availability and consequently wheat growth. Same results were also reported by Liu *et al.* [4].

Table 2. Soil organic matter (SOM), bulk density (BD), saturation percentage (SP) and water holding capacity (WHC) as affected by residual application of biochar and summer legumes

Legumes	S.O.M (%)	B.D (g cm ⁻³)	S.P (%)	W.H.C (%)
Cowpea	0.80 ab	1.21 ab	48.1 b	12.10 ab
Mungbean	0.73 b	1.19 b	46.2 c	11.80 b
Sesbania	0.85 a	1.13 c	52.3 a	13.50 a
Fallow	0.47 c	1.23 a	42.6 d	7.10 c
LSD (0.05)	0.074	0.020	1.15	1.20
Biochar (tons ha⁻¹)				
0	0.48 c	1.25 a	43.5 c	9.10 c
5	0.70 b	1.19 b	47.4 b	10.70 b
10	0.96 a	1.14 c	50.0 a	13.60 a
LSD (0.05)	0.064	0.017	0.99	1.03
Interaction				
L x B	*	*	*	*

Means followed by different letter(s) in the same column are significantly different from one another at 5% level of probability; * = Significant at 5 % level of probability, respectively

Figure 1. Soil organic matter (%) content as influenced by residual application of biochar and summer legumes after wheat harvest

Figure 2. Soil bulk density (g cm⁻³) as influenced by residual application of biochar and summer legumes after wheat harvest

Figure 3. Soil Saturation percentage (%) as influenced by residual application of biochar and summer legumes after wheat harvest

Figure 4. Water holding capacity (%) as influenced by residual application of biochar and summer legumes after wheat harvest

Grains spike⁻¹

Grains spike⁻¹ of wheat as affected by the residual application of biochar and summer legumes are given in (Table 3). Statistical analysis of the data revealed that previously applied biochar and preceding legumes significantly affected ($p \leq 0.05$) Grains spike⁻¹ of the wheat crop. The legumes and biochar interaction was non-significant. The plots incorporated with sesbania produced the maximum number of grains spike⁻¹ (50), followed by mungbean (47) and cowpea (47), while the fallow plot produced the minimum number of grains spike⁻¹ (46) which were statistically at par with each other. In case of biochar, the maximum number of grains spike⁻¹ (51) were recorded in the plots where biochar was applied previously at the rate of 10 tons ha⁻¹, which was statistically at par with 5 tons ha⁻¹ (48), while the plots previously received biochar at the rate of 0

tons ha⁻¹ produced the minimum grains spike⁻¹ (45). Gerami *et al.* [32] reported that yield and growth parameters of wheat is significantly affected by green manures as compare to no-green manures. This is due to the release of different macro and micronutrients specifically nitrogen from the residues of these green manures which have a positive effect on the stem elongation of subsequent crop. Similarly, Ali *et al.* [33] reported that plots previously sown with legumes (sesbania, cowpea, mungbean and fallow) have a significant effect on plant grains spike⁻¹ which may be due to the residual soil fertility improved by the previous legumes. Olmo *et al.* [34] reported that plots treated with biochar improved soil characteristics, nutrients availability and consequently wheat growth. Same results were also reported by Liu *et al.* [4].

Spikes m⁻²

Spike m⁻² of wheat as affected by the residual application of biochar and summer legumes are given in (Table 3). Previously applied biochar and preceding legumes significantly affected ($p \leq 0.05$) spike m⁻² of the wheat crop. The legumes and biochar interaction was non-significant. The plots incorporated with sesbania produced the maximum number of Spike m⁻² (322), followed by cowpea (303) and mungbean (299), while the fallow plot produced the minimum number of spike m⁻² (291). In case of biochar, the maximum number of spike m⁻² (318) were recorded in the plots where biochar was applied previously at the rate of 10 tons ha⁻¹, followed by 5 tons ha⁻¹ (306), while the plots previously received biochar at the rate of 0 tons ha⁻¹ produced the minimum spike m⁻²

(287). Gerami *et al.* [32] reported that yield and growth parameters of wheat are significantly affected by green manures as compare to no-green manures. This is due to the release of different macro and micronutrients specifically nitrogen from the residues of these green manures which have a positive effect on the stem elongation of subsequent crop. Similarly, Ali *et al.* [33] reported that plots previously sown with legumes (sesbania, cowpea, mungbean and fallow) have a significant effect on plant grains spike⁻¹ which may be due to the residual soil fertility improved by the previous legumes. Olmo *et al.* [34] reported that plots treated with biochar improved soil characteristics, nutrients availability and consequently wheat growth. Same results were also reported by Liu *et al.* [4].

Table 3. Plant height, grains spike⁻¹ and spike m⁻² as affected by residual application of biochar and summer legumes

Legumes	Plant Height (cm)	Grains Spike ⁻¹	Spike m ⁻²
Cowpea	96.1 b	47 b	303 b
Mungbean	96.4 b	47 b	299 b
Sesbania	101.4 a	50 a	322 a
Fallow	94.8 b	46 b	291c
LSD (0.05)	1.853	1.4	6.9
Biochar (tons ha ⁻¹)			
0	95.2 b	45 c	287 c
5	97.9 a	48 b	306 b
10	98.3 a	51 a	318 a
LSD (0.05)	1.604	1.19	5.9
Interaction			
L x B	Ns	Ns	Ns

Means followed by different letter(s) in the same column are significantly different from one another at 5% level of probability; Ns= non-significant

Conclusions

On the basis of experimental results, it is concluded that residual application of biochar and preceding legumes had a significant effect on the soil physical properties and of growth of subsequent wheat. Previously applied biochar at the rate of 10 tons ha⁻¹ and preceding legumes especially previously incorporated sesbania had a significant carryover effect on the soil physical

properties and of growth of subsequent wheat. Similarly, the interactive effect of residual biochar application at the rate of 10 tons ha⁻¹ with previously incorporated sesbania had a significant effect on the soil physical properties and of growth of subsequent wheat.

Authors' contributions

Conceived and designed the experiments: IA Mian & HU Rahim, Performed the

experiments: IA Mian, Analyzed the data: ZU Rahim, S Ahmad & Z Khan, Contributed materials/ analysis/ tools: MA Khan, M Haris & L Zada, Wrote the paper: IA Mian & HU Rahim.

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