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Short Term Effect of Biochar with Reduced Irrigation on Post-Harvest Soil Properties in Wheat (*Triticum aestivum* L.) Field

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Abstract: Wheat (*Triticum aestivum* L.) is one of the major cereal crop and excellent source of vegetable protein in human diet worldwide. Continuous crop cultivation without adding sufficient inputs to soil seriously influencing soil health and productivity. Improving soil fertility in drought regions to ensure food security through increase crop production is a great concern in Bangladesh. To evaluate the effect of biochar on soil properties at harvest in wheat field at reduced irrigated condition, we conducted a research at Sher-e-Bangla Agricultural University, Bangladesh in winter season during 2017 to 2018. The experiment was laid out in two factors split plot design with three replications. There were five levels of biochar application (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). There were 45-unit plots and 15 treatments combination. The results showed that the highest organic carbon (0.74%), highest organic matter (1.28%), maximum total nitrogen (0.076%) and highest available phosphoru, maximum exchangeable potassium and maximum available sulphur were found in treatment combination of W_3B_3 (Irrigation skipped at heading and flowering stage + 4 t/ha biochar). Biochar application in soil can enrich soil organic matter as well as improve soil properties resulting improved aeration and better water holding capacity of soil.

Key words: Soil properties・Fertility・Biochar・Water holding capacity・Reduced irrigation

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the third most important cereal grain in the world [1-3]. China ranked first in global wheat production followed by India and Russia [4]. In Bangladesh, it ranked 2nd next to rice which is covered an area of 804, 703 and production estimated 1, 180 MT in 2020 [5, 6]. Wheat consumption has increased in Bangladesh over the last two decades but its production has declined due to different climatic conditions. Wheat is mostly growing in northwestern regions especially Dinajpur, Pabna, Rajshahi, Bogura, Naogaon and Joypurhat districts. Drought is considered one of the most limiting factor of wheat production in Bangladesh as it significantly effects on winter wheat production [7, 8]. It is estimated that around 3.5 million ha cropping land are vulnerable to the drought including wheat crop which may adversely affect approximate 8 million people by 2050 [9]. Besides, injudicious application of fertilizers, adoption of high yielding crop cultivars with increased irrigation have exerted profound effect on pedogenic process resulting in declining soil fertility in arid or semi-arid regions [10-12]. It has been reported that some agricultural practices enhance the nutrient availability and water holding capacity without compromising crop yield [13, 14]. Reduced precipitation (average annual rainfall 1329 mm) and injudicious use of groundwater resources are making surface water scarcity during the winter season [15-17]. Shortage of optimum level of water supply greatly impacts photosynthesis, cellular elongation, gaseous exchange, dry matter production which ultimately results reduced quality and crop yield [18, 19]. To overcome this problem, an integrated approach such as soil amendments, using drought tolerant cultivars etc. are very important for sustainable agriculture. However, development of drought tolerant cultivar is time consuming and challenging too.

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Biochar is ecologically clean and stable form of carbon-rich complex of physical and chemical properties which make it a potentially powerful soil additive for improvement of soil quality. It has been widely investigated that soil remediation with biochar has the potential to improve soil properties and increase yield [20- 23]. Biochar is a pyrogenous, organic material synthesized through pyrolysis of different biomass which is an environmentally friendly and emerging multi-purpose innovation [24-28]. When biochar added with compost or manure it will absorb soluble minerals and reduce greenhouse gaseous to the atmosphere [29] also increase the water-holding capacity, pore size which enrich soil organic carbon and micro-nutrient availability thus regulates the soil pH, cation exchange capacity and stimulates the growth of rhizosphere microorganisms and mycorrhizal fungi [30-35]. Biochar has significant positive effects on soil physiochemical properties to the most degraded soils [36]. Leach *et al.* [27] and Lehmann and Rondon [37] documented that application of biochar to the soil enabling increases in agricultural productivity without, or with much reduced, applications of inorganic fertilizer. Modest additions of biochar to soil can act as liming agent. The pyrolysis temperature for producing biochar varying from 200°C to above 500°C. This high temperature causes disappearance of acid functional group and appearance of basic functional group which increases the pH (pH ranges 6.5-10.8) of biochar thus making it a powerful liming agent [38- 40]. Biochar has high specific surface area and high content of surface functional groups which reduce leaching of pesticides and nutrient to the surface [41- 47]. Therefore, we investigated the effect of addition of biochar with reduced irrigation on post-harvest soil properties in wheat field.

MATERIALS AND METHODS

Location of the Experiment and Climate Conditions: In November 2017 to March 2018, the experiment 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. The experimental field belongs to the Agro-Ecological Zone of The Madhupur Tract, AEZ-28 (Figure 1). 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 experiment belongs to the Tejgaon series under the Agro ecological Zone, Madhupur Tract (AEZ 28) and the general soil type is “Shallow Red Brown Terrace Soils”. A composite sample was made by collecting soil from several spots of the field at as 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. Morphological characteristics of the soil are shown in Table 1. The soil of the experimental site belongs to the General Soil Type, “Shallow Red Brown Terrace Soils” under Tejgaon Series. Top soils were clay loam in texture, olive-gray with come fine to medium distinct dark yellow brown mottles. Soil pH ranged from 5.5-5.8 and had organic matter 1.21%. The experimental area was flat having available irrigation and drainage system and above flood level. Composite soil sample from 0-15 cm depths were collected from experimental field. The analyses were done at Soil Science Laboratory, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh. The physico-chemical properties of the soil are presented in Table 2.

Preparation of Biochar: Biochar was collected from a 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 (Figure 2B).

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 50 cm and distance between two adjacent replications (block) was 50 cm. There were two factors; 5-levels of Biochar and 3-levels of water stress. 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.

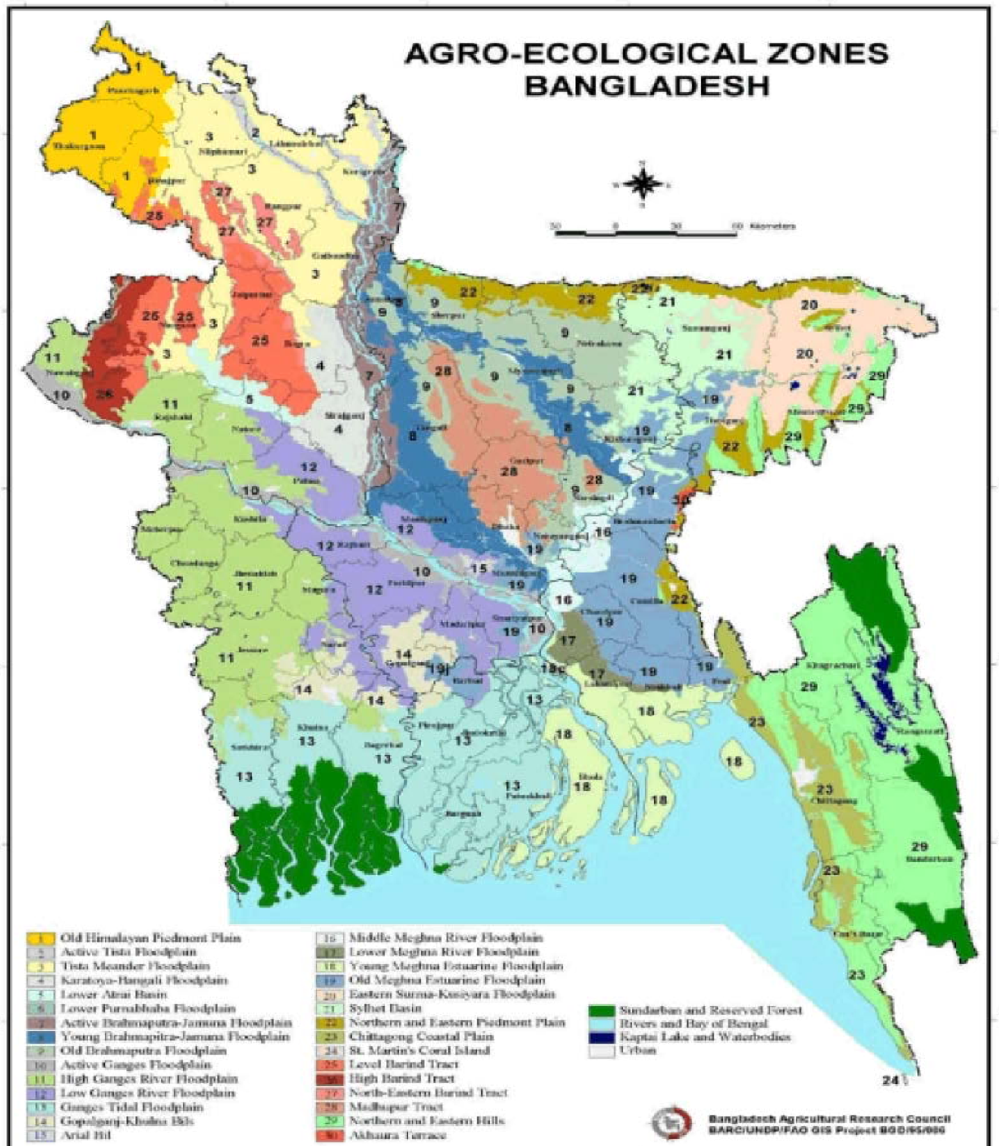

Fig. 1: Agro Ecological Zone (AEZ) of Bangladesh

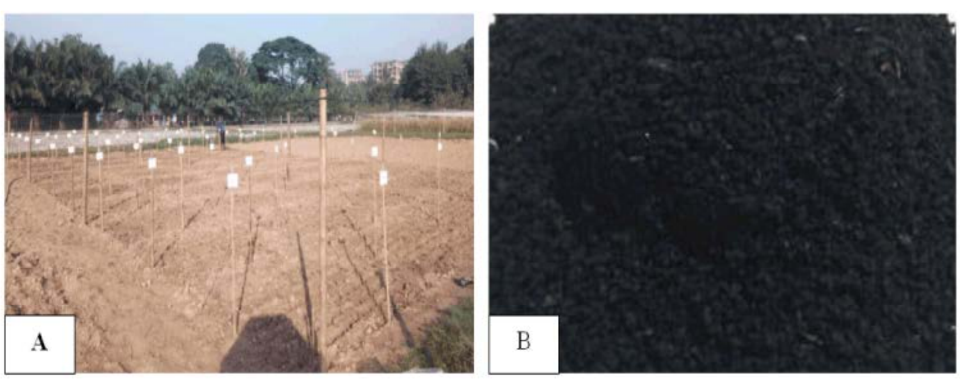

Fig. 2: Experimental plot (A) and the biochar used for field research (B)

Table 1: Morphological characteristics of experimental field

Morphological Features	Characteristics
Location	Sher-e-Bangla Agricultural University
AEZ Number and Name	AEZ-28, Madhupur Tract
General Soil Type	Shallow Red Brown Terrace Soil
Soil Series	Tejgaon
Topography	Fairly leveled
Depth of inundation	Above flood level
Drainage condition	Well drained
Land Type	High land

Source: Bangladesh Agro-Meteorological Information Portal

Table 2: 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

Courtesy: Dept. of Soil Science, Sher-e-Bangla Agricultural University

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.

Experimental Procedure and Field Management: 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 t ha^{-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, 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 November 20, 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. 1A). 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.

Collection and Preparation of Soil Sample: The initial soil samples before land preparation and post-harvest soil samples from 45 plots were collected from a 0-15 cm soil depth. The samples were drawn by means of an auger from different location covering the whole experimental plot and mixed thoroughly to make a composite sample. After collection of soil samples, the plant roots, leaves etc. were picked up and removed. Then the samples were air-dried ground and sieved through a 10-mesh sieve and stored in a clean plastic container for physical and chemical analysis.

Chemical Analysis of Soil Samples: Soil samples were analyzed for both physical and chemical properties in the laboratory of Soil Science Department, Sher-e-Bangla Agricultural University, Dhaka-1207. The properties studied included soil pH, organic carbon, organic matter content, total N, available P, exchangeable K and available S. The soil was analyzed by standard methods. Particle size analysis of soil was done by Hydrometer Method and the textural class was determined by plotting the values for % sand, % silt and % clay to the 'Marshall' s Textural Triangular Coordinate" according to the USDA system (Table 2). Soil pH was measured with the help of a Glass electrode pH meter using soil and water at the ratio of 1:2.5 as described by Jackson [48]. Organic carbon in soil was determined by Walkley and Black's Wet Oxidation Method [49]. The underlying principle is to oxidize the organic carbon with an excess of 1N $K_2Cr_2O_7$ in presence of conc. H_2SO_4 and to titrate the residual $K_2Cr_2O_7$ solution with 1N $FeSO_4$ solution. To obtain the organic matter content, the amount of organic carbon was multiplied by the Van Bemmelen factor, 1.73. The result was expressed in percentage. Total nitrogen of soil was determined by Micro-Kjeldahl method where soil was digested with 30% H_2O_2 conc. H_2SO_4 and catalyst mixture (K_2SO_4 : $CuSO_4$. $5H_2O$: Se powder in the ratio of 100:10:1). Nitrogen in the digest was estimated by distillation with 40% NaOH followed by titration of the distillate trapped in H_3BO_3 with 0.01N H_2SO_4 [50].

Determination of Available Phosphorus, Sulphur and Exchangeable Potassium: Available phosphorus was extracted from soil by shaking with 0.5 M $NaHCO_3$ solution of pH 8.5 [51]. The phosphorus in the extract was then determined by developing blue color using ascorbic acid reduction of phosphomolybdate complex. The absorbance of the phosphomolybdate blue color was measured at 660 nm wave length by Spectrophotometer and available P was calculated with the help of standard curve. Exchangeable potassium was determined by 1N NH_4OAc (pH 7.0) extract of the soil by using Flame photometer [52]. Available sulphur in soil was determined by extracting the soil samples with 0.15% $CaCl_2$ solution [53]. The S content in the extract was determined by the turbidimetric method as described by Hunt [54] and the intensity of turbid was measured by Spectrophotometer at 420 nm wave length.

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

Effect of Water Stress on Post-Harvest Properties of Soil: Effect of irrigation on post-harvest soil pH had been found non-significant. Highest organic carbon and organic matter found in W_3 treated plot where lowest organic carbon and organic matter found in W_1 treatment (Table 3). Total nitrogen was significantly influenced by different water stresses. Maximum total nitrogen percentage found in W_3 treatment and lowest total nitrogen calculated in W_1 treatment. The different treatments showed non-significant variation for available phosphorus. Significant variation was observed in case of exchangeable potassium when different water stresses were applied (Table 3). Highest exchangeable potassium calculated in W_3 treated plot and lowest exchangeable potassium found in W_1 treatment. Highest available sulphur found in W_3 treated plot where statistically similar result found in between W_1 and W_2 treatments (Table 3).

Effect of Biochar on Post-Harvest Properties of Soil: Effect of biochar on post-harvest soil pH had been found non-significant. Highest organic carbon and organic matter found in B3 treatment which was statistically identical to B4 and B5 treatments. On the other hand, organic carbon and organic matter which found in B2 treatment statistically similar to B1 treatment showed in Table 4. Total nitrogen was significantly influenced by different doses of biochar. Maximum total nitrogen percentage found in B_3 treatment and lowest found in B_1 treatment. On the other hand, statistically identical result found in between B_4 and B_5 treatments.

Table 3: Effect of reduced irrigation on post-harvest soil properties

Irrigation	Soil pH	Organic carbon (%)	Organic matter (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq/100g soil)	Available S (ppm)
W_1	5.6	0.70 c	1.21 c	0.057 c	19.11	0.15 c	22.87 b
W_2	5.6	0.71 b	1.23 b	0.059 b	19.17	0.17 b	22.75 b
W_3	5.7	0.72 a	1.24 a	0.062 a	19.16	0.20 a	23.66 a
CV (%)	0.06	2.59	2.09	1.53	6.58	11.86	4.75
Level of significance	NS	**	**	**	NS	**	**

** indicates 1% level of significance and NS indicates non-significant. W_1=Regular irrigation, W_2= Irrigation skipped at booting stage, W_3= Irrigation skipped at heading and flowering stage

Table 4: Effect of biochar on post-harvest soil properties

Biochar	Soil pH	Organic carbon (%)	Organic matter (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq/100g soil)	Available S (ppm)
B_1	5.6	0.72b	1.24 b	0.055 d	20.02	0.184 c	22.623c
B_2	5.6	0.73b	1.26 b	0.058 c	20.04	0.185 bc	22.683bc
B_3	5.7	0.74 a	1.28 a	0.062 a	20.08	0.206 a	23.067 a
B_4	5.7	0.74 a	1.28 a	0.060 b	20.07	0.188 b	22.392 b
B_5	5.7	0.74a	1.28 a	0.060b	20.05	0.203 ab	23.042ab
CV (%)	0.06	2.59	2.09	1.53	6.58	11.86	4.75
Level of significance	NS	**	**	**	NS	**	**

** indicates 1% level of significance and NS indicates non-significant. 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}

Table 5: Combined effect of reduced irrigation and biochar on post-harvest soil properties

Combination of irrigation and biochar	Soil pH	Organic carbon (%)	Organic matter (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq/100g soil)	Available S (ppm)
W_1B_1	5.6	0.70 e	1.21 e	0.054 j	20.383 b	0.146 f	21.673 d
W_1B_2	5.6	0.70 e	1.21 e	0.055 j	20.797b	0.140 f	22.020 cd
W_1B_3	5.6	0.70 e	1.21 e	0.057j	21.247ab	0.159 e	21.677 d
W_1B_4	5.6	0.70 e	1.21 e	0.051 ij	20.400 b	0.166 d	21.020 cd
W_1B_5	5.6	0.70 e	1.21 e	0.059 f	21.670ab	0.167 d	21.967cd
W_2B_1	5.6	0.70 e	1.21 e	0.050 j	20.327bc	0.166 d	21.987 cd
W_2B_2	5.6	0.71cd	1.23 cd	0.053hi	21.070ab	0.170 c	23.067abcd
W_2B_3	5.6	0.71cd	1.23 cd	0.055gh	21.697ab	0.170c	22.333 bcd
W_2B_4	5.7	0.71cd	1.23 cd	0.060 e	20.537 b	0.170 c	22.333 bcd
W_2B_5	5.7	0.71 cd	1.23 cd	0.058 fg	20.797ab	0.171 b	24.033ab
W_3B_1	5.7	0.72 bc	1.24 bc	0.070cd	20.120c	0.172 b	23.517bc
W_3B_2	5.7	0.72 bc	1.24bc	0.072bc	21.873b	0.172 b	23.167bcd
W_3B_3	5.7	0.74a	1.28 a	0.076a	22.012 a	0.181 a	24.390 a
W_3B_4	5.7	0.73ab	1.26 ab	0.073ab	21.980b	0.182 a	24.040ab
W_3B_5	5.7	0.72 bc	1.24bc	0.075ab	21.860b	0.180 ab	23.200bcd
CV (%)	0.06	2.59	2.09	1.53	6.58	11.86	4.75
Level of significance	NS	*	*	**	**	*	*

*indicates 5% level of significance and ** indicates 1% level of significance and NS indicates non-significant. Where: 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 t ha^{-1}.

The different biochar treatments showed non-significant variation in the available phosphorus showed in Table 4. Significant variation was observed in case of exchangeable potassium when different doses of biochar were applied. Highest exchangeable potassium observed in B_3 treatment statistically similar to B_5 treatment where lowest exchangeable potassium calculated in B_1 treatment. In case of available sulphur highest available sulphur observed in B_3 which was statistically similar to B_5 treatment and lowest available sulphur found in B_1 treatment (Table 4).

Combined Effect of Irrigation and Biochar on Post-Harvest Properties of Soil: Effect of treatment combination reduced irrigation and biochar on post-harvest soil pH had been found non-significant. There was significant influence of combination of irrigation and biochar on soil organic carbon and organic matter. Highest organic carbon and organic matter found in W_3B_3 treatment combination which was statistically similar to W_3B_4 treatment combination. On the other hand, statistically similar organic carbon and organic matter found in W_3B_1, W_3B_2, W_3B_5 treatment combinations. Statistically similar results found from treatment combinations W_1B_1, W_1B_2, W_1B_3, W_1B_4, W_1B_5, W_2B_1 which resembles the lowest value for organic carbon and organic matter (Table 5).

Total nitrogen was significantly influenced by different treatment combinations of irrigation and biochar. Maximum total nitrogen found in W_3B_3 treatment combination which was statistically similar with W_3B_4, W_3B_5 treatment combinations and lowest total nitrogen percentage found in W_1B_1 treatment combination which was statistically similar to W_1B_2 treatment combination. Significant variation in the available phosphorus observed in different treatment combinations of irrigation and biochar showed in Table 5. Maximum available phosphorus found in W_3B_3 treatment combination and lowest available phosphorus calculated in W_3B_1 treatment combination. Exchangeable potassium was significantly influenced by different treatment combinations of irrigation and biochar. Maximum exchangeable potassium observed in W_3B_3 treatment combination which was statistically identical to W_3B_4 treatment combination and lowest exchangeable potassium found in W_1B_2 treatment combination which was statistically similar to W_1B_1 treatment combination. Different treatment combinations of irrigation and biochar showed significant variation in case of available sulphur. Maximum available sulphur found in W_3B_3 treatment combination which was statistically similar to W_3B_4 and W_2B_5 treatment combinations where lowest available sulphur found in W_1B_3 statistically similar to W_1B_1 treatment combination (Table 5).

DISCUSSION

Biochar offers numerous benefits to soil which makes its a popular soil amendment agent in sustainable agriculture worldwide. Biochar has an extensive surface area, physical properties that make it readily able to bond with other substances and a very-stable structure which makes it long-lasting. While biochar is not a fertilizer, research indicates it can help retain nutrients in the soil due to its charged surface and high surface area, which allows it to absorb nutrients [55]. Soil surface area can increase up to 4.8 times in biochar amended soils compared to other soil [56]. Fertilization with biochar also has a positive effect on water holding capacity [57]. Biochar can absorb water up to 5.0 times its own weight [58]. Our investigation regarding post-harvest evaluation of biochar added soil where irrigation skipped at heading and flowering stage of wheat revealed the increasing in the percentage of organic carbon, organic matter, total nitrogen, available phosphorus, exchangeable potassium and available sulphur. Non-significant variation was observed in soil pH as our study was done for only short-term period. Soil pH greatly influenced when biochar applied in soil for longer period. Our research findings also similar to other previous research results where application of biochar to soil in traditional agricultural practices significantly improve soil fertility and increase crop productivity [59- 65].

Biochar are abundant in mineral elements such as Na, K, Ca, Fe and Mg [66]. Approximately, 70% of its composition is amorphous carbon and remaining percentage consists of nitrogen, hydrogen and oxygen among other elements. The addition of biochar to the soil contributes carbon content improvement which stimulates the humification and carbon sequestration processes thus improve the soil density and water retention capacity [67]. It has been previously reported that the addition of biochar to the soil should increase the concentrations of micronutrients that are easily available to plants [68, 67]. Cybulak *et al*. [69] found that biochar application can increase the hygroscopic moisture content of soil by 1.5 to 3.0%, which would be very beneficial to dry and degraded soils. It is widely known that a high CEC corresponds to high nutrient contents [55]. Guo *et al.* [70] showed that biochar has a high CEC and is expected to retain more nutrients in soil and to decrease nutrient leaching. Surface area increases during pyrolysis due to the decomposition of cellulose and hemicelluloses and the formation of channel structures [71]. The carbonized and a non-carbonized fraction of biochar interacts with soil contaminants through oxygen-containing carboxyl, phenolic, hydroxyl and lactonic surface functional groups, which can play significant roles in the adsorption process [72]. Biochar interacts sub-molecularly with clay and silt particles, as well as with soil organic matter, occur through van der Waals forces and hydrophobic interactions [73, 74]. Danish *et al.* [59]

reported that biochar application enhanced water holding capacity of sandy soil which reduces the effect of drought in half irrigation treatment. We also found that wheat yield increased when biochar applied with skipped irrigation at heading and flowering stage.

CONCLUSION

Biochar has high potential for increasing soil carbon, soil nutrient retention through changes in soil chemical and physical properties which ultimately increase plant productivity. The addition of biochar to the soil increases the concentrations of micronutrients that are easily available to plants. So, biochar's application in soils can reduce the need for commercial fertilizers along with irrigation. It was a short-term research work. Therefore, it can be recommended that further research in other Agro Ecological Zones (AEZs) of Bangladesh is needed, which will be useful for sustainable agriculture.

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