



Field-based investigation of aged biochar coupled with summer legumes effect on wheat yield in Pakistan

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ABSTRACT

There is a debate about the effect of the aged biochar on the crop yield. Herein, a field-based experimental data set and analysis provide the information on the effect of the aged biochar coupled with summer legumes on the yield of wheat. During summer 2016, three different legumes (mungbean, sesbania, and cowpea) were grown with the intention of grain for human consumption, green manuring for soil fertility improvement and fodder for livestock consumption. A fallow (control) was also included in the experiment with the purpose of comparison. Biochar was applied to each experimental plot in triplicates at the rate of 0, 5, and 10 tons ha⁻¹. Afterward, the harvesting of legumes, the biomass of the sesbania treatment plot, was mixed in the field, although the biomass of mungbean and cowpea were detached from each respective plot. The wheat crop was grown on the same field layout and design (randomized complete block) of legumes. The data analysis highlighted that significantly maximum grain yield (kg ha⁻¹), biological yield (kg ha⁻¹), thousand-grain weight (g), and straw yield (kg ha⁻¹) were obtained in the plots mixed with sesbania. Regarding the aged biochar effect, maximum yield was obtained in the plots with 10 tons ha⁻¹ treatment. Additionally, the interaction of aged biochar, coupled with legumes, was non-significant. In conclusion, this work could prove that aged biochar, coupled with summer legumes enhanced the yield of wheat on a sustainable basis due to its numerous benefits to the plant system.

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important cereal crop of the family Poaceae, and it is the major staple food of about 35% of the population worldwide. It gives carbohydrates of 55% and calories of 20% of the total consumption globally (Breiman & Graur, 1995; Kronstad, 1997). It is observed that livestock is consuming more than 40% of the wheat grain globally. A wide range of

climates and soils can be used for the cultivation of the wheat crop. It is the cereal crop that is mostly consumed compared to other crops worldwide (Singh, Singh, Kushwaha, & Singh, 2007). The world-leading producer countries of the wheat grain are China, the USA, Canada, India, Russia, Europe, and Africa (Varshney, Balyan, & Langridge, 2006).

Wheat is the major cultivated and most consuming staple food in Pakistan. In the

agriculture sector, its contribution is 10.0%, while 2.1 % is its part in the Gross Domestic Product (GDP) of the country. In 2015-2016, the total occupied area of wheat was 9.25 million hectares, with the production of 25.45 million tons (Ministry of national food security and research MNFSR, 2015-2016). Pakistan is among the top ten countries in the world which are producing high yield and production of wheat. Wheat is grown in Pakistan both in irrigated and rainfed areas but mostly under irrigated conditions for which the requirement of water ranges from 20 to 21 inches per acre (Sarwar & Nawaz, 1985).

Biochar is the carbon-rich by product that is prepared from different types of raw materials under various temperatures, generally ranging from 300°C to 700°C and or under zero oxygen supply (Lehmann & Joseph, 2015; Sohi, Krull, Lopez-Capel, & Bol, 2010). It is a highly stable and slowly decomposable product and can remain in the soil for an extended time. It plays a vital role in soil quality improvement, environmental remediation, climate change mitigation, and crop yield enhancement. It has been reported that the application of biochar enhance the Physicochemical and biological properties of the soil, increase the nutrient's availability and boost up the pH of the soil (Lehmann et al., 2003; Novak et al., 2009). As a result, biochar exhibits considerable potential in agricultural use by enhancing the overall quality of soil and hence the yield output (Jeffery, Verheijen, van der Velde, & Bastos, 2011).

The use of nitrogen contains fertilizers in the agricultural system is required in a high amount for the maximum crop yield. However, in developing countries like Pakistan, it is limited due to the high-cost, low income of farmers, lack of facilities, and others. On the other hand, the excessive use of these fertilizers, causing global warms. So, in these situations, the inclusion of summer legumes in the cropping system is necessary because of the ability of legumes to fix the nitrogen from the air into the soil, also to increase the productivity of the soil to obtain maximum crop yield (Herridge, Rupela, Serraj, & Beck, 1993).

Therein, the goal of this research work was to investigate the long-term/aged effect of biochar coupled with summer legumes on subsequent wheat

yield with the intention of slow decomposition of biochar and legume (sesbania residues), subsequently slow release of nutrients to soil system and its positive effect on wheat yield under natural field conditions.

MATERIAL AND METHODS

Experimental Setup

The detailed information about materials and methods can be found in our recently published articles (Rahim et al., 2019; Rahim, Mian, Arif, Ahmad, & Khan, 2020). Briefly, Field-scale experiment for enhancing wheat yield with the aged effect of biochar and summer legumes were carried out on farmland located at the University of Agriculture Peshawar-Pakistan. The land was sown for summer legumes with a specific purpose in the summer season-2016. The as-prepared biochar was added to summer legumes once (mungbean, sesbania, and cowpea). The treatment rate was 0, 5, and 10 tons ha⁻¹ (Table 1). When the legumes were harvested, the residues of sesbania with the purpose of green manuring have been thoroughly mixed with the farmland, while the mungbean and cowpea biomasses were through away from the farmland. The field trial was performed in a randomized complete block with a split-plot design that has three replicates. The layout was kept the same as that of legumes. The plot size was 13.5 m x 4.2 m. The variety used was Pir-Sabaq-2013, and the sowing rate was 120 kg ha⁻¹. Urea, Diammonium phosphate (DAP), and Muriate of Potash (MOP) were applied at a recommended rate (120, 90, 60 kg ha⁻¹). The same procedure, steps, and practices were followed according to the recommended standards.

Table 1. Treatment group with their respective specific purpose and control group

S.no	Factor-A	Purpose	Factor-B
	Legumes		Biochar (tons ha ⁻¹)
1	Mungbean	Grain	0
2	Cowpea	Fodder	5
3	Sesbania	Green manuring	10
4	Fallow	Control	

Data Collection

The agronomic data based on dry weight were recorded on thousand-grain weight (g), grain yield (kg ha⁻¹), biological yield (kg ha⁻¹), and straw yield (kg ha⁻¹) according to the reported standard guidelines.

Data Analysis

The data were analyzed statistically, and the results were shown as a means with standard deviation. The Least Significant Difference (LSD) test at a 5% level of significance was used to determine significant differences among the treatments.

RESULTS AND DISCUSSION

Grain Yield (kg ha⁻¹)

The aged biochar effect coupled with legumes on the yield of wheat grain was proved that both treatments significantly ($p \leq 0.05$) increased the yield of wheat grain as compared to control in each replicate. However, the interaction of both treatments towards grain yield was not significant

(Table 2). In comparison to control plots (2996 kg ha⁻¹), the maximum grain yield was recorded in the plots incorporated with sesbania (3263 kg ha⁻¹). Soil received with 10 tons ha⁻¹ of aged biochar, gave the highest grain yield (3278 kg ha⁻¹), while the control plots produced the minimum grain yield (2935 kg ha⁻¹).

Biological Yield (kg ha⁻¹)

The aged biochar effect, coupled with legumes, showed a significant ($p \leq 0.05$) effect on the biological yield of wheat as compared to control. However, the interaction of both treatments was not significant (Table 2). The maximum biological yield was obtained in the plots mixed with sesbania (8655 kg ha⁻¹), while the plots previously kept fallow produced the lowest biological yield (6959 kg ha⁻¹). In the case of aged biochar effect, maximum biological yield (8475 kg ha⁻¹) was recorded with 10 tons ha⁻¹, followed by 5 tons ha⁻¹ (7795 kg ha⁻¹), in comparison, the plots previously received biochar at the rate of 0 tons ha⁻¹ produced the minimum biological yield (7191 kg ha⁻¹).

Table 2. Grain yield (kg ha⁻¹), biological yield (kg ha⁻¹), straw yield (kg ha⁻¹) and thousand-grain weights (T.G.W.) (g) of wheat as affected by the residual effect of biochar application and summer legumes

Treatments	Grain Yield	Biological Yield	T. G. W.	Straw Yield
Legumes				
Cowpea	3137 b	8135 b	47 c	4998 a
Mungbean	3093 b	7533 c	49 b	4440 b
Sesbania	3263 a	8655 a	50 a	5392 a
Fallow	2996 b	6959 d	46 c	3959 c
LSD (0.05)	146.2	146.2	0.993	464.6
Biochar (tons ha⁻¹)				
0	2935 b	7191 c	47 b	4253 b
5	3154 a	7795 b	48 a	4641 b
10	3278 a	8475 a	49 a	5198 a
LSD (0.05)	126.64	351.46	0.859	402.36
Interaction				
L x B	ns	ns	ns	ns

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

Thousand Grain Weight (g)

The data concerning the thousand-grain weight of wheat as affected by aged biochar application coupled with legumes are shown in

(Table 2). Statistical analysis of the data revealed that aged biochar coupled with legumes significantly affected ($p \leq 0.05$) thousand-grain weight of the wheat. No interaction was observed. The plots mixed with sesbania produced maximum

thousand-grain weight (50 g) followed by mungbean (49 g) and cowpea (47 g), while the plots previously kept fallow produced minimum thousand-grain weight (46 g). With aged biochar effect, 10 tons ha⁻¹ enhanced thousand-grain weights (49 g), which were statistically at par with 5 tons ha⁻¹ (48.9 g) as compared to plots previously received biochar at the rate of 0 tons ha⁻¹ (47.6 g).

Straw Yield (kg ha⁻¹)

The mean values of the data revealed that aged biochar, coupled with legumes, significantly affected the ($p \leq 0.05$) straw yield of wheat (Table 2). No interaction was observed. The plots mixed with sesbania produced a maximum straw yield (5392 kg ha⁻¹) followed by cowpea (4998 kg ha⁻¹) and mungbean (4440 kg ha⁻¹), while the plots previously kept fallow produced minimum straw yield (3959 kg ha⁻¹). With aged biochar effect, 10 tons ha⁻¹ treatment dose produced maximum straw yield (5198 kg ha⁻¹) followed by 5 tons ha⁻¹ (4641 kg ha⁻¹) as compared to plots previously received biochar at the rate of 0 tons ha⁻¹ (4253 kg ha⁻¹).

Discussion

Several research articles have been published on the effect of biochar application and various legumes residues on the crop yield. However, there is difficulty in comparing those results due to types of biochar, synthesis conditions, application of biochar, soil properties. Most importantly, it is challenging to address and compare short-term biochar applications to long-term applications. The reason is that biochar is resistant to rapid decomposition in soil and showed little change. However, most of the studies on biochar effects are laboratory-based (Atkinson, Fitzgerald, & Hipps, 2010; Jien & Wang, 2013; Lehmann & Rondon, 2006).

Fewer studies were found on the long-term impacts of biochar on crop yield (Jones, Rousk, Edwards-Jones, DeLuca, & Murphy, 2012). Major, Rondon, Molina, Riha, & Lehmann (2010) reported that in a four-year field-based study, biochar application did not significantly increase maize yield in the first year. In contrast, in the following three years, the yield was significantly increased. Similarly, Vaccari *et al.* (2011) published that biochar application in the Mediterranean region

enhanced the yield crop over two seasons. Likewise, Liang, Li, Lin, & Zhao (2014) stated that crop yield with biochar application in the first season was not significantly enhanced; however, it was increased in the following two experiments. In three years of field study, biochar induced small temporary shifts in soil respiration, microbial community structures, and only small changes in soil carbon and nitrogen cycling. Biochar applied had no observed adverse effect on crop production (Jones *et al.*, 2012).

Concerning residual legume's effects on crop yield, Maadi, Fathi, Siadat, Saeid, & Jafari (2012) reported that wheat yield was significantly enhanced in a crop rotation system due to legume's preceding effect. Similarly, Siadat *et al.* (2011) stated that the benefits of legumes crop in a rotation system is due to the residual nitrogen in the soil. Aslam, Mahmood, Peoples, Schwenke, & Herridge (2003) reported that the cereal yield was significantly maximum after legumes crop due to numerous benefits of legumes to the soil system. They are residual nitrogen, increased the soil organic matter content and improved soil's physical properties, such as water holding capacity, saturation percentage, and moisture content.

The previously published research articles from this work reported that residual biochar, coupled with summer legumes significantly enhanced the fertility of the soil in terms of specific macro (N, P, K) and micronutrients (Cu, Fe, Zn, and Mn), soil physical properties such as water-holding capacity, saturation percentage, reduced bulk density of soil and improved the growth of the wheat crop such as plant height, the number of grains per spike, spikes m⁻², and spike length. Keeping the advantages of all these previously published results in consideration, it is evident that aged biochar, coupled with summer legumes, significantly enhanced the yield of wheat crop (Rahim *et al.*, 2019; Rahim *et al.*, 2020).

CONCLUSION AND RECOMMENDATIONS

The data presented biochar and summer legumes' potential as an innovative, safe, eco-friendly, and sustainable climate-smart agricultural approach for improving subsequent wheat yield. Moreover, the data described the long-term effect of biochar and summer legumes on the yield of

subsequent wheat in relation to the slow decomposition of biochar and legume (sesbania residues) in soil. This article would collectively help the agricultural and environmental research community to design more innovative experiments, both laboratory and field-based to scientifically address the long-term/ aged effect of biochar and legumes on crop yield and soil quality. We hope that the data will be beneficial and significant for individual researchers, agricultural research institutions, academic institutions, and different NGOs who interested to work on the climate-smart agricultural system.

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