EFFECT OF BIOCHAR ON THE GROWTH AND YIELD OF WHEAT (*Triticum aestivum* L) UNDER REDUCED IRRIGATED CONDITION

MAHMUDA AKTER

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EFFECT OF BIOCHAR ON THE GROWTH AND YIELD OF WHEAT (*Triticum aestivum* L) UNDER REDUCED IRRIGATED CONDITION

BY

MAHMUDA AKTER

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Approved by

Mst. Afrose Jahan
Professor
Department of Soil Science
Sher-e-Bangla Agricultural University,
Dhaka-1207
Supervisor

Dr. Alok Kumar Paul
Professor
Department of Soil Science
Sher-e-Bangla Agricultural University,
Dhaka-1207
Co-Supervisor

Dr. Saikat Chowdhury
Professor and Chairman
Department of Soil Science
Sher-e-Bangla Agricultural University
Dhaka-1207

Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207

PABX: +88029144270-9
Fax: +88029112649
www.sau.edu.bd

Memo No. SAU/SSC

CERTIFICATE

This is to certify that the thesis entitled **"EFFECT OF BIOCHAR ON THE GROWTH AND YIELD OF WHEAT UNDER REDUCED IRRIGATED CONDITION"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka in partial fulfillment of the requirement for the degree of **MASTER OF SCIENCE (MS) IN SOIL SCIENCE**, embodies the result of a piece of bonafide research work carried out by **MAHMUDA AKTER**, Registration No. **12-05048** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged by her.

Dated:
Place: Dhaka, Banglaseh

Mst. Afrose Jahan
Professor
Department of Soil Science
Sher-e-Bangla Agricultural University
Dhaka-1207
Supervisor

Dedicated to My Beloved Parents

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ABSTRACT

An experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka-1207, to evaluate the effect of biochar on the growth and yield of wheat (BARI Gom-29) under reduced irrigated condition during 15 November 2017 to 15 March 2018. The experiment was laid out in two factors split plot design with three replications. There were five levels of biochar application viz., B_1 = 0 t ha^{-1}, B_2 = 2 t ha^{-1}, B_3 = 4 t ha^{-1}, B_5 = 6 t ha^{-1}, B_6 = 8 t ha^{-1} and three levels of water stress such as 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 the size of the plot was 2m × 1.5m i.e. $3m^2$. There were 15 treatments combination. Wheat seed of cv. BARI Gom-29 was sown as planting material. The tallest plant (93.12cm), highest spike length (20.30 cm), maximum filled grain (48.80), highest number of total grain (51.40), highest 1000-seed weight (48.0 g), highest grain yield (3.23 t ha^{-1}) and highest straw yield (2.98 t ha^{-1}) were obtained under W_3B_3 (Irrigation skipped at heading and flowering stage + 4 t/ha biochar) treatment combination. While the lowest values for above mentioned cases were recorded under W_1B_1 (Regular irrigation + no addition of biochar) treatment combination. On the other hand, a significant effect was observed on post-harvest soil properties. The highest organic carbon (0.75%), highest organic matter (1.29%), maximum total nitrogen (0.086%), highest available phosphorus (22.533 ppm), maximum exchangeable potassium (0.233 meq/100g soil) and maximum available sulphur (24.390 ppm) were found in treatment combination of W_3B_3 (Irrigation skipped at heading and flowering stage + 4 t/ha biochar).While the values were lowest in W_1B_1 treatment combination. However, it can be concluded that application of biochar can reduce the irrigation frequency without reducing wheat yield significantly. 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.

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LIST OF ABBREVIATIONS

ABBREVIATION	FULL WORD
AEZ	Agro Ecological Zone
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
N	Nitrogen
P	Phosphorous
S	Sulphur
K	Potassium
0C	Degree Celsius
CV%	Percent Coefficient of Variance
DAS	Days After Sowing
FAO	Food and Agriculture Organization
FYM	Farm Yard Manure
e.g.	For example
et al.	And others
g	Gram (s)
i.e.	For example
Kg	Kilogram
Kg ha-1	Kilogram per hectare
LSD	Least Significant Difference
TSP	Triple Super Phosphate
MoP	Muriate of Potash
m	Meter
cm	Centimeter
NS	Non-significant
OM	Organic Matter
pH	Hydrogen Ion Concentration
%	Percent
SAU	Sher-e-Bangla Agricultural University
t ha-1	Ton per hectare
OC	Organic carbon Content

LIST OF ABBREVIATIONS (cont'd)

ABBREVIATION	FULL WORD
UNDP	United Nations Development Program
SOC	Soil Organic Carbon
DMRT	Duncan's Multiple range Test
NaOH	Sodium Hydroxide
DOC	Dissolved Organic Carbon
BC	Biochar
ppm	Parts Per Million
SRDI	Soil Resource Development Institute
TN	Total Nitrogen

CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a cereal grain considered one of the most important staple food throughout the world (Shewry, 2009; Elham *et al*., 2009). It is the third most-produced cereal after maize and rice (FAO, 2012). It is used to make bread, pasta such as spaghetti and macaroni, cake, crackers, cookies, pastries, and flours. Additionally, some wheat is used by industry for the production of starch, pasta, malt, dextrose, gluten alcohol and other products (Day *et al*., 2016). On an average, 100 grams wheat kernel provides 327 kilocalories and is a rich source of multiple essential nutrients such as protein, dietary fiber, manganese, phosphorus and niacin. It contains 12% water, 70% carbohydrates, 12% protein, 2% fat, 1.8% minerals, and 2.2% crude fibers. Thiamin, riboflavin, niacin, and small amounts of vitamin A are present, but the milling process removes most of those nutrients with the bran and germ. Its 13% protein content is mostly gluten (Shewry *et al*., 2002).

Wheat is grown on more land area than any other food crop (220.4 million hectares (FAO, 2014). In 2016, world production of wheat was 749 million tones (FAO, 2016) making it the second most-produced cereal after maize (FAO, 2014 and 2016). In Bangladesh, wheat is ranked in second next to rice according to the consumption value. In the first half of the 1980s, domestic wheat production rose to more than 1 million tons year^{-1}, but was still only 7–9 % of total food grain production (BARI, 2010). The total area under wheat crop has been estimated 10,99,158 acres (4,44,805 hectares) compared to 10,79,411 acres (4,36,814 hectares) of the last year (BBS, 2015-2016). Wheat covered an area of 350,000 ha and production is estimated 1185,000 MT in 2017-2018 in Bangladesh (USDA, 2018; BBS, 2017-2018). Bangladesh has become highly dependent on wheat imports while dietary preferences are changing such that wheat is becoming a highly desirable food supplement to rice. Over 80 percent of Bangladesh’s wheat consumption is fulfilled by imports. The year of release and new wheat varieties developed in Bangladesh from 1974 to 2012 (Hossain and da Silva, 2012).

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 (Julie, 2010, Geoffrey, 2008). Application of biochar under stressed water condition is more important for the wheat behaviors. It has been argued that use of charcoal as a fuel replacing wood leads to lower levels of household indoor pollution and an associated reduction in mortality (Bailis *et al*., 2005). 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 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 (Bakry *et al.*,2015).

Biochar as ecologically clean and stable form of carbon has complex of physical and chemical properties which make it a potentially powerful soil amendment (Mutezo, 2013). 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 (Lehmann and Rondon, 2005; Leach *et al*., 2010) documented that application of biochar to the soil enabling increases in agricultural productivity without, or with much reduced, applications of inorganic fertilizer. 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. Mousa and Abdel-Maksoud (2004), El Afandy (2006) 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 retains 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 (Lehmann, 2007a) 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 (Alburquerque *et al*., 2013; Li and Shangguan, 2018; Gebremedhin *et al*., 2015; Kulyk, 2012). 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 (Laird, 2008, Glaser *et al.,* 2002, Novak *et al*., 2009, Lehmann *et al.,* 2003, Atkinson *et al.,* 2010; Sohi *et al*., 2010; Stavi and Lal 2013 and Brooks *et al*., 2010). A lot of research works 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. In view of the above background, the present piece of research work has been undertaken with biochar application during water stress condition in wheat cultivation using the cultivar of BARI Gom-29 with the following objectives:

- ✓ To evaluate the effect of biochar on the growth and yield of wheat.
- ✓ To determine optimum combination of water stress level and biochar on the growth and yield of wheat.

CHAPTER II

REVIEW OF LITERATURE

Biochar offering several benefits for soil health. Biochar is currently a subject of active research worldwide because it can constitute a viable option for sustainable agriculture due to its potential as a long-term sink for carbon in soil and benefits for crops. Biochar can improve water holding capacity of soil, reduce soil emissions of greenhouse gases, reduce nutrient leaching, reduce soil acidity, and reduce irrigation and fertilizer requirements (Laird, 2008, Novak *et al*., 2009, Brooks *et al*., 2010). Modest additions of biochar to soil reduce nitrous oxide N_2O emissions by up to 80% and eliminate methane emissions (Lehmann, 2007a) and used as a soil amendment to improve yield for high potash and elevated pH requiring plants. Biochar addition enhanced wheat yield under different mineral fertilization levels regardless of nitrogen and water conditions (Alburquerque *et al*., 2013, Li and Shangguan, 2018; Zee *et al.*, 2017). However, the research work so far done at home and abroad regarding the effect of biochar on the growth and yield of wheat under reduced irrigated condition along with other relevant information are given below.

2.1 Biochar impact on soil and wheat yield

2.1.1 Effect on soil quality and wheat plant growth

Abrishamkesh *et al.* (2015) evaluated the effects of biochar application on some properties of an alkaline soil and on wheat growth. Wheat's were grown in the soil amended with the rates of 0.4, 0.8, 1.6, 2.4, and 3.3 weight percent of two biochars (B_1 and B_2), produced from rice husk under different pyrolysis conditions. Wheat's were harvested after 100 days. Soil samples were also analyzed for changes in physico-chemical properties. The results indicated that biochar application significantly increased soil organic carbon, cation exchange capacity, available potassium and below ground biomass of Wheat, while it decreased soil bulk density. The results suggested that biochar application to alkaline soils has benefits to both soil quality and plant growth. Biochar-amended soils enhance crop growth and yield via several mechanisms: expanded plant nutrient and water availability through increased use efficiencies, improved soil quality, and suppression of soil and plant diseases. Yield response to BC has been shown to be more evident in acidic and sandy soils than in alkaline and fine-textured soils. Biochar composition and properties vary considerably with feedstock and pyrolysis conditions so much that its concentrations of toxic compounds and heavy metals can negatively impact crop and soil health.

2.1.2 Effect on soil fertility and crop yield

Dume *et al*. (2015) reported that physical and chemical properties of the biochar varied as a function of feedstock selection and pyrolysis temperatures. Biochar additions to acidic soils have the potential to improve soil fertility and crop yield. Biochar materials were produced from coffee husk and corn cob at temperatures of 3500c and 500°C and characterized by their physical and chemical properties. These were mixed with acidic soil at the rates of 0, 5, 10 and 15 t ha^{-1} and were laboratory incubated for 2 months at ambient temperature to examine changes in soil properties. Types of feedstock used at two different pyrolysis temperatures and application rate had no significant effects on soil textural classes but showed highly significant effects ($p<0.01$) on soil pH, Electrical Conductivity (EC), Cation Exchange Capacity (CEC), Organic Carbon (OC), Organic Matter (OM), Total Nitrogen (TN), exchangeable cations and available phosphorous. Application of coffee husk biochar showed relatively better improvement in soil chemical properties (pH, EC, CEC, OC, OM, TN, exchangeable cations and available phosphorous) than corn cob biochar at all application rates. The highest values of chemical properties were recorded when coffee husk biochar produced at 500°C temperature was applied at a rate of 15 t ha^{-1}. Therefore, they generated evidence that application of biochar is very important to improve physical and chemical properties of acidic soil.

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 was done by Bakry *et al*. (2015). To assess these benefits, two field experiments were carried out at the Research and Production Station of the National

Research Centre, Al Nubaria district, El-Behaira Governorate, Egypt during 2012-13 and 2013-14 winter seasons to study the effect of four levels of bio-char application (control, 2, 4, and 6 tons/feddan) and two levels of water requirements ((2000 m3/feddan (80%) and 2500 m3 /feddan (100 %)) on growth, yield, and yield components of wheat (Misr1). The results showed that at 75 days from sowing, flag leaf area (cm^2), and proline content were significantly affected by the two levels of water requirements, however, plant fresh weight (g), number of leaves/plants, chlorophyll a, chlorophyll b, and carotenoids were not significantly affected. On the other hand, the biochar application did not significantly affect flag leaf area (cm^2), number of leaves/plants, and carotenoids, however, it did significantly affect plant fresh weight (g), chlorophyll a, chlorophyll b, and proline content. At the end of the experiment the two levels of water requirements did not significantly affect plant height (cm), spike length (cm), number of spikelet's/spikes, biological yield (tons/fed.), straw yield (tons/fed.), and harvest index, however, number of grain/spikes, grain weight/spike, and grain yield (tons/fed.) were significantly affected. Bio-char application did not significantly affect plant height (cm), spike length (cm), number of spikelet's/spikes, and harvest index, and however, number of grain/spikes, grain weight/spike, biological yield (tons/fed.), grain yield (tons/fed.), and straw yield (tons/fed.) were significantly affected. Finally, the addition of biochar at the rate of 4 tons/feddan could produce high grain yield and saving about 20% of water under sandy soil conditions of Egypt.

2.1.3 Effect on water use efficiency and wheat crop yield

Zhongyang *et al*. (2015) observed the effects of biochar on winter wheat growth, yield, water use efficiency and root morphology, a one-year field experiment with different application amounts (0, 20, 30, 40, 50 and 60 t/hm2) of wheat straw biochar (pyrolysis temperature of 600) was carried out under subsurface drip irrigation condition. The preliminary results showed that the tiller number, efficient spike number and yield of winter wheat were significantly affected by biochar, increased by 1.6-4.9%, 0.7-1.5%, and 1.0-5.9%, respectively. Plant height and spike length were not affected by wheat straw biochar. Grain number and 1000-grain weight were significantly increased (P0.05) only under the treatments of 30, 40, and 50 t/hm^2 application of wheat straw biochar. Grain number increased by 4.7%, 8.6% and 2.7%, respectively and 1000-grain weight increased by 5.6%, 8.0% and 5.0%, respectively, which showed biochar application could effectively increase winter wheat yield through the increase of tiller number, efficient spike number, grain number and 1000-grain weight. The water consumption of winter wheat decreased significantly (P0.05) with the increase of application amount of wheat straw biochar, which decreased by 2.6%, 7.0%, 7.7%, 9.1% and 9.4% respectively under the biochar application amounts of 20, 30, 40, 50 and 60 t/hm2. The water use efficiency increased from 17.06 to 17.69-19.57 kg/hm^2 with the increase of application amount of wheat straw biochar, and the highest value was obtained under the treatment of 40 t/hm^2. The root morphology characteristics of winter wheat were significantly affected by wheat straw biochar. The application of wheat straw biochar increased total root length of 0-20 and 20-40 cm for winter wheat by 2.8%-14.6% and 8.4%-21.2%, respectively, increased root surface area by 5.6%-19.5% and 1.9%-13.6%, respectively and increased average root diameter by 0.4%-4.1% and 1.4%-2.0%, respectively. The application of wheat straw biochar had less positive effect on average root diameter of winter wheat, compared with total root length and root surface area. In comparison with other levels of biochar application, the treatment of 40 t/hm^2 was more effective in the improvement of winter wheat root growth. The root morphology characteristics were very significantly correlated with the yield of winter wheat (P0.001). Compared to other application amounts of wheat straw biochar, the treatment of 40 t/hm^2 had the most significant impact on the growth, yield, water use efficiency and root morphology characteristics of winter wheat. This study provides references for scientific and rational utilization of biochar in agriculture.

2.1.4 Effect on drought and crop productivity

Danish *et al*. (2014) conducted research on 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 especially in Pakistan where handiness of better-quality irrigational water is very less. To overcome that problem addition of biochar as an amendment in our experiment was examined. Cotton sticks waste biochar was prepared by pyrolysis at 3850C whose pH and EC were 8.42 and 2.33 dS/m respectively. There were 6 treatments and 6 replications having half and full doze of irrigational water with biochar 3 implication rates (0%, 1% and 2%) in sandy soils. Results revealed significant increase in almost all the attributes of tested plants (fresh biomass, dry biomass, stem length, root length) at the amended rates of 1% and 2% biochar in sandy soils as compared to control. Chlorophyll pigments (a, b and total), carotenoids and anthocyanin (except lycopene) production was also improved due to biochar addition in the sandy soils. Biochar application enhanced water holding capacity of sandy soil which reduces the effect of drought in half irrigation treatment. Based on the results it is concluded that cotton sticks waste biochar can be effectively used (1% and 2%) to improve water holding capacity of sandy soils due to which drought stress can be reduced while crop yield is also enhanced as supplement availability of water which assist photosynthesis to produce photosynthetic and accessory pigments.

2.1.5 Effect on drought and plant growth

Svoboda *et al.* (2017) investigated to evaluate the effect of applying biochar and activated carbon on winter wheat affected by drought in laboratory conditions. Cultivation tests of the soil-microorganisms-plant (winter wheat) system were focused on understanding the interactions between microbial soil communities and experimental plants in response to specific cultivation measures, in combination with the modeled effect of drought. The containers were formed as a split root rhizotron. In this container experiment, the root system of one and the same plant was divided into two separate compartments where into one half, biochar or activated carbon has been added. The other half without additives was a control. Plants favored the formation of the root system in the treated part of the container under both drought and irrigation modes. In drought mode there was lower production of CO_2, lower overall length and surface of the roots of winter wheat compared to variants in irrigation mode. The application of biochar and activated carbon, therefore, supported the colonization of roots by mycorrhiza in general. The scientific merit of this paper was to investigate the possibility of mitigating the effects of a long-term drought on winter wheat through the application of biochar or the application of activated carbon.

2.1.6 Effect on combined Cadmium and drought stress condition

Abbas *et al.* (2018) experimented on Cadmium (Cd) and drought stress in plants is a worldwide problem, whereas little is known about the effect of biochar (BC) under combined Cd and drought stress. A current study was conducted to determine the impact of BC on Cd uptake in wheat sown in Cd-contaminated soil under drought stress. Wheat was grown in a soil after incubating the soil for 15 days with three levels of BC (0%, 3.0% and 5.0% w/w). Three levels of drought stress (well-watered, mild drought and severe drought containing 70%, 50%, and 35% of soil water holding capacity respectively) were applied to 45-d-old wheat plants. Drought stress decreased plant height, spike length, chlorophyll contents, gas exchange parameters, root and shoot dry biomasses and grain yields. Drought stress also caused oxidative stress and decreased the antioxidant enzymes activities whereas increased the Cd concentration in plants. Biochar increased morphological and physiological parameters of wheat under combined drought and Cd stress and reduced the oxidative stress and Cd contents and increased antioxidant enzymes activities. The decrease in Cd concentration with BC application in drought-stressed plant might be attributed to BC-induced increase in crop biomass production and reduction in oxidative stress. These results indicate that BC could be used as an amendment in metal contaminated soil for improving wheat growth and reducing Cd concentrations under semiarid conditions.

2.1.7 Effect on Fertilizer use efficiency and wheat crop yield

Blackwell *et al.* (2010) investigated on the effects of banded biochar application on dry land wheat production and fertilizer use in 4 experiments in Western Australia and South Australia suggest that biochar has the potential to reduce fertilizer requirement while crop productivity is maintained, and biochar additions can increase crop yields at lower rates of fertilizer use. Banding was used to minimize wind erosion risk and place biochar close to crop roots. The biochars/metallurgical chars used in this study were made at relatively high temperatures from woody materials, forming stable, low-nutrient chars. The results suggest that a low biochar application rate (~1t/ha) by banding may provide significant positive effects on yield and fertilizer requirement. Benefits are likely to result from improved crop nutrient and water uptake and crop water supply from increased arbuscular mycorrhizal fungal colonization during dry seasons and in low P soils, rather than through direct nutrient or water supply from biochars. Financial analysis using farm cash flow over 12 years suggests that a break-even total cost of initial biochar use can range from AU$40 to 190/ha if the benefits decline linearly to nil over 12 years, considering a P fertilizer saving of 50% or a yield increase of 10%, or both, assuming long-term soil fertility is not compromised. Accreditation of biochar for carbon trading may assist cost reduction.

2.1.8 Effect on nutrient use efficiency and wheat yield quality

Ali *et al.* (2015) studied on wheat quality, nutrient uptake and nutrient use efficiency are significantly influenced by nutrient sources and application rate. To investigate the integrative effect of biochar, farmyard manure (FYM) and nitrogen (organic and inorganic soil amendments) in a wheat-maize cropping system, a two-year study was designed to assess the interactive outcome of biochar, FYM and nitrogenous fertilizer on wheat nitrogen (N) parameters and associated soil quality parameters. Three levels of biochar (0, 25 and 50 t ha-^{1}), two levels of FYM (5 and 10 t ha^{-1}) and two levels of nitrogen fertilizer (60 and 120 kg ha^{-1}) were used in the study. Biochar application displayed a significantly increased in wheat leaf, stem, straw and grain N content; grain and total N-uptake and grain protein content by 24, 20, 24, 56, 50, 17 and 20% respectively. Similarly, biochar application significantly increased soil total N (TN) and soil mineral N (SMN) by 63 and 40% respectively in second year. FYM application increased grain, leaf and straw N content by 20, 19.5 and 18% respectively, and increased total N-uptake and grain protein content by 49 and 19% respectively. FYM increased soil TN and SMN by 63 and 32% in both the years of the experiment. Mineral N application increased soil TN by over a half and SMN by a third, and grain protein content increased 16%. In contrast, nitrogen use efficiency (NUE) decreased for all amendments relative to the control. However, biochar treated plots improved NUE by 38% compared to plots without biochar. In conclusion, this field experiment has illustrated the potential of biochar to bring about short-term benefits in wheat and soil quality parameters in wheat-maize cropping systems. However, the long-term benefits remain to be quantified.

Wabel *et al.* (2017) summarizes the influences of pyrolysis conditions and feedstock types on biochar properties and how biochar properties in turn affect soil properties. Mechanistic evidence of biochar's potential for enhancing crop productivity, carbon sequestration, and nutrient use efficiency are also discussed. The review identifies the knowledge gaps, limitations, and future research directions for large scale use of biochar. Both pyrolytic parameters and feedstock types are the main factors controlling biochar properties such as nutrient content, recalcitrance, and pH. Biochar produced at low temperatures may improve nutrient availability and crop yield in acidic and alkaline soils, whereas high temperature biochar may enhance long term soil carbon sequestration. Biochar can also improve the efficiency of inorganic and organic fertilizers by enhancing microbial functions and reducing nutrient loss, thereby making nutrients more available to plants. Integration of biochar and chemical or organic fertilizers generally provides for better nutrient management and crop yield in most types of soils.

2.2 Biochar impact on soil chemical properties

The effect of biochar addition on the chemical properties of acidic soil such as soil pH, electrical conductivity (EC), cation exchange capacity (CEC), and exchangeable acidity were investigated to determine the liming potential of biochars by Chintala *et al.* (2013). This study was conducted by incubating acidic soil (clayey, smectitic, acid, mesic, shallow, Aridic Ustorthent) of pH < 4.80 with biochars for 165 days. The biochars were produced from two biomass feed stocks such as corn stover (*Zea mays L*.) and switch grass (*Panicum virgatum L*.) using microwave pyrolysis (at 650°C). Corn stover biochar , switch grass biochar, and lime (calcium carbonate) were applied at four rates (0, 52, 104, and 156 Mg ha^{-1}) to acidic soil. Amendment type, application rate, and their interaction had significant effects ($p < 0.05$) on soil pH, EC, and CEC of acidic soil. Exchangeable acidity was significantly affected by amendment type. Application of corn stover biochar had shown a relatively larger increase in soil pH than switch grass biochar at all application rates. The ameliorating effect of biochars on chemical properties of acidic soil was consistent with their chemical composition.

2.2.1 Biochar effect on soil pH

In China, it is critical to develop new soil amendments to decrease soil acidity because of the severe soil acidification problems that exist. In the present study, the effects of biochars derived from different feed stocks on soil pH, N transformation, and pH buffering in three acid soils and the mechanisms of changes in these parameters were examined by Dai *et al.* (2013). Soil pH had stabilized by Day 100, and biochar addition increased soil pH by 0.5 to 1 unit at the 1% incorporation rate and by 1 to 2 units at 3%, respectively, by 180 d of incubation. The effects of biochar additions on pH changes were determined both by the alkalinity (excess cations) of biochar and N nitrification in soils. With the Psammaquent (loamy, mixed, super active, thermic Typic Psammaquent) soil, the alkalinity of biochars was the main factor affecting the soil pH increase, while with the Plinthudult (clayey loamy, kaolinitic, thermicTypic Plinthudult) and Paleudalf (clayey loamy, illitic, thermic Typic Paleudalf) soils, both the alkalinity of the biochars and nitrification in the soils contributed to the soil pH changes. In addition, biochar alkalinity made a large contribution to the pH increase while N nitrification made a relatively small contribution to the pH decrease. A positive priming effect of biochar on soil organic N probably occurred during the incubation. Generally, the biochars increased soil pH buffering, and the changes in pH buffering differed between soils and biochars. In conclusion, the incorporation of tested biochars in this study can both increase and maintain soil pH for long periods, and the swine manure biochar had the greatest effect while the reed straw biochar had little effect. The magnitude of the effects depends on soil type, biochar type, and incorporation rate.

Liu *et al.* (2012) conducted an incubation experiment was conducted to determine the effects of biochar on the pH of alkaline soils. Five types of alkaline soils collected at the Loess Plateau and one type of biochar with a slightly lower pH than the soils were used. After incubation for 4 months and 11 months, the control soil and biochar-amended soils (4, 8 & 16 g of biochar/kg of soil) were sampled and tested. The application of alkaline biochar did not increase the soil pH but instead produced a decreasing pH trend, especially with higher biochar application rates. The decrease in soil pH was more significant at the 10 cm to 20 cm layer than in the 0 cm to 10 cm layer. The soil type (Aeolian sandy soil), which had the highest pH, showed the largest decrease in pH after 11 months of incubation. Acidic materials produced by the oxidation of biochar and organic matters may have caused the pH decrease. The high soil cation exchange capacity caused by the biochar application might restrict the soil salinization process to some extent.

2.2.2 Biochar effect on pH buffer capacity in soil

Tonutare *et al.* (2014) conducted an experiment to evaluate the effect of biochar to soil pH buffering properties, the aim of our investigation was to investigate the changes in soil pH buffer capacity in a result of addition of carbonated material to temperate region soils. In the experiment different kind of softwood biochars, activated carbon and different soil types with various organic matter and pH were used. The study soils were Albeluvisols, Leptosols, Cambisols, Regosols and Histosols. In the experiment the series of the soil: biochar mixtures with the biochar content 0 to 100% were used. The times of equilibration between solid and liquid phase were from 1 to 168 hours. The suspension of soil: biochar mixtures were titrated with HCl solution. The titration curves were established, and pH buffer capacities were calculated for the pH interval from 3.0 to 10.0. The results demonstrate the dependence of pH buffer capacity from soil type, organic matter and type of added carbonated material. The study showed that the biochar content has significant role in total pH buffer capacity in soil: biochar system. Biochar can retain elements in soil directly through the negative charge that develops on its surfaces, and this negative charge can buffer acidity in the soil.

2.2.3 Biochar effect on soil organic carbon

Biochar as ecologically clean and stable form of carbon has complex of physical and chemical properties which make it a potentially powerful soil amendment (Mutezo, 2013). Therefore, during the last decade, the biochar application as soil amendment has been a matter for a great number of investigations. For the ecological viewpoint the trend of decreasing of soil organic matter in European agricultural land is a major problem. The availability of different functional groups (e.g. carboxylic, phenolic, acidic, alcoholic, amine, amide) allows soil organic matter to buffer over a wide range of soil pH values (Krull *et al*., 2004). Therefore, the loss of soil organic matter also reduces cation exchange capacity resulting in lower nutrient retention (Kimetu *et al*., 2008).

Lehmann *et al.* (2007) reported that biochar can influence native soil organic carbon (SOC) mineralisation through "priming effects". However, the long-term direction, persistence and extent of SOC priming by biochar remain uncertain. Using natural 13C abundance and under controlled laboratory conditions, we show that biochar-stimulated SOC mineralisation ("positive priming") caused a loss of 4 to 44 mg C g^{-1} SOC over 2.3 years in a clayey, unplanted soil (0.42% OC). Positive priming was greater for manure-based or 400°C biochars, *cf*. plant-based or 550°C biochars, but was trivial relative to recalcitrant C in biochar. From 2.3 to 5.0 years, the amount of positively-primed soil CO_2-C in the biochar treatments decreased by 4 to 7 mg C g^{-1} SOC. They concluded that biochar stimulates native SOC mineralisation in the low-C clayey soil but that this effect decreases with time, possibly due to depletion of labile SOC from initial positive priming, and/or stabilisation of SOC caused by biochar-induced organo-mineral interactions.

2.2.4 Biochar effect on nutrient availability

Biochar, a co-product of thermo-chemical bioenergy production, may be a valuable soil amendment. In order to gain more information, experiment was performed to see if the addition of biochar, in comparison to lime and fertilizer treatments, has the potential to return key nutrients back to the soil or increase crop yield. A field study to investigate the effects of biochar on plant growth was initiated in 2011 near St. John, KS. Treatments included biochar applied at 16.6 ton/a (biochar), lime and annual applications of phosphorus and potassium fertilizer (lime + P&K), and a control. Four rates of nitrogen (N) fertilizer were applied within each treatment (0, 45, 90, and 135 lb N/ha). Winter wheat was planted in 2015 and harvested in 2016. The biochar treatment had greater wheat yield and better plant growth than the control, but it was like the lime + P&K treatment. The greater yields from the biochar and the lime + P&K were likely due to increased soil pH from the lime and biochar. Biochar appears to be an effective method of supplying phosphorus (P), potassium (K), and increasing soil pH, and there was no effect on nitrogen availability.

2.2.5 Biochar effect on soil acidity

Berihun *et al.* (2017) conducted an research to know the effect of biochar on soil physicochemical properties. The aim of this research was to investigate the effect of biochar amendment on soil acidity and other physicochemical properties of soil in Southern Ethiopia using a field experiment of three treatments: (1) biochar made of corn cobs, (2) biochar made of chopped *Lantana camara* stem, and (3) biochar made of *Eucalyptus globulus* feedstock and a control, in which neither of the biochar was used. Each treatment had three levels of 6, 12 and 18 t ha^{-1}. The experiment was setup with RCBD in a factorial arrangement with three replications. In this regard, a total of 36 plots (each 2×2 m size) were applied with three replications to the depth of 0–15cm. From these 36 plots, composite soil samples were collected to the depth of 0–30 cm and analyzed for bulk density, total porosity, pH, soil organic carbon, total nitrogen, available phosphorus, potassium, and exchangeable acidity using standard procedures before and after biochar application. Two way ANOVA was also used to analyze the impact of the biochars on soil acidity and other properties. For the treatments that had significant effects, a mean separation was made using Least Significance Difference (LSD) test. The results showed the application of biochar significantly reduced, soil bulk density and exchangeable acidity when compared with a control ($p < 0.05$). Moreover, the total soil porosity, soil pH, total nitrogen, soil organic carbon, available phosphorus, and potassium were significantly increased in the soil. From among applied biochar treatments, *Lantana camara* applied at the level of 18 t ha^{-1} had a higher impact in changing soil physicochemical properties. In general, the study suggests that the soil acidity can be reduced by applying biochar as it can amend other soil physicochemical properties.

2.3 Biochar effect on soil microbes and crop yield

A large proportion of phosphate (P) fertilizer applied to Andosols reacts with reactive aluminum (Al) and iron (Fe) to become unavailable for plant uptake. Shen *et al*. (2016) investigated whether biochar could enhance plant growth by (i) mobilizing soil P through changing soil pH or facilitating the growth of arbuscular mycorrhizal fungi (AMF), and/or (ii) introducing additional P .They grew *Lotus pedunculatus cv* barsille in two Andosols of contrasting P status amended with three biochars (with distinct porosity, nutrient and liming properties) at a dose of 10 t $ha^{-1}$for 32 weeks. The growth medium was divided into a root and a hyphal *zone* through a nylon mesh and a tephra layer that allowed the P in the hyphal *zone* to be transferred only by AMF hyphae. The addition of a relative nutrient–rich biochar (e.g. made from willow woodchips) with liming properties to the *root zone* of the P–deficient soil increased plant growth by 59% and P uptake by 73%. Pine–based biochar provided no extra nutrient acquisition and no plant–growth stimulation when added to the *root zone* of the P–deficient soil. However, when hyphae of those plants had access to a P–rich soil patch, the presence of pine biochar in the soil patch greatly enhanced P uptake and plant growth (e.g., by 76% and 40% when using biochar produced at 450^{o}C compared to the absence of it). None of the tested biochars conferred advantages in the *root zone* of a high–P soil. They concluded that the benefits from biochar addition to nutrient uptake and plant growth are biochar and soil-specific. Thus, biochars need to be tailored–made for certain soils by optimizing feedstock and pyrolysis conditions before application.

2.4 Biochar effect on wheat crop productivity

Biochar is a solid material obtained from the carbonization of any biomass including weeds, crop residues and other wastes of plant origin. A greenhouse pot experiment was conducted on biochar, obtained from carbonization of *Prosopis juliflora*, to evaluate effects on wheat productivity and post-harvest soil properties. This experiment has used four different combinations of biochar and compost besides the chemical fertilizers (Gebremedhin *et al*., 2015). Biochar was significantly increased grain and straw yields of wheat by 15.7% and 16.5% respectively, over the NP application (control). Moreover, the root biomass was significantly increased by 20%. This shows that biochar retains nutrients and water to improve wheat productivity. Hence, the biochar produced from *Prosopis juliflora* could be used for wheat productivity improvement.

Biochar production and its use in agriculture can play a key role in climate change mitigation and help to improve the quality and management of waste materials coming from agriculture and forestry (Alburquerque *et al.,* 2013). Biochar is a carbonaceous material obtained from thermal decomposition of residual biomass at relatively low temperature and under oxygen limited conditions (pyrolysis). Biochar is currently a subject of active research worldwide because it can constitute a viable option for sustainable agriculture due to its potential as a long-term sink for carbon in soil and benefits for crops. However, to date, the results of research studies on biochar effects on crop production show great variability, depending on the biochar type and experimental conditions. Therefore, it is important to identify the beneficial aspects of biochar addition to soil on crop yield in order to promote the adoption of this practice in agriculture. In this study, the effects of two types of biochar from agricultural wastes typical of Southern Spain: wheat straw and olive tree pruning, combined with different mineral fertilization levels on the growth and yield of wheat (*Triticum durum* L. cv. Vitron) were evaluated. Durum wheat was pot-grown for 2 months in a growth chamber on a soil collected from an agricultural field near Córdoba, Southern Spain. Soil properties and plant growth variables were studied in order to assess the agronomic efficiency of biochar. The results showed that biochar addition to a nutrient-poor, slightly acidic loamy sand soil had little effect on wheat yield in the absence of mineral fertilization. However, at the highest mineral fertilizer rate, addition of biochar led to about 20–30 % increase in grain yield compared with the use of the mineral fertilizer alone. Both biochars acted as a source of available P, which led to beneficial effects on crop production. In contrast, the addition of biochar resulted in decreases in available N and Mn. A maximum reduction in plant nutrient concentration of 25 and 80 % compared to non biochar-treated soils for N and Mn, respectively, was detected. This fact was related to the own nature of biochar: low available nitrogen content, high adsorption capacity, and low mineralization rate for N;

and alkaline pH and high carbonate content for Mn. Our results indicate that biochar-based soil management strategies can enhance wheat production with the environmental benefits of global warming mitigation. This can contribute positively to the viability and benefits of agricultural production systems. However, the nutrient-biochar interactions should receive special attention due to the great variability in the properties of biochar-type materials.

CHAPTER III

MATERIALS AND METHODS

The research was carried out at Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207, and Bangladesh during the period from November 2017 to March 2018 to investigate the effect of biochar on growth and yield of wheat under reduced irrigated condition. This chapter includes a description of location of experimental plot, characteristics of soil, climate, wheat variety, land preparation, experimental design, cultural operations, data recording, collection of soil samples etc. and analytical methods followed in the experiment. The details of the research methodology are given below:

3.1 Experimental site

The research work was conducted at the Sher-e-Bangla Agricultural University farm, Dhaka-1207 during Rabi season of 2017.

3.2 Location of the study

3.2.1 Geographical Location

The experiment area was situated at $23^{0}77'$ N latitude and $90^{0}33'$ E longitude at an altitude of 8.6 meter above the sea level (Anon, 2004).The field was located at the southeast-west corner of main academic building. Morphological characteristics of experimental field are presented in Table 1.

3.2.2 Agro-Ecological Region

The experimental filed belongs to the Agro-Ecological Zone of The Madhupur Tract, AEZ-28 (Anon, 2003a). This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediment buried the discrete edges of the Madhupur Tract leaving small hillocks of red soils as ‘Island’ surrounded by floodplain (Anon, 2003b). The experimental site was shown in the map of AEZ of Bangladesh in Figure 1.

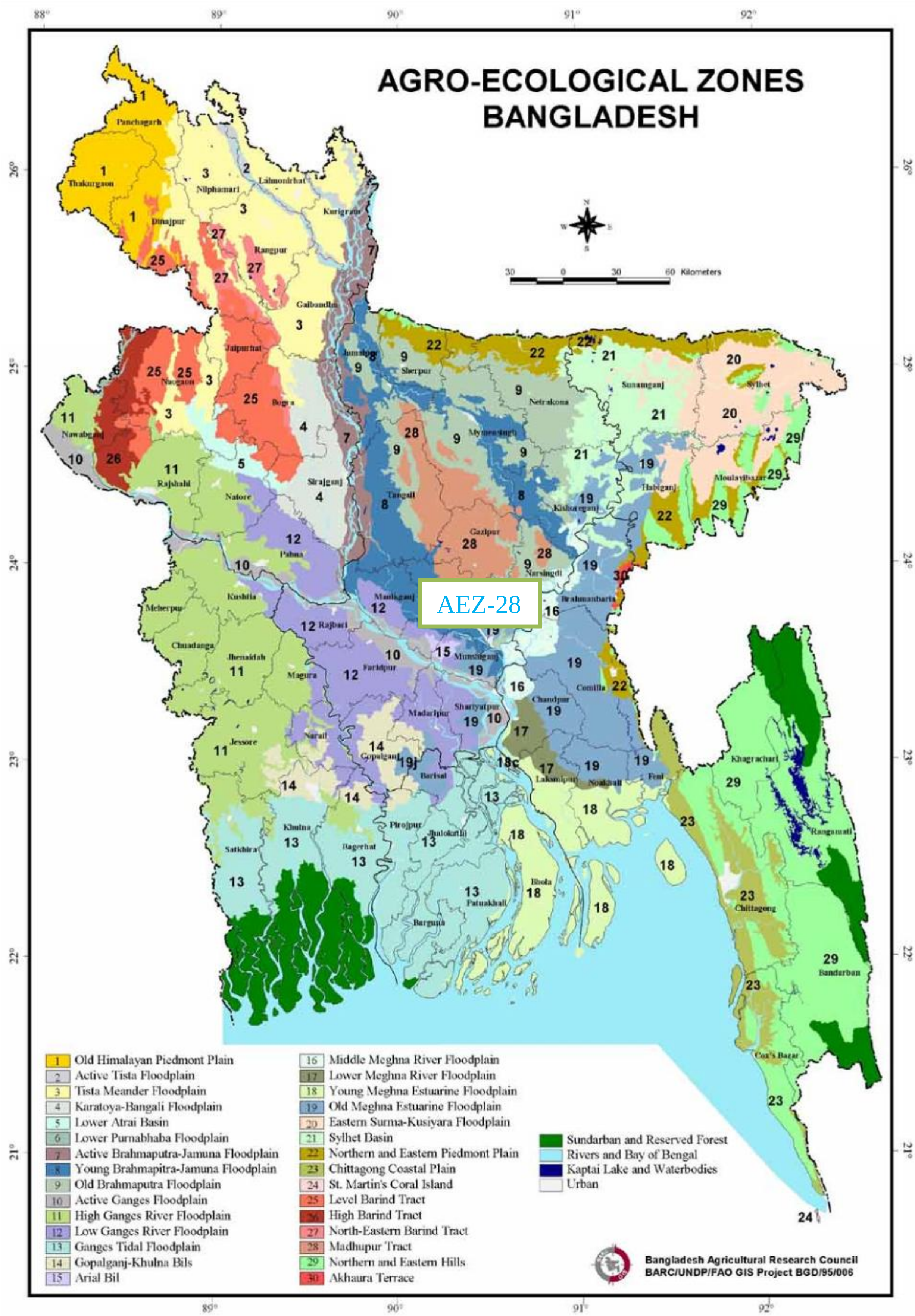


Figure 1. Agro Ecological Zone (AEZ) of Bangladesh

3.3 Climate

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). Weather information regarding temperature (^{0}c), relative humidity (%), rainfall (mm) and sunshine hours prevailed at the experimental site during the study period was presented in Appendix1.

3.4 Description 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.

3.4.1 Characteristics of soil

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. The physico-chemical properties of the soil are presented in Table 2.

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

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

3.5 Planting material

The wheat variety (*Triticum aestivum* L.) BARI Gom-29 (Figure 2) was used as plant material. Bangladesh Agricultural Research Institute (BARI) developed this variety and released in 2014. It is becoming a popular variety now-a-days due to its 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 55-60 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 4.0-5.0 t ha^{-1}. Plants are deep green with straight tiller in seedling stage, contains few hairs in upper node of Culm. Flag leaves are straight and glum of lower portion of spikelet shoulder is medium broad and indented, lip is tall (>12.1 mm) and spine is present in lip.

Figure 2. Seeds of BARI Gom-29.

3.6 Preparation of land

The field selected for the experiment was opened by the power tiller on15thNovember 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.

3.7 Design and layout of the experiment

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 fifteen (15) combinations. The distance maintained between two plots was 50cm and distance between two adjacent replications (block) was 50cm. The layout of the experiment is shown in Figure 3 (Field view) and in Appendix 2.

Figure 3. Layout of the experimental field

3.8 Treatments: There were two factors; 5-levels of Biochar and 3-levels of water stress

3.8.1 Factor A: Biochar (5 levels):

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}

3.8.2 Factor B: Water stress (3 levels)

W_1 = Regular irrigation (depending on shortage of soil moisture)

W_2= Skipped irrigation at booting stage.

W_3 = Skipped irrigation at heading and flowering stage.

3.8.3 Treatment combination: Combining two factors, there were 15 treatment combinations obtained

W_1B_1	W_1B_2	W_1B_3
W_1B_4	W_1B_5	W_2B_1
W_2B_2	W_2B_3	W_2B_4
W_2B_5	W_3B_1	W_3B_2
W_3B_3	W_3B_4	W_3B_5

3.9 Application of fertilizers

Fertilizer was applied based on BARC fertilizer recommendation guide-2012 for wheat given below:

Name of the Nutrients	Dose/Rate
N	101 kg ha^{-1}
P	38 kg ha^{-1}
K	25 kg ha^{-1}
S	22 kg ha^{-1}

(Source: BARC fertilizer recommendation guide-2012)

The unit plots were fertilized with 220 kg Urea, 180 kg TSP, 50 kg MoP, and gypsum 120 kg ha^{1} respectively. 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 sat 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 1^{st} and 2^{nd} irrigation).

3.10 Preparation and application of biochar

Collected from a private organization and then biochar was grinded 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.

3.11 Sowing of seeds

The seeds of wheat (BARI Gom-29) 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.

3.12 Fencing of Experimental field

The whole experimental area was covered by net protecting from birds and other animals (Figure 4 and 5).

Figure 4. Fencing of experimental field   Figure 5. Experimental field

3.13 Cultural and Management Practices:

3.13.1 Weeding and thinning

Various intercultural operations such as thinning of plants, weeding and irrigation were done. Thinning was done at 15 DAS (days after sowing). The crop field was weeded twice; first weeding was done at 25 DAS (Days after sowing) and second weeding at 40 DAS. Demarcation boundaries and drainage channels were also kept weed free.

3.13.2 Irrigation

Total three irrigation was 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 inW_3 treated plot).

3.13.3 Protection against insects and pathogens

Spraying of recommended dose of pesticides were accomplished whenever required to keep the plants healthy and the field pathogen free. At the very early stage of growth (after 10 days of emergence of seedlings) the plants were attacked by few aphids and ants which was controlled by applying Malathion 57EC @ 1ml/L and Sevin dust 80 WSP @ 1g/L, Bavistin 80 WP @ 1g/L for 5 decimals of land.

3.14 Crops sampling and data collection

The crop sampling was done at the time of harvest. Harvesting date was 3/3/2018. 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 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 (kg plot^{-1}), grain yield (tha^{-1}), Straw yield (tha^{-1})were recorded separately.

3.15 Harvest and post-harvest operations

The crop was harvested at maturity when 90% of the crops became brown in color on March 3, 2018. 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}.

3.16 Recording of data

The data were recorded on the following parameters:

I. Plant height (cm)

II. Length of spike (cm)

III. Number of filled grains spike^{-1}

IV. Number of unfilled grains spike^{-1}

V. Total number of grains/spike

VI. Weight of 1000 seeds (g plot^{-1})

VII. Grain yield (t ha^{-1})

VIII. Straw yield (t ha^{-1})

3.17 Procedure of data collection

3.17.1 Plant height

The heights of five plants were measured with a meter scale from the ground level to the top of the plants and the mean height was expressed in cm. It was done at 20, 40, 60, 80 DAS and during harvesting time.

3.17.2 Length of spike

Spike length were counted from five plants and then averaged. This was taken at the time of harvest and it was expressed in cm.

3.17.3 Number of filled grains spike^{-1}

Total number of filled grains was counted by observing from each spikelet's that was obtained from pre-selected five plants. After that it was averaged and expressed as number of filled grains spike^{-1}.

3.17.4 Number of unfilled grains spike^{-1}

Total number of unfilled grains spike^{-1} was counted from total spike that was obtained from pre-selected five plants. After that it was averaged and expressed as number of unfilled grains spike^{-1}.

3.17.5 Weight of 1000 seeds

One thousand cleaned dried seeds were counted randomly from each plot harvest sample and weighed by using a digital electric balance and the mean weight was expressed in gram.

3.17.6 Total grain yield plot^{-1}

Total sum of filled and unfilled grains was collected from each plot. After that it was expressed in kg.

3.17.7 Grain yield (t ha^{-1})

Weight of grains of the demarcated area (3m^2) of each plot was taken and then converted to the grain yield in t ha^{-1}.

3.17.8 Straw yield (t ha^{-1})

Straw yield was weighed from per plot and then averaged. This was taken after harvest and it is expressed in g then converted straw yield in t ha^{-1}.

3.18 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.

3.19 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 texture, pH, organic carbon, organic matter content, total N, available P, exchangeable K and available S. The chemical properties of post-harvest soil have been presented in Table 14. The soil was analyzed by standard methods:

3.19.1 Particle size analysis

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.

3.19.2 Soil pH

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 (1962).

3.19.3 Organic Carbon

Organic carbon in soil was determined by Walkley and Black's (1934) Wet Oxidation Method. 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.

3.19.4 Total Nitrogen

Total nitrogen of soil was determined by Micro-Kjeldahl method where soil was digested with 30% H_2O_2conc. 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 (Bremner and Mulvaney, 1982).

3.19.5 Available Phosphorus

Available phosphorus was extracted from soil by shaking with 0.5 M $NaHCO_3$ solution of pH 8.5 (Olsen *et al*., 1954). 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.

3.19.6 Exchangeable Potassium

Exchangeable potassium was determined by 1N NH_4OAc (pH 7.0) extract of the soil by using Flame photometer (Black, 1965).

3.19.7 Available Sulphur

Available sulphur in soil was determined by extracting the soil samples with 0.15% $CaCl_2$ solution (Page *et al*., 1982) The S content in the extract was determined by the turbidmetric method as described by hunt (1980) and the intensity of turbid was measured by Spectrophotometer at 420 nm wave length.

3.20 Statistical analysis of data

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 or DMRT at 1% or 5% level of significance.

CHAPTER IV

RESULTS AND DISCUSSION

The results obtained from present study from the effect of biochar application with different irrigation on yield and yield contributing characteristics of wheat (BARI Gom-29) and analyzed data of post-harvest soils have been presented and discussed in this chapter.

4.1 Effect on growth parameters

4.1.1 Plant height

4.1.1.1 Effect of irrigation on plant height

According to the present study, plant height of wheat was significantly influenced by application of irrigation at different days after sowing (DAS) of wheat seeds (Table 3). The highest plant height (31.30 cm) was recorded in W_3 (Skipped irrigation at heading and flowering stage) treatment at 20 DAS and lowest plant height (29.20 cm) measured in W_1 (Regular irrigation) treatment followed by W_2 (29.95 cm). Accordingly, at 40 DAS, 60 DAS and 80 DAS, highest plant height was recorded in W_3 treatment whereas the lowest plant height was obtained in W_1 treatment. At after harvest, highest plant height (87.99 cm) recorded in W_3 (Skipped irrigation at heading and flowering stage) treatment and the lowest plant height (85.52 cm) in W_1 (Regular irrigation) treatment. The plant height obtained at 20 DAS, 80 DAS and after harvest was statistically similar in treatments W_1 and W_2. Hwary and Yagoub (2011) and Dang *et. al*. (2012) studied the effect of irrigation at different stage of plant growth of wheat and found plant height was significantly influenced by irrigation at different level.

Table 3: Effect of irrigation on plant height at different DAS and at harvest

Treatments	20 DAS	40 DAS	60 DAS	80 DAS	At harvest
W_1	29.2 b	57.13 ab	80.68 b	83.6 b	85.52 b
W_2	29.95 b	55.52 b	79.41 ab	83.4 b	85.78 b
W_3	31.3 a	58.56 a	81.66 a	85.43 a	87.99 a
CV(%)	5.48	4.58	4.02	2.52	2.87
Level of significance	**	*	*	*	*

**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

4.1.1.2 Effect of biochar on plant height

Addition of different level of biochar showed significant variation on wheat plant height (Table 4). It indicated that the highest plant height (33.08 cm) was recorded in B_3 (4 t/ha) treatment followed by B_4 (6 t/ha) treatment (31.89 cm) and the lowest plant height in B_1 (0 t/ha) treatment (28.17 cm) at 20 DAS. Results obtained in treatment B_3 and B_4 at 40 DAS, 60 DAS and 80 DAS were statistically similar. It was also observed that treatments B_1, B_2 and B_5 showed similar results regarding plant height at 20 DAS, 40 DAS, 80 DAS. At harvest, maximum plant height was obtained in treatment B_3 (90.01cm). Gebremedhin *et al*. (2015), Zee *et al*. (2017), Iqbal (2017), Alburquerque *et al*. (2013), Li and Shangguan (2018) investigated on effect of biochar and found that plant height of wheat was increased with different level of biochar application.

Table 4: Effect of biochar on plant height at different DAS and at harvest

Treatments	20 DAS	40 DAS	60 DAS	80 DAS	At harvest
B_1	28.17 b	54.86 b	77.39 b	82.21 b	84.67 b
B_2	28.61 b	54.00 b	77.92 b	82.93 b	84.74 b
B_3	33.08 a	60.71 a	85.04 a	87.11 a	90.01 a
B_4	31.89 a	60.48 a	84.99 a	87.08 a	89.42 a
B_5	29.01 b	55.28 b	77.56 b	81.39 b	83.32 b
CV(%)	5.48	4.58	4.02	2.87	2.52
Level of significance	**	*	*	*	*

**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}

4.1.1.3 Combined effect of irrigation and biochar on plant height

Application of different dose of biochar with irrigation at different days after sowing showed significant variation in plant height of wheat shown in Table 5. The highest plant height (34.84 cm) was obtained in W_3B_3 (Skipped irrigation at heading and flowering stage + 4 t/ha biochar) treatment combination and the lowest plant height (27 cm) was in W_1B_1 (Regular irrigation + no addition of biochar) treatment combination at 20 DAS. Plant height recorded 33.82 cm in W_3B_4 treatment combination, 33.02 cm in W_2B_4 treatment combination, 31.40 cm in W_1B_4 treatment combination respectively at 20 DAS was statistically similar with all treatment combinations at 40 DAS, 60 DAS and 80 DAS.

After harvest, the highest plant height (93.12 cm) was obtained in W_3B_3 treatment combination followed by W_3B_4 treatment combination (91.86 cm) and the lowest plant height (83.35cm) in W_1B_1 treatment combination. Svoboda *et al.* (2017), Bakry *et al.* (2015) studied the combined effect of biochar and irrigation stress on plant height of wheat and it revealed that plant height was increased with application of biochar and irrigation stress.

Table 5: Combined effect of irrigation and biochar on plant height different DAS and at harvest

Treatments	20DAS	40DAS	60DAS	80DAS	At harvest
W_1B_1	27.00 g	55.86 bcde	78.72 cdef	82.73 bcde	83.35 ef
W_1B_2	28.65 defg	55.26 bcde	77.38 def	81.88 cde	84.52 ef
W_1B_3	30.93 cde	52.13 e	74.85 f	81.16 de	88.51bc
W_1B_4	31.40 bcd	58.93 bc	82.08 bcd	84.92 bcd	88.47 bc
W_1B_5	28.04 fg	56.13 bcde	81.17 cde	82.06 cde	83.92 ef
W_2B_1	28.38 efg	54.13 de	75.77 ef	86.43 ab	84.27 def
W_2B_2	28.46 efg	59.46 b	79.3 cdef	82.73 bcde	84.32 def
W_2B_3	30.92 cde	58.13 bcd	83.84 bc	85.42 bc	87.91 cd
W_2B_4	33.02 abc	58.40 bcd	83.3 bc	86.24 ab	88.43 bc
W_2B_5	29.00 defg	54.80 cde	84.04 bc	81.46 cde	82.7 f
W_3B_1	29.14 defg	54.60 cde	77.68 def	82.76 bcde	85.28 cdef
W_3B_2	28.72 defg	54.60 cde	77.09 def	84.18 bcde	86.36 cde
W_3B_3	34.84 a	64.8 a	89.76 a	90.09 a	93.12 a
W_3B_4	33.82 ab	63.86 a	87.09 ab	89.49 a	91.86 ab
W_3B_5	30.00 def	54.93 cde	76.68 def	80.66 e	84.46 def
CV(%)	5.48	4.58	4.02	2.87	2.52
Level of significance	**	*	*	*	*

**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

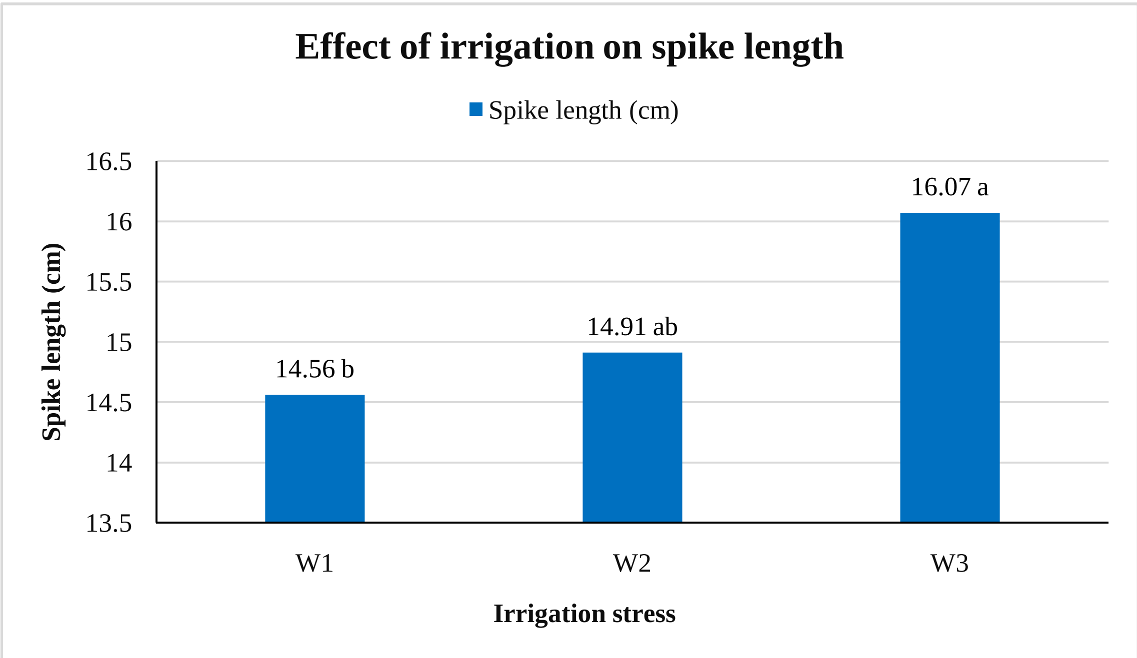
B_1= No addition of biochar (0 t ha^{-1}), B_2= 2 t ha^{-1}, B_3= 4 t ha^{-1}, B_4= 6 t ha^{-1}, B_5= 8 t ha^{-1}

4.1.2 Effect on spike and grain after harvest

4.1.2.1 Spike length

4.1.2.1.1 Effect of irrigation on spike length of wheat

Significant variation was observed on spike length of wheat when different water stress was applied (Appendix 3 and figure 6). Highest spike length (16.07 cm) was recorded in W_3 treated plot (where skipped irrigation at heading and flowering stage). On the other hand lowest spike length (14.56 cm) was recorded in W_1 treated plot where irrigation is done on the depending of shortage of water. Similar research was done by Hwary and Yagoub (2011), Bakry *et al.* (2015) and Dang *et al.* (2012). They concluded spike length and number of grain and their weight increased significantly upon irrigation.

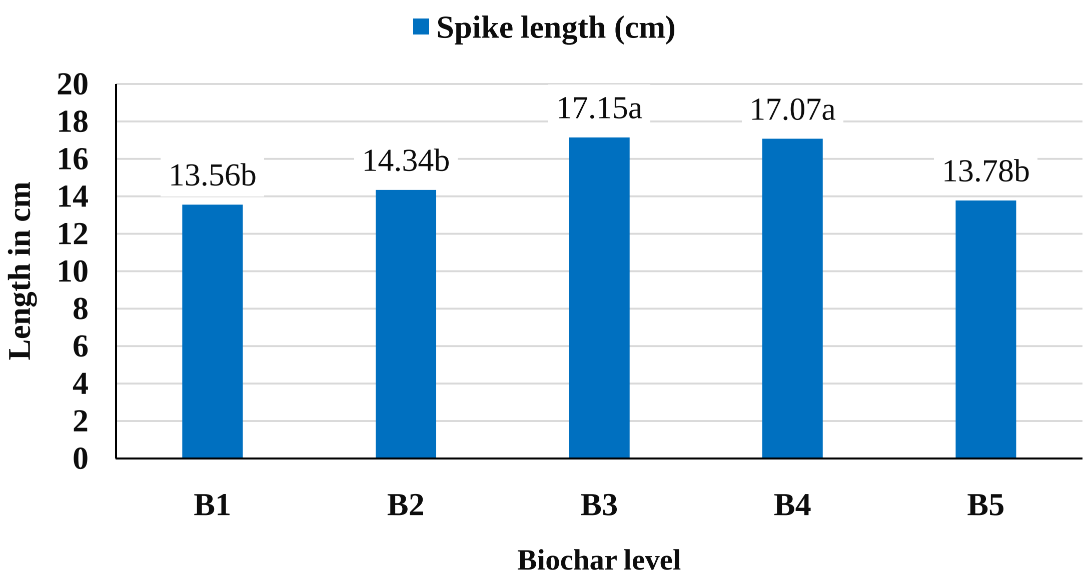


W_1=Regular irrigation, W_2=Irrigation skipped at booting stage, W_3= Irrigation skipped at heading and flowering stage

Figure 6: Effect of irrigation on spike length of wheat

4.1.2.1.2 Effect of biochar on spike length of wheat

Wheat plant showed significant variation in respect of spike length when biochar in different dose were applied (Appendix 4 and figure 7). Among the different biochar doses B_3 (4 t/ha) treatment showed the highest spike length (17.15 cm) which is statistically similar to B_4(6 t/ha) treatment. On the other hand, lowest spike length (13.56 cm) was observed in the treatment B_1 where no biochar was applied. Gebremedhin *et al*. (2015), Zee *et al.* (2017), Iqbal (2017), Alburquerque *et al*. (2013), Li and Shangguan (2018) investigated biochar dose on spike length and grain number and their weight and summarized that spike length, grain counts, and weight influenced significantly by biochar application.

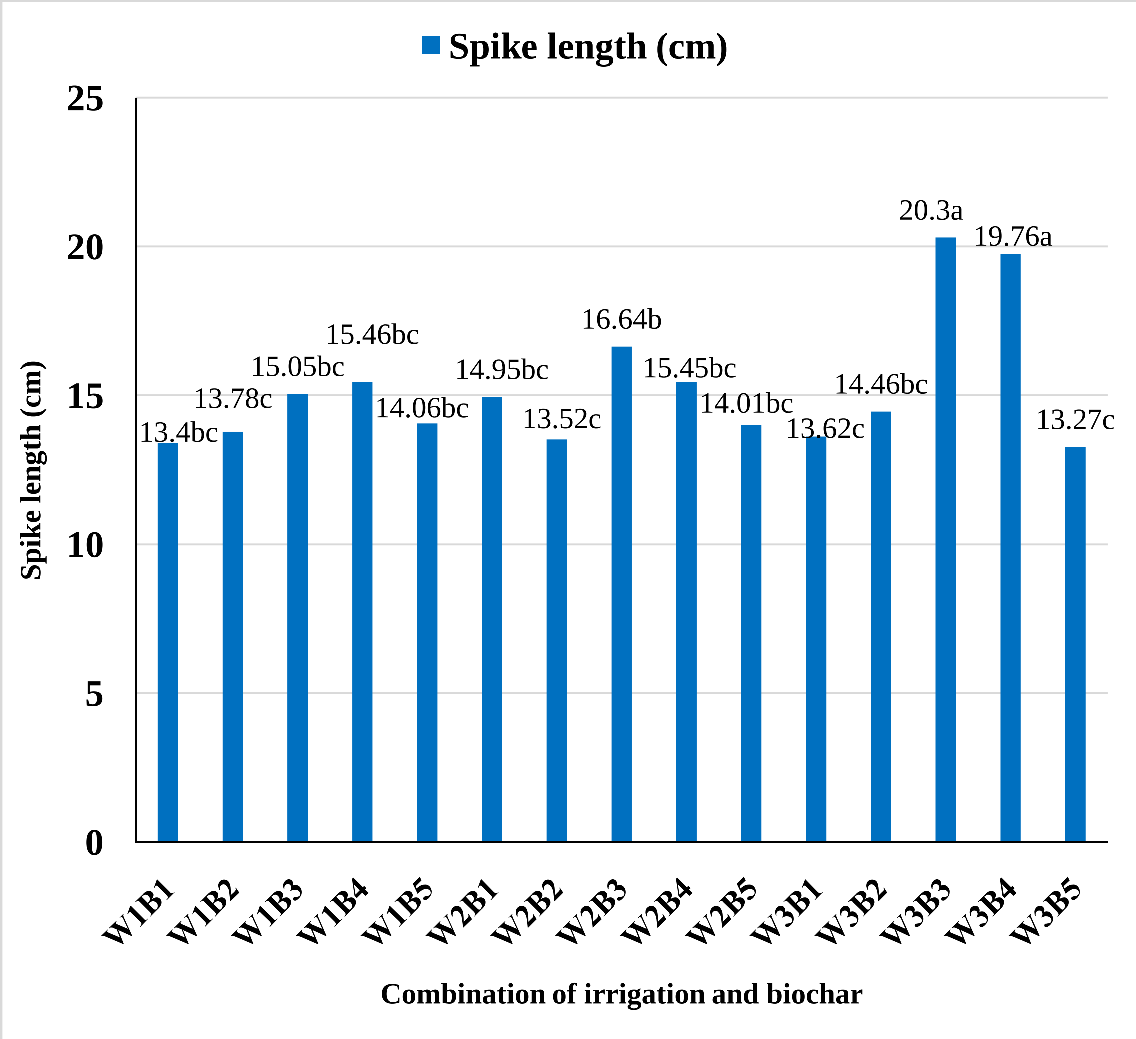


B_1= No addition of biochar (0 t ha^{-1}), B_2= 2 t ha^{-1}, B_3= 4 t ha^{-1}, B_4= 6 t ha^{-1}, B_5= 8 t ha^{-1}

Figure 7: Effect of biochar on spike length of wheat

4.1.2.1.3 Combined effect of irrigation and biochar on spike length of wheat

Combined application of different doses of biochar and irrigation had significant effect on spike length of wheat (Appendix 5 and figure 8). It was observed that the highest spike length (20.30 cm) was recorded with W_3B_3 treatment combination (Skipped irrigation at heading and flowering stage + 4 t/ha biochar) which was statistically similar to W_3B_4 (Skipped irrigation at heading and flowering stage + 6 t/ha). On the other hand, the lowest spike length (13.40 cm) was observed in the treatment combination of W_1B_1 (regular irrigation + no biochar). The result obtained from the rest of treatment showed significant variation compared to the highest and lowest spike length of wheat. Svoboda et al. (2017), Bakry *et al*. (2015) and Alburquerque *et al*. (2013) studied on irrigation stress and biochar application effect on wheat yield contributing characters and found significant results.



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

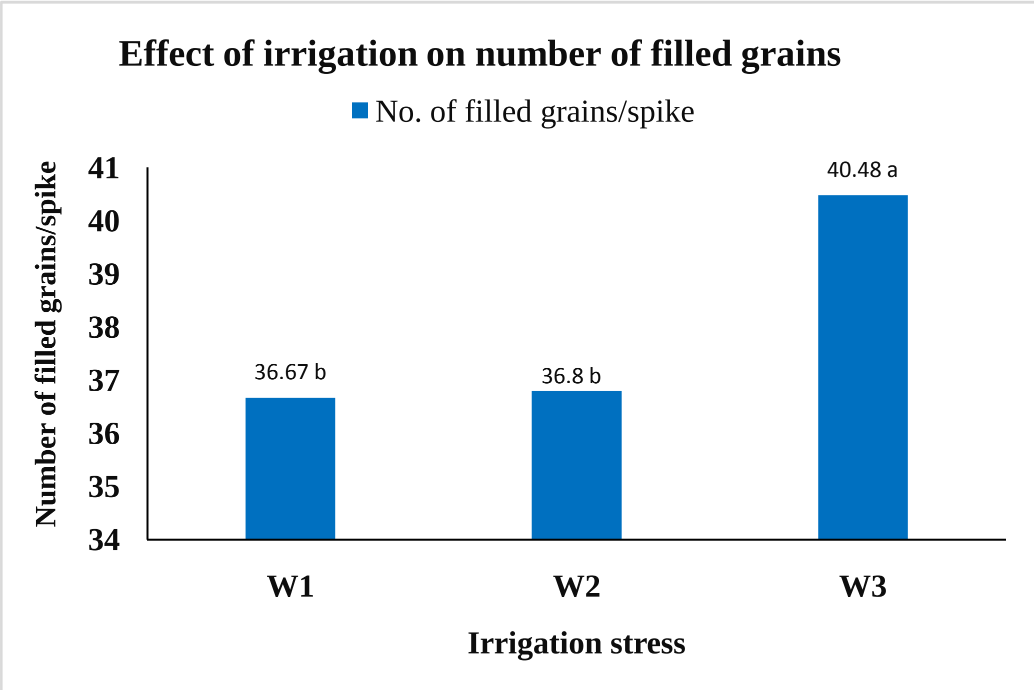
B_1= No addition of biochar (0 t ha^{-1}), B_2= 2 t ha^{-1}, B_3= 4 t ha^{-1}, B_4= 6 t ha^{-1}, B_5= 8 t ha^{-1}

Figure 8: Combined effect of irrigation and biochar on spike length of wheat

4.1.2.2 Number of filled grains per spike of wheat

4.1.2.2.1 Effect of irrigation on number of filled grains/spike of wheat

Significant variation was observed on number of filled grains/spike of wheat when different water stress was applied (Appendix 3 and figure 9). Highest number of filled grains/spike (40.48) was recorded in W_3 treated plot (where skipped irrigation at heading and booting stage) followed by W_2 (36.8) treatment. On the other hand, lowest number of filled grains/spike (36.67) was recorded in W_1 treated plot where irrigation was done on the depending of shortage of water.

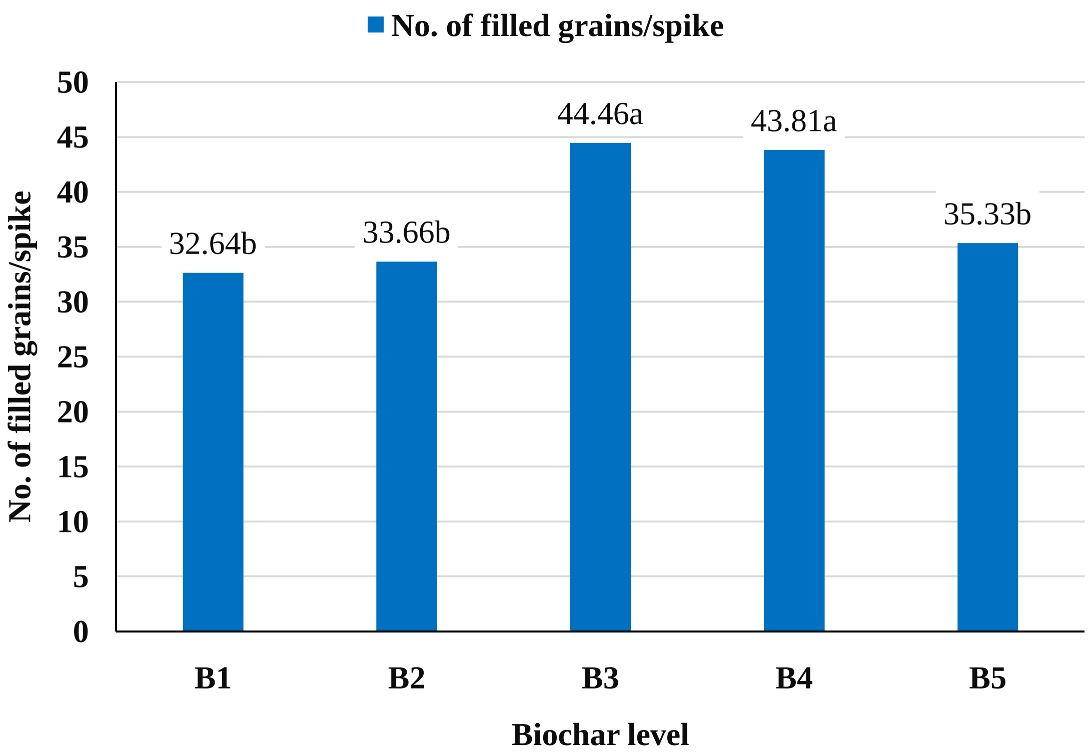


W_1=Regular irrigation, W_2=Irrigation skipped at booting stage, W_3= Irrigation skipped at heading and flowering stage

Figure 9: Effect of irrigation on number of filled grains/spikes of wheat

4.1.2.2.2 Effect of biochar on number of filled grains/spikes of wheat

Wheat plant showed significant variation in respect of number of filled grains/spike when biochar in different doses were applied (Appendix 4 and figure 10). Among the different biochar doses B_3 (4 t/ha) treatment showed the highest number of filled grains/spike (44.46) which is statistically similar to B_4 (6 t/ha) treatment showed number of filled grains/spike (43.81). On the other hand, lowest number of filled grains/spike (32.64) was observed in the treatment B_1 (0 t/ha) treatment.

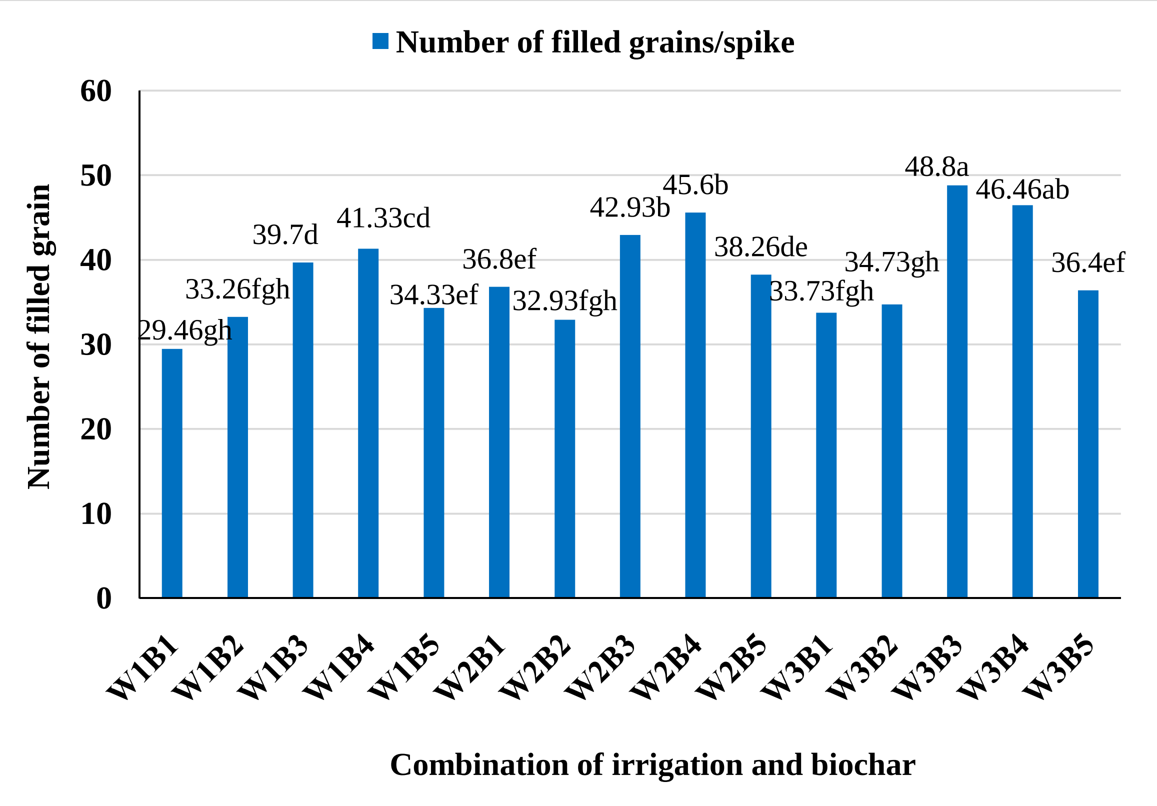


B_1= No addition of biochar (0 t ha^{-1}), B_2= 2 t ha^{-1}, B_3= 4 t ha^{-1}, B_4= 6 t ha^{-1}, B_5= 8 t ha^{-1}

Figure 10: Effect of biochar on number of filled grains/spikes of wheat

4.1.2.2.3 Combined effect of irrigation and biochar on number of filled grains/spike of wheat

Combined application of different doses of biochar and irrigation had significant effect on number of filled grains/spike of wheat (Appendix 5 and figure 11). It was observed that the highest number of filled grains/spike (48.80) 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 (46.46) treatment combination. On the other hand, the lowest number of filled grains/spike (29.46) was observed in the treatment combination of W_1B_1 (Regular irrigation + no biochar). The result obtained from the rest of treatment combination showed significant variation compared to the highest and lowest number of filled grains/spike of wheat .



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

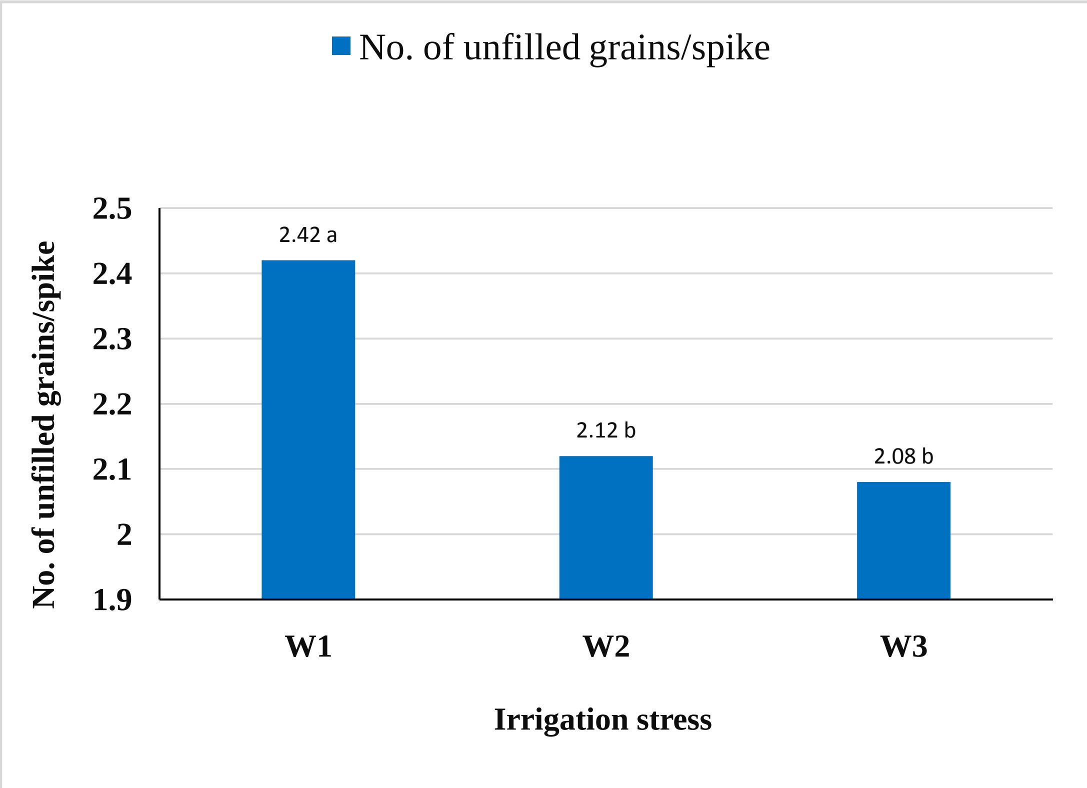
B_1= No addition of biochar (0 t ha^{-1}), B_2= 2 t ha^{-1}, B_3= 4 t ha^{-1}, B_4= 6 t ha^{-1}, B_5= 8 t ha^{-1}

Figure 11: Combined effect of irrigation and biochar on number of filled grains/spike of wheat

4.1.2.3 Number of unfilled grains per spike

4.1.2.3.1 Effect of irrigation on number of unfilled grains/spike of wheat

Significant variation was observed on number of unfilled grains/spike of wheat when different water stress was applied (Appendix 3 and figure 12). Lowest number of unfilled grains/spike (2.08) was recorded in W_3 treated plot (where skipped irrigation at heading and booting stage) followed by W_2 (2.12) treatment. On the other hand, highest number of unfilled grains/spike (2.42) was recorded in W_1 treated plot where irrigation is done on the depending of shortage of water.

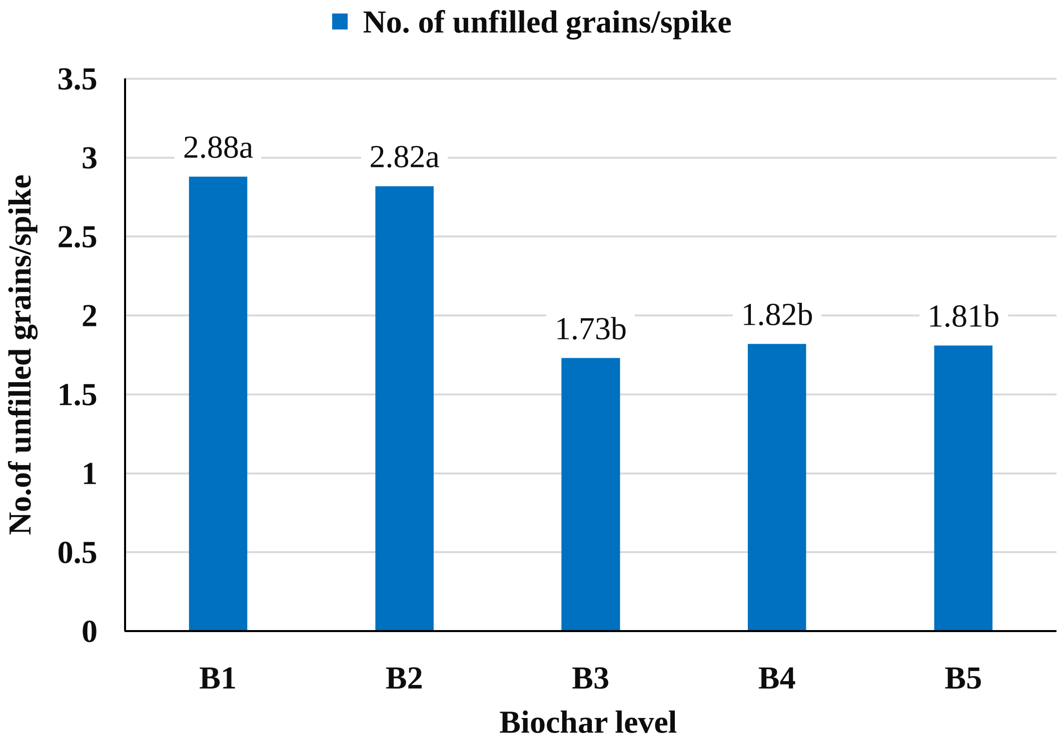


W_1=Regular irrigation, W_2= Irrigation skipped at booting stage, W_3= Irrigation skipped at heading and flowering stage

Figure 12: Effect of irrigation on number of unfilled grains/spike of wheat

4.1.2.3.2 Effect of biochar on number of unfilled grains/spike of wheat

Different doses of biochar showed significant variation in respect of number of unfilled grains/spike of wheat (Appendix 4 and figure 13). Among the different doses of biochar B_3 (4 t/ha) treatment showed the lowest number of unfilled grains/spike (1.73) which was statistically similar to treatments B_4 (6 t/ha) and B_5 (8 t/ha). On the other hand, highest number of unfilled grains/spike (2.88) was observed in the B_1 (0 t/ha) treatment.

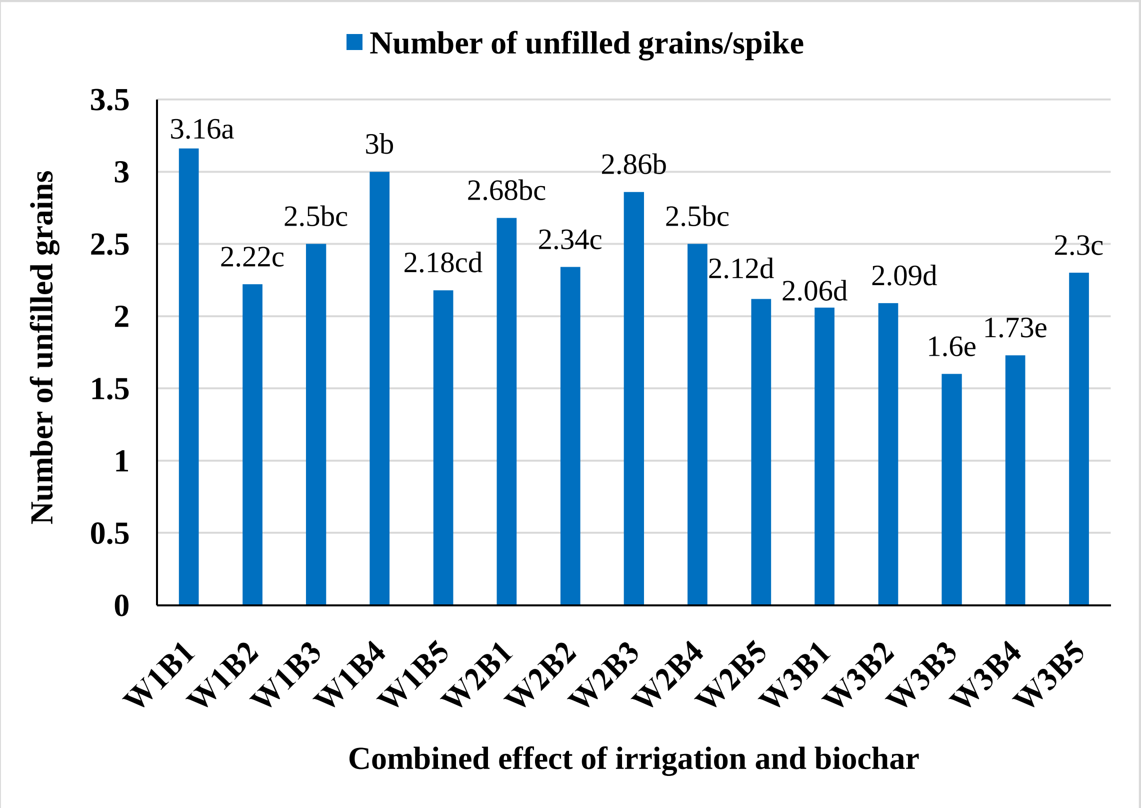


B_1= No addition of biochar (0 t ha^{-1}), B_2= 2 t ha^{-1}, B_3= 4 t ha^{-1}, B_4= 6 t ha^{-1}, B_5= 8 t ha^{-1}

Figure 13: Effect of biochar on number of unfilled grains/spike of wheat

4.1.2.3.3 Combined effect of irrigation and biochar on number of unfilled grains/spike of wheat

Combined application of different doses of biochar and irrigation had significant effect on number of unfilled grains/spike of wheat (Appendix 5 and figure 14). It was observed that the lowest number of unfilled grains/spike (1.60) was recorded with W_3B_3 (Skipped irrigation at heading and flowering stage + 4 t/ha biochar) treatment combination which is statistically similar to W_3B_4 (1.73) treatment combination. On the other hand, the highest number of unfilled grains/spike (3.16) was observed in the treatment combination of 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.



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

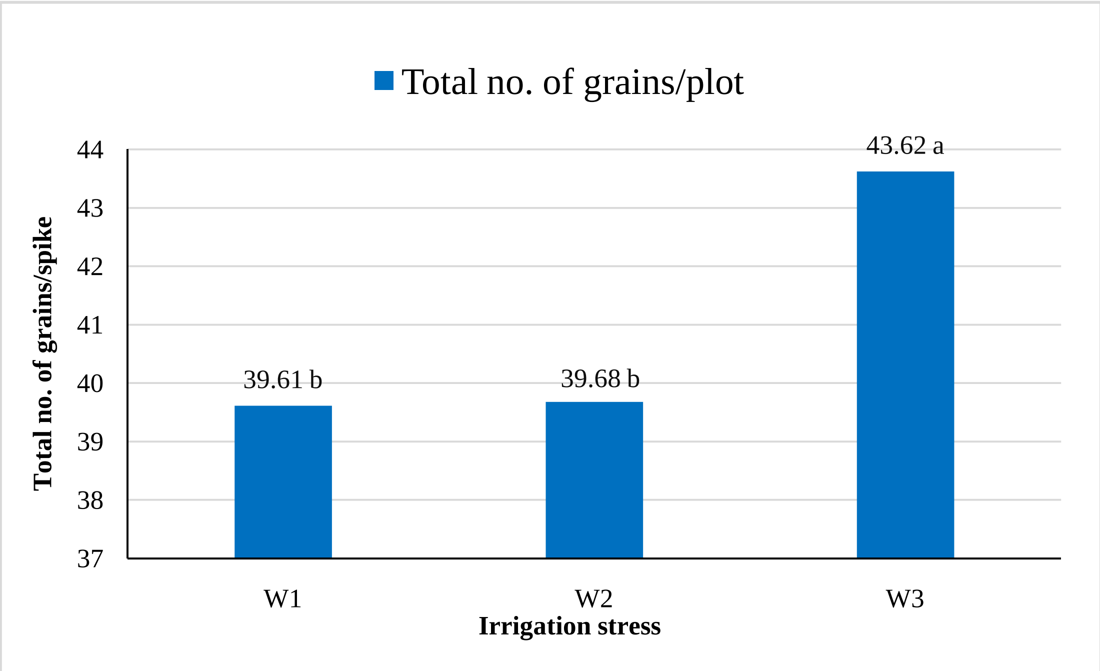
B_1= No addition of biochar (0 t ha^{-1}), B_2= 2 t ha^{-1}, B_3= 4 t ha^{-1}, B_4= 6 t ha^{-1}, B_5= 8 t ha^{-1}

Figure 14: combined effect of irrigation and biochar on no. of unfilled grains/spike of wheat

4.1.2.4 Total number of grains/spike

4.1.2.4.1 Effect of irrigation on total number of grains/spike of wheat

Significant variation on number of total grains/spike of wheat was observed due to application of water stress (Appendix 3 and figure 15). Highest number of total grains/spike (43.62) was recorded in W_3 treated plot (where skipped irrigation at heading and flowering stage). On the other hand, lowest number of total grains/spike (39.61) 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 (39.68) treated plot where on irrigation was skipped at booting stage.

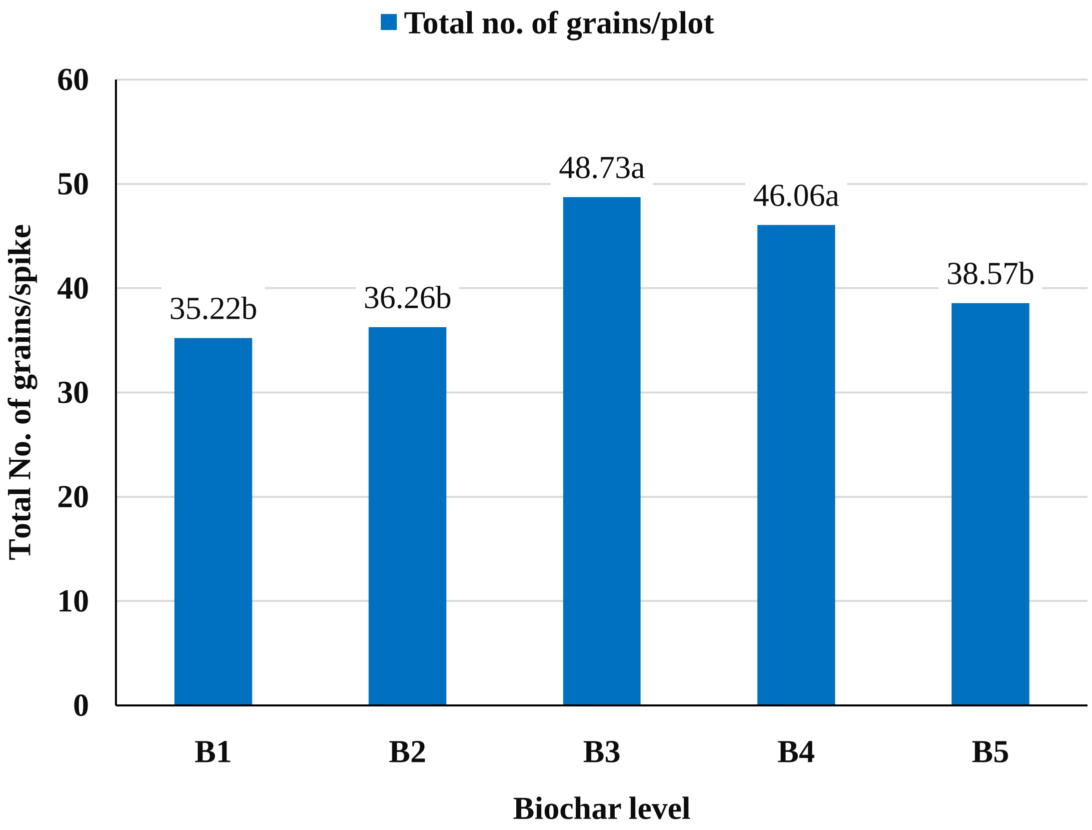


W_1=Regular irrigation, W_2= Irrigation skipped at booting stage, W_3= Irrigation skipped at heading and flowering stage

Figure 15: Effect of irrigation on total number of grains/spike of wheat

4.1.2.4.2 Effect of biochar on total number of grains/spike of wheat

Different doses of biochar showed significant variation in respect of number of total grains/spike of wheat (Appendix 4 and figure 16). Among the different biochar doses B_3 (4 t/ha) treatment showed the highest number of total grains/spike (48.73) which was statistically similar to B_4 (6 t/ha) treatment. On the other hand lowest number of total grains/spike (35.22) was observed in the treatment B_1 (0 t/ha) treatment.

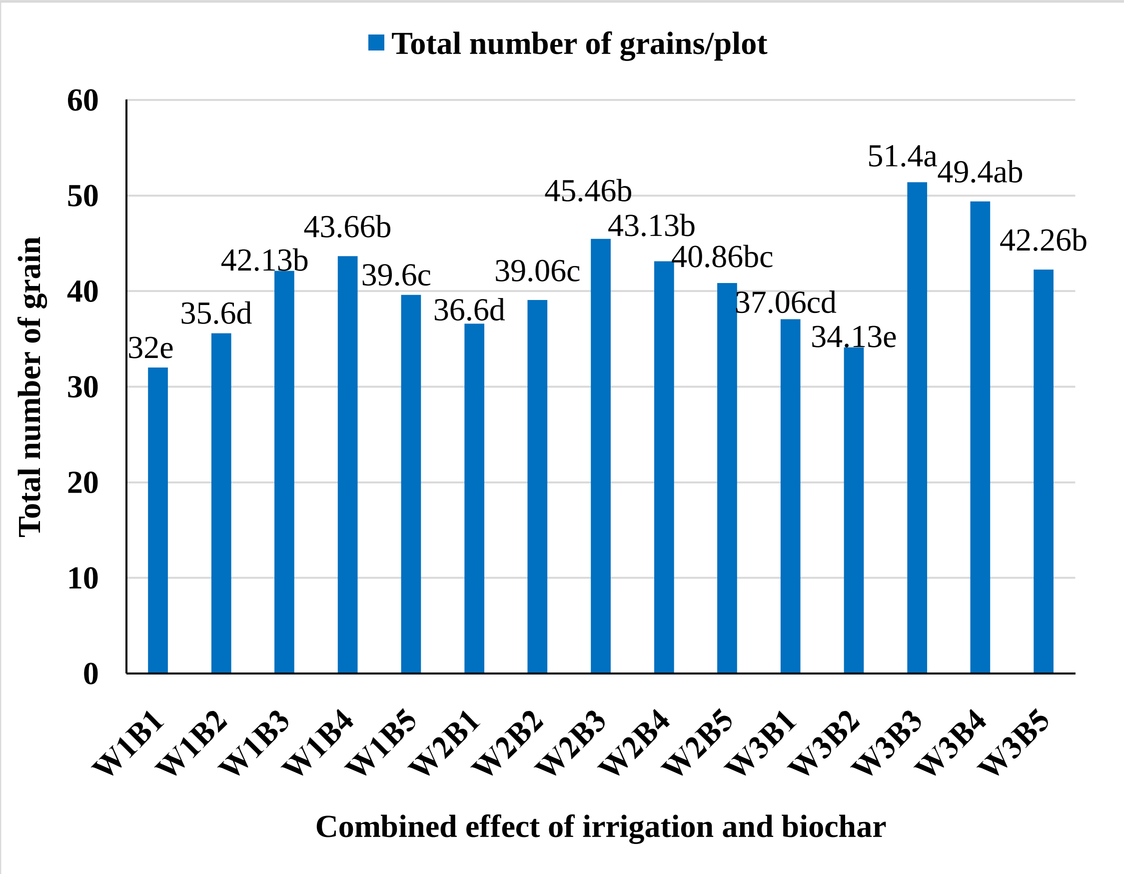


B_1= No addition of biochar (0 t ha^{-1}), B_2= 2 t ha^{-1}, B_3= 4 t ha^{-1}, B_4= 6 t ha^{-1}, B_5= 8 t ha^{-1}

Figure 16: Effect of biochar on total number of grains/spike of wheat

4.1.2.4.3 Combined effect of irrigation and biochar on total number of grains/spike of wheat

Combined application of different doses of biochar and irrigation had significant effect on number of total grains/spike of wheat (Appendix 5 and figure 17). It was observed that the highest number of total grains/spike (51.40) was recorded with W_3B_3 treatment combination (Skipped irrigation at heading and flowering stage + 4 t/ha biochar) which was statistically similar to treatment combination W_3B_4 (49.4). On the other hand, the lowest number of total grains/spike (32.00) was observed in the treatment combination of W_1B_1 (Regular irrigation + no biochar). The result obtained from the rest of treatment combination showed significant variation compared to the highest and lowest number of total grains/spike of wheat.



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}

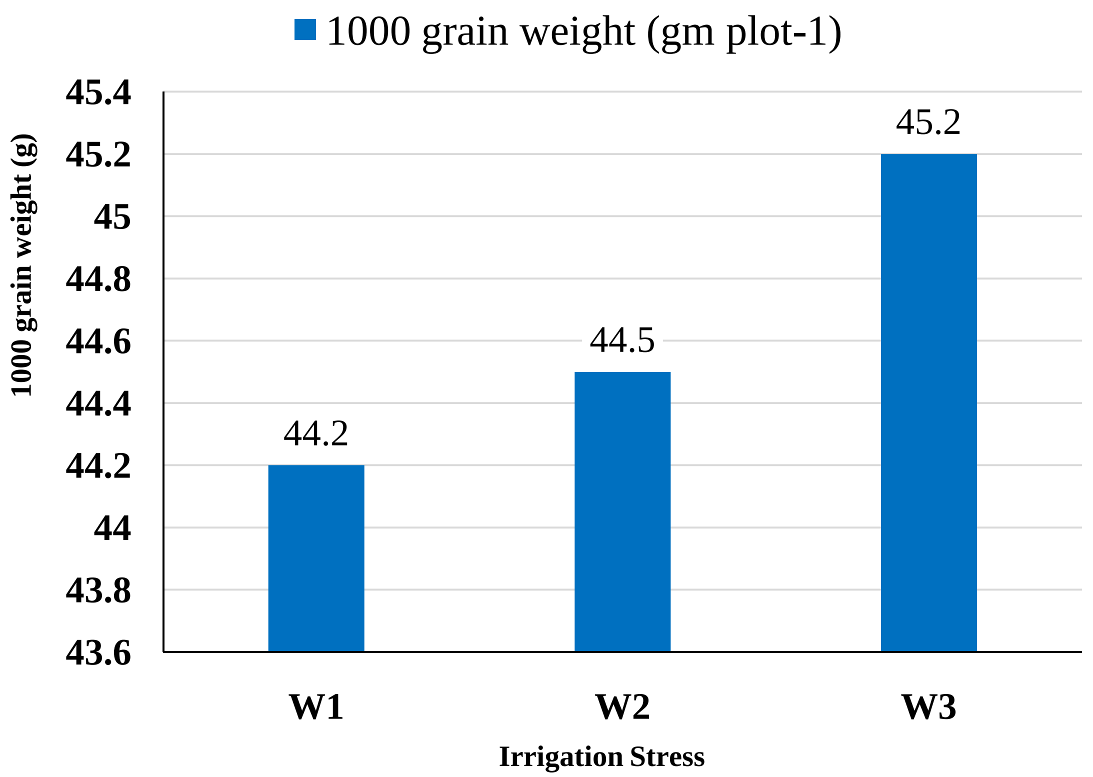
Figure 17: Combined effect of irrigation and biochar on total number of grains/spike of wheat

4.2 Effect on yield contributing parameters

4.2.1 1000-seed weight (gm/plot)

4.2.1.1 Effect of irrigation on 1000 seed weight of wheat per plot

Significant variation was observed in case of 1000-seed weight of wheat when different water stress was applied (Appendix 3 and figure 18). Highest 1000-seed weight (45.2g) was recorded in W_3 treated plot (where skipped irrigation at heading and flowering stage). On the other hand, lowest 1000-seed weight (44.2g) was recorded in W_1 treated plot where irrigation is done on the depending of shortage of water which was non significantly variable to W_2 (44.5g) treatment where skipped irrigation at booting stage.

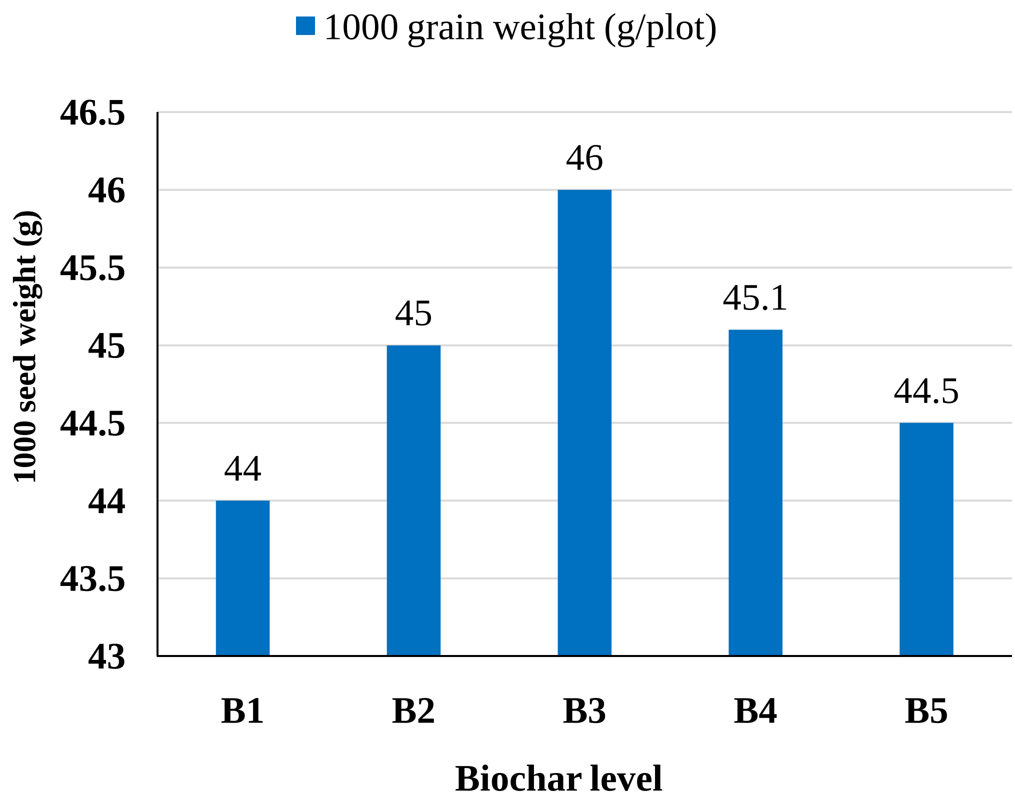


W_1= Regular irrigation, W_2= Irrigation skipped at booting stage, W_3= Irrigation skipped at heading and flowering stage

Figure 18: Effect of irrigation on 1000 seed weight

4.2.1.2 Effect of biochar on 1000 seed weight of wheat per plot

Different doses of biochar showed significant variation in respect of 1000 seed weight of wheat per plot (Appendix 4 and figure 19). Among the different doses of biochar B_3 (4 t/ha) treatment showed the highest 1000 seed weight (46.00g) which was non significantly variable to B_4, B_5, B_2 and B_1 treatments.

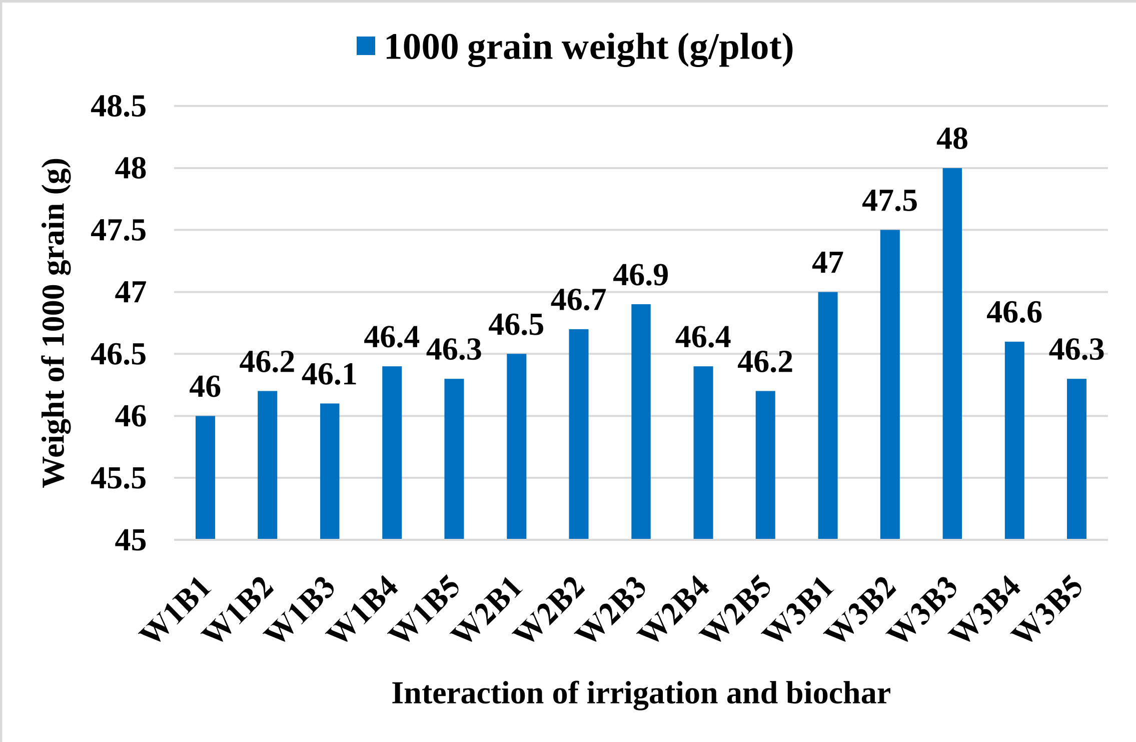


B_1= No addition of biochar (0 t ha^{-1}), B_2= 2 t ha^{-1}, B_3= 4 t ha^{-1}, B_4= 6 t ha^{-1}, B_5= 8 t ha^{-1}

Figure 19. Effect of biochar on 1000 seed weight of wheat

4.2.1.3 Combined effect of irrigation and biochar on 1000 seed weight of wheat per plot

Combined application of different doses of biochar and irrigation had significant effect on 1000 seed weight of wheat per plot (Appendix 5 and figure 20). It was observed that the maximum 1000 seed weight (48.00g) of wheat per plot was recorded in W_3B_3 (Skipped irrigation at heading and flowering stage + 4 t/ha biochar) .On the other hand lowest 1000 grain weight (46.00g) found from W_1B_1 treatment combination. The result obtained from the rest of treatment combination showed non significant variation compared to the highest and lowest 1000 seed weight of wheat per plot.



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}

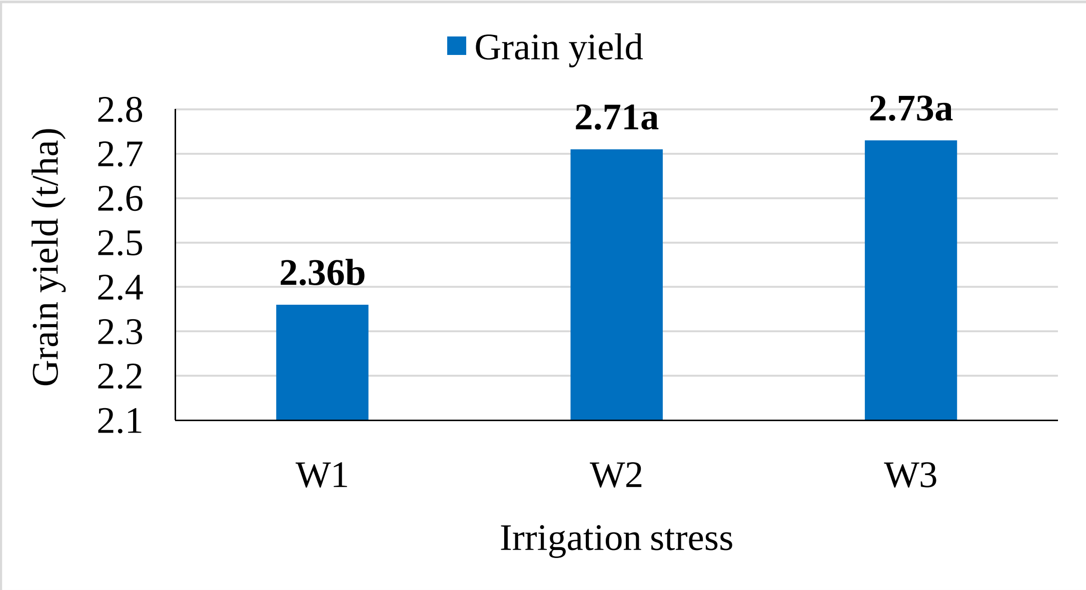
Figure 20: Combined effect of irrigation and biochar on 1000 seed weight

4.2.2 Grain yield of wheat (t/ha)

4.2.2.1 Effect of irrigation on grain yield of wheat (t/ha)

Significant variation was observed in case of grain yield of wheat when different water stress was applied (Appendix 6 and figure 21). Highest grain yield (2.73 t/ha) of wheat was recorded in W_3 treated plot (where skipped irrigation at heading and flowering stage) which was statistically similar to W_2 treatment where skipped irrigation at booting stage. On the other hand, lowest grain yield (2.36 t/ha) of wheat was recorded in W_1 treated plot where irrigation was done on the depending of shortage of water. Hwary and Yagoub

(2011) and Dang *et. al*. (2012) studied the effect of irrigation stress on wheat plant and proved that grain yield increased significantly.

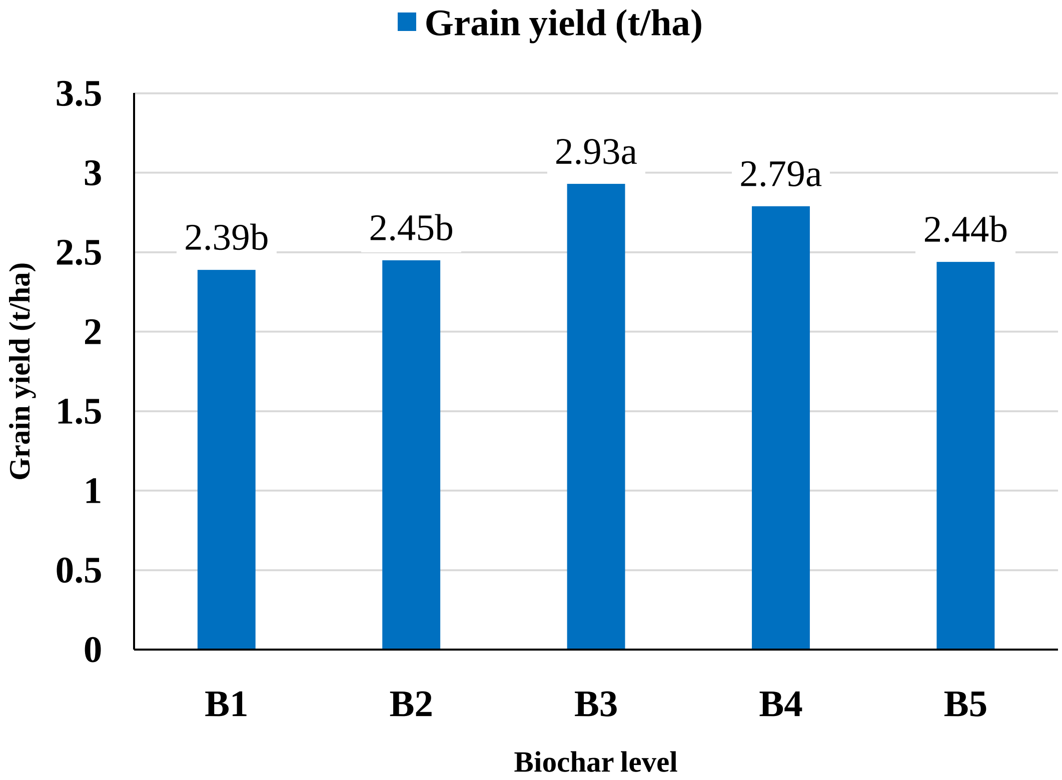


W_1=Regular irrigation, W_2=Irrigation skipped at booting stage, W_3= Irrigation skipped at heading and flowering stage

Figure 21: Effect of irrigation on grain yield of wheat

4.2.2.2 Effect of biochar on grain yield of wheat (t/ha)

Different doses of biochar showed significant variation in respect of grain yield (t/ ha) of wheat (Appendix 7 and figure 22). Among the different doses of biochar B_3 (4 t/ha) treatment showed the highest grain yield (2.93 t/ha) which was statistically similar to B_4 (6 t/ha) treatment. On the other hand, lowest grain yield (2.39 t/ha) was observed in the B_1 (0 t/ha) treatment which was statistically similar to B_5 and B_2 treatments.

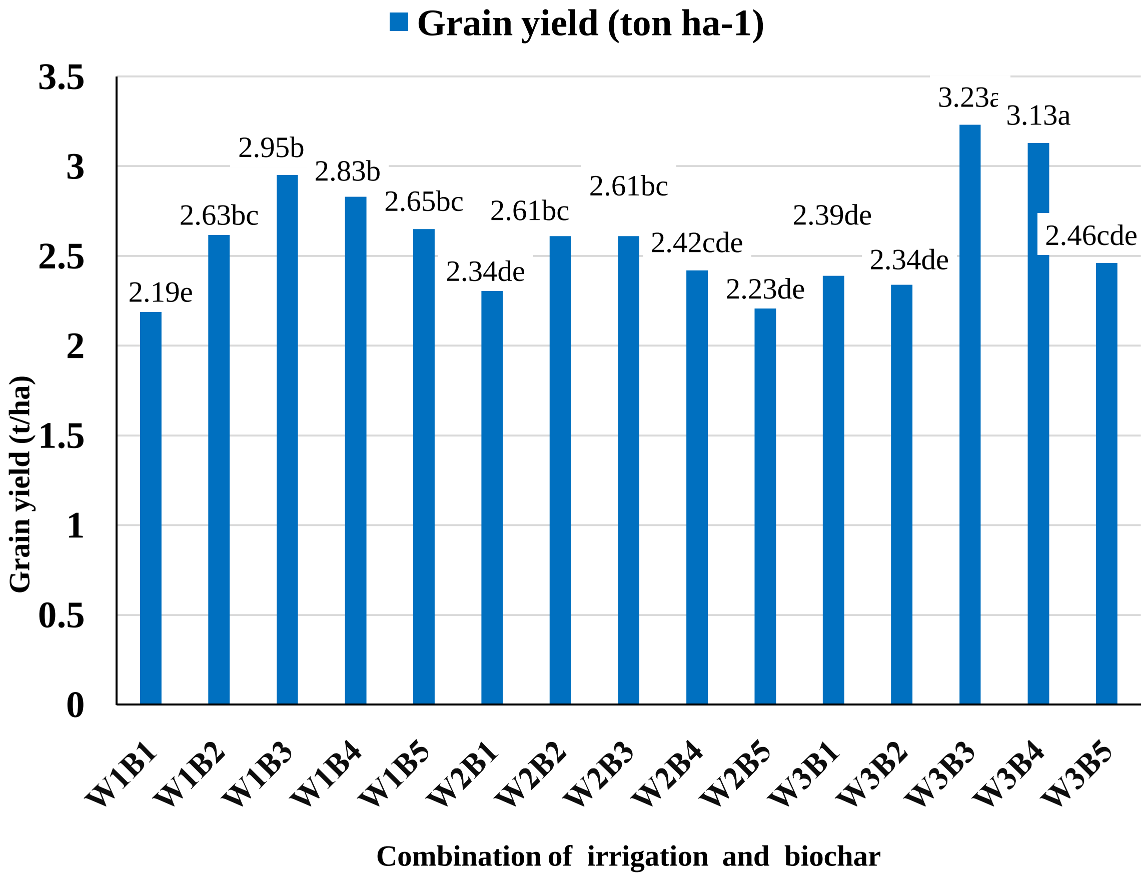


B_1= No addition of biochar (0 t ha^{-1}), B_2= 2 t ha^{-1}, B_3= 4 t ha^{-1}, B_4= 6 t ha^{-1}, B_5= 8 t ha^{-1}

Figure 22: Effect of biochar on grain yield of wheat

4.2.2.3 Combined effect of irrigation and biochar on grain yield of wheat

Combined application of different doses of biochar and irrigation had significant effect on grain yield of wheat (Appendix 8 and figure 23). It was observed that the highest grain yield (3.23 t/ha) 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 (2.19 t/ha) 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. Alburquerque *et al*. (2013), Gebremedhin *et al*. (2015) and Svoboda *et al*. (2017) worked on irrigation stress and biochar dose on wheat productivity and found significant results.



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

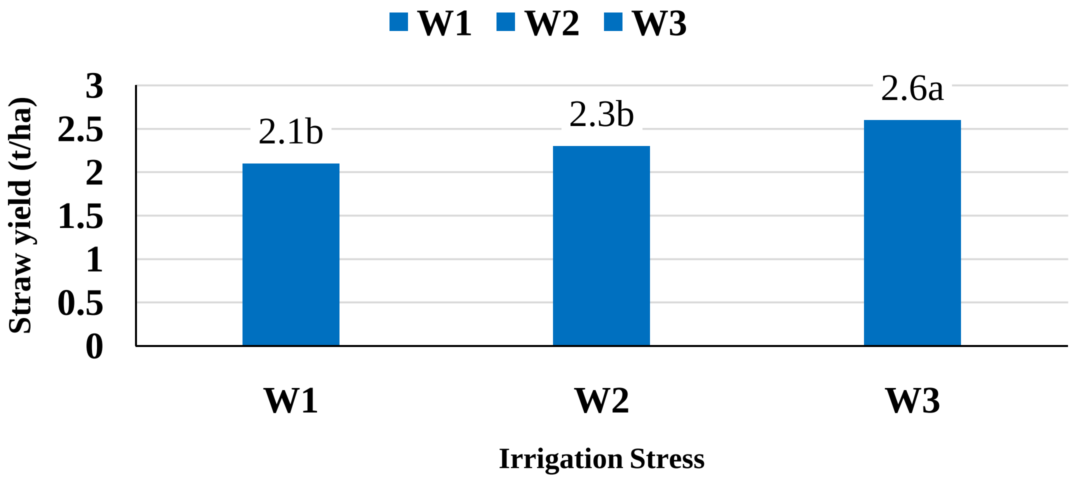
B_1= No addition of biochar (0 t ha^{-1}), B_2= 2 t ha^{-1}, B_3= 4 t ha^{-1}, B_4= 6 t ha^{-1}, B_5 = 8 t ha^{-1}

Figure 23: Combined effect of irrigation and biochar on grain yield of wheat.

4.2.3 Straw yield of wheat (t/ha)

4.2.3.1 Effect of irrigation on straw yield of wheat (t/ha)

Significant variation was observed in case of straw yield of wheat when different water stresses were applied (Appendix 6 and figure 24). Maximum straw yield (2.6 t/ha) of wheat was recorded in W_3 treated plot (where skipped irrigation at heading and flowering stage). On the other hand, lowest straw yield (2.10 t/ha) of wheat was recorded in W_1treated plot where regular irrigation depending on shortage of water was done which was statistically similar to W_2 treatment. Hwary and Yagoub (2011) and Dang *et. al*. (2012) studied the effect of water stress on wheat plant.

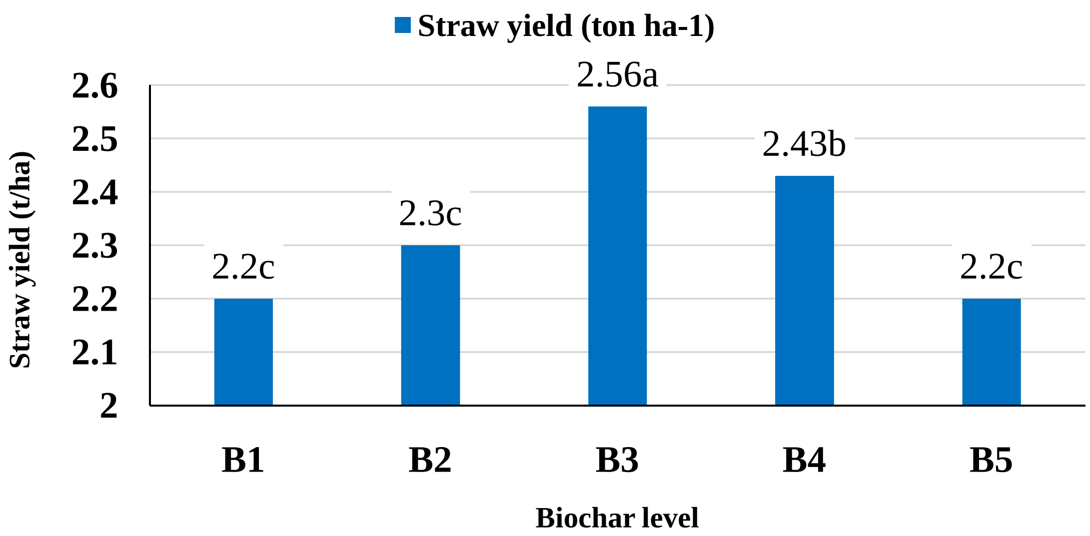


W_1=Regular irrigation, W_2= Irrigation skipped at booting stage, W_3= Irrigation skipped at heading and flowering stage

Figure 24: Effect of irrigation on straw yield

4.2.3.2 Effect of biochar on straw yield of wheat (t/ha)

Different doses of biochar showed significant variation in respect of straw yield (t/ ha) of wheat (Appendix 7and figure 25). Among the different biochar doses B_3 (4 t/ha) treatment showed the highest straw yield (2.56 t/ha). On the other hand, lowest straw yield (2.2 t/ha) was observed in B_1 (0 t/ha) treatment which is statistically identical to B_5 treatment and statistically similar to B_2 treatment.

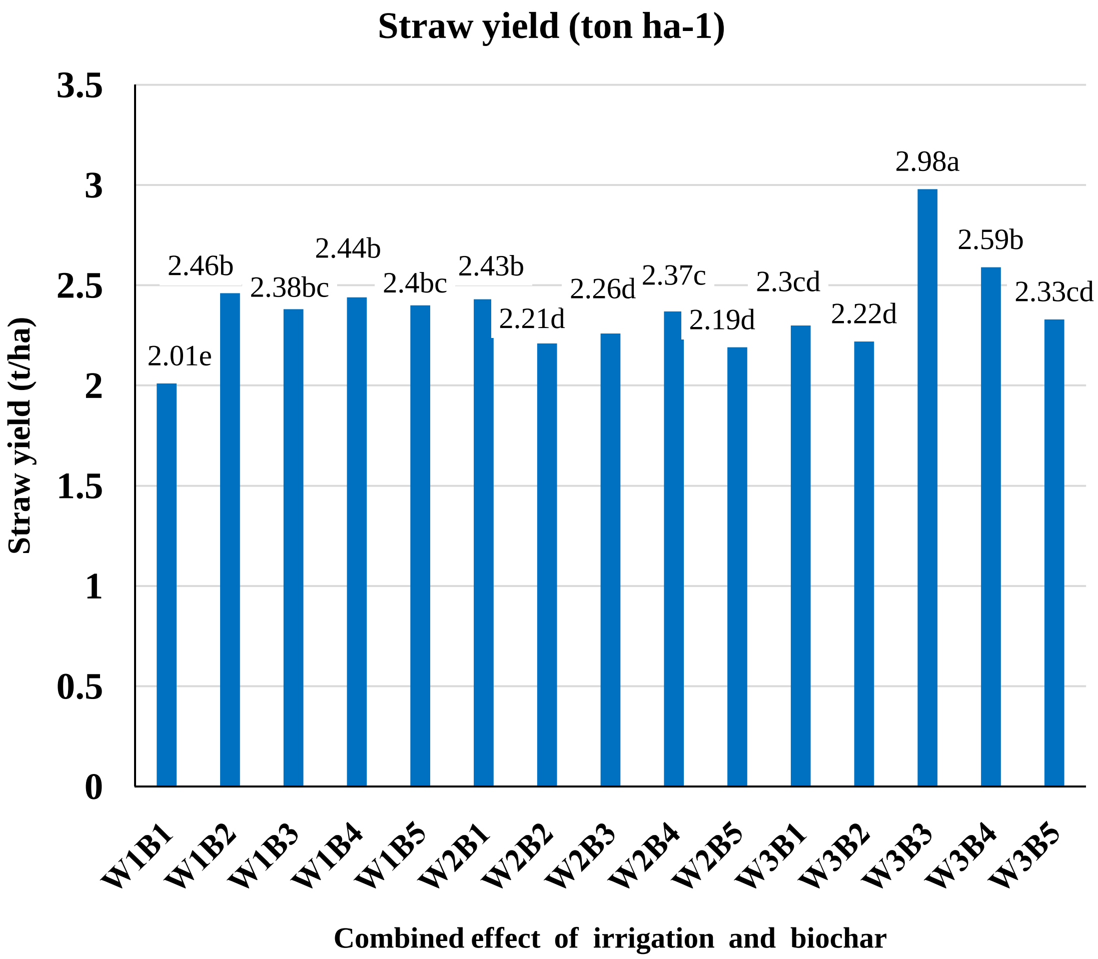


B_1= No addition of biochar (0 t ha^{-1}), B_2= 2 t ha^{-1}, B_3= 4 t ha^{-1}, B_4= 6 t ha^{-1}, B_5= 8 t ha^{-1}

Figure 25: Effect of biochar on straw yield

4.2.3.3 Combined effect of irrigation and biochar on straw yield of wheat

Combined application of different doses of biochar and irrigation had significant effect on straw yield of wheat (Appendix 8 and figure 26). It was observed that the maximum straw yield (2.98 t/ha) of wheat was recorded in treatment combination W_3B_3 (Skipped irrigation at heading and flowering stage + 4 t/ha biochar). On the other hand, the lowest straw yield (2.01 t/ha) was observed in the treatment combination of W_1B_1 (Regular irrigation + 0 t/ha biochar). The result obtained from the rest of treatment combinations showed significant variation compared to the highest and lowest straw yield of wheat. Alburquerque *et al.* (2013), Gebremedhin *et al*. (2015) and Svoboda *et al.* (2017) worked on irrigation stress and biochar dose on wheat productivity and found significant results.



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}

Figure 26: Combined effect of irrigation and biochar on straw yield

4.3 Post-harvest properties of Soil

4.3.1 Effect of irrigation on post-harvest properties of Soil

4.3.1.1 Soil pH

Effect of irrigation on post harvest soil pH had been found non significant (Table 6).

4.3.1.2 Organic carbon

Highest organic carbon (0.73%) found in W_3 treated plot where lowest organic carbon (0.70%) found in W_1 treated plot (Table 6).

4.3.1.3 Organic matter

Highest organic matter (1.26 %) found in W_3 treated plot where lowest organic matter (1.21%) found in W_1 treated plot. Organic matter found in W_2 treated plot (1.23%) showed in Table 6.

4.3.1.4 Total Nitrogen

Total nitrogen was significantly influenced by different water stresses .Maximum total nitrogen (0.068%) found in W_3 treatment and lowest total nitrogen (0.057%) found in W_1 treatment (Table 6).

4.3.1.5 Available phosphorus

The different treatments showed non significant variation in the available phosphorus showed in Table 6.

4.3.1.6 Exchangeable potassium

Significant variation was observed in case of exchangeable potassium when different water stresses were applied (Table 6). Highest exchangeable potassium (0.22 meq/100g soil) observed in W_3 treated plot and lowest exchangeable potassium (0.15 meq/100 g soils) found in W_1 treatment.

4.3.1.7 Available sulphur

Significant variation was observed in case of available sulphur when different water stresses were applied (Table 6). Highest available sulphur (23.66 ppm) observed in W_3 treated plot and lowest available sulphur (21.87 ppm) found in W_1 treatment

Table 6: Effect of 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	21.11	0.15 c	21.87 c
W_2	5.6	0.71 b	1.23 b	0.065 b	21.17	0.19 b	22.75 b
W_3	5.7	0.73 a	1.26 a	0.068 a	21.16	0.22 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

4.3.2 Effect of biochar on post-harvest properties of Soil

4.3.2.1 Soil pH

Effect of biochar on post harvest soil pH had been found non significant (Table 7).

4.3.2.2 Organic carbon

Highest organic carbon (0.74%) found in B3 treatment which was statistically identical to $B_4$and B_5 treatments. On the other hand, organic carbon (0.73%) found in B_2 treatment statistically similar to B_1 treatment showed in Table 7.

4.3.2.3 Organic matter

Highest organic matter (1.28 %) found in B_3 treatment which was statistically identical to B_4 and B_5 treatments. On the other hand organic matter (1.26%) found in B_2 treatment statistically similar to B_1 treatment showed in Table 7.

4.3.2.4 Total Nitrogen

Total nitrogen was significantly influenced by different doses of biochar. Maximum total nitrogen (0.071%) found in B_3 treatment and lowest total nitrogen (0.065%) found in B_1 treatment (Table 7).

4.3.2.5 Available phosphorus

The different treatments showed non significant variation in the available phosphorus showed in Table 7.

4.3.2.6 Exchangeable potassium

Significant variation was observed in case of exchangeable potassium when different doses of biochar were applied (Table 7). Highest exchangeable potassium (0.206 meq/100g soil) observed in B_3 treatment which was statistically similar to B_5 treatment and lowest exchangeable potassium (0.176 meq/100 g soils) found in B_1 treatment.

4.3.2.7 Available sulphur

Significant variation was observed in case of available sulphur when different doses of biochar were applied (Table 7). Highest available sulphur (23.067 ppm) observed in B_3 treatment and lowest available sulphur (22.623 ppm) found in B_1 treatment

Table 7: 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	0.065 d	20.89	0.176 c	22.623c
B_2	5.6	0.73b	1.26 b	0.066 c	21.06	0.185 bc	22.683bc
B_3	5.7	0.74 a	1.28 a	0.071 a	21.22	0.206 a	23.067 a
B_4	5.7	0.74 a	1.28 a	0.069 b	21.08	0.188 b	22.392 b
B_5	5.7	0.74a	1.28 a	0.070ab	20.66	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

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}

4.3.3 Combined effect of irrigation and biochar on post harvest properties of soil

4.3.3.1 Soil pH

Effect of treatment combination irrigation and biochar on post harvest soil pH had been found non significant (Table 8).

4.3.3.2 Organic carbon

There was significant influence of combination of irrigation and biochar on soil organic carbon. Highest organic carbon (0.75%) 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 (0.73%) found in W_3B_1, W_3B_2, W_3B_5treatment combinations. While the lowest organic carbon (0.69%) observed in W_1B_2 treatment combination. Statistically similar results found from treatment combinations W_1B_1, W_1B_3, W_1B_4, W_1B_5 showed in Table 8.

4.3.3.3 Organic matter

A significant variation in the soil organic matter found from combination of irrigation and biochar showed in Table 14. Highest organic matter (1.29%) found in W_3B_3 treatment combination which was statistically similar to W_3B_4 treatment combination on the other hand, statistically similar organic matter (1.27%) found in W_3B_1, W_3B_2, W_3B_5 treatment combinations. While the lowest organic matter (1.19%) observed in W_1B_2 treatment combination. Statistically similar results found from W_1B_1, W_1B_3, W_1B_4, W_1B_5 treatment combinations showed in Table 8.

4.3.3.4 Total Nitrogen

Total nitrogen was significantly influenced by different treatment combinations of irrigation and biochar. Maximum total nitrogen (0.086%) found in W_3B_3 treatment combination which was statistically similar with W_3B_5, W_3B_3 treatment combinations and lowest total nitrogen (0.0.054%) found in W_1B_1 treatment combination which was statistically similar to W_1B_2 treatment combination (Table 8).

4.3.3.5 Available phosphorus

The different treatment combinations of irrigation and biochar showed significant variation in the available phosphorus showed in Table 8. Maximum available phosphorus (22.533 ppm) found in W_3B_3 treatment combination and lowest available phosphorus (20.120 ppm) found in W_3B_1 treatment combination.

4.3.3.6 Exchangeable potassium

Exchangeable potassium was significantly influenced by different treatment combinations of irrigation and biochar. Maximum exchangeable potassium (0.233meq/100g soil) found in W_3B_3 treatment combination which was statistically identical to W_3B_4 treatment combination and lowest exchangeable potassium (0.133 meq/100 g soils) found in W_1B_3 treatment combination which was statistically similar to W_1B_2 treatment combination (Table 8).

4.3.3.7 Available sulphur

The different treatment combinations of irrigation and biochar showed significant variation in the showed in Table 8. Maximum available sulphur (24.390 ppm) found in W_3B_3 treatment combination which was statistically similar to W_3B_4 and W_2B_5 treatment combinations and lowest available sulphur (21.677 ppm) found in W_1B_3 treatment combination.

Table 8: Combined effect of 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 ef	1.21 de	0.054 j	20.383 b	0.146 d	21.673 d
W_1B_2	5.6	0.69 f	1.19 e	0.055 j	20.797b	0.140 de	22.020 cd
W_1B_3	5.6	0.70 ef	1.21 e	0.057ij	21.247ab	0.133 e	21.677 d
W_1B_4	5.6	0.70 ef	1.21 e	0.061 hi	20.400 b	0.173 cd	22.020 cd
W_1B_5	5.6	0.70 ef	1.21 e	0.059 ij	21.670ab	0.170 cd	21.967cd
W_2B_1	5.6	0.70 ef	1.21 e	0.060 i	20.327bc	0.166 cd	21.987 cd
W_2B_2	5.6	0.71cde	1.23 d	0.063ghi	21.070ab	0.203 c	23.067abcd
W_2B_3	5.6	0.71cde	1.23 d	0.065gh	21.697ab	0.200 c	22.333 bcd
W_2B_4	5.7	0.71cde	1.23 d	0.070 e	20.537 b	0.203 c	22.333 bcd
W_2B_5	5.7	0.74 ab	1.28 ab	0.068 ef	20.797ab	0.223 ab	24.033ab
W_3B_1	5.7	0.73 bc	1.26 cd	0.080cd	20.120c	0.216 b	23.517abc
W_3B_2	5.7	0.73 bc	1.27bc	0.082bc	21.873ab	0.213 b	23.167abcd
W_3B_3	5.7	0.75a	1.29 a	0.086a	22.533 a	0.233 a	24.390 a
W_3B_4	5.7	0.74 ab	1.28 ab	0.083ab	21.980ab	0.233 a	24.040ab
W_3B_5	5.7	0.73 bc	1.27bc	0.085ab	21.860ab	0.226 ab	23.200abcd
CV (%)	0.06	2.59	2.09	1.53	6.58	11.86	4.75
Level of significance	NS	*	*	**	**	*	*

*indicates 5% level of significance, ** 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

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}

CHAPTER V

SUMMARY AND CONCLUSION

An experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka-1207 (Tejgaon series under AEZ No.28) to evaluate the effect of biochar on the growth and yield of wheat (BARI Gom-29) under reduced irrigated condition during 15 November 2017 to 15 March 2018. The soil was silty clay in texture having pH 5.6 and organic carbon content of 0.70%. The experiment was laid out in two factor split plot design with three replications. There were five levels of biochar viz., 0 t ha^{-1}, 2 t ha^{-1}, 4 t ha^{-1}, 6 t ha^{-1}, 8 t ha^{-1} and three levels of water stress such as regular irrigation, irrigation skipped at booting stage and irrigation skipped at heading and flowering stage. There were 45-unit plots and the size of the plot was 2m × 1.5m i.e. $3m^2$. There were 15 treatments combinations. Wheat seed of cv. BARI Gom-29 was sown as test crop. Data on different plant growth, yield and yield contributing parameters were recorded and analyzed statistically. The tallest plant(87.99 cm), highest spike length (16.07 cm), maximum filled grains (40.48), maximum number total grains (43.62), highest 1000 seed weight (45.20 g/plot), highest grain yield (2.73 t ha^{-1}) and highest straw yield (2.60 t ha^{-1}) were found upon irrigation stress in W_3 treatment (where irrigation skipped at heading and flowering stage).Correspondingly lowest values of these parameters were found in W_1 treatment where regular irrigation was done on the depending of shortage of water.

Application of different levels of biochar had significant effect on different parameters of wheat. The highest plant height (90.01cm), longest spike length (17.15 cm), maximum filled grain (44.46), maximum total number of grain (48.78), highest 1000 seed weight (46.0 g/plot) and highest grain yield (2.93 t ha^{-1}) and highest straw yield (2.56 t ha^{-1}) were recorded when biochar was added @ 4 t ha^{-1}in wheat field. On the other hand, the lowest value of these parameters were obtained in B_1 (0 t ha^{-1}) treatment.

Yield and yield contributing characters of wheat plant showed significant results when irrigation stress and biochar application interacted combinedly. The highest plant height (93.12cm), highest spike length (20.30 cm), maximum number of filled grain (48.80), highest number of total grain (51.40), highest 1000 seed weight (48.00 g/plot), highest grain yield (3.23 t ha^{-1}) and highest straw yield (2.98 t ha^{-1}) were obtained in W_3B_3

treatments combination (Irrigation skipped at heading and flowering stage + 4 t/ha biochar).The lowest values were recorded in treatments combination W_1B_1 (Regular irrigation + no biochar addition).

Chemical analysis (soil pH, organic carbon, organic matter, N, P, K, S) of post harvest soil surface (0-15 cm) showed significant variation under different treatments. Soil pH (5.7) the highest organic carbon (0.73%), highest organic matter (1.26%), highest total nitrogen (0.068%), highest available phosphorus (21.16 ppm), highest exchangeable potassium (0.22 meq/100 g soils) and highest available sulphur (23.66 ppm) were found in W_3 treatment (where irrigation skipped at heading and flowering stage). Correspondingly lowest values of these soil properties were found in W_1 treatment where regular irrigation was done on the depending of shortage of water.

Application of different levels of biochar had significant effect on different post harvest soil properties. Soil pH (5.7) the highest organic carbon (0.74%), highest organic matter (1.28%), maximum total nitrogen (0.071%), maximum available phosphorus (21.22 ppm), highest exchangeable potassium (0.206 meq/100 g soils) and highest available sulphur (23.067 ppm) were recorded when biochar was added @ 4 t ha^{-1} in wheat field. On the other hand, the lowest value of these properties were obtained in B_1 (0 t ha^{-1}) treatment.

Post harvest properties of soil showed significant results when irrigation stress and biochar application interacted combinedly. Soil pH (5.7), highest organic carbon (0.75%), highest organic matter (1.29%), maximum total nitrogen (0.086%), highest available phosphorus (22.533 ppm), highest exchangeable potassium (0.233meq/100g soil) and maximum available sulphur (24.390 ppm) were found in W_3B_3 treatment combination (Irrigation skipped at heading and flowering stage + 4 t/ha biochar). The lowest values were recorded in W_1B_1 treatments combination (Regular irrigation + no biochar addition).

However, 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 significantly. 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. However, to reach a specific conclusion and recommendation, the study needs further investigation in other Agro Ecological Zones (AEZs) of Bangladesh for wide recommendation which will be useful.

CHAPTER VI

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APPENDICES

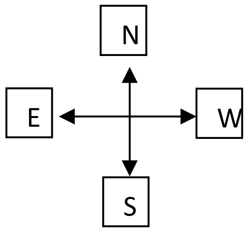
Appendix 1. Monthly records of air temperature, relative humidity, rainfall and sunshine hours during the period from November 2017 to March 2018

Month	Year	Monthly average air temperature			Average relative humidity (%)	Total rainfall (mm)	Total sunshine (hours)
		Maximum	Minimum	Mean			
November	2017	28.50	16.50	22.5	70.80	116	1205.00
December	2017	27.10	15.00	21.05	68.02	105	1100.00
January	2018	24.20	13.57	18.89	72.90	100	1505.00
February	2018	25.00	14.05	19.53	64.78	Trace	1822.00
March	2018	31.30	20.40	25.85	60.13	Trace	1890.00

Source: Bangladesh Meteorological Department (Climate division), Dhaka-1212.

Appendix 2

Layout of the Experimental Plot

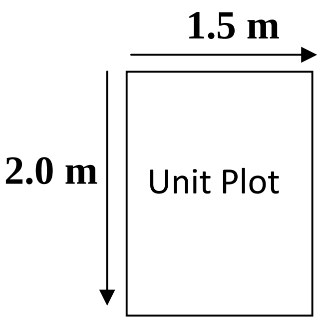


18.05 m (width)

W_1R_1	W_2R_1	W_3R_1	W_3R_2	W_2R_2	W_1R_2	W_1R_3	W_2R_3	W_3R_3
B_4	B_2	B_3	B_1	B_5	B_2	B_3	B_4	B_1
B_2	B_1	B_4	B_2	B_4	B_5	B_1	B_5	B_3
B_1	B_3	B_5	B_3	B_2	B_1	B_2	B_3	B_4
B_3	B_5	B_1	B_4	B_1	B_3	B_4	B_2	B_5
B_5	B_4	B_2	B_5	B_3	B_4	B_5	B_1	B_2

12.50 m Length

Layout



Plot to plot distance= 0.5m

Distance between two adjacent replication= 0.5m

Appendix 3

Effect of irrigation on spike and grain after harvest

Treatments	Spike length (cm)	Number of filled grains/spike	Number of unfilled grains/spike	Number of total grains/spike	1000 seed weight (gm plot^{-1})
W_1	14.56 b	36.67 b	2.42 a	39.61 b	44.2
W_2	14.91 ab	36.80 b	2.12 b	39.68 b	44.5
W_3	16.07 a	40.48 a	2.08 b	43.62 a	45.2
CV (%)	11.13	10.20	25.38	10.05	7.37
Level of significance	**	**	NS	**	NS

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

Appendix 4

Effect of biochar on spike and grain after harvest

Treatments	Spike length (cm)	Number of filled grains/spike	Number of unfilled grains/spike	Number of total grains/spike	1000 seed weight (gm plot^{1})
B_1	13.56 b	32.64 b	2.88 a	35.22 b	44.00
B_2	14.34 b	33.66 b	2.82 a	36.26 b	45.00
B_3	17.15 a	44.46 a	1.73b	48.73 a	46.00
B_4	17.07 a	43.81 a	1.82 b	46.06 a	45.10
B_5	13.78 b	35.33 b	1.81 b	38.57 b	44.50
CV (%)	11.13	10.20	25.38	10.05	7.37
Level of significance	*	*	NS	*	NS

* indicates 5% level of significance and NS indicates non-significant

BC_1= No addition of biochar (0 t ha^{-1}), BC_2= 2 t ha^{-1}, BC_3=4 t ha^{-1}, BC_4=6 t ha^{-1}, BC_5=8 t ha^{-1}

Appendix 5

Combined effect of irrigation and biochar on spike and grain after harvest.

Treatments	Spike length (cm)	Number of filled grains/spike	Number of unfilled grains/spike	Number of total grains/spike	1000 seed weight (gm $plot^{-1}$)
W_1B_1	14.46c	29.46 gh	3.16 a	32.00 c	46.00
W_1B_2	13.78c	33.26 fgh	2.22 c	35.60 d	46.20
W_1B_3	15.05bc	39.70 d	2.50 bc	42.13 b	46.10
W_1B_4	15.46bc	41.33 cd	3.00 b	43.66 b	46.40
W_1B_5	14.06bc	34.33 ef	2.18cd	39.60 c	46.30
W_2B_1	14.95bc	36.80 ef	2.68bc	36.60 d	46.50
W_2B_2	13.52c	32.93 fgh	2.34c	39.06 c	46.70
W_2B_3	16.64b	42.93 b	2.86 b	45.46b	46.90
W_2B_4	15.45bc	45.60 b	2.50 bc	43.13b	46.40
W_2B_5	14.01bc	38.26 de	2.12 d	40.86 bc	46.20
W_3B_1	13.62c	33.73 fgh	2.06 d	37.06 cd	47.00
W_3B_2	14.46bc	34.73 gh	2.09 d	34.13 e	47.50
W_3B_3	20.30a	48.80 a	1.60 e	51.40 a	48.00
W_3B_4	19.76a	46.46 ab	1.73 e	49.40ab	46.60
W_3B_5	13.27c	36.40 ef	2.30c	42.26b	46.30
CV (%)	11.13	10.20	25.38	10.05	7.37
Level of significance	**	**	*	**	NS

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

WS_1=Regular irrigation, WS_2=Skipped at booting stage, WS_3=Skipped at heading and flowering stage

BC_1= No addition of biochar (0 t ha^{-1}), BC_2= 2 t ha^{-1}, BC_3= 4 t ha^{-1}, BC_4= 6 t ha^{-1}, BC_5= 8 t ha^{-1}

Appendix 6

Effect of irrigation on Grain and straw yield of wheat

Treatments	Grain yield (ton ha^{-1})	Straw yield (ton ha^{-1})
W_1	2.36 b	2.10b
W_2	2.71 a	2.30b
W_3	2.73 a	2.60a
CV (%)	9.75	8.27
Level of significance	**	**

**indicates 1% level of significance

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

Appendix 7

Effect of biochar on grain and straw yield of wheat

Treatments	Grain yield (ton ha^{-1})	Straw yield (ton ha^{-1})
B_1	2.39 b	2.2 c
B_2	2.45 b	2.3 c
B_3	2.93 a	2.56 a
B_4	2.79 a	2.43 b
B_5	2.44 b	2.2 c
CV (%)	9.75	8.27
Level of significance	**	**

**indicates 1% 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}

Appendix 8

Combined effect of irrigation and biochar on grain and straw yield of wheat

Treatments	Grain yield (ton ha^{-1})	Straw yield (ton ha^{-1})
W_1B_1	2.19 e	2.01e
W_1B_2	2.63 bc	2.46b
W_1B_3	2.95 b	2.38bc
W_1B_4	2.83 b	2.44b
W_1B_5	2.65 bc	2.40bc
W_2B_1	2.34 de	2.43b
W_2B_2	2.61 bc	2.21d
W_2B_3	2.61 bc	2.26d
W_2B_4	2.42 cde	2.37c
W_2B_5	2.23 de	2.19d
W_3B_1	2.39 de	2.3cd
W_3B_2	2.34 de	2.22d
W_3B_3	3.23 a	2.98a
W_3B_4	3.13 a	2.59b
W_3B_5	2.46 cde	2.33cd
CV (%)	9.75	8.27
Level of significance	*	*

*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 t ha

Appendix 9

Factorial ANOVA table for plant height at 20DAS

Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	7.644	3.8220		
Irrigation	2	33.998	16.9990	6.23**	0.0058
Biochar	4	172.964	43.2410	15.84**	0.0000
Irrigation x Biochar	8	13.567	1.6958	0.62**	0.7528
Error	28	76.438	2.7299		
Total	44	304.611			
Grand Mean	30.15				
CV	5.48				

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

Appendix 10

Factorial ANOVA table for plant height at 40DAS

Source	DF	SS	MS	F	P
Replication	2	19.874	9.9369		
Irrigation	2	69.399	34.6996	5.08*	0.0132
Biochar	4	381.586	95.3964	13.95*	0.0000
Irrigation x Biochar	8	84.681	10.5851	1.55*	0.1857
Error	28	191.433	6.8369		
Total	44	746.972			
Grand Mean	57.071				
CV	4.58				

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

Appendix 11

Factorial ANOVA table for plant height at 60DAS

Source	DF	SS	MS	F	P
Replication	2	47.05	23.525		
Irrigation	2	38.01	19.006	1.81*	0.1822
Biochar	4	591.50	147.874	14.09*	0.0000
Irrigation x Biochar	8	169.58	21.198	2.02*	0.0810
Error	28	293.95	10.498		
Total	44	1140.09			
Grand Mean	80.586				
CV	4.02				

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

Appendix 12

Factorial ANOVA table for plant height at 80DAS

Source	DF	SS	MS	F	P
Replication	2	14.739	7.3695		
Irrigation	2	37.602	18.8009	3.23*	0.0548
Biochar	4	272.032	68.0079	11.67*	0.0000
Irrigation*Biochar	8	48.720	6.090	1.05*	0.4273
Error	28	163.126	5.8259		
Total	44	536.218			
Grand Mean	84.150				
CV	2.87				

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

Appendix 13

Factorial ANOVA table for plant height after harvest

Source	DF	SS	MS	F	P
Replication	2	19.864	9.9318		
Irrigation	2	55.415	27.7073	5.84*	0.0076
Biochar	4	336.565	84.1414	17.74*	0.0000
Irrigation x Biochar	8	32.244	4.0306	0.85*	0.5684
Error	28	132.810	4.7432		
Total	44	576.898			
Grand Mean	86.436				
CV	2.52				

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

Appendix 14

Factorial ANOVA table for spike length

Source	DF	SS	MS	F	P
Replication	2	15.019	7.5097		
Irrigation	2	18.636	9.3180	3.26**	0.0532
Biochar	4	114.391	28.5977	10.02*	0.0000
Irrigation x Biochar	8	66.716	8.3395	2.92**	0.0167
Error	28	79.930	2.8547		
Total	44	294.692			
Grand Mean	15.185				
CV	11.13				

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

Appendix 15

Factorial ANOVA table for filled grain

Source	DF	SS	MS	F	P
Replication	2	155.50	77.748		
Irrigation	2	140.25	70.123	4.67**	0.0178
Biochar	4	1171.41	292.852	19.50*	0.0000
Irrigation x Biochar	8	162.46	20.307	1.35**	0.2599
Error	28	420.51	15.018		
Total	44	2050.12			
Grand Mean	37.984				
CV	10.20				

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

Appendix 16

Factorial ANOVA table for unfilled grain

Source	DF	SS	MS	F	P
Replication	2	2.1871	1.09356		
Irrigation	2	1.0538	0.52689	1.67^{NS}	0.2059
Biochar	4	12.5111	3.12778	9.93^{NS}	0.0000
Irrigation x Biochar	8	1.5129	0.18911	0.60^{NS}	0.7694
Error	28	8.8196	0.31498		
Total	44	26.0844			
Grand Mean	2.2111				
CV	25.38				

NS indicates non significant

Appendix 17

Factorial ANOVA table for total grain

Source	DF	SS	MS	F	P
Replication	2	232.13	116.067		
Irrigation	2	158.44	79.219	4.67**	0.0178
Biochar	4	1324.14	331.034	19.50*	0.0000
Irrigation x Biochar	8	199.63	24.954	1.47**	0.2125
Error	28	475.23	16.972		
Total	44	2389.57			
Grand Mean	40.973				
CV	10.05				

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

Appendix 18

Factorial ANOVA table for weight of 1000-seeds

Source	DF	SS	MS	F	P
Replication	2	293.64	146.822		
Irrigation	2	149.64	74.822	3.10**	0.0606
Biochar	4	943.64	235.911	9.79*	0.0000
Irrigation x Biochar	8	209.02	26.128	1.08**	0.4026
Error	28	675.02	24.108		
Total	44	2270.98			
Grand Mean	66.578				
CV	7.37				

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

Appendix 19

Factorial ANOVA table for grain yield (g/plot)

Source	DF	SS	MS	F	P
Replication	2	97641	48820.4		
Irrigation	2	105803	52901.5	11.14**	0.0003
Biochar	4	163831	40957.9	8.63**	0.0001
Irrigation x Biochar	8	37433	4679.1	0.99*	0.4679
Error	28	132955	4748.4		
Total	44	537662			
Grand Mean	775.64				
CV	8.88				

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

Appendix 20

Factorial ANOVA table for grain yield (t/ha)

Source	DF	SS	MS	F	P
Replication	2	0.92005	0.46003		
Irrigation	2	1.31577	0.65789	10.22**	0.0005
Biochar	4	2.14627	0.53657	8.33**	0.0001
Irrigation*Biochar	8	0.70663	0.08833	1.37*	0.2516
Error	28	1.80328	0.06440		
Total	44	6.89200			
Grand Mean	2.6033				
CV	9.75				

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

Appendix 21

Factorial ANOVA table for straw yield (gram/plot)

Source	DF	SS	MS	F	P
Replication	2	29677	14838.5		
Irrigation	2	62549	31274.7	10.85**	0.0003
Biochar	4	230811	57702.8	20.02**	0.0000
Irrigatio*Biochar	8	48503	6062.9	2.10*	0.0698
Error	28	80716	2882.7		
Total	44	452257			
Grand Mean	683.02				
CV	7.86				

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

Appendix 22

Factorial ANOVA table for straw yield (t/ha)

Source	DF	SS	MS	F	P
Replication	2	0.54192	0.27096		
Irrigation	2	0.72364	0.36182	10.15**	0.0005
Biochar	4	2.57459	0.64365	18.06**	0.0000
Irrigation x Biochar	8	0.51129	0.06391	1.79*	0.1208
Error	28	0.99788	0.03564		
Total	44	5.34932			
Grand Mean	2.2820				
CV	8.27				

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

Appendix 23

Factorial ANOVA table for soil pH in post harvest soil

Source	DF	SS	MS	F	P
Replication	2	0.00363	0.00182		
Irrigation	2	0.13470	0.06735	6239.68^{NS}	0.0000
Biochar	4	0.04107	0.01027	951.18^{NS}	0.0000
Irrigation x Biochar	8	0.00115	0.00014	13.28^{NS}	0.0000
Error	28	0.00030	0.00001		
Total	44	0.18084			
Grand Mean	5.6811				
CV	0.06				

******indicates 1% level of significance and * indicates 5% level of significance and NS indicates non significant

Appendix 24

Factorial ANOVA table for organic carbon in post harvest soil

Source	DF	SS	MS	F	P
Replication	2	0.00677	3.387E-03		
Irrigation	2	0.01137	5.687E-03	16.43**	0.0000
Biochar	4	0.00125	3.133E-04	0.91**	0.4744
Irrigation x Biochar	8	0.00283	3.533E-04	1.02*	0.4434
Error	28	0.00969	3.462E-04		
Total	44				
Grand Mean	0.7180				
CV	2.59				

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

Appendix 25

Factorial ANOVA table for organic matter in post harvest soil

Source	DF	SS	MS	F	P
Replication	2	0.02226	0.01113		
Irrigation	2	0.04120	0.02060	30.56**	0.0000
Biochar	4	0.00430	0.00108	1.06**	0.2031
Irrigation x Biochar	8	0.00962	0.00120	1.78*	0.1230
Error	28	0.01888	0.00067		
Total	44	0.09626			
Grand Mean	1.2418				
CV	2.09				

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

Appendix 26

Factorial ANOVA table for total nitrogen in post harvest soil

Source	DF	SS	MS	F	P
Replication	2	0.00036	0.00018		
Irrigation	2	3.92799	1.96399	1149.40**	0.0000
Biochar	4	0.47635	0.11909	6970.02**	0.0000
Irrigation x Biochar	8	0.91317	0.11415	6680.80**	0.0000
Error	28	0.00048	0.00002		
Total	44	5.31835			
Grand Mean	0.2702				
CV	1.53				

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

Appendix 27

Factorial ANOVA table for available phosphorus in post harvest soil

Source	DF	SS	MS	F	P
Replication	2	17.7896	8.89481		
Irrigation	2	0.0380	0.01898	0.01^{NS}	0.9903
Biochar	4	7.6014	1.90035	0.98^{NS}	0.4337
Irrigation x Biochar	8	15.5495	1.94369	1.00**	0.4554
Error	28	54.2306	1.93681		
Total	44	95.2091			
Grand Mean	21.153				
CV	6.58				

******indicates 1% level of significance and * indicates 5% level of significance and NS indicates non significant

Appendix 28

Factorial ANOVA table for exchangeable potassium in post harvest soil

Source	DF	SS	MS	F	P
Replication	2	0.04846	0.02423		
Irrigation	2	0.04002	0.02001	38.53**	0.0000
Biochar	4	0.00567	0.00142	2.73**	0.0492
Irrigation x Biochar	8	0.00429	0.00054	1.03*	0.4353
Error	28	0.01454	0.00052		
Total	44	0.11298			
Grand Mean	0.1922				
CV	11.86				

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

Appendix 29

Factorial ANOVA table for available sulphur in post harvest soil

Source	DF	SS	MS	F	P
Replication	2	66.403	33.2014		
Irrigation	2	24.069	12.0346	10.30**	0.0004
Biochar	4	3.001	0.7504	0.64**	0.6363
Irrigation x Biochar	8	8.879	1.1099	0.95*	0.4930
Error	28	32.710	1.16892		
Total	44	135.063			
Grand Mean	22.762				
CV	4.75				

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

Planting Material

Prepared field for sowing seeds

A

B

C

Figure: (A,B,C) Different stages of plant growth

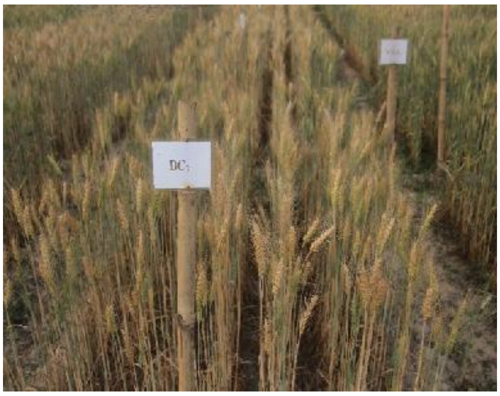


Figure: Treatment BC_1

Figure: Treatment BC_3

Figure: The whole experimental area.

A

B

Figure: (A, B) Wheat Grains after harvest.