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Effect of Biochar with Traditional Farming Practices on the Growth and Yield of Wheat (*Triticum aestivum* L.) At Reduced Irrigated Condition

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Abstract: Wheat (*Triticum aestivum* L.) is a leading cereal crop and important source of vegetable protein in human diet worldwide. Improving soil fertility in drought areas to ensure food security through increase wheat production is a major challenge. An experiment was conducted to evaluate the effect of biochar with conventional farming practices on growth and yield of wheat under different level of water stress condition in 2017 to 2018 at Sher-e-Bangla Agricultural University, Dhaka-1207. The field experiment was laid out in two factors split plot design with three replications. Five different levels of biochar (B_1 = 0 t ha^{-1}, B_2 = 2 t ha^{-1}, B_3 = 4 t ha^{-1}, B_4 = 6 t ha^{-1}, B_5= 8 t ha^{-1}) and three levels of water stress (W_1 = regular irrigation, W_2 = irrigation skipped at booting stage, W_3 = irrigation skipped at heading and flowering stage) were applied alone or in combination. The results showed that addition of biochar with traditional farming practices increased growth and yield parameters significantly. The highest plant height, spike length and maximum filled grains were recorded when irrigation skipped at heading and flowering stage + 4 t ha^{-1} biochar applied. Therefore, integration of biochar with prevailing crop production techniques could be a better option for sustainable agriculture.

Key words: Biochar · Wheat · Farming Practices · Sustainable Agriculture · Reduced Irrigation

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a cereal grain considered one of the most important staple foods throughout the world [1, 2]. It is the third most-produced cereal after maize and rice [3]. Wheat is grown on more land area than any other food crop. In 2020, world production of wheat was 758.3 million tones [4]. In Bangladesh, wheat is ranked in second next to rice according to the consumption value. Wheat covered an area of 804, 703 ha and production is estimated 1, 180 MT in 2020 in Bangladesh [5, 6]. Wheat is one of the major cereal crops in Bangladesh. Over the last two decades, wheat consumption has passionately amplified in Bangladesh but its production has declined due to various stress environments.

Water plays an important role in agricultural production, however, demand and water supply to agriculture greatly impacted in the tropical parts of the world. Drought is one of the most limiting stress factors for crop growth and development, dry matter production and potential yield [7] and is a prevalent limiting factor of wheat production in northern and central part of Bangladesh. The northwestern part of Bangladesh has been more exposed to drought event than other regions over the last 2-3 decades [8-10]. Recurrent drought events in the northern parts of Bangladesh due to climate change that threatens the countries food safety has become a serious concern. Besides, injudicious application of fertilizers is also a major concern for declining soil fertility in arid or semi-arid regions [11-13]. It has been reported that some agricultural practices enhance the nutrient availability and water holding capacity without compromising crop yield [14, 15]. The production of wheat varied by many factors such as irrigation levels, fertilizers, cultivating high yield varieties and adoption of improved cultural practices like adding biochar. Biochar is a stable solid, rich in carbon, fine-grained residue which is produced through modern pyrolysis processes of any biomass including weeds, crop residues and other wastes of plant origin and can endure in soil for thousands of years [16, 17]. Charcoal waste can be applied as biochar to agricultural soils and turned into a valuable resource for improving crop yields on acid and infertile soils

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where nutrient resources are scarce such as sandy soils. The application of biochar (charcoal or biomass-derived black carbon) to soil is proposed as a novel approach to improve soil fertility, improve soil water holding capacity and consequently water conservation and to increase crop production of newly reclaimed sandy soil [18]. Biochar as ecologically clean and stable form of carbon has complex of physical and chemical properties which make it a potentially powerful soil amendment [19].

Researchers had reported that biochar significantly improve the soil hydro-physical properties through modification of soil physical properties such as porosity, texture, structure and aggregate stability of soil [12, 14, 20- 25]. Application of biochar under stressed water condition can play a potential role in increasing productivity of wheat. Combination of biochar, Organic farming and chemical fertilizer-based agriculture can be promoted for managing the agricultural sustainability [21, 26- 28]. Biochar can act as a soil conditioner enhances the growth of the plants by supplying and more importantly retaining nutrients and improving soil physical and biological properties and consequently improving soil water holding capacity [29, 30]. Efficient use of water for the cultivation of crops is the need of time especially in those areas of world where water has becoming scared. This shortage of water supply imposes drought stress that reduces the yield of many cereals like (*Triticum aestivum* L.) up to many folds. Moussa and Abdel-Maksoud [31], El Afandy [32] found that subjecting wheat plants to drought stress resulted in a significant reduction in grain yield and its components of wheat. Modest additions of biochar to soil retain nutrients and water to improve wheat productivity. Addition of biochar to soil can reduce nitrous oxide (N_2O) emissions by up to 80% and eliminate methane emissions [33] and used as a soil amendment to improve yield for high potash and elevated pH requiring plants. Addition of biochar enhanced wheat yield under different mineral fertilization levels regardless of nitrogen and water conditions [34-36]. Application of biochar to soil is hypothesized to increased bio available water, build soil organic matter, enhance nutrient cycling, lower bulk density, act as a liming agent and reduce leaching of pesticides and nutrients to surface and ground water and reduce irrigation and fertilizer requirements [23, 37-41]. A lot of research works had already been performed in abroad, but the research so far done to evaluate the effect of biochar on growth and yield of wheat under reduced irrigated condition in Bangladesh were inadequate and conclusive. This research work was done to determine the optimum combination of biochar with reduced irrigation on the growth and yield of wheat in traditional farming practices.

MATERIALS AND METHODS

Experimental Location and Climate Conditions: The research was carried out at Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207 (23°77" N latitude and 90°33" E longitude), Bangladesh during the period from November 2017 to March 2018. The experimental field belongs to the Agro-Ecological Zone of The Madhupur Tract, AEZ-28 (Source: Bangladesh Agro-Meterological Information Portal). The area has sub-tropical climate, characterized by the high temperature, high relative humidity and heavy rainfall with occasional gusty winds in Kharif season (April- September) and scanty rainfall with moderately low temperature during the Rabi season (October-March). The mean rainfall, temperature and relative humidity in Rabi season were 107 mm, 18°C and 71%, respectively (Source: Bangladesh Meteorological Department, Dhaka).

Characteristics of Soil: The soil of the experimental site belongs to the General Soil Type, “Shallow Red Brown Terrace Soils” under Tejgaon Series (Source: Bangladesh Agro-Meterological Information Portal). The experimental area was flat having available irrigation and drainage system and above flood level. A composite sample was made by collecting soil from several spots of the field at depth of 0-15 cm before the initiation of the experiment. The collected soil was air-dried, ground and passed through 2mm sieve and analyzed for some important physical and chemical parameters. The analyses were done at Soil Science Laboratory, Sher-e-Bangla Agricultural University, Dhaka-1207. The physico-chemical properties of the soil are presented in Table 1.

Planting Material and Preparation of Biochar: The wheat variety (*Triticum aestivum* L.) BARI Gom-25 was used as plant material. Bangladesh Agricultural Research Institute (BARI) developed this variety and released in 2010. It is becoming a popular variety due to its early maturing and high yielding potentials, short duration life cycle and tolerant to leaf rust and leaf blight diseases. It attains plant height of about 95-100 cm. It takes 51-61 days for spike initiation; spike is broad and 45-50 grain/spike. Grains are white, bright and medium. The 1000 grain weight is 44-48 g, crop duration 102-108 days. Average yield is 3.0 to 4.0 t ha^{-1}. Biochar was collected from a

Table 1: Initial physical and chemical properties of the experimental soil

Soil parameter	Value
A. Physical properties	
1. Particle size analysis of soil	
% Sand	8
% Silt	50
% Clay	42
2. Soil texture	Silty clay
3. Consistency	Granular and friable when dry
4. Bulk Density (g/cc)	1.45
5. Particle Density (g/cc)	2.52
B. Chemical properties	
Soil pH	5.6
Organic carbon (%)	0.70
Organic matter (%)	1.21
Total N (%)	0.05
Available P (ppm)	18.85
Exchangeable K (meq/100g soil)	0.14
Available S (ppm)	22

private organization and then grinded into small particle followed by sieving for using in the field. Then biochar was added to the soil of each plot according to the recommended doses along with fertilizers at the time of final land preparation (Fig. 1A).

Experimental Design and Treatments: The experiment was laid out into two factors Split Plot Design with three replications. The total number of plots was 45, each measuring 2m X 1.5m ($3m^2$). The treatment combination of the experiment was assigned at random into 15 combinations. The distance maintained between two plots was 50cm and distance between two adjacent replications (block) was 50 cm. There were two factors; 5-levels of Biochar and 3-levels of waters tress. The 5-levels of biochar were B_1 = no addition of biochar (0 t ha^{-1}), B_2 = 2 t ha^{-1}, B_3 = 4 t ha^{-1}, B_4 = 6 t ha^{-1} and B_5= 8 t ha^{-1}. Three water stress levels were W_1 = Regular irrigation (depending on shortage of soil moisture), W_2= Skipped irrigation at booting stage and W_3 = Skipped irrigation at heading and flowering stage.

Experimental Procedure and Field Management: The field selected for the experiment was opened by the power tiller on 15th November 2017, afterwards on 18 November 2017, the land was ploughed and cross ploughed several times followed by laddering to obtain a good tilth. Weeds and stubbles were removed and the large clods were broken in to smaller pieces to obtain a side seeable 3 tilth of the soil for sowing of seeds. Finally, the land was leveled and the experimental field was partitioned into the unit plots in accordance with the experimental design. The unit plots were fertilized with 220 kg Urea, 180 kg TSP, 50 kg MoP and gypsum 120 kg ha^{-1} respectively. Organic manure was applied @ 16-20 tha^{-1} to each unit plot following BARC fertilizer recommendation guide-2018. Urea, Triple Super Phosphate (TSP) and Muriate of Potash (MoP) and gypsum were used as source of nitrogen, phosphorus and potassium and sulfur respectively. The whole calculated and required amount of P, K, S fertilizers and 50% of the N fertilizer (Urea) were uniformly spread on the surface of the individual plot following the treatment combination at the time of final land preparation prior to sowing. The applied fertilizers in the individual plot were mixed by hand spading. The remaining 50% of N (Urea) was applied in two splits (after 1st and 2nd irrigation). The seeds of wheat (BARI Gom-25) were sown in rows made by hand plough on November20, 2017 at the rate of 120 kg ha^{-1}. The seeds were sown in solid rows in the furrows having a depth of 2-3 cm from the soil surface. Seeds were then covered properly with soil. Row to row distance was 20 cm. The whole experimental area was covered by net protecting from birds and other animals (Fig. 1D). Total three irrigations were provided a) first single irrigation during 17-21 DAS at crown root initiation stage, b) the second one was at 55 DAS at booting stage (it was skipped in W_2 treated plot) and c) the third one is at 70 DAS at heading and flowering stage (was skipped in W_3 treated plot). Common intercultural operations such as thinning of plants, weeding and recommended doses of pesticides were accomplished whenever required to keep the plants healthy and the field pathogen free.

Crop Sampling and Data Collection: The crop sampling was done at the time of harvest. The crop was harvested at maturity when 90% of the crops became brown in color at first week of March 2018. At harvest, five plants were selected randomly from each plot. The selected plants of each plot were cut carefully at the soil surface level. The harvested crop of each individual plot was bundled separately. After harvesting, the samples were sun dried. Grain and straw yields were recorded plot wise and the yield was presented in t ha^{-1}. Data were recorded on following parameters, plant height (cm), length of spike (cm), number of filled grains $spike^{-1}$, number of deformed grains $spike^{-1}$, number of total grains $plant^{-1}$, weight of 1000 seeds (gm), grain yield (tha^{-1}), straw yield (tha^{-1}) were recorded separately.

Statistical Analysis: The data collected on different parameters were statistically analyzed to obtain the level of significance following computer-based software Statistix10 and mean comparison was made by LSD (Least Significant Difference) or DMRT (Duncan's Multiple Range Test) at 1% or 5% level of significance.

RESULTS AND DISCUSSION

Effect on Growth Parameters: We found that the highest plant height, spike length was recorded in W_3 treatment whereas no significant difference found on plant height in treatment W_1 and W_2 but in case of spike length, treatment W_1 and W_2 were statistically different (Table 2). In case of different level of biochar treatments, the highest plant height and spike length were observed in B_3 and B_4 treatment compared to other treatments (Table 3). Combined application of different doses of biochar and irrigation had significant effect on plant height and spike length of wheat. Treatment W_3B_3 (skipped irrigation at heading and flowering stage+4 t ha^{-1}) showed relatively higher plant height and spike length but not significantly different than other treatments. In case of other treatments combination, no significant difference was found for plant height and spike length (Table 4; Fig. 1C).

In case of irrigation, highest number of filled grains/spike was recorded in W_3 treated plot followed by W_2 and lowest number of filled grains/spike was recorded in W_1 treated plot (Fig. 2). Among the different biochar doses B_3 treatment showed the highest number of filled grains/spike which is statistically similar to B_4 treatment where the lowest number of filled grains/spike was observed in the treatment B_1 (Fig. 3). Combined application of different doses of biochar and irrigation had significant effect on number of filled grains/spike of wheat (Fig. 4).

It was observed that the highest number of filled grains/spike was recorded with W_3B_3 (Skipped irrigation at heading and flowering stage + 4 t/ha biochar) treatment combination which was statistically similar to W_3B_4 treatment combination. On the other hand, the lowest number of filled grains/spike was observed in the treatment combination of W_1B_1. Significant variation was observed on number of unfilled grains/spike of wheat when different water stresses were applied. Lowest number of unfilled grains/spike was recorded in W_3 treated plot followed by W_2 treatment (Fig. 2). Different doses of biochar B_3 treatment showed the lowest number of unfilled grains/spike which was statistically similar to treatments B_4 and B_5 (Fig. 3). In case of treatment combinations, highest number of unfilled grains/spike was observed in W_1B_1 (Regular irrigation + no biochar) which was statistically similar to W_1B_4 treatment combination. The result obtained from the rest of treatment combination showed significant variation compared to the highest and lowest number of unfilled grains/spike of wheat. It was observed that the lowest number of unfilled grains/spike was recorded with W_3B_3 treatment combination which is statistically similar to W_3B_4 treatment combination (Fig. 4).

In case of total number of grains/spike, the highest number was recorded in W_3 treated plot. On the other hand, lowest number was recorded in W_1 treated plot where irrigation is done on the depending of shortage of soil water which was statistically similar to W_2 treated plot (Table 2). Among different doses of biochar B_3 treatment showed the highest number of total grains/spike statistically similar to B_4 treatment and lowest number of total grains/spike was observed in the treatment B_1 treatment (Table 3). Combined application of different doses of biochar and irrigation had significant effect on number of total grains/spike of wheat (Table 4). Highest number was recorded with W_3B_3 treatment combination which was statistically similar to treatment combination W_3B_4 and lowest number of total grains/spike was observed in the treatment combination of W_1B_1.

Highest 1000-seed weight was recorded in W_3 treated plot where lowest 1000-seed weight was recorded in W_1 treated plot which was non-significantly variable to W_2 treatment (Table 2). Among the different doses of biochar B_3 treatment showed the highest 1000-seed weight which was non-significantly variable to B_4, B_5, B_2 and B_1 treatments (Table 3). In the treatment combination maximum 1000 seed weight per plot was recorded in W_3B_3. On the other hand lowest 1000 grain weight found from W_1B_1 treatment combination. The result obtained from the rest showed no significant variation compared to the highest and lowest (Table 4).

We observed significant variation in grain yield of wheat when different water stresses were applied. Highest grain yield (t/ha) of wheat was recorded in W_3 treated plot which was statistically similar to W_2 treatment. On the other hand, lowest grain yield of wheat was recorded in W_1 treated plot (Table 2). Among biochar treatments B_3 treatment showed the highest grain yield which was statistically similar to B_4 treatment. On the other hand, lowest grain yield was observed in the B_1 treatment which was statistically similar to B_5 and B_2 treatments (Table 3). Combined application of different doses of biochar and irrigation had significant effect on grain yield of wheat. Highest grain yield of wheat was recorded in W_3B_3 (Skipped irrigation at heading and flowering stage + 4 t/ha biochar) treatment combination which was statistically similar to treatment combination W_3B_4. On the other hand, the lowest grain yield was observed in the treatment combination of W_1B_1 (Regular irrigation + no biochar addition). The result obtained from the rest of treatment combination showed significant variation compared to the highest and lowest grain yield of wheat (Table 4). Maximum straw yield of

Table 2: Effect of irrigation growth and yield parameters of wheat at harvest

Treatments	Plant height (cm)	Spike length (cm)	Total number of grains/spike	1000-seed weight/plot (g)	Grain yield (t/ha)	Straw yield (t/ha)
W_1	85.52 b	14.56 b	39.61 b	44.2	2.36 b	2.10 b
W_2	85.78 b	14.91 ab	39.68 b	44.5	2.71 a	2.30 b
W_3	87.99 a	16.07 a	43.62 a	45.2	2.73 a	2.60 a
CV (%)	2.87	11.13	10.05	7.37	9.75	8.27
Level of significance	*	**	**	NS	**	**

**indicates 1% level of significance and *indicates 5% level of significance

W_1 = Regular irrigation, W_2 = Irrigation skipped at booting stage, W_3 = Irrigation skipped at heading and flowering stage

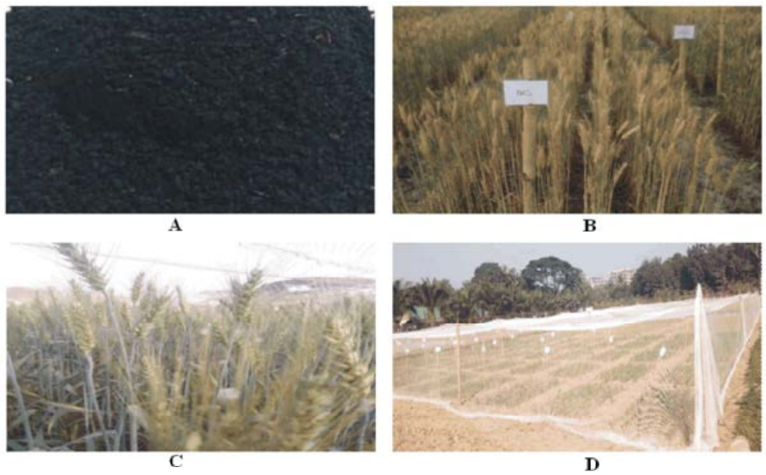

Fig. 1: Biochar for field experiment (A), treatment B_3 applied plot (B), combination of biochar and reduced irrigation (C), the whole experimental plot covered by protecting net (D)

Table 3: Effect of biochar on growth and yield parameters of wheat at harvest

Treatments	Plant height (cm)	Spike length (cm)	Total number of grains/spike	1000-seed weight/plot (g)	Grain yield (t/ha)	Straw yield (t/ha)
B_1	84.67 b	13.56 b	35.22 b	44.00	2.39 b	2.2 c
B_2	84.74 b	14.34 b	36.26 b	45.00	2.45 b	2.3 c
B_3	90.01 a	17.15 a	48.73 a	46.00	2.93 a	2.56 a
B_4	89.42 a	17.07 a	46.06 a	45.10	2.79 a	2.43 b
B_5	83.32 b	13.78 b	38.57 b	44.50	2.44 b	2.2 c
CV (%)	2.52	11.13	10.05	7.37	9.75	8.27
Level of significance	*	*	*	NS	**	**

**indicates 1% level of significance and *indicates 5% level of significance

B_1 = No addition of biochar (0 t ha^{-1}), B_2 = 2 t ha^{-1}, B_3 = 4 t ha^{-1}, B_4 = 6 t ha^{-1}, B_5 = 8 t ha^{-1}

Table 4: Combined effect of irrigation and biochar on growth and yield parameters of wheat at harvest

Treatments	Plant height (cm)	Spike length (cm)	Total number of grains/spikes	1000-seed weight/plot (g)	Grain yield (t/ha)	Straw yield (t/ha)
W_1B_1	83.35 ef	14.46c	32.00 c	46.00	2.19 e	2.01e
W_1B_2	84.52 ef	13.78c	35.60 d	46.20	2.63 bc	2.46b
W_1B_3	88.51bc	15.05bc	42.13 b	46.10	2.95 b	2.38bc
W_1B_4	88.47 bc	15.46bc	43.66 b	46.40	2.83 b	2.44b
W_1B_5	83.92 ef	14.06bc	39.60 c	46.30	2.65 bc	2.40bc
W_2B_1	84.27 def	14.95bc	36.60 d	46.50	2.34 de	2.43b
W_2B_2	84.32 def	13.52c	39.06 c	46.70	2.61 bc	2.21d
W_2B_3	87.91 cd	16.64b	45.46b	46.90	2.61 bc	2.26d
W_2B_4	88.43 bc	15.45bc	43.13b	46.40	2.42 cde	2.37c
W_2B_5	82.7 f	14.01bc	40.86 bc	46.20	2.23 de	2.19d
W_3B_1	85.28 cdef	13.62c	37.06 cd	47.00	2.39 de	2.3cd
W_3B_2	86.36 cde	14.46bc	34.13 e	47.50	2.34 de	2.22d
W_3B_3	93.12 a	20.30a	51.40 a	48.00	3.23 a	2.98a
W_3B_4	91.86 ab	19.76a	49.40ab	46.60	3.13 a	2.59b
W_3B_5	84.46 def	13.27c	42.26b	46.30	2.46 cde	2.33cd
CV (%)	2.52	11.13	10.05	7.37	9.75	8.27
Level of significance	*	**	**	NS	*	*

**indicates 1% level of significance and *indicates 5% level of significance.

W_1 = Regular irrigation, W_2 = Irrigation skipped at booting stage, W_3 = Irrigation skipped at heading and flowering stage, B_1 = No addition of biochar (0 t ha^{-1}), B_2 = 2 t ha^{-1}, B_3 = 4 t ha^{-1}, B_4 = 6 t ha^{-1}, B_5 = 8 tha^{-1}

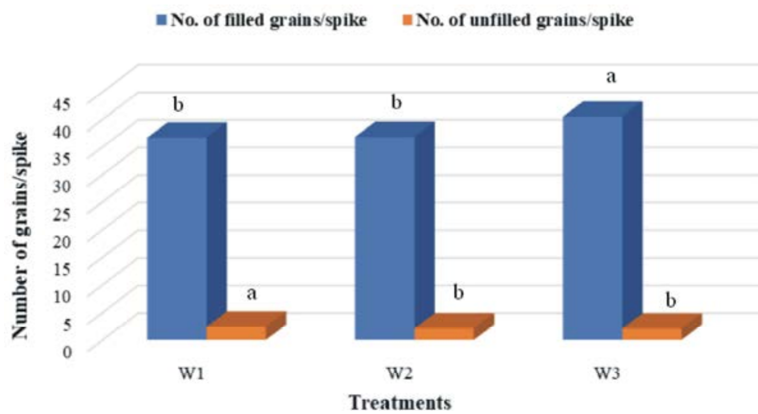

Fig. 2: Effect of irrigation on filled and unfilled grains/spike of wheat. LS mean with same alphabetic letter indicates non-significant treatment effect at 95% level of confidence. Where: W_1=Regular irrigation, W_2=Irrigation skipped at booting stage, W_3= Irrigation skipped at heading and flowering stage

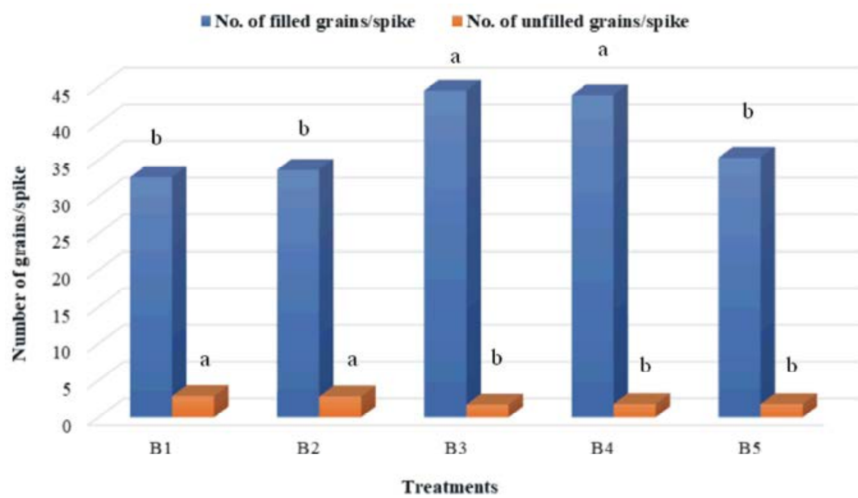

Fig. 3: Effect of biochar on filled and unfilled grains/spike of wheat where B_1 = No addition of biochar (0 t ha^{-1}), B_2 = 2 t ha^{-1}, B_3 = 4 t ha^{-1}, B_4 = 6 t ha^{-1}, B_5 = 8 t ha^{-1}. LS mean with same alphabetic letter indicates non-significant treatment effect at 95% level of confidence

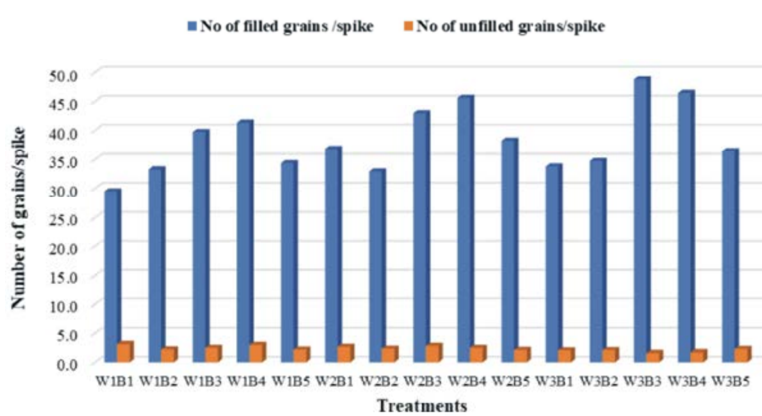

Fig. 4: Combined effect of irrigation and biochar on filled and unfilled grains/spike of wheat where W_1 = Regular irrigation, W_2 = Irrigation skipped at booting stage, W_3 = Irrigation skipped at heading and flowering stage and B_1 = No addition of biochar (0 t ha^{-1}), B_2 = 2 t ha^{-1}, B_3 = 4 t ha^{-1}, B_4 = 6 t ha^{-1}, B_5 = 8 t ha^{-1}

wheat was recorded in W_3 treated plot and lowest straw yield was recorded in W_1treated plot which was statistically similar to W_2 treatment (Table 2). Among the different biochar doses B_3 treatment showed the highest straw yield where lowest straw yield was observed in B_1 treatment which is statistically identical to B_5 treatment and statistically similar to B_2treatment (Table 3). Maximum straw yield of wheat was recorded in treatment combination W_3B_3. On the other hand, the lowest straw yield was observed in the treatment combination of W_1B_1. The result obtained from the rest of treatment combinations showed significant variation compared to the highest and lowest (Table 4).

DISCUSSION

Biochar application to soil improves soil and water conditions which increase the crop productivity [42]. Presence of intra-pores providing higher surface area and permeability for the water and air as well as higher carbon content may lead to the improvement in soil hydro-physical properties. Many researchers also reported improved soil properties under biochar with conventional farming practices [27, 28, 43, 44]. However, the detailed mechanism of such changes is still needed to be explored [12]. Combined effect of biochar and water stress had potential effect on wheat productivity thus potentially increases the plant height and yield of wheat [18, 45]. It has been reported that effect of irrigation at different stage of plant growth of wheat had significantly influenced by different level of irrigation [46, 47]. Addition of biochar to conventional agricultural practices had positive effect on growth and yield contributing parameter for example plant height, spike length, grain counts and wheat yield [34, 35, 48, 49]. Previously, other researchers studied on effect of different level of irrigation on growth and yield of wheat [47]. However, our results revealed improved yield under combined biochar with traditional farming practices with reduced irrigation. The better performance observed under integrated treatment applied plots was possibly due to improved water availability, consistent nutrient supply by organic manure and labile nutrient supply from the chemical fertilizers and retention and exchange of nutrient on the biochar surfaces led to the improved nutrient availability to the plant at critical growth stages [14, 27]. However, a combined (but reduced rate) application of biochar with organic manure and chemical fertilizers under reduced irrigated conditions may improve crop water productivity by better retention of rainwater in the dry tropical agro-ecosystems [26]. As the study was conducted for a short-term; thus, the relations may differ with the aging of biochar applied in the soil system in long-term. Overall, based on the results of this short-term study, exploration of underlying mechanisms for better understanding and robust generalization of the findings is further required.

CONCLUSION

It is obvious that biochar has potentiality to improve soil fertility and enhance crop yield when applied alone or combined with conventional farming practices at reduced irrigation condition. Our results revealed that addition of biochar with traditional agricultural practices of wheat increased plant height, spike length, grain and straw yield. Considering the overall results on different parameters of wheat it may be concluded that application of biochar can reduce the irrigation frequency without reducing wheat yield. To sum up, combination of biochar, organic manure, chemical fertilizer with reduced irrigation can be introduced as a new approach for sustainable agricultural development.

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