COMBINED EFFECT OF BIOCHAR AND PHOSPHORUS ON GROWTH AND YIELD OF WHEAT UNDER DIFFERENT IRRIGATION REGIME

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CERTIFICATE

This is to certify that the thesis entitled, '**COMBINED EFFECT OF BIOCHAR AND PHOSPHORUS ON GROWTH AND YIELD OF WHEAT UNDER DIFFERENT IRRIGATION REGIME**' submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE** in **AGRONOMY**, embodies the result of a piece of bona fide research work carried out by **ISHRAT ANJUM**, **Registration No. 13-05607** 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.

Dated:

Place: Dhaka, Bangladesh.

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Prof. Dr. Md. Abdullahil Baque

DEDICATED

TO MY

PARENTS

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ABSTRACT

A field experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka-1207, to evaluate combined effect of biochar and phosphorus on growth and yield of wheat under different irrigation regime during November 2019 to March 2020. The experiment was laid out in two factor split plot design with three replications. Irrigation regime under main factor were I_0 = Control, I_1 = At Crown Root Initiation (CRI), I_2 = At CRI +Flower Initiation (FI) stage, I_3 =At CRI+FI+ Grain Filling (GF) stage and four different combinations of biochar and phosphorus doses were in sub factor viz., BP_0= 5 ton Biochar ha^{-1}, BP_1 =5 ton Biochar + 20 kg Phosphorus ha^{-1}, BP_2=5 ton Biochar +15 kg Phosphorus ha^{-1}, BP_3 =20 kg Phosphorus ha^{-1}. There were 16 treatment combinations. The tallest plant (100.16cm), maximum number of tiller (5.64), highest leaf length (16.92cm), maximum ear $plant^{-1}$ (5.36), highest ear length (14.86cm), maximum spikelet $spike^{-1}$ (17.76), highest grains $spike^{-1}$ (50.77), highest 1000-grain weight (47.86g), highest grain yield (3.67tha^{-1}), highest straw yield (4.03tha^{-1}), highest biological yield (7.71tha^{-1}) and harvest index (47.75%) were obtained from I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}). It can be concluded that treatment I_2BP_2 is recommendable for improved wheat production.

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LIST OF ABBRVIATION

ABBREVIATION	FULL WORD
AEZ	Agro Ecological Zones
BARI	Bangladesh Agricultural Research Institute
BARC	Bangladesh Agricultural Research Council
BBS	Bangladesh Bureau of Statistics
cm	Centi-meter
CRI	Crown Root Initiation
CEC	Cation Exchange Capacity
CV%	Percent Coefficient of Variance
cv	Cultivar (s)
^{0}C	Degree Celsius
DAS	Days After Sowing
et al.	And others
e.g.	For example, *exampli gratia* (L)
etc	Etcetera
FAO	Food and Agricultural Organization
FI	Flower Initiation
g	Gram (s)
GF	Grain Filling
HI	Harvest Index
i.e.	that is, *id est* (L)
kg	Kilogram
kg ha^{-1}	Kilogram per hectare
K	Potassium
LSD	Least Significant Difference
MS	Master of Science
m	Meter
m^2	Meter square
MoP	Muriate of Potash
N	Nitrogen
P	Phosphorus
NS	Non-significant
No	Number
OM	Organic Matter
pH	Hydrogen ion concentration
%	Percent
SAU	Sher-e-Bangla Agricultural University
var.	Variety
TSP	Triple Super Phosphate
t ha^{-1}	Ton per hectare

CHAPTER I

INTRODUCTION

Wheat is an important cereal crop considered one of the most important staple foods throughout the world. It is the third largest cereal production in the world after maize and rice (FAO, 2020). Worldwide total wheat production during the year 2019-2020 is 763.93 million metric ton. According to USDA, 100 g of wheat provides 327 kilocalories and source of essential nutrients. In contains 12% water, 70% carbohydrates, 12% protein, 2% fat, 1.8% minerals and 2.2% crude fibers. Small amount of thiamin, riboflavin, niacin, and vitamin A are present, but most of those nutrients are removed with the bran and germ through milling process.13% protein content is mostly gluten (Shewry *et al*., 2002). About 70% of produced wheat is used as food, 17 % for animal feed and 13 % in industrial used.

In Bangladesh among the other cereal crops, wheat production is next to rice. It contributes to the national economy of our country by reducing the volume of import of cereals for fulfilling the food requirements (Razzaque *et al*., 1992) but its total production is not sufficient enough to feed the increasing population as the yield is very low. 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. In 2018-2019 wheat production area was estimated up to 330,348 ha and production was estimated at 1,016,811 MT (BBS, 2019). The amount was decreased almost 82,562 MT due to the problem of wheat blast, unfavorable weather and lower yield in previous year (Mottaleb *et al*., 2019). Wheat import was recorded 6.3 MMT during the year 2019-20. There are several reasons that can explain the variation of yield. Both biotic and abiotic factors are responsible for low yield. Among the biotic factors incidence of disease and pests (Hossain *et al*., 2011), unavailability of high yielding varieties (Rerkasem *et al*., 1991) are noticeable. Abiotic factors includes high temperature, moisture stress (Binghum, 1966) and nutrient deficiency (Rerkasem *et al*., 1993; Islam *et al*., 1997). There are several improved technologies can be used to improve wheat production, use of biochar is one of those.

Biochar is a fine grained charcoal like materials, rich in carbon, produced by the process pyrolysis of biomass at temperatures between 300 °C and 600 °C in absence of oxygen. It is said that biochar can endure in soil for thousands of years (Julie, 2010). It has been noticed that use of charcoal as a fuel replacing wood leads to lower levels of household indoor pollution (Bailis *et al*., 2005). The application of biochar (charcoal or biomass-derived black carbon) to agricultural soil is proposed as a novel approach to improve soil fertility, improve soil water holding capacity and consequently moisture retention, and to increase crop production of newly reclaimed sandy soil (Bakry *et al*., 2015). Biochar is a stable form of carbon has complex of physical and chemical properties which make it a potentially powerful soil amendment material (Mutezo, 2013). It can act as a soil conditioner enhances the growth of the plants by supplying and more specifically retaining nutrients and improving soil physical and biological properties and consequently improving soil water holding capacity (Lehmann and Rondon, 2005). Biochar is produced from a variety of biomass residues (feedstocks) and under different pyrolytic conditions, and thus has varying nutrient contents. For example, in case of biochar produced from feedstocks of animal higher amount of nitrogen and phosphorus in compare to plant origin (Chan and Xu, 2009).

Phosphorus is an essential nutrient for plant development form seedling to maturity stage. It plays role in uniform heading, quality and formation of seeds, faster maturity and strengthening the plant to survive in winter. Biochar application could be a great practice in order to enhance phosphorus availability in soil. It is said that biochar act as a phosphate adsorbent and a source of available phosphorus for plant (Zhang *et al*., 2016). Addition of biochar enhanced wheat yield under different mineral fertilization levels regardless of nitrogen and water stressed conditions (Alburquerque *et al*., 2013). It improves water holding capacity of soil, build soil organic matter, enhances nutrient cycling and fertilizer requirements (Laird, 2008; Glaser *et al*., 2007; Novak *et al*., 2009; Lehmann *et al*., 2003).

A lot of research works already been performed in abroad, but the amount of research work done in Bangladesh were inadequate and not conclusive. In view of the above background, the present research work has been taken on biochar application with phosphorus doses under different irrigation in wheat cultivation using the cultivar of BARI Gom-30 with the following objectives:

- To monitor the irrigation effect with biochar on wheat.
- To analysis the effect of biochar and phosphorus combination on growth and yield of wheat.
- To explore the combined effect of different level of biochar and phosphorus under different irrigation regime on growth and yield of wheat.

CHAPTER II

REVIEW OF LITERATURE

Wheat is an important cereal crop which gets less attention because of rice crop dependency in our country. Both wheat and Boro rice is winter crop which grows in during Rabi season. Most of the crops grown during this period are mainly irrigated. Many research works on wheat has been performed specially in South Asia countries for its improvement in growth and yield. A very few studies have been done in our country related to growth, yield and development of wheat due to water stress. The number is not so far adequate and conclusive. This chapter includes results of different researches done both in home and abroad regarding the effect of biochar, phosphorus and irrigation regimes on growth, yield parameter and yield of wheat and other crops.

2.1 Effect of biochar on plant growth and yield

Biochar is now a days an active research topic worldwide for being an opportunity of sustainable agriculture. Its acts as long term sink for carbon and benefits crops. Biochar improves soil moisture holding capacity, reduce the emission of greenhouse gases in soil, increase cation exchange capacity (CEC), reduce nutrient leaching and soil acidity, Experiments proves that it also reduce the requirement of irrigation and fertilizer in soil during crop grown (Laird, 2008; Novak *et al*., 2009; Brooks *et al*., 2010). Biochar used as soil amendment to the yield for high potash and elevated pH requiring crops (Lehmann and Joseph, 2009).

Biochar (10, 50 and 100 t ha^{-1}) produced from green waste by pyrolysis when applied with and without additional nitrogen application (100 kg N ha^{-1}) no significant difference of radish (*Raphanus sativus* var. Long Scarlet) yield in absence of N fertilizer with biochar application. But a significant interaction between biochar × N fertilizer was observed (Chan *et al*., 2008). On the other hand in a separate experiment Brandstaka *et al*. (2010) proved that there was no significant effect of biochar rates (0, 7 and 15 tons ha^{-1}).

It was observed that two types of biochar from agricultural wastes typical of Southern Spain: wheat straw and olive tree pruning combined with different level of mineral fertilizer had significant effect on growth and yield of Darum wheat (*Triticum durum* L. cv. Vitron). Experiment result showed that biochar had little effect on wheat growth in absence of mineral fertilization to a nutrient poor, slightly acidic loamy sand soil. On the other hand at the highest mineral fertilizer rate, addition of biochar increased grain yield about 20–30 % compared with the use of the mineral fertilizer alone. Both biochar acted as a source of available P leading to beneficial effects for crop production (Alburquerque *et al*., 2013).

Lahmann and Josheph (2009) stated that biochar has a great impact in soil fertility. Either it add nutrient by itself or can make nutrient available through increasing decomposition of organic matters in soil. Addition of biochar also results larger surface area, increased CEC which prevents leaching thus Eutropication. A significant decrease of nutrient leaching observed after addition of charcoal (Lehmann *et al*., 2003). Applied fertilizers are adsorbed to the soil surface due to high CEC which causes more nutrient availability for the plant. Incorporation of biochar with same or less amount of fertilizer causes higher yield (Steinbeiss *et al*., 2009).

It is required to understand the effectiveness of use biochar as biomass recycling in agriculture to improve both crop production and environmental performance. It's also important to understand its effect on soil nutrients i.e. nitrogen, phosphorus and C storage. It was observed that Nitrogen and Phosphorus use efficiencies in a rice-wheat rotation field consecutive 6 years after soli amendment (20 t ha^{-1} and 40 t ha^{-1}). Biochar application increased crop (both rice and wheat) root (3–19%), straw (10–19%) and grain (10–16%) biomasses. A significant effect found in grain N use efficiency (20–53%) and P use efficiency (38–230%) compared with N and P fertilization only. Biochar also improved soil organic carbon (26–53%), total N (14–16%) and P (6–19%) compared to N and P fertilization. Improvement of soil carbon storage and nutrient pools (i.e., N, P), promoted root growth, uptake of N and P fertilizers as well as crop production. It proved that biochar application is an effective strategy to increase crop yield, even in the long-term, and is connected not only with the improvement of soil structure and carbon storage but also with increases in nutrient use efficiency (Zhanga *et al*., 2020).

In Brazil the dark anthropogenic soils known as Amazonian Dark Earths (ADE) refer to black fertile soils called *terra preta de Indio* (Woods and Denevan, 2009). These rich black earths are highly fertile and produce large crop yields despite the fact that the surrounding soils are infertile (Renner, 2007). Several studies revealed that terra perta was formed about 7000 years ago during Pre Columbian civilization near the bank of Amazon River. Accumulation of charcoal in this soil led to formation of *terra preta* (Glaser, 2007).

Use of saline water for irrigation is essential to mitigate increasing demand of agricultural water in arid and semi-arid regions. It was observed that using straw biochar with saline water irrigation have significant impact on wheat production from experiment conducted in a clay loam soil from eastern China during winter wheat season of 2016-18. There were five treatments of different level of saline water irrigation along with freshwater irrigation. Saline water irrigation alone caused soil salinization and decreased wheat growth and yield. On the other hand incorporation of biochar decreased soil bulk density by 5.5%–11.6% and increased permeability by 35.4%–49.5% thus improved soil nutrient status. Biochar also reduced soil sodium adsorption ratio under saline water irrigation. Saline water irrigation with biochar application of 10 and 20 t ha^{-1} significantly increased wheat grain yield by 8.6 and 8.4%, respectively compared to saline water irrigation alone. Biochar amendment at 10 t ha^{-1} was resulted as proper practice to facilitate saline water irrigation for wheat production. It was also recommended that high dose of biochar might increase soil salinity and limit N availability (Huang *et al*., 2019).

Rice husk biochar was used as treatment in four different doses with inorganic fertilizer and lime on two sesame cultivars, named ‘Nishikimaru’ and ‘Gomazou’ in 2015. Experiment results indicated that plant height, seed yield, and 1000-seed weight were all significantly influenced by biochar application in compared to controlled plot (Wacal *et al*., 2016).

It was investigated that biochar shows significant effect on maize yield and greenhouse gases (GHGs) in a calcareous loamy soil poor in organic carbon from Henan, central great plain, China. Biochar amendments significantly increased maize production by 15.8% and 7.3% without N fertilization, and by 8.8% and 12.1% with N fertilization under biochar amendment at 20 t ha^{-1} and 40 t ha^{-1} respectively. Soil emissions of CO_2, CH_4 and N_2O were monitored and result evaluated that total N_2O emission was decreased by 10.7% and by 41.8% under biochar amendment at 20 t ha^{-1} and 40 t ha^{-1} compared to no biochar amendment with N fertilization. Biochar amendments also decreased soil bulk density and increased soil total N. The experimental results suggested that application of biochar to calcareous and infertile dry crop lands poor in soil organic carbon will enhance crop productivity and reduce GHGs emissions (Zhang *et al*., 2012).

Gebremedhin *et al*. (2015) revealed that biochar can significantly increase grain and straw yields of wheat by 15.7% and 16.5% respectively, over the N and P application (control). Moreover, the root biomass was significantly increased by 20% by applying biochar. This result shows that biochar can retain nutrients and water in soil which improves wheat productivity. Biochar produced from *Prosopis juliflora* could be used for improvement of wheat production.

It was observed that when biochar was applied in a nutrient-poor, slightly acidic loamy sand soil had little effect on wheat yield in the absence of mineral fertilizers but when applied with the highest rate of mineral fertilization, it produced yield 20–30 % more than mineral fertilizers alone (Alburquerque *et al*., 2014). In another experiment laid by Liang *et al*., (2014) evaluated that biochar did not increased annual yield of winter wheat and summer maize in 1st year but the cumulative yield over four growing season was significantly increased by application of biochar in a calcareous soil. Biochar produced from maple was tested at different concentrations for root elongation of pea and wheat but no significant difference was observed due to little effect of biochar in the short-term (Borsari, 2011). Biochar produced from wood chips at 290^oC and 700^0 C had no effect on growth and yield of either rice or leaf beet (Liang *et al*., 2014). An experiment proved that biochar significantly increased growth and yield of French bean as compared to no biochar applied to soil (Saxena *et al*., 2013).

Biochar application can increase crop yields by improving the nitrogen (N) uptake and utilization of added inorganic fertilizers as well as sequestering significant quantities of carbon. Experiment results showed that biochar addition led to significant increase in spring barley grain yield in the first year of biochar application along with improved water utilization. In the second year in case of sunflower production there were no significant effects were found of the previous year's biochar addition on the yield, N status, fertilizer recovery or any signs of improved water utilization. This experiment concluded suggesting that biochar addition has only slightly positive or neutral effects on crop growth and fertilizer retention but has the potential to higher amount of carbon sequestration in the soil with minimum yield losses in temperate agriculture (Rebecca *et al*., 2018).

Sustainable rice production in Sierra Leone had some constraints due to soil acidity, low cation exchange capacity (CEC), low nutrient contents accelerated mineralization of soil organic matter and soil loss by erosion for upland. Biochar produced by recycling rice residue showed significant effects on soil physicochemical properties and the early growth characteristics of two rice varieties i.e. NERICA L19 and ROK3. Experimental result evaluated that application of biochar improved available phosphorus, exchangeable cations and cation exchange capacity in biochar treated soils compared to the control soil without biochar. Plant height, tiller number, and dry biomass weight of both rice varieties grown in soils amended with rice straw biochar were significantly higher than untreated soils. The most remarkable increase in plant growth characteristics as a result of biochar addition to soil was reflected in the biomass yield and tiller numbers. Converting rice residues to biochar and applying to soil had a significant improve in rice production of Sierra Leone (Kamara *et al*., 2015).

A greenhouse experiment was conducted with a view to investigate the effect of biochar produced from cow manure on maize yield, nutrient uptake and physio-chemical properties in dryland sandy soil. Biochar was obtained from dry cow manure pyrolysed at 500°C and mixed with a sandy soil. Result of the study indicated that cow manure had significant effect on maize crop growth. Application of biochar significantly increased maize grain yield as compared with the control. Net water use efficiency (WUE) also increased. Nutrient uptake by maize grain was significantly increased with higher biochar applications. Soil analysis result after the harvesting indicated significant increase in the pH, total C, total N, Oslen-P, exchangeable cations and cation exchange capacity in sandy soil. The results of this study indicated that application of cow manure biochar to sandy soil is not only beneficial for crop growth but it also significantly improved the physio-chemical properties of the coarse soil (Uzoma *et al*., 2011).

A comparison was done with charcoal and compost on a permeable humid tropic soil in an experiment to determine the influence of on N retention of soil. It was found that soil amended by charcoal enhanced the efficiency of mineral N fertilizer more than the compost amendment. There was a significant recovery difference of 7.2 % between the total N recovered in soils with biochar and the compost amendment. This result indicated an improvement in the fertilizer usage of N, P, and K in soil (Steiner *et al*., 2008).

It was studied that biochar can change the physical and chemical properties of the soil resulting increase of nutrient availability in the soil as well as increases plant root colonization by mycorrhizal fungi (Yamato *et al*., 2006). Biochar changes emissions of other greenhouse gases from soil such as nitrous oxide (N_2O) methane (CH_4) (Rondon *et al*., 2005). Addition of biochar improves plant productivity directly because of its nutrient holding capacity. Lehmann and Joseph (2015) reported significant crop yield benefits from biochar application to soils for various crops and plants in different environments.

Soils of tropical regions are poor in plant available phosphorus resulting in P deficient environments due to presence of sesquioxides which have the ability to sorb phosphate (Turner *et al*., 2006) in soil creating a sink of inorganic phosphorus for plants (Oberson *et al*., 2006). Experiments proves that P level increases with the addition of biochar (Novak *et al*., 2009). This increase caused due to the high concentrations of available P found in the biochar (Chan *et al*., 2007).

A study result evaluated that the yield of tomato fruit was significantly higher in beds treated with charcoal than without charcoal treatment (Yilangai *et al*., 2014). It is examined that biochar application increases vegetable yields by 4.7-25.5% as compared to farmer's traditional practices without biochar (Vinh *et al*., 2014).

Biochar improves the hydraulic conductivity of top soil. A significant effect was observed in grain yield of upland rice with low phosphorus availability and response to N and P fertilizer treatment. Biochar treatment showed reduced leaf SPAD values indicating that CA without additional N fertilizer application could reduce grain yields in soils with a low indigenous N supply. Experimental result suggested that biochar has the potentiality to improve soil productivity of upland rice production in Laos, but that the effect of biochar is highly dependent on soil fertility and fertilizer management (Asai *et al*., 2009).

Impact of pecan shell based biochar was investigated on soil fertility of agricultural soil in the Southeastern U.S. which had meager soil fertility due to sandy texture. They come to a conclusion that biochar addition to Norfolk soil shows significant improvement in soil fertility (Novak *et al*., 2009). Biochar produced from pyrolysis process contains a huge amount of carbon from plant biomass. Application of biochar to soil can trap carbon for a long time even for millennium. It also increase moisture holding capacity of soil, 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 (Laird, 2008).

Experiment through amendment of two agricultural soil with two biochar produced from the slow pyrolysis of paper mill waste evaluated that both the biochar slightly differed in their liming values (33% and 29% respectively) along with carbon content (50% and 52% respectively). Both biochar significantly increased N uptake and increased biomass (about 250%) in wheat grown in ferrosol. No significant effect of biochar was found without fertilizers in wheat and soybean while increase biomass in radish found. Earthworm preference was significantly found in ferrosol over calcarosol with biochar treatment. This study result evaluated that the agronomic benefits for papermill biochar varies for different soil types and crops (Van-Zwieten *et al*., 2010).

Pyrolysis temperature and feedstock type used to produce biochar influence the physicochemical properties of biochar (Conz *et al*., 2017). Biochar was produced from four different agricultural organic residues: Poultry litter, sugarcane straw, rice hull and sawdust pyrolysed at final temperatures of 350°C, 450°C, 550°C and 650°C. The effect of temperature and feedstock shows differences in pH, electrical conductivity, cation exchange capacity, nutrient content. Results showed that increasing pyrolysis temperature supported biochar stability regardless of feedstock. Animal manure biochar showed higher potential as nutrient source rather than a C sequestration strategy.

2.2 Effects of phosphorus on plant growth and yield

Differences in P uptake and utilization showed significance influence on three different cereal crops i.e. Triticle (*Triticale octoploide* cv DT-46),its parents wheat (*Triticum aestivum* L) and rye (*Scale cereal* L) under two rates (0 and 60ka ha^{-1} P_2O_5). The number of tiller reduction was 13%, 37% and 50% for rye, wheat and triticle respectively for control compared to 60ka ha^{-1} P_2O_5 (Renu *et al*., 2005).

Water stress and low phosphorus availability are the limiting factors for growth and yield of wheat. A significant effect had found for higher dose of phosphorus with optimum irrigation. Stressed at vegetative + reproductive stages had more severe affect in compared to stress at reproductive stage. Plant height, number of tillers, spike length, number of grains $spike^{-1}$, 1000 grains weight, grain yield and straw yield were reduced for lower rate of phosphorus with water stress. Application of phosphorus at the rate of 120 kg ha^{-1} under water stress had maximum yield compared to other phosphorus levels (Mumtaz *et al*., 2014).

It is observed that plants grown at low levels of applied P had shown lower growth rates and lower concentrations of phosphate in the shoots in compared to plants grown with high P. Activities of both insoluble and soluble phosphatase increased with P deficiency in the mature leaves but severe nitrogen deficiency had no effect on phosphatase activity. Soluble phosphatase activities in mature leaves of plants grown under conditions of water deficit rapidly decreased after re watering them. The high soluble phosphatase activities in mature leaves of P deficient wheat prolonged for up to 12 d after the resupply of P to adequate levels (Barrett-Lennard, *et al*., 1982).

To understand the effect of different phosphate fertilizers on the growth attribute of wheat a pot experiment in green house at during Rabi season was studied. Result evaluated that all the growth parameters of wheat were significantly improved by addition of 80kg ha^{-1} SSP in compared to TSP, NP and DAP on P deficient soil (Khan *et al*., 2010). A field trial in alkaline soil in Southern Australia showed significant responses to liquid P in compare to traditional granular form of P (Holloway *et al*., 2001). Another observation by Baon *et al*. (1992) proved that phosphorous had a significant impact on various cereal crops growth and yield attributes when application of phosphate fertilizers are done at early growth stages.

Different doses of Phosphorus addition wheat in a saline-sodic silty clay loam and silt loam soils respectively revealed that growth and yield of wheat increased significantly with all different P rates over control in both the soils. The increase in growth and yield was more in silty clay loam than silt loam soils. Results also indicated that maximum grain and straw yields were obtained when 100 kg ha^{-1} P was applied both the soils. N and P uptake by straw was recorded maximum at 150 kg ha^{-1} P (Abid *et al*., 2012).

Significant impact was observed for direct and residual effects of phosphate rock (PR) on the growth and yield attributes of wheat (*Triticum aestivum* L cv. Kanchan) during Rabi season of 2004-2005 under Old Brahmaputra floodplain soils. Effective tillers hill^{-1} and grains panicles^{-1} significantly varied with different P treatments. The highest grain yield (3.10 t ha^{-1}) and straw yield (5.54 t ha^{-1}) were found in T_3 treatment (Mamun *et al*., 2012).

A field experiment was conducted during the winter (rabi) season of 2001 at Jobner to study the effect of phosphorus, sulphur and zinc on wheat (*Triticum aestivum* L emend. Fiori & Paol). Analysis revealed that the growth parameters, yield attributes, yield, net return and benefit: cost ratio was significantly increased with the application of 40 kg P_2O_5, 40 kg S and 5 kg Zn ha^{-1} (Dewal and Pareek, 2004).

To understand the impact of phosphorus application and irrigation scheduling on wheat a field experiment was conducted with four different P fertilizer doses along with four irrigations were applied at different critical stages of wheat. 130 and 65 kg ha^{-1} N and K was applied as basal dose. Maximum wheat grain yield was observed with 81 kg P_2O_5 ha^{-1} along with three irrigations at critical stage of wheat plant growth. Tillering in wheat plant increased significantly with the increase of phosphorus level (Rahim *et al*., 2010).

Judicious use of phosphorus was studied on wheat variety Inqlab-91 during winter 2001-02. Significant result was observed. Maximum germination count and fertile tillers were observed in plots treated with NP 128-84 kg ha^{-1}.Highest dose of phosphorus combined with N, yielded maximum number of grains spike^{-1}, maximum 1000 grainns weight were obtained from plots treated with 128-128 kg NP ha^{-1}. Statistically significant grain yield ha^{-1} was also increased with higher application of P (Kaleem *et al*., 2009).

Significant change in grain yield was noticed by the application of phosphorus on crop yields in wheat soybean cropping sequence in acid Alfisols. The soil was amended with lime and gypsum was studied with four levels of phosphorus. Addition of P increased wheat production over control. (Verma *et al*., 1999).

Phosphorus deficiency has a great impact on crop production especially in rain-fed agricultural conditions. This response significantly influences the balance of all plant nutrients with different root and stem development. An experiment conducted to understand the effects of P fertilization on nutrient composition of both straw and grain for 12 bread and 3 durum wheat varieties, widely cultivated in the Mediterranean Region under rain-fed conditions. Phosphorous fertilization affected the concentration of P, N and Mn in the grain positively, while having negative effect on the concentration of Ca, Mg, Na, Fe, Cu and Zn. In straw, N concentration was not affected by P fertilization. Different varieties showed different responses to P fertilization in terms of their nutrient composition (Uygur and Sen, 2018).

In order to optimize the doses of Zinc and Phosphorus to maximize wheat productivity in arid region experiment was conducted with three doses of phosphorus and zinc. Results evaluated that that application of P had a positive influence on growth and grain yield of wheat. Highest growth and yield of wheat was recorded at 120 kg ha^{-1} P_2O_5 application whereas Zn application did not change in growth or yield of wheat (Hussain *et al*., 2011).

Wheat yield can be limited due to reducing number of ear because of poor emergence of tiller. With an objective to understand the effect of P deficiency on tiller emergence of wheat plant Rodriguez *et al*. (1999) conducted an experiment on wheat (*Triticum aestivum* L. cv. INTA Oasis) under drip irrigation on a typic Argiudol having low in P (5.5 μg P g^{-1} soil) in Balcarce, Argentina. Phosphorus treatments significantly modified the pattern of growth and development of the plants. Leaf photosynthetic rate was reduced by P deficiency and directly altered the normal pattern of tiller emergence by slowing the emergence of leaves on the main stem (i.e. increasing the phyllochron).

Diammonium phosphate (DAP) and triple superphosphate (TSP) as phosphorus (P) sources and r application methods of those had significant effect on the grain yield, yield components and other characteristics of winter wheat (Gokmen and Sencer, 1999). Two cultivars Bezostaja-I and Kirkpinar-79 cultivars were used for experiment. Significant effect was not found for DAP and TSP on the characteristics of wheat but application method significantly affected by showing emergence period, maximum number of plants m^{-2} and highest grain yield were obtained from application 5 cm below the seed in both years.

2.3 Effect of irrigation on plant growth and yield

It was investigate that different irrigation schedules shows significant effect on growth and yield performance of different varieties of wheat during Rabi season. Three different wheat varieties i.e. Sassui, TD-1 and Rashkoh-2005 was used to evaluate their performance against different irrigation schedules i.e. five irrigations. The results showed that plant height, Spikelet's $spike^{-1}$ and seed index differed significantly for different irrigation schedules. The wheat crop irrigated five times showed superior result in compared to four irrigations and three irrigations (Baloch *et al*., 2014).

An experiment was conducted at Mymensingh to evaluate the effect of irrigation regimes and nitrogen levels on the growth and yield of wheat (*Triticum aestivum* L cv. Kanchan). Availability of well distributed soil moisture at different growth stages due to more irrigation shows enhanced growth of plant. Maximum plant height was recorded in 300 mm irrigation treatment and shortest in the control. Ears per plant were significantly increased and followed similar pattern as in the case of ear length and in number of tillers per plant. Maximum number of tiller per plant was produced in 200 mm irrigation treatment which was statistically similar with other irrigation treatments except for the control. Influence of irrigation on grain yield was statistically significant also. Maximum grain yield was obtained in 200 mm irrigation treatment and minimum in control. Straw yield showed the tendency of increasing with the influence of irrigation levels. This is due to the lush in vegetative growth in terms of plant height and number of tillers per plant. The maximum straw yield was obtained with 200 mm irrigation and minimum in control (Shirazi *et al*., 2014).

A field experiment was conducted by Ranjita *et al*. (2007) at University of Agricultural Sciences, Dharwad to determine the effect of irrigation schedules, mulching and antitranspirant on growth, yield attributes and economics of wheat. Irrigations scheduled at five critical growth stages resulted in significantly higher grain yield (2545 kg ha^{-1}) over single, two and three irrigations but was on par with four irrigations scheduled at CRI + tillering + late jointing + milk stage. Increase in yield was due to higher number of effective tillers per m^{-2}, number of grains per ear and 1000 grain weight. Plant heights, total dry matter production per m^{-2} were higher in frequently irrigated treatments.

Islam (1997) in his Ms Thesis reported the plant height increased with the increase of number of irrigation schedule. The maximum plant height was observed by applying three irrigations at 25 DAS, 50 DAS and 75 DAS respectively.

Atikullah *et al*. (2014) conducted an experiment during November 2012 to March 2013 in experimental field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh to find out the consequence of different irrigation levels on growth, yield attributes and yield of wheat (BARI Gom-26). Four different irrigations was applied at different growth stages. Results evaluated that maximum dry matter content (18.8 g $plant^{-1}$), crop growth rate (CGR) (13.5 g m^{-2} day^{-1}), relative growth rate (RGR) (0.024 g $m^{-2}day^{-1}$) were found from two irrigation which was statistically identical with three irrigation whereas minimum from control. Plant height (80.7 cm), number of tiller (4.9/hill), number of spike (4.7/hill), number of spikelets (18.5/spike), spike length (19.2 cm), filled grains (29.3/spike), total grains (31.3/spike), 1000-grains weight (44.4 g), yield (grain 3.4 t ha^{-1}, straw 5.7 t ha^{-1} and biological 9.1 t ha^{-1}) and harvest index were similarly showed higher results as of growth characters.

A field experiment was conducted for two consecutive winter seasons (2008/09 to 2009/010) to study the effect of different irrigation intervals on growth, yield, yield components and water use efficiency of wheat (*Triticum aestivum* L.). Wheat cultivar Condor was grown with different irrigation intervals. Parameters i.e. plant height, dry matter accumulation, number of plants m^{-2}, number of tillers $plant^{-1}$, days to five leaf stages, days to 50% heading, days to maturity, number of spikes m^2,spikelets $spike^{-1}$, number of grains $spike^{-1}$, 1000-grain weight, grain and straw yield ,water use efficiency and protein% were observed. The results showed significant differences in those parameters due to irrigation intervals, except for days to fifth leaf stage and harvest index in the first season and number of plant/m^2 in second season. Irrigation every 7days recorded higher values, slightly different from 10 days. Irrigation every 7 and 10 days gave the highest protein content, grain, straw yield and field water use efficiency. For economics aspect irrigation every 10 days is recommended and irrigation every 21, and 28 days must be avoided under this semi-arid condition (Hwary and Yagoub, 2011).

A field experiment for consecutive three years during winter to evaluated the effect of irrigation scheduling and nutrient management practices on productivity, profitability and nutrient uptake of wheat (*Triticum aestivum* L. emend. Fiori & Paol) under zero-tillage condition Two irrigation treatment viz. irrigation water: cumulative pan evaporation (IW: CPE 0.8 and IW: CPE 1.0) and three nutrient-management practices were combined. Irrigation at CPE of 1.0 significantly increased growth attributes i.e. plant height, leaf-area index and dry-matter accumulation at 90 days after sowing (DAS). Effective tillers/m^2, ear length, grains/ear and 1000-seed weight, grain yield, straw yield, N (69.6 and 44.0 kg/ha), P (15.7 and 3.52 kg/ha) and K (20.6 and 153.1 kg/ha) uptake by grain and straw, respectively, protein content (10.5%), net returns (56, 004/ha) was also higher in compare to CPE of 0.8 (Narolia *et al*. 2016).

It was observed that different irrigation schedules have significant impact on water use and yield of wheat. An experiment was conducted on single variety of wheat and four irrigation intervals in main plot and two pan levels i.e. equal to pan evaporation (P_1) and half of pan evaporation (P_2) in sub plot. Result showed significant effects of irrigations on yield components viz. grain yield, number of grain per spike, grain weight per spike and number of tillers per plant. Maximum yield was obtained from the treatment irrigation at five weeks interval. Higher moisture content also had effect on tiller emergence (Khan *et al*. 2007).

Water deficiency during tillering, stem elongation, and grain-filling growth stages was more sensitive than at dormant stage. Grain yield was significantly decreased (15–91%) when water deficit was at all four growth stages. Supplemental irrigation applied during dormant or grain-filling stage increased grain yield (12% and 35%, respectively). Supplemental irrigation at elongation stage increased biomass and N, P, and K uptake in the whole plant. It was observed that water deficiency retarded plant growth and irrigation increased yield of wheat significantly than under control condition (Wang *et al*. 2002).

A mobile rain shelter experiment was conducted during 2017–2019 growing seasons to investigate the effects of water stress at different growth stages on various traits in winter wheat. Three different limited irrigation treatments were applied. Two year averages showed that no irrigation at the reviving and jointing stages resulted in the highest grain yield (6470 kg ha^{-1}). Post-anthesis biomass, net photosynthetic rate were significantly higher for this treatment than other treatments (Cao *et al*. 2021).

Mishra and Padmakar (2010) conducted this experiment to study the effect of irrigation frequencies on yield and water use efficiency of different wheat varieties during Rabi seasons. The irrigation treatment combinations comprised of four irrigation levels viz., $I_{1:}$

(one irrigation at CRI stage), $I_{2:}$ (two irrigations-one each at CRI and flowering stages), $I_{3:}$ (three irrigations: one each at CRI, LT and flowering stages) and $I_{4:}$ (four irrigations: one each at CRI + LT + LJ + ear head formation stages) over three varieties viz. HUW-234, HD-2285 and PBW-154.Increasing of the number of irrigations from 1 to 4 increased various yield contributing characters i.e. effective tillers m^{-2} , ear length, no. of grains ear^{-1}. The highest grain yield (40.65 q ha^{-1}) was found with four irrigations was significantly superior over other treatments.

Mugabea and Nyakatawab (2000) experimented over six wheat genotypes (P_1, P_2, Pote, Deka, Nata and Ruya) grown under three irrigation regimes which were supplying irrigation water according to the crop water requirements, supplying three quarters of the crop water requirements and half of the crop water requirements at each irrigation day. The result of two years experiment revealed that applying three quarters and half of the crop water requirements resulted in a yield decrease. P_2 gave the highest yields and was the least affected by deficit irrigation. On the other hand Deka gave the least decrease in yield when the three-quarters and half water requirements were supplied. Experiment result concluded that more than half the water is required to meet the crop water requirements of wheat.

Two studies were experimented in Hebei, China and one in Baoding in 2006-2007 and the other in Gaocheng in 2007-2008. Four irrigation treatments (W) were combined with 3 nitrogen (N) doses. In 2006-2007 influences of irrigation was significantly higher in W_1, W_2 and W_3 than in W_0, but no significant difference among W_1, W_2 and W_3. Maximum grain yield was obtained from W_3 and the lowest in W_0, and the highest in N_1 and the lowest in N_0 (Zhao *et al*. 2009).

Water stressed condition shows influence on wheat production. An experiment was carried out to evaluate the performance of yield and yield components of wheat genotypes under water stress conditions. Four wheat varieties were cultivated under water stress conditions having different irrigation treatments during various crop growth stages. Grain yield and grain yield contributing traits of wheat varieties were significantly affected under water stress conditions. Grain yield was ranged between 373 kg ha^{-1} in single irrigation treatment to 3931 kg ha^{-1} in four irrigations (Mangan *et al*. 2008).

Bian *et al*. (2016) conducted an experiment to evaluate the effect of irrigation frequency and planting pattern on grain yield and water use efficiency (WUC) of wheat. Two planting pattern wide spaced and conventional planting were treated with three irrigations I_1: irrigation (120 mm) at the jointing stage; I_2: irrigation (60 mm) at both the jointing and heading stages; I_3: and irrigation (40 mm) at the jointing, heading, and milking stages). Applying 60 mm of water at jointing and heading stages resulted in the highest grain yield among the treatments.

A field experiment was conducted to evaluate the influence of limited and adequate irrigation and moisture conservation practices (rice straw mulch and hydrogel) on yield and water use efficiency in wheat. Maximum wheat yield (3.92 t ha^{-1}) and water use efficiency (15.72 kg ha^{-1} mm^{-1}) was recorded with four irrigations at crown root initiation stage, tillering, late jointing, and milk stage (Singh *et al*. 2018).

Chouhan *et al*. (2017) conducted an experiment on wheat during two consecutive Rabi seasons 2013-15. The experiment consisted of three IW/CPE ratios in main plot, three sowing methods (line sowing, crisscross sowing and FIRB) and three weed control (weedy check, sulfosulfuron + metsulfuron(RM) and isoproturon + 2, 4-D (TM) at 35 DAS) measures in sub plot. IW/CPE ratio at 1.0 showed significant increase in plant height, dry mater accumulation at 60, 90 DAS and harvest and yield of wheat over IW/CPE ratio at 08. IW/CPE ratio at 1.2 and 1.0 gave significantly higher plant height by 8.79 and 5.96, 5.93 and 5.45and 7.92 and 6.05 % over IW/CPE ratio 0.8 level for all sowing method. Irrigation in the crop at IW/CPE ratio 1.0 recorded significantly highest dry matter accumulation at 60, 90 DAS and harvest over IW/ CPE ratio at 0.8.

In order to examine the effect of deficit irrigation on growth and productivity of bread wheat cultivars field experiment was conducted in Egypt, during the winter season 2015-17 having three irrigation regimes on five wheat cultivars (Sids 13, Gemmeiza 12, Sakha 94 and Misr 2). Plant growth parameters and yield parameters in addition to water productivity (WP) were determined and results showed that skipping irrigation significantly decreased plant growth and yield parameters in both seasons. Wheat plants irrigated five times showed maximum biomass weight, spikes plant^{-1}, spike length, grain weight spike^{-1}, and grain yield as compared to skip 2nd irrigation and skip 3rd irrigation. They concluded with statement that of full irrigations proved optimum for obtaining maximum grain yield and skipping 2nd irrigation treatment proved maximum water productivity with wheat cultivars (El-Gabry and Hashem 2018).

Different levels of supplemental irrigation regimes was implemented on four wheat (*Triticum aestivum* L.) genotypes in order to assess the effect of deficit irrigation pattern on yield traits performance and to determine most suitable genotype for local semi-arid conditions. The experimental result showed that supplemental irrigation improved the investigated genotypes yield (Aissaoui and Fenni, 2021).

In the semi-arid area of Pakistan an experiment was conducted to estimate the impact of number of irrigations on yield of wheat having three different irrigation treatments. The experimental result revealed that the grain yield and yield contributing parameters were significantly higher when crop was irrigated five irrigations. The highest grain yield was also recorded with five irrigations at different critical growth stages of wheat crop. They expressed that the possible reason might be availability of more moisture. Application of irrigation at tillering stage played a vital role to increase wheat yield and whereas irrigation at maturity caused decrease in wheat yield (Malik *et al*. 2010).

Chapter III

MATERIALS AND METHODS

The experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University, Dhaka during the period from November 2019 to March 2020 to observe the combined effect of Biochar and Phosphorus and different irrigation regime on growth and yield of wheat. This chapter contains a description of location of experimental plot, climatic variations, soil properties, treatments of the experiment, information of seeds, land preparation, experimental design used for this experiment, intercultural operations done during the work, fertilizers and pesticides used, data collection and analytical methods followed in this experiment. The details of this research methodology are given below:

3.1 Experimental site

The research work was conducted at the Sher-e-Bangla Agricultural University farm, Sher-e-Bangla Nagar, Dhaka during Rabi season of 2019 in the month of November.

3.2 Description of the location

3.2.1 Geographical Location

The experiment site was situated at $23^0 77'$ North latitude and $90^0 33'$ East longitude and altitude of this site is 8.6 meter above the sea level. The morphological characteristics of the experimental site are described in Table 1.

3.2.2 Agro-Ecological Region

The experimental field belongs to the Agro-Ecological Zone named 'The Madhupur Tract' AEZ 28.This region is a complex relief and soil developed over Madhupur clay. Eleven general soil types are exists in this area of which Deep red brown terrace, sallow red brown terrace soils and Acid basin clay are main. Soils in the valleys are dark grey heavy clay. In Fig. 24 the experimental site is shown in the map of AEZ of Bangladesh.

3.3 Climatic condition

The geographical location of the experimental site was under the subtropical climate, characterized by high temperature, high relative humidity and heavy rainfall with occasional gusty wind in Kharif season and scanty rainfall with low temperature during the Rabi season.

3.4 Description of soil

The soil of the experimental site belongs to the Tejgaon series under the Agro Ecological Zone Madhupur Tract (AEZ 28). The general soil type is Sallow Red Brown Terrace Soils. Top soil was silty clay in texture, olive-grey with common fine to medium distinct dark yellowish brown mottles. Soil pH was ranged from 5.5 to 5.8 .The experimental was flat having irrigation and drainage system and the selected plot was medium high land. The properties of soils of experimental site are given in Table 2.

Table 1. Morphological characteristics of the experimental field

Morphological Features	Characteristics
Location	Sher-e-Bangla Agricultural University
AEZ Number and Name	AEZ 28, Madhupur tract
General soil type	Sallow 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 properties of the experimental soil

Soil parameter	Value
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.Soil pH	5.5-5.8

3.5 Treatments of the experiment

The Treatment consists of two factors as follows:

3.5.1 Factor A: Level of irrigation

i. I_0 = Control (No irrigation)

ii. I_1 = Single irrigation at Crown Root Initiation (CRI)

iii. I_2 = Two irrigation at CRI +Flower Initiation (FI) stage

vi. I_3 =Three irrigation at CRI+FI+ Grain Filling (GF) stage

3.5.2 Factor B: Biochar and Phosphorus (P) management

i. BP_0= 5 ton Biochar per hectare

ii. BP_1 = 5 ton Biochar + 20 kg Phosphorus per hectare

iii. BP_2= 5 ton Biochar +15 kg Phosphorus per hectare

vi. BP_3 = 20 kg Phosphorus per hectare

3.5.3 Treatment combination:

After combining these two factors we got following 16 treatment combinations

I_0BP_0	**I_1BP_0**	**I_2BP_0**	**I_3BP_0**
I_0BP_1	**I_1BP_1**	**I_2BP_1**	**I_3BP_1**
I_0BP_2	**I_1BP_2**	**I_2BP_2**	**I_3BP_2**
I_0BP_3	**I_1BP_3**	**I_2BP_3**	**I_3BP_3**

3.6 Experimental Design and Layout of the experiment

The experiment was laid out in Split-plot design with 3 replications. There were 48 plots having the size 2.0m×1.0 m i.e. $2m^2$ and 16 treatment combinations were randomly distributed among these plots. Irrigation was assigned in the main plot and combination of Biochar and phosphorus was in sub-plot.

3.7 Seed collection

Seed of BARI Gom 30 was collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur, Bangladesh. It was heat tolerant variety released in 2014. This variety is short duration crop having 102-108 days duration. Plant height ranges from 95-100 cm having 4-5 tiller^{-1}. Grain color white, bright and medium sized. Yield varies from 4000-5000 kg ha^{-1}. This variety is claimed to be resistant to Leaf rust and Leas spot disease (Blight).

Figure 1: Sowing material BARI Gom 30

3.8 Preparation of the experimental site

At first the land was plough on 18th November with a power tiller and kept open to the sun for a week. Then the land was harrowed followed by laddering to obtain a good tilth. Weeds and stables were removed and the land was leveled. The experimental field was partitioned into the unit plots as per the experimental design.

3.9 Application of fertilizer

Fertilizers were applied as per recommendation (BARC, 2012).

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

The experimental site was fertilized with 220 kg urea, 50 kg MoP and Gypsum 120 kg ha^{-1} respectively. Urea, Muriate of Potash (MoP) and Gypsum were used as source of nitrogen, phosphorus and sulfur respectively. Urea, MoP and Gypsum were incorporated with the soil during final land preparation. 10 kg cow dung was also added to the soil as organic manure. Triple Super Phosphate (TSP) was used as source of phosphorus and applied to unit plots as per the treatment.

3.10 Application of Biochar

Biochar was collected from Manikgonj which was in black powdered form. Required amount of biochar was measured as per the treatment and applied to the individual plots having biochar treatment.

3.11 Sowing of seeds

Seeds were sown on 27th November 2019. Seeds of wheat (BARI Gom-30) were treated with Sevin to protect from ant. Seeds were sown in line and covered with soil. The line to line distance was 20cm. After sowing the whole field was covered with net to protect from birds and animals.

3.12 Intercultural operations

Various intercultural operations such as thinning, weeding and irrigations were done during the experiment.

3.12.1 Thinning and Weeding

Thinning was done at 15 DAS (Days After Sowing). The crop field was weeded twice where 1^{st} weeding was done at 20 DAS and 2^{nd} one was done at 40 DAS.

3.12.2 Irrigation

Three irrigations were done as per the treatments of the experiment. First irrigation was done 18 DAS during Crown Root Initiation (skipped in I_0 treated plots). Second irrigation was done during Flower Initiation (skipped in I_0 and I_1 treated plots). Third irrigation was done during Grain filling (skipped in I_0, I_1 and I_2 treated plots).

3.12.3 Protection against Insects and Pathogens

Wheat field was infested by cutworm as the experimental site was located near cabbage field. Along with that the plot was infected by Aphid also. For cutworm the filed was treated with Virtaco @ 40g/100 liter of water and sprayed. For preventing Aphid infestation the wheat field was treated with insecticide named Actara @ 200g/ha and foliar application was done.

3.13 Harvesting and Postharvest operations

Maturity of the crop was determined when 90% of the plants become golden yellow in color. Five plants from each unit plots were separated from which data for yield attributes were collected. $1m^2$ area from the middle of the each plots were harvested separately and bundled properly with the tags. They were brought to the threshing floor to obtain grain and straw data. The grains were cleaned and sun dried to moisture content 14%.

3.14 Recording of data

Experimental data were recorded from 20 days of sowing up to harvest at 20 days interval. Five plants from each plot was marked for data collection. Following data were recorded during the experiment.

3.15 Growth Parameters

3.15.1 Plant height

The height of five wheat plant was recorded in centimeter (cm) at 20, 40, 60, 80 DAS and at harvest. The height was measured from the ground level to the tip of the plant with the help of a meter scale.

3.15.2 Number of tillers hill^{-1}

The tiller number of five wheat plant was counted from each unit plot and the average value was recorded as data.

3.15.3 Leaf length

Leaf length of the flag leaf of five plants from each plot were measured in centimeter .The average value was recorded as data.

3.16 Yield Parameters

3.16.1 Number of ear plant^{-1}

Total number of ears was counted from ten random plants selected from each plot and average number was taken for data.

3.16.2 Spike length

Spike length was counted from ten random spikes and then averaged. This data was collected after harvest and expressed in Centimeter (cm).

3.16.3 Number of spikelet spike^{-1}

Total number of the spikelet per spike was counted from ten random spikes selected from each plot and then average number was taken for data.

3.16.4 Number of grains spike^{-1}

Total number of the grains spike^{-1} was counted from 10 random spikes and the average was recorded as data.

3.16.5 Weight of 1000-grain

One thousand grains were counted from grains obtained from each plot were cleaned properly. The weight was measured by balance and recorded as data. The weight was expressed in grams (g).

3.16.6 Grain yield

Grains obtained from 1m^2 of each plot was cleaned and dried properly. The weight was measured carefully in gram (g). Later they were converted into ton to obtain yield ha^{-1}.

3.16.7 Straw yield

Straw obtained from m^{-2} from each plot was sun dried and weighted. The weight of straw was obtained in gram (g) which was later converted into ton to obtain yield per ha.

3.16.8 Biological yield

Grain yield and straw yield form each plot together expressed the biological yield from each plot.

Biological yield was calculated with the following formula:

$$\text{Biological yield} = \text{Grain yield} + \text{Straw yield}$$

3.16.9 Harvest index

Harvest Index denotes the ratio of grain yield to biological yield and expressed in percentage.

The following formula was used to calculate harvesting index:

$$\text{Harvest Index (H.I.)} = (\text{Grain yield} \div \text{Biological yield}) \times 100$$

CHAPTER IV

RESULTS AND DISCUSSIONS

The present experiment was conducted to study the growth and yield response of wheat to different irrigation level and combination of biochar and phosphorus. Data on different growth and yield parameters were recorded. This chapter comprised with presentation and discussion from the result obtained from the study has been presented in Tables and Figures.

4.1 Growth parameters

4.1.1 Plant height

4.1.1.1 Effect of irrigation

Plant height of wheat was significantly influenced by different irrigation regimes at different days after sowing (DAS) of wheat seeds (Table 3). At 20 DAS, the highest plant height was recorded 29.51 cm for I_2 (Irrigation at CRI +FI stage) treatment and the lowest plant height was observed 25.99 cm in I_0 (Control). Accordingly, at 40DAS, 60DAS and 80DAS the highest plant height 49.77 cm, 75.88 cm and 90.41 cm was recorded from treatment I_2 and the lowest plant height 46.26 cm,72.62 cm and 86.45 cm was recorded for treatment I_0 (Control) respectively. At harvest the highest plant the height was observed 94.00 cm for I_2 treatment and the lowest plant height 89.32 cm from I_0 treatment. The plant height observed at 60 DAS, 80 DAS and at harvest was statistically similar in treatments I_3 (Irrigation at CRI+FI+ GF stage) and I_1 (Irrigation at CRI).

Baloch *et al*. (2014) and Islam (1997) also observed similar effect of irrigation on plant height,

Table 3. Effect of irrigation on plant height at different days after sowing

Treatments	Plant height (cm) at different days after sowing (DAS)				
	20	**40**	**60**	**80**	**At harvest**
I_0	25.99 c	46.26 c	72.62 c	86.45 c	89.32 c
I_1	27.27 b	47.34 bc	74.57 ab	88.20 b	91.76 b
I_2	29.51 a	49.77 a	75.88 a	90.41 a	94.00 a
I_3	26.97 bc	48.22 b	73.92 bc	87.51 bc	91.45 b
CV (%)	4.26	2.60	2.43	1.76	2.21
$LSD_{(0.05)}$	1.17	1.2459	1.80	1.60	2.025
Level of significance	**	**	*	**	**

** indicated 1% level of significance and * indicates 5% level of significance
I_0 = Control, I_1 = At Crown Root Initiation (CRI), I_2 = At CRI +Flower Initiation (FI) stage, I_3 =At CRI+FI+ Grain Filling (GF) stage

4.1.1.2 Effect of biochar and phosphorus

Addition of different level of biochar and phosphorus showed significant variation on plant height of wheat (Table 4). The highest plant heights 29.74 cm, 50.06 cm, 76.49 cm and 91.19 cm was recorded for treatment BP_2 (5 ton biochar +15 kg phosphorus ha^{-1}) and the lowest plant height 24.95 cm, 46.06 cm, 72.22 cm and 84.92 cm was from treatment BP_3 (20 kg biochar ha^{-1}) at 20 DAS, 40 DAS, 60 DAS and 80 DAS respectively. It was observed that plant height obtained from BP_0 (5 ton Biochar ha^{-1}) and BP_1 (5 ton Biochar + 20 kg Phosphorus ha^{-1}) were statistically similar at 20 DAS, 40 DAS, 60 DAS and 80 DAS. At harvest maximum plant height 95.33 cm was recorded in BP_2 treatment and lowest 88.13 cm from BP_3 treatment. It was observed that the tallest plant height was obtained when irrigation was done at Crown root initiation and flowering stage.

Alburquerque *et al*. (2013) observed that biochar act as a source of available phosphorus leading to improving yield.

Table 4. Effect of biochar and phosphorus on plant height at different days after sowing

Treatments	Plant height (cm) at different days after sowing (DAS)				
	20	40	60	80	At harvest
BP_0	27.85 b	47.48 b	73.77 b	88.34 b	91.41 b
BP_1	27.21 b	47.98 b	74.49 b	88.12 b	91.66 b
BP_2	29.74 a	50.06 a	76.49 a	91.19 a	95.33 a
BP_3	24.95 c	46.06 c	72.22 c	84.92 c	88.13 c
CV (%)	4.95	3.00	1.79	2.12	2.09
$LSD_{(0.05)}$	1.14	1.21	1.12	1.61	1.61
Level of significance	**	**	**	**	**

** indicated 1% level of significance

BP_0= 5 ton Biochar ha^{-1}, BP_1 =5 ton Biochar + 20 kg Phosphorus ha^{-1}, BP_2=5 ton Biochar +15 kg Phosphorus ha^{-1}, BP_3 =20 kg Phosphorus ha^{-1}

4.1.1.3 Interaction effect of irrigation with biochar and phosphorus

Application of biochar and phosphorus along with different irrigation level showed non significant influence on plant height of wheat (Table 5). At 20 DAS, the highest plant height 32.96 cm was recorded in I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}) treatment and the lowest plant height 21.97 cm was recorded in treatment I_0BP_3 (Control and 20 kg biochar ha^{-1}) . Similarly at 40 DAS, 60 DAS and 80 DAS the highest plant height 52.61 cm, 79.72 cm and 95.64 cm was recorded in I_2BP_2 treatment and the lowest plant height 43.37 cm, 69.49 cm and 82.27 cm was recorded in treatment I_3BP_3 respectively. Plant height 85.29 cm and 82.27 cm in treatment I_0BP_3 was statistically similar. After harvest the highest plant height 100.16 cm was recorded in treatment I_2BP_2 and the lowest plant height 84.78 cm was recorded in treatment I_0BP_3. It was noticed that application of biochar improved irrigation efficiency of wheat. Bakry *et al.*, (2015) studied the combined effect of biochar and irrigation and it evaluated that plant height was increased with application of biochar and irrigation stress.

Table 5. Interaction effect of irrigation with biochar and phosphorus on plant height at different days after sowing

Treatments	Plant height (cm) at different days after sowing (DAS)				
	20	40	60	80	At harvest
I_0BP_0	27.59 b-d	46.42 e	72.58 ef	88.84 c-f	89.82 ef
I_0BP_1	26.69 c-e	46.89 de	73.76 c-f	86.24 ef	90.30 d-f
I_0BP_2	27.73 b-d	48.36 b-e	74.63 c-f	88.45 d-f	92.37 b-e
I_0BP_3	21.97 f	43.37 f	69.49 g	82.27 g	84.78 g
I_1BP_0	26.91 c-e	47.06 c-e	74.330 c-f	88.28 c-f	91.16 c-f
I_1BP_1	26.93 c-e	46.85 de	73.53 c-f	87.59 c-f	91.47 c-f
I_1BP_2	29.60 b	49.37 bc	75.72 bc	91.63 b	95.02 b
I_1BP_3	25.64 de	46.07 e	74.69 b-e	85.29 fg	89.38 ef
I_2BP_0	29.66 b	49.06 b-d	75.38 b-d	89.39 b-d	93.64 b-d
I_2BP_1	28.27 bc	50.00 b	76.37 b	90.44 bc	93.53 b-d
I_2BP_2	32.96 a	52.61 a	79.72 a	95.64 a	100.16 a
I_2BP_3	27.17 c-e	47.39 c-e	72.05 fg	86.17 ef	88.69 f
I_3BP_0	27.26 c-e	47.40 c-e	72.77 d-f	86.83 d-f	91.02 c-f
I_3BP_1	26.95 c-e	48.18 b-e	74.33 c-f	88.22 c-f	91.35 c-f
I_3BP_2	28.67 bc	49.91 b	75.91 bc	89.06 b-e	93.77 bc
I_3BP_3	25.01 e	47.39 c-e	72.66 ef	85.95 ef	89.67 ef
CV (%)	4.95	3.00	1.79	2.12	2.09
$LSD_{(0.05)}$	2.28	2.42	2.23	3.30	3.22
Level of significance	NS	NS	**	NS	NS

** indicated 1% level of significance and NS indicates not significant

I_0BP_0=Control and 5 t ha^{-1} biochar, I_0BP_1=Control and 5 t ha^{-1} biochar + 20 kg ha^{-1} P, I_0BP_2= Control and 5 t ha^{-1} biochar + 15 kg ha^{-1} P, I_0BP_3= Control and 20 kg ha^{-1} P, I_1BP_0= Irrigation at CRI and 5 t ha^{-1} biochar, I_1BP_1= Irrigation at CRI and 5 t ha^{-1} biochar + 20 kg ha^{-1} P,I_1BP_2 = Irrigation at CRI and 5 t ha^{-1} biochar + 15 kg ha^{-1} P,I_1BP_3= Irrigation at CRI and 20 kg ha^{-1} P,I_2BP_0= Irrigation at CRI+FI and 5 t ha^{-1} biochar, I_2BP_1= Irrigation at CRI+FI and 5 t ha^{-1} biochar + 20 kg ha^{-1} P, I_2BP_2= Irrigation at CRI+FI and 5 t ha^{-1} biochar + 15 kg ha^{-1} P, I_2BP_3= Irrigation at CRI+FI and 20 kg ha^{-1} P, I_3BP_0= Irrigation at CRI+FI+GF and 5 t ha^{-1} biochar, I_3BP_1= Irrigation at CRI+FI+GF and 5 t ha^{-1} biochar + 20 kg ha^{-1} P, I_3BP_2= Irrigation at CRI+FI+GF and 5 t ha^{-1} biochar + 15 kg ha^{-1} P, I_3BP_3= Irrigation at CRI+FI+GF and 20 kg ha^{-1} P.

4.1.2 Number of tillers hill^{-1}

4.1.2.1 Effect of irrigation

Number of tillers hill^{-1} showed significant difference for different level of irrigation at 20 DAS, 40 DAS, 60 DAS and 80 DAS (Table 6). At 20 DAS maximum number of tillers hill^{-1} (1.52) in treatment I_2 and minimum number of tillers hill^{-1} (1.25) was recorded in treatment I_0. Number of tillers hill^{-1} (1.34) and (1.32) was recorded in treatment I_1 and I_3 which was statistically similar to I_0. At 40 DAS, maximum number of tillers hill^{-1} (3.06) was recorded in treatment I_2 which is statistically similar to number of tillers hill^{-1} (2.89) in I_1 and minimum number of tiller hill^{-1} (2.51) was recorded in treatment I_0 statistically similar to number of tillers hill^{-1} (2.59) in I_3. At 60 and 80 DAS, maximum number of tillers hill^{-1} (4.45 and 4.71) was recorded in treatment I_2 and minimum number of tillers hill^{-1} (3.31 and 3.58) was in treatment I_3. Number of tillers hill^{-1} in treatment I_1 and I_3 are statistically similar at 60 DAS (3.87 and 3.82) and 80 DAS (4.18 and 4.11) respectively. Shirazi *et al*. (2014) studied the effect of irrigation on number of tiller which showed significant influence on wheat.

Table 6. Effect of irrigation on number of tillers hill^{-1} at different days after sowing

Treatments	Number of tillers at different days after sowing (DAS)			
	20	**40**	**60**	**80**
I_0	1.25 b	2.51 c	3.31 b	3.58 b
I_1	1.32 b	2.89 ab	3.82 b	4.11 ab
I_2	1.52 a	3.06 a	4.45 a	4.71 a
I_3	1.34 b	2.59 bc	3.87 ab	4.18 ab
CV (%)	10.06	12.64	15.17	15.10
$LSD_{(0.05)}$	0.14	0.35	0.58	0.63
Level of significance	**	*	**	*

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

I_0 = Control, I_1 = At Crown Root Initiation (CRI), I_2 = At CRI +Flower Initiation (FI) stage, I_3 =At CRI+FI+ Grain Filling (GF) stage

4.1.2.2 Effect of biochar and phosphorus

At 20 DAS, maximum number of tillers hill^{-1} (1.55) was recorded in treatment BP_2 and minimum number of tillers hill^{-1} (1.06) was recorded in treatment BP_3. Number of tillers hill^{-1} in BP_2 and BP_0 (1.36 and 1.46) are statistically similar. At 40, 60 and 80 DAS maximum number of tillers hill^{-1} (3.21, 4.71 and 4.94) was observed in treatment BP_2 and minimum number of tillers hil^{-1} (2.29, 2.98 and 3.26) was in treatment BP_3 respectively. Number of tillers per hill in treatment BP_0 and BP_1 are statistically similar for different DAS. Kamara *et al*. (2015) also stated that application of biochar increases tiller number.

Table 7. Effect of Biochar and Phosphorus on number of tillers hill^{-1} at different days after sowing

Treatments	Number of tillers at different days after sowing (DAS)			
	20	**40**	**60**	**80**
BP_0	1.46 ab	2.85 b	3.74 b	4.05 b
BP_1	1.36 b	2.71 b	4.02 b	4.32 b
BP_2	1.55 a	3.21a	4.71 a	4.94 a
BP_3	1.06 c	2.29 c	2.98 c	3.26 c
CV (%)	8.99	10.26	10.33	10.79
$LSD_{(0.05)}$	0.10	0.24	0.34	0.38
Level of significance	**	**	**	**

** indicated 1% level of significance and

BP_0= 5 ton Biochar ha^{-1}, BP_1 =5 ton Biochar + 20 kg Phosphorus ha^{-1}, BP_2=5 ton Biochar +15 kg Phosphorus ha^{-1}, BP_3 =20 kg Phosphorus ha^{-1}

4.1.2.3 Interaction effect of irrigation with biochar and phosphorus

Number of tillers hill^{-1} of wheat showed statistically non significant variation due to interaction of different irrigation level with biochar and phosphorus (Table 8). At 20 DAS, maximum number of tillers hill^{-1} (1.77) was recorded in treatment I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}) and minimum number of tillers hill^{-1} (1.03) was recorded in treatment I_0BP_3 (Control and 20 kg biochar ha^{-1}). Similarly at 40DAS, 60DAS and 80DAS maximum number of tillers hill^{-1}(3.46, 5.49 and 5.64) was recorded in treatment I_2BP_2 and minimum tillers hill^{-1} (1.60, 1.96 and 2.23) in treatment I_0BP_3.

Table 8. Interaction effect of irrigation with biochar and phosphorus on number of tillers hill^{-1} at different days after sowing

Treatments	Number of tiller at different days after sowing (DAS)			
	20	**40**	**60**	**80**
I_0BP_0	1.27 e-h	2.69 cd	3.62 e	3.91 e
I_0BP_1	1.19 f-i	2.58 cd	3.71 de	3.95 e
I_0BP_2	1.49 b-d	3.18 a	3.94 c-e	4.24 c-e
I_0BP_3	1.03 i	1.60 e	1.96 f	2.23 f
I_1BP_0	1.42 b-f	2.85 bc	3.46 e	3.78 e
I_1BP_1	1.37 c-f	2.68 c	3.94 c-e	4.24 cd
I_1BP_2	1.47 b-e	3.42 a	4.59 bc	4.75 b-d
I_1BP_3	1.04 i	2.62 cd	3.29 e	3.65 e
I_2BP_0	1.60 ab	3.18 a	4.50 b-d	4.84 bc
I_2BP_1	1.59 a-c	2.99 a-c	4.57 bc	4.87 bc
I_2BP_2	1.77 a	3.46 a	5.49 a	5.64 a
I_2BP_3	1.09 g-i	2.61 cd	3.23 e	3.47 e
I_3BP_0	1.54 a-c	2.70 b-d	3.35 e	3.68 e
I_3BP_1	1.28 d-g	2.58 cd	3.88 c-e	4.22 c-e
I_3BP_2	1.48 b-e	2.76 b-d	4.81 ab	5.12 a
I_3BP_3	1.06 hi	2.34 e	3.43 e	3.70 e
CV (%)	8.99	10.26	10.33	10.79
$LSD_{(0.05)}$	0.20	0.48	0.67	0.753
Level of significance	NS	NS	*	NS

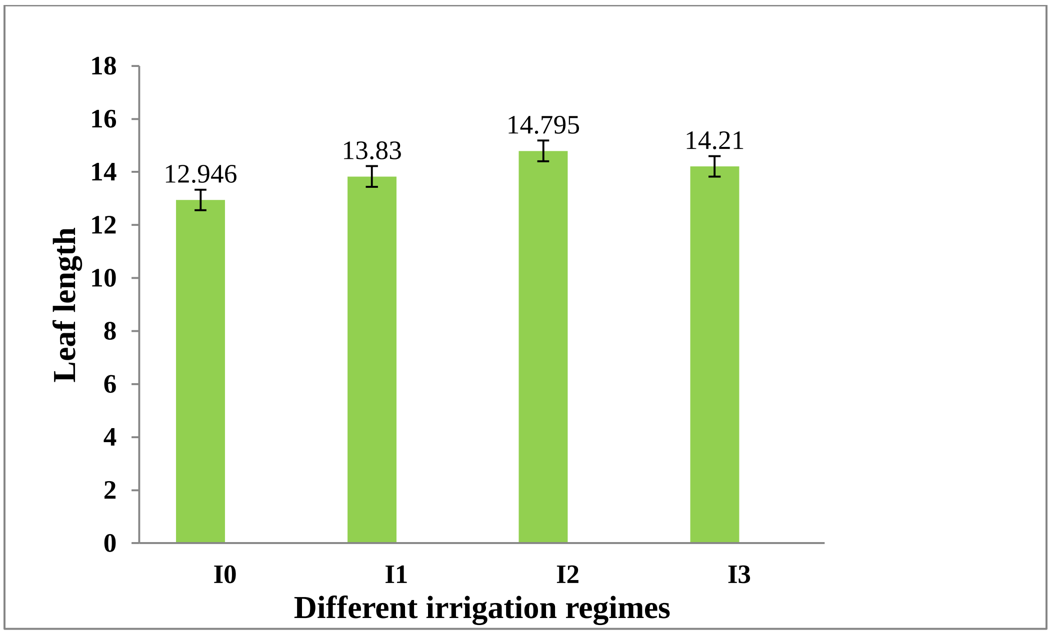
* indicates 5% level of significance and NS indicates not significant

I_0BP_0=Control and 5 t ha^{-1} biochar, I_0BP_1=Control and 5 t ha^{-1} biochar + 20 kg ha^{-1} P, I_0BP_2= Control and 5 t ha^{-1} biochar + 15 kg ha^{-1} P, I_0BP_3= Control and 20 kg ha^{-1} P, I_1BP_0= Irrigation at CRI and 5 t ha^{-1} biochar,I_1BP_1= Irrigation at CRI and 5 t ha^{-1} biochar + 20 kg ha^{-1} P,I_1BP_2 = Irrigation at CRI and 5 t ha^{-1} biochar + 15 kg ha^{-1} P, I_1BP_3= Irrigation at CRI and 20 kg ha^{-1} P,I_2BP_0= Irrigation at CRI+FI and 5 t ha^{-1} biochar, I_2BP_1= Irrigation at CRI+FI and 5 t ha^{-1} biochar + 20 kg ha^{-1} P, I_2BP_2= Irrigation at CRI+FI and 5 t ha^{-1} biochar + 15 kg ha^{-1} P, I_2BP_3= Irrigation at CRI+FI and 20 kg ha^{-1} P, I_3BP_0= Irrigation at CRI+FI+GF and 5 t ha^{-1} biochar, I_3BP_1= Irrigation at CRI+FI+GF and 5 t ha^{-1} biochar + 20 kg ha^{-1} P, I_3BP_2= Irrigation at CRI+FI+GF and 5 t ha^{-1} biochar + 15 kg ha^{-1} P, I_3BP_3= Irrigation at CRI+FI+GF and 20 kg ha^{-1} P.

4.1.3 Leaf length

4.1.3.1 Effect of irrigation

Leaf length at 60 DAS, of wheat was significantly influenced by different irrigation (Fig. 2). The highest leaf length (14.79 cm) was recorded in treatment I_2 (Irrigation at CRI +FI stage) and the lowest leaf length (12.95 cm) was recorded in treatment I_0 (Control). Leaf lengths (14.21 cm and 13.83 cm) obtained from treatment I_3 (Irrigation at CRI+FI+ GF stage) and I_1 (Irrigation at CRI) are statistically similar.

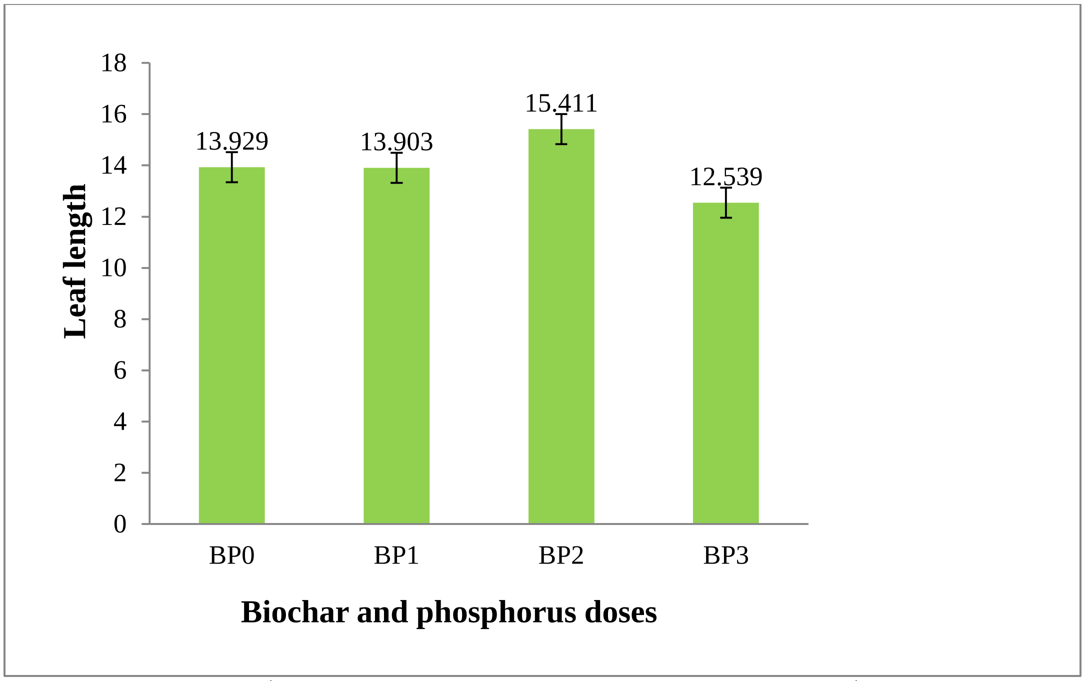


I_0 = Control, I_1 = At Crown Root Initiation (CRI), I_2 = At CRI +Flower Initiation (FI) stage, I_3 =At CRI+FI+ Grain Filling (GF) stage

Figure 2. Effect of different irrigation regime on leaf length of wheat plant ($LSD_{0.05}$=0.67).

4.1.3.2 Effect of biochar and phosphorus

Biochar and phosphorus shows significant impact on leaf length (Fig. 3). The highest leaf length (15.41 cm) was recorded in treatment BP_2 and the lowest leaf length (12.54 cm) was from treatment BP_3. Leaf length (13.93 cm and 13.90 cm) obtained from treatment BP_0 and BP_1 are seems statistically similar.



BP_0= 5 ton Biochar ha^{-1}, BP_1 =5 ton Biochar + 20 kg Phosphorus ha^{-1}, BP_2=5 ton Biochar +15 kg Phosphorus ha^{-1}, BP_3 =20 kg Phosphorus ha^{-1}

Figure 3. Effect of biochar and phosphorus on leaf length of wheat plant ($LSD_{0.05}$=0.58).

4.1.3.3 Interaction effect of irrigation with biochar and phosphorus

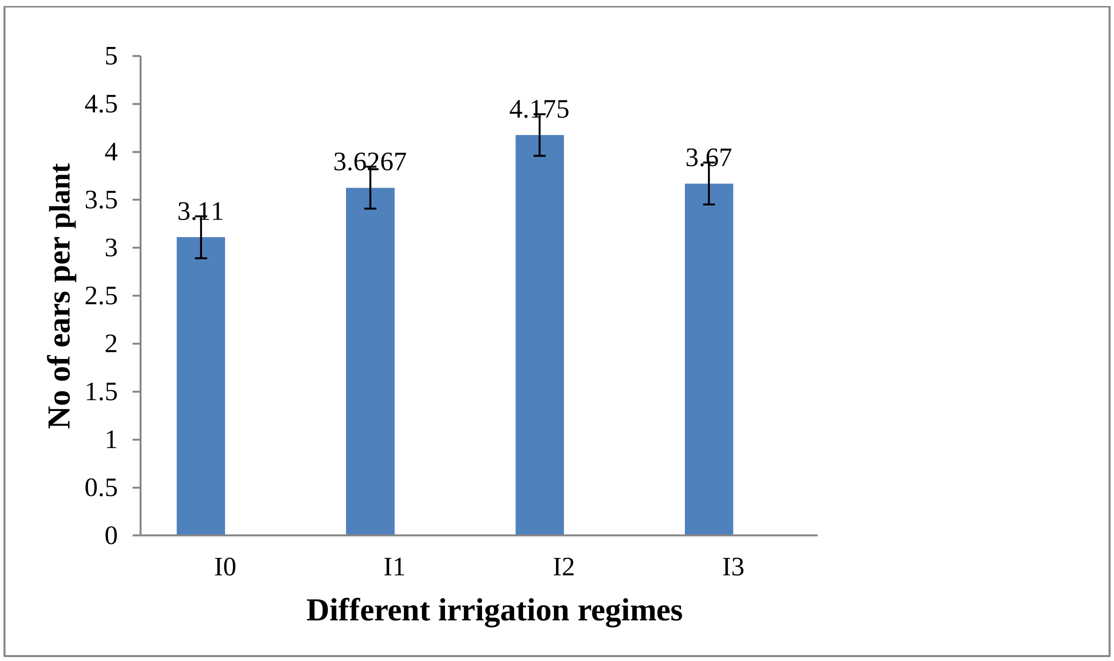
Combined application of different doses of biochar and phosphorus along with different irrigation regime had not significant effect on leaf length of wheat (Table 9). It was observed that highest leaf length (16.92 cm) was recorded in treatment I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}) and lowest leaf length (11.0 cm) was recorded in treatment I_0BP_3 (Control Irrigation and 20 kg biochar ha^{-1}).

4.2 Yield parameters

4.2.1 Number of ear per plant

4.2.1.1 Effect of irrigation

Ear/head formation of wheat had significantly influenced by different irrigation regime (Fig. 4 and Appendix 1). Maximum number of ear plant^{-1} (4.18) was recorded in treatment I_2 (Irrigation at CRI +FI stage) whereas minimum number of ear plant^{-1} (3.11) in I_0 (Control) treatment. Number of ear plant^{-1} (3.67 and 3.63) in treatment I_3 (Irrigation at CRI+FI+ GF stage) and I_1 (irrigation at CRI) are statistically similar.

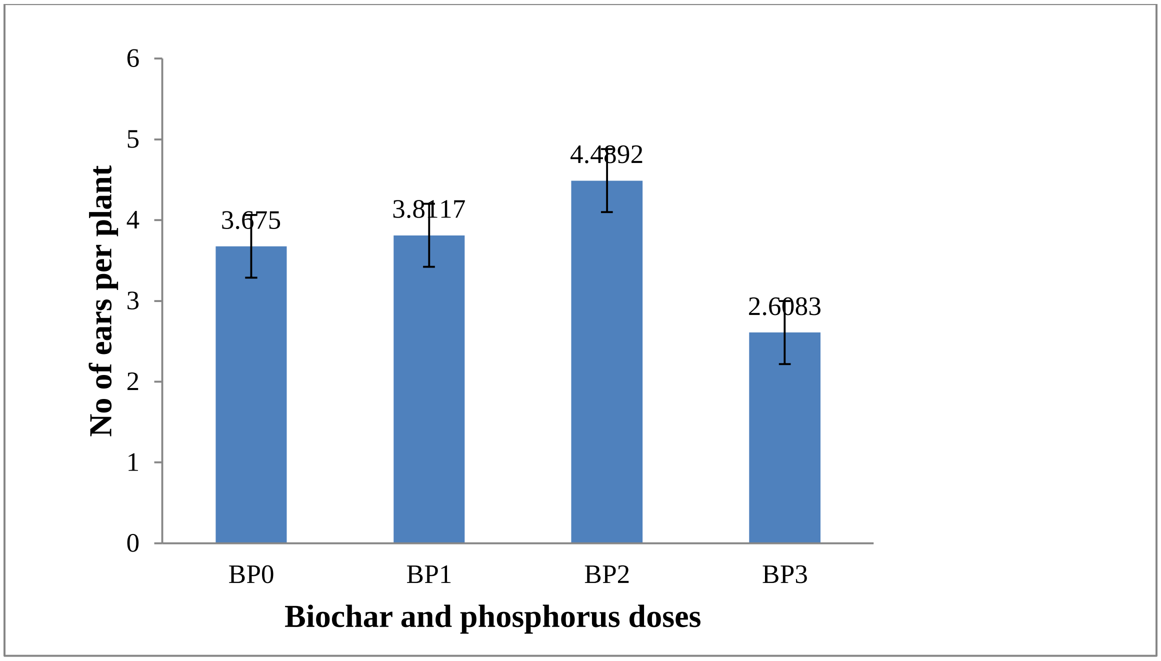


I_0 = Control, I_1 = At Crown Root Initiation (CRI), I_2 = At CRI +Flower Initiation (FI) stage, I_3 =At CRI+FI+ Grain Filling (GF) stage

Figure 4. Effect of different irrigation regime on number of ear per plant of wheat ($LSD_{0.05}$=0.54).

4.2.1.2 Effect of biochar and phosphorus

Different doses of biochar and phosphorus have shown significant effect on number of ear per plant in wheat (Fig. 5 and Appendix 2). Highest number of ear $plant^{-1}$ (4.49) was recorded in treatment BP_2 and lowest number of ear $plant^{-1}$ (2.61) was recorded in treatment BP_3. Treatment BP_0 and BP_1 gives statistically similar result (3.68 and 3.81) in case of number of ear per plant.



BP_0= 5 ton Biochar ha^{-1}, BP_1 =5 ton Biochar + 20 kg Phosphorus ha^{-1}, BP_2=5 ton Biochar +15 kg Phosphorus ha^{-1}, BP_3 =20 kg Phosphorus ha^{-1}

Figure 5: Effect of biochar and phosphorus doses on number of ear per plant of wheat ($LSD_{0.05}$=0.43).

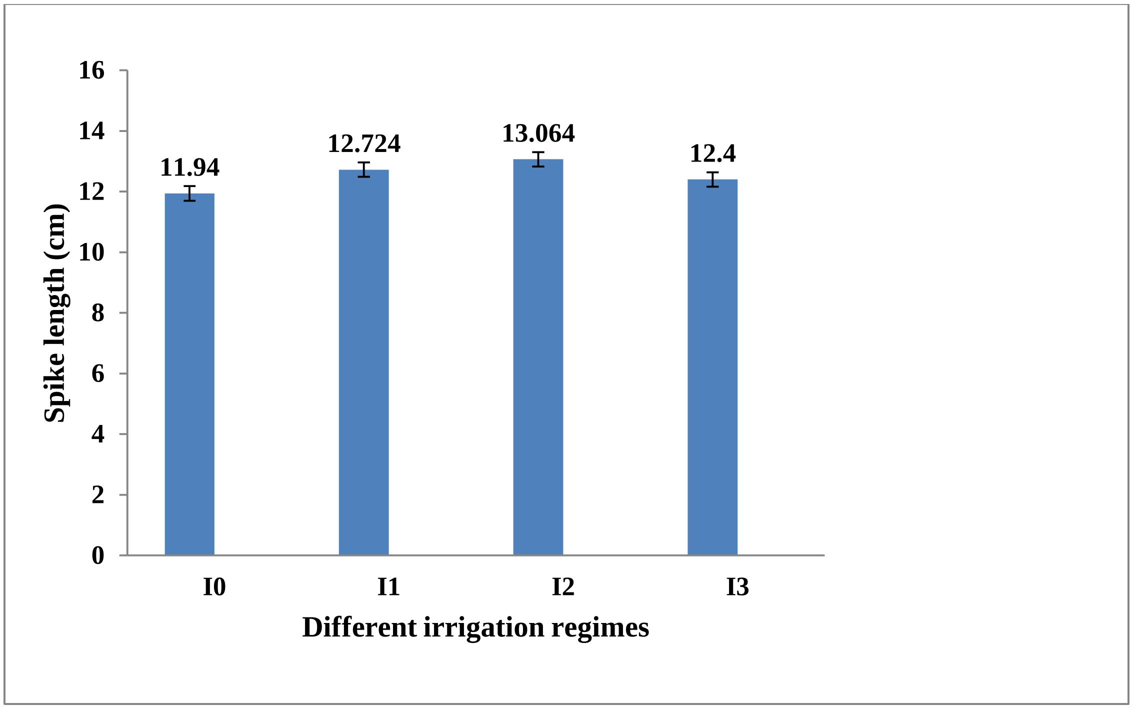
4.2.1.3 Interaction effect of irrigation with biochar and phosphorus

Interaction effect of irrigation with biochar and phosphorus showed not significant influences on number of ear per plant (Table 9). Maximum number of ear plant^{-1} (5.37) was recorded from treatment I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}) which is statistically similar (4.7) with treatment I_3BP_2 (Irrigation at CRI+FI+ GF stage and 5 ton Biochar +15 kg Phosphorus ha^{-1}). Lowest number of ear plant^{-1} (1.67) was recorded from treatment I_0BP_3 (Control Irrigation and 20 kg biochar ha^{-1}).

4.2.2 Spike length (cm)

4.2.2.1 Effect of irrigation

In case of wheat different irrigation regime shows significant effect on spike length of wheat (Fig. 6 and Appendix 1). The longest spike (13.06 cm) was observed in treatment I_2 (Irrigation at CRI +FI stage) which is statistically similar to ear length (12.72 cm) obtained from treatment I_1 (Irrigation at CRI). The shortest ear/head length (11.94 cm) was recorded from treatment I_0 (Control) which is statistically similar to I_3 (12.41). Narolia *et al*., (2016) also studied significant influence of irrigation on spike length of wheat.

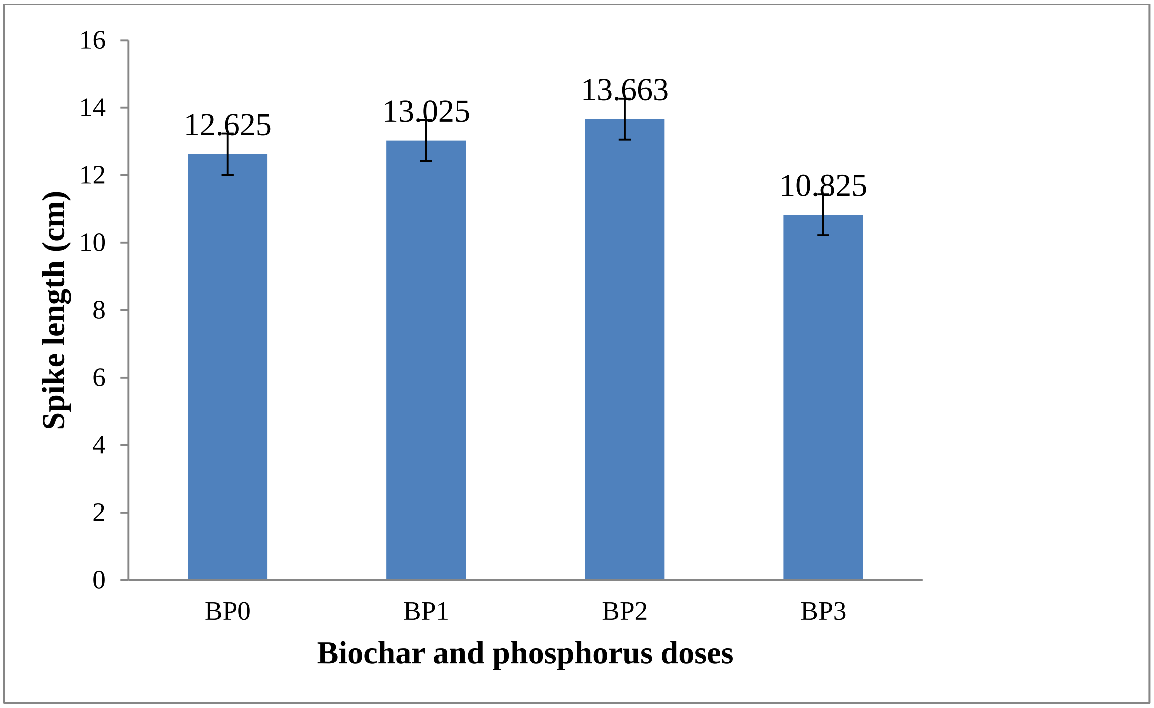


I_0 = Control, I_1 = At Crown Root Initiation (CRI), I_2 = At CRI +Flower Initiation (FI) stage,I_3 =At CRI+FI+ Grain Filling (GF) stage

Figure 6. Effect of different irrigation regime on spike length of wheat plant ($LSD_{0.05}$=0.56).

4.2.2.2 Effect of biochar and phosphorus

Wheat shows significant variation in respect of spike length when biochar and phosphorus applied in different doses (Fig. 7 and Appendix 2). Among different doses of biochar and phosphorus highest ear length (13.66 cm) was recorded in treatment BP_2 (5 ton Biochar +15 kg Phosphorus ha^{-1}). On the other hand, lowest ear length (10.83 cm) was recorded in treatment BP_3 where only 20 kg phosphorus ha^{-1} was applied. Ear lengths (12.63 cm and 13.03 cm) obtained from treatment BP_0 (5 ton Biochar ha^{-1}) and BP_1 (5 ton Biochar + 20 kg Phosphorus ha^{-1}) are statistically similar.



BP_0= 5 ton Biochar ha^{-1}, BP_1 =5 ton Biochar + 20 kg Phosphorus ha^{-1}, BP_2=5 ton Biochar +15 kg Phosphorus ha^{-1}, BP_3 =20 kg Phosphorus ha^{-1}

Figure 7. Effect of biochar and phosphorus on spike length of wheat ($LSD_{0.05}$=0.47).

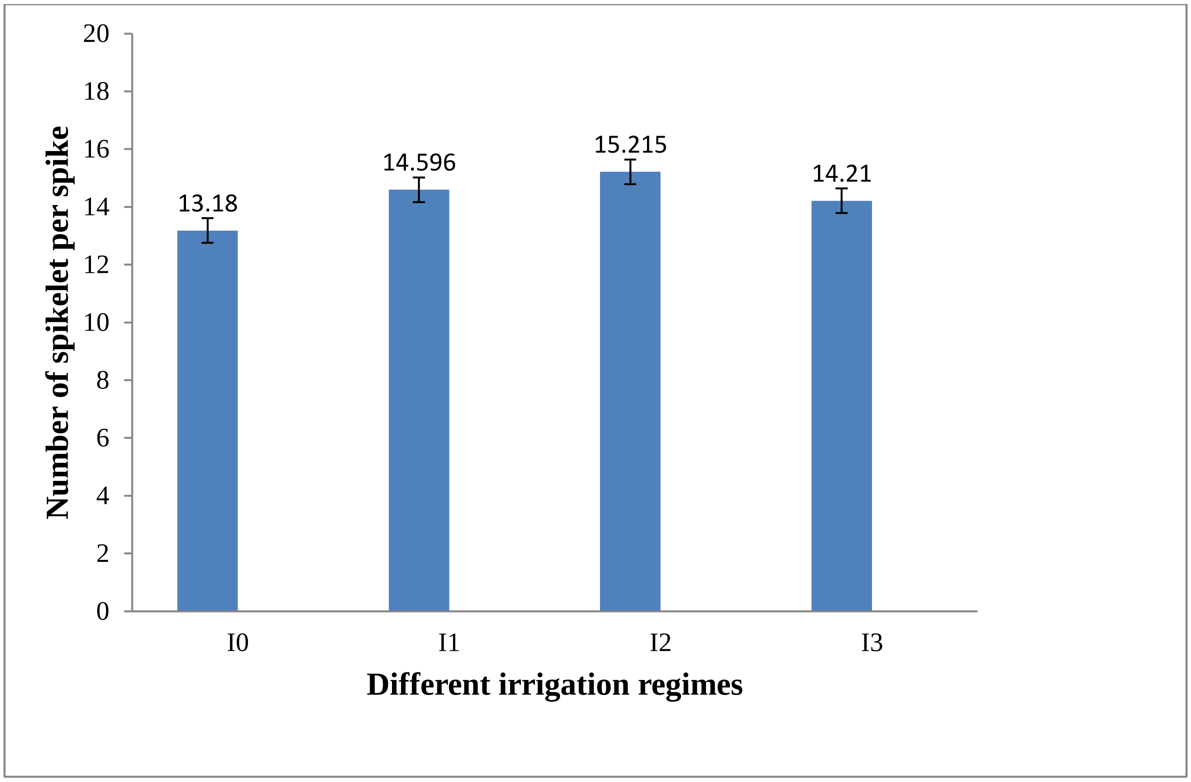
4.2.2.3 Interaction effect of irrigation with biochar and phosphorus

Combined application of different doses of biochar and phosphorus with different irrigations had significant effect on ear length of wheat (Table 9). It was observed that the highest ear length (14.86 cm) was recorded from treatment I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}). On the other hand lowest ear length (9.25 cm) was observed in treatment I_0BP_3 (Control Irrigation and 20 kg biochar ha^{-1}). Mumtaz *et al*., (2014) observed that spike length of wheat was reduced for lower rate of P with water stress. In this following experiment application of biochar improved yield under low rate of P and water stress.

4.2.3 Number of Spikelet per spike

4.2.3.1 Effect of irrigation

Significant variation was observed in case of number of spikelet spike^{-1} of wheat when different irrigation regime was applied (Fig. 8 and Appendix 1). Maximum number of spikelet spike^{-1} (15.21) was obtained from treatment I_2 Where irrigation was applied at CRI and FI stage. On the other hand minimum number of spikelet spike^{-1} (13.18) was recorded form treatment I_0 (Control).

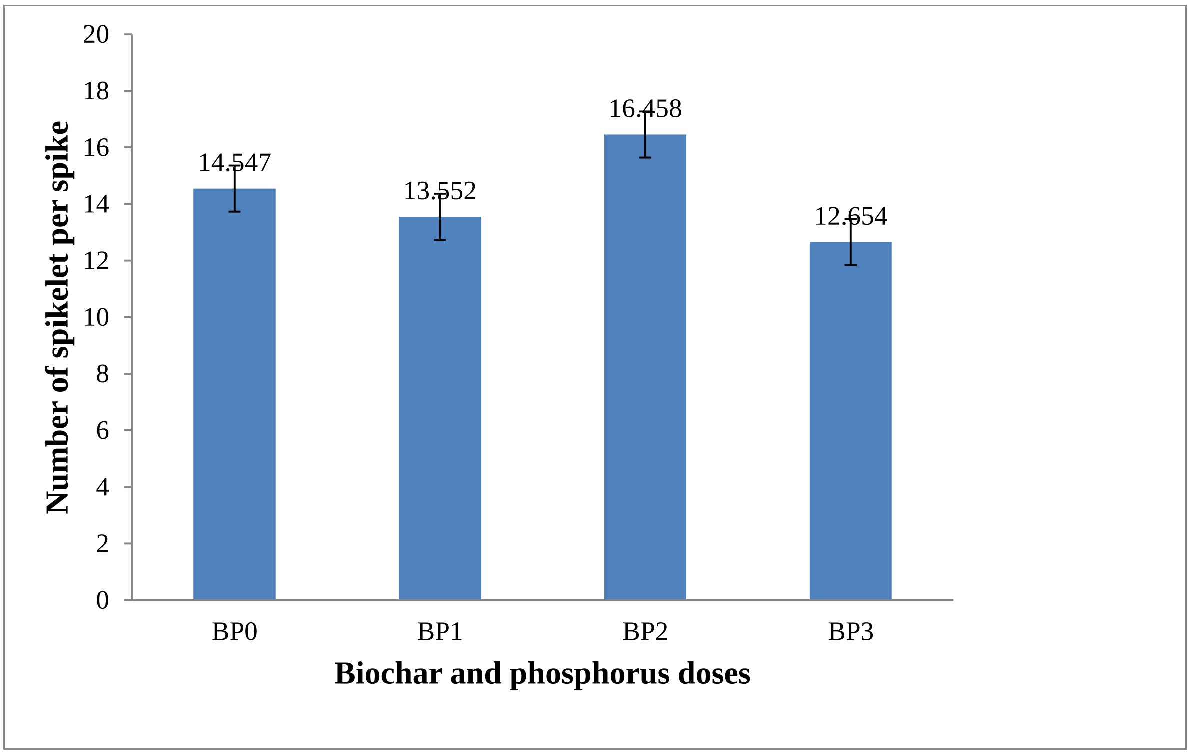


I_0 = Control, I_1 = At Crown Root Initiation (CRI), I_2 = At CRI +Flower Initiation (FI) stage,
I_3 =At CRI+FI+ Grain Filling (GF) stage

Figure 8. Effect of irrigation on number of spikelet per spike ($LSD_{0.05}$=0.31).

4.2.3.2 Effect of biochar and phosphorus

Application of different doses of biochar and phosphorus had shown significance influence on number of spikelet spike^{-1} of wheat (Fig. 9 and Appendix 2). Maximum number of spikelet per spike (16.46) was recorded in treatment BP_2 (5 ton Biochar +15 kg Phosphorus ha^{-1}) and minimum number of spikelet per spike (12.65) was recorded in treatment BP_3 (20 kg Phosphorus ha^{-1}).



BP_0= 5 ton Biochar ha^{-1}, BP_1 =5 ton Biochar + 20 kg Phosphorus ha^{-1}, BP_2=5 ton Biochar +15 kg Phosphorus ha^{-1}, BP_3 =20 kg Phosphorus ha^{-1}

Figure 9. Effect of biochar and phosphorus on number of spikelet per spike ($LSD_{0.05}$=0.36).

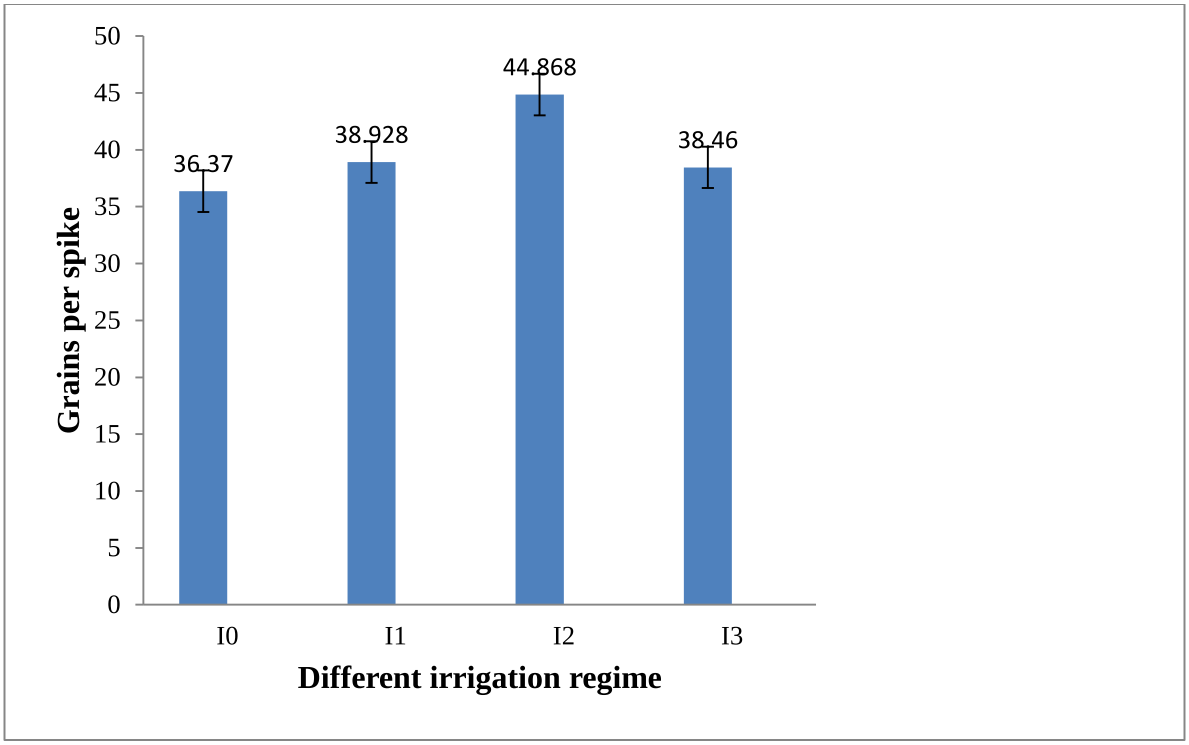
4.2.3.3 Interaction effect of irrigation with biochar and phosphorus

Combined application of different doses of biochar and phosphorus along with different irrigation regime showed significant variation on number of spikelet spike^{-1} of wheat (Table 9). It was recorded that maximum number of spikelet spike^{-1} (17.76) was obtained from treatment I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}). On the other minimum number of spikelet spike^{-1} (11.01) was recorded in treatment I_0BP_3 (Control Irrigation and 20 kg biochar ha^{-1}).

4.2.4 Number of grains spike^{-1}

4.2.4.1 Effect of irrigation

Significant variation was observed on number of grains spike^{-1} of wheat when different irrigation was applied (Fig. 10 and Appendix 1). Highest number of grains spike^{-1} (44.87) was recorded in I_2 treated plot (Irrigation at CRI +FI stage). On the other hand lowest number of grains spike^{-1} (36.37) was recorded in treatment I_0 (Control). Number of grains spike^{-1} (38.46 and 38.92) obtained from treatment I_3 (Irrigation at CRI+FI+GF) and I_1 (Irrigation at CRI) was statistically similar. Mishra and Padmakar (2010) observed significant influence of irrigation number of grains spike^{-1} in wheat production.

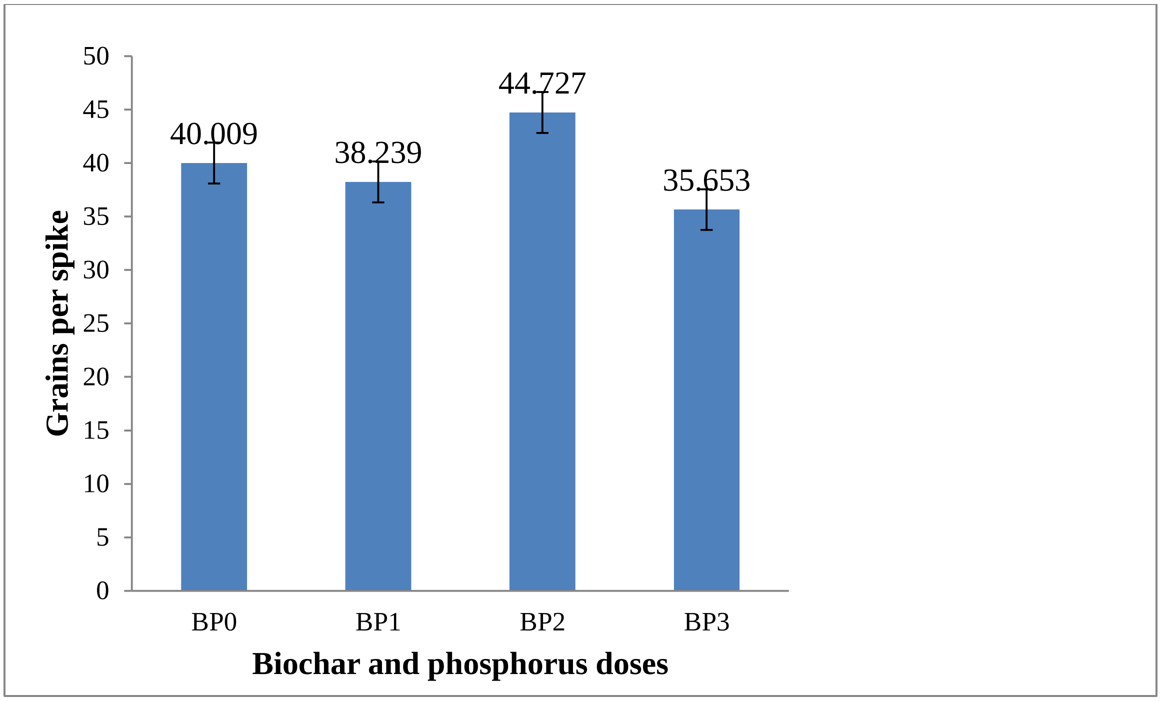


I_0 = Control, I_1 = At Crown Root Initiation (CRI), I_2 = At CRI +Flower Initiation (FI) stage,I_3 =At CRI+FI+ Grain Filling (GF) stage

Figure 10. Effect of irrigation on grains spike^{-1} of wheat ($LSD_{0.05}$=2.65).

4.2.4.2 Effect of biochar and phosphorus

Significant influence on grains spike^{-1} was observed in case of different doses of biochar and phosphorus doses (Fig. 11 and Appendix 2). Highest number of grains spike^{-1} (44.73) was recorded in treatment BP_2 (5 ton Biochar +15 kg Phosphorus ha^{-1}). On the other hand lowest number of grains spike^{-1} (35.65) was recorded in plots treated with BP_3 (20 kg Phosphorus ha^{-1}). Kaleem *et al.*, (2009) and Mamun *et al.*, (2012) noticed that phosphorus fertilizer can influence number of grains spike^{-1} of wheat



BP_0= 5 ton Biochar ha^{-1}, BP_1 =5 ton Biochar + 20 kg Phosphorus ha^{-1}, BP_2=5 ton Biochar +15 kg Phosphorus ha^{-1}, BP_3 =20 kg Phosphorus ha^{-1}

Figure 11. Effect of biochar and phosphorus on number of grains spike^{-1} ($LSD_{0.05}$=1.65).

4.2.4.3 Interaction effect of irrigation with biochar and phosphorus

In case of interaction effect of different irrigation with biochar and phosphorus not significant variation was recorded (Table 9). Maximum number of grains spike^{-1} (50.77) was obtained from plot treated with treatment I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}). Lowest number of grains spike^{-1} (30.71) was recorded in treatment I_0BP_3 (Control Irrigation and 20 kg biochar ha^{-1}). Brooks *et al*., (2010) also proved that application of biochar reduces the requirement of irrigation and fertilizer in soil during crop production.

Table 9. Interaction effect of irrigation with biochar and phosphorus doses on leaf length, ear hill^{-1}, spike length (cm), spikelet spike^{-1}, grains spike^{-1} of wheat

Treatment	Leaf length (cm)	No of Ear hill^{-1}	Spike length (cm)	Spikelet spike^{-1}	Grains spike^{-1}
I_0BP_0	13.32 d-g	3.40 c-f	12.64 b-d	13.19 h	38.31 e-g
I_0BP_1	12.80 g	3.57 c-f	12.57 cd	12.79 h	35.85 fg
I_0BP_2	14.66 bc	3.82 b-e	13.32 bc	15.73 b-d	40.62 c-e
I_0BP_3	11.00 h	1.67 g	9.25 g	11.01 i	30.71 h
I_1BP_0	13.81 c-g	3.77 c-f	12.44 cd	15.10 de	39.02 d-f
I_1BP_1	14.01 c-f	3.67 c-f	13.21 bc	14.01 fg	36.52 fg
I_1BP_2	14.46 b-d	4.07 b-d	13.30 bc	16.23 b	43.83 bc
I_1BP_3	13.04 fg	3.00 ef	11.94 de	13.04 h	36.34 fg
I_2BP_0	14.62 bc	4.30 bc	13.03 bc	15.43 cd	44.86 b
I_2BP_1	14.48 b-d	4.13 b-d	13.56 b	14.27 f	42.81 b-d
I_2BP_2	16.92 a	5.37 a	14.86 a	17.76 a	50.77 a
I_2BP_3	13.15 e-g	2.90 f	10.80 f	13.40 gh	41.03 c-e
I_3BP_0	13.97 c-g	3.23 d-f	12.38 cd	14.47 ef	37.84 e-g
I_3BP_1	14.32 c-e	3.87 b-e	12.77 b-d	13.13 h	37.77 e-g
I_3BP_2	15.60 b	4.70 ab	13.17 bc	16.11 bc	43.69 bc
I_3BP_3	12.96 fg	2.87 f	11.31 ef	13.17 h	34.54 gh
CV%	4.95	13.97	4.48	3.01	4.93
$LSD_{(0.05)}$	1.17	0.86	0.95	0.73	3.30
Level of significance	NS	NS	**	**	NS

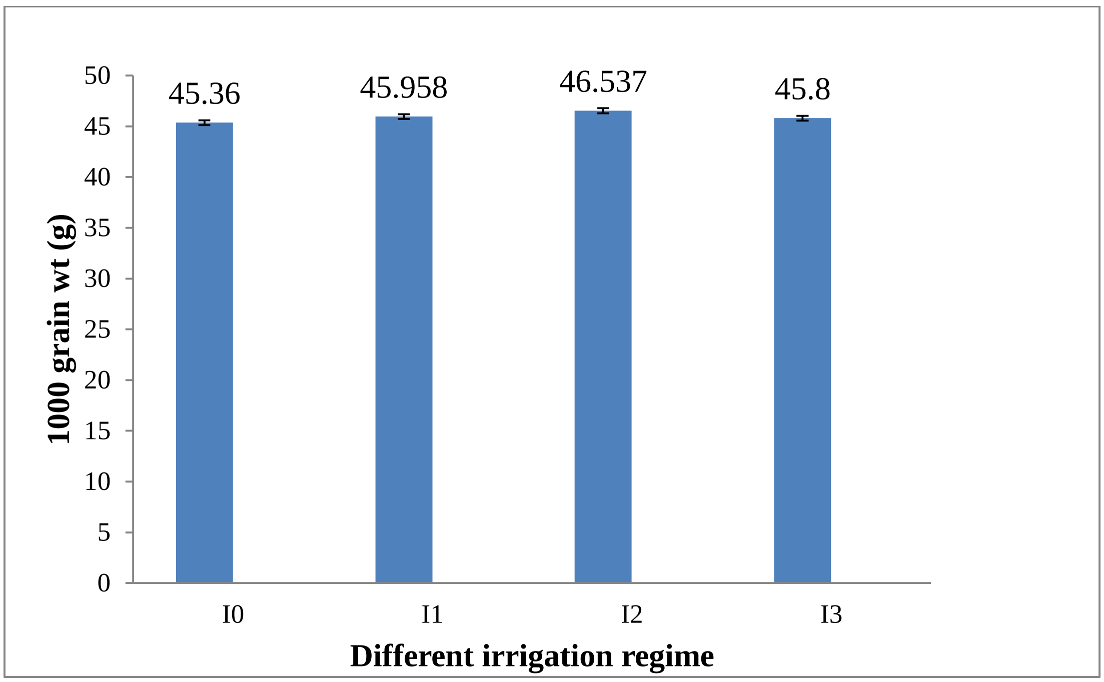
** indicated 1% level of significance and NS indicates not significant

I_0BP_0=Control and 5 t ha^{-1} biochar, I_0BP_1=Control and 5 t ha^{-1} biochar + 20 kg ha^{-1} P, I_0BP_2= Control and 5 t ha^{-1} biochar + 15 kg ha^{-1} P, I_0BP_3= Control and 20 kg ha^{-1} P,I_1BP_0= Irrigation at CRI and 5 t ha^{-1} biochar,I_1BP_1= Irrigation at CRI and 5 t ha^{-1} biochar + 20 kg ha^{-1} P,I_1BP_2 = Irrigation at CRI and 5 t ha^{-1} biochar + 15 kg ha^{-1} P,I_1BP_3= Irrigation at CRI and 20 kg ha^{-1} P,I_2BP_0= Irrigation at CRI+FI and 5 t ha^{-1} biochar, I_2BP_1= Irrigation at CRI+FI and 5 t ha^{-1} biochar + 20 kg ha^{-1} P, I_2BP_2= Irrigation at CRI+FI and 5 t ha^{-1} biochar + 15 kg ha^{-1} P, I_2BP_3= Irrigation at CRI and 20 kg ha^{-1} P, I_2BP_3= Irrigation at CRI+FI and 20 kg ha^{-1} P, I_3BP_0= Irrigation at CRI+FI+GF and 5 t ha^{-1} biochar, I_3BP_1= Irrigation at CRI+FI+GF and 5 t ha^{-1} biochar + 20 kg ha^{-1} P, I_3BP_2= Irrigation at CRI+FI+GF and 5 t ha^{-1} biochar + 15 kg ha^{-1} P, I_3BP_3= Irrigation at CRI+FI+GF and 20 kg ha^{-1} P.

4.2.5 Weight of 1000 grain (g)

4.2.5.1 Effect of irrigation

In case of 1000 grain weight a significant influence was observed in case of different irrigation regime (Fig.12). Highest 1000 grain weight (46.53g) was recorded in treatment I_2 (Irrigation at CRI +FI stage) and lowest 1000 grain weight (45.36 g) was recorded in treatment I_3 (Control). 1000 grain weight obtained from I_3 and I_1 (45.80 g and 45.93 g) are statistically similar. Hwary and Yagoub, (2011) also studied irrigation influences 1000 seed weight significantly.

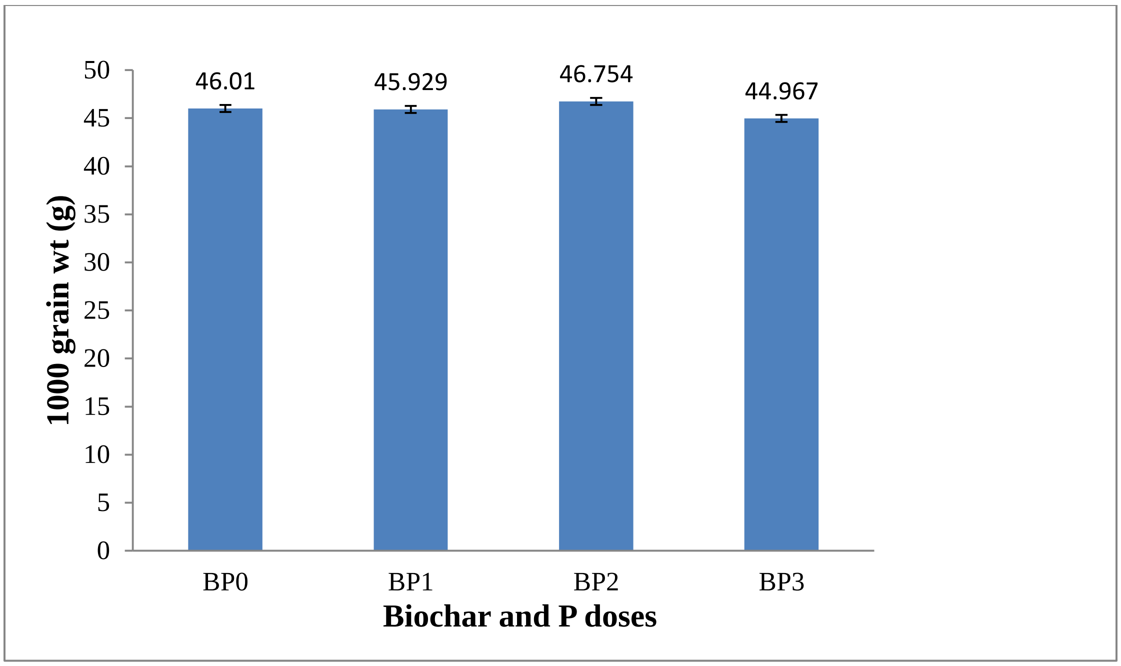


I_0 = Control, I_1 = At Crown Root Initiation (CRI), I_2 = At CRI +Flower Initiation (FI) stage, I_3 =At CRI+FI+ Grain Filling (GF) stage

Figure 12. Effect of different irrigation regime on 1000 grain weight (g) ($LSD_{0.05}$=0.87).

4.2.5.2 Effect of biochar and phosphorus

Different doses of biochar and phosphorus had influence on 1000 grain weight of wheat (Fig. 13). Highest 1000 grain weight (46.75 g) was recorded in treatment BP_2 (5 ton Biochar +15 kg P ha^{-1}) and lowest weight of 1000 grain (44.97 g) was obtained in treatment BP_3 (20 kg Phosphorus ha^{-1}). 1000 grain weight obtained from I_0 and I_1 (46.01 g and 45.89 g) are statistically similar.



B_0P_0= 5 ton Biochar ha^{-1}, B_1P_1 =5 ton Biochar + 20 kg Phosphorus ha^{-1}, B_2P_2=5 ton Biochar +15 kg Phosphorus ha^{-1}, B_3P_3 =20 kg Phosphorus ha^{-1}

Figure 13. Effect of biochar and phosphorus doses on 1000 grain weight (g) of wheat ($LSD_{0.05}$=0.37).

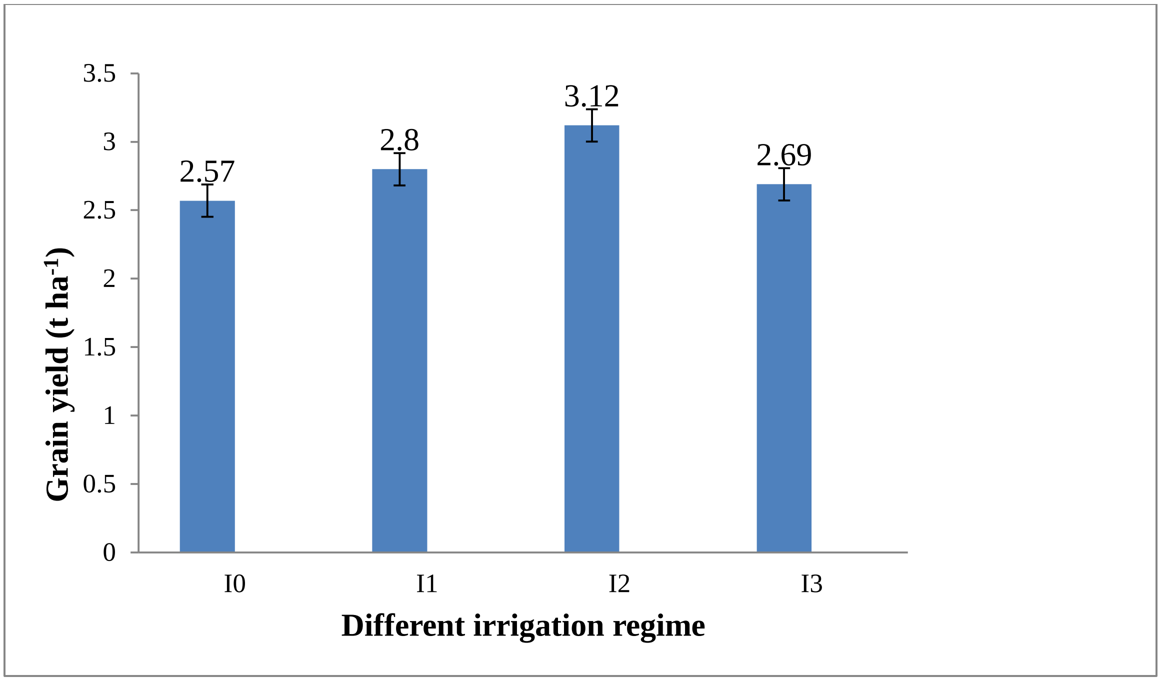
4.2.5.3 Interaction effect of irrigation with biochar and phosphorus

In case of interaction effect of irrigation with biochar and phosphorus not significant variation was observed (Table 10). Highest weight of 1000 grain of wheat (47.87 g) was recorded in treatment I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}).

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

4.2.6.1 Effect of irrigation

Different irrigation regime showed significant influence on grain yield ha^{-1} (Fig. 14 and Appendix 3). Maximum grain yield (3.12 t ha^{-1}) was recorded in treatment I_2 where irrigation was applied at CRI and FI. Lowest grain yield (2.57 t ha^{-1}) was recorded from that plot where treatment I_0 (Control) was applied. Grain yields (2.69 t ha^{-1} and 2.80 t ha^{-1}) obtained from treatment I_3 and I_1 are statistically similar to each other. Atikullah *et al*. (2014) evaluated significant influence was noticed in case of grain yield under different irrigation level for wheat production.

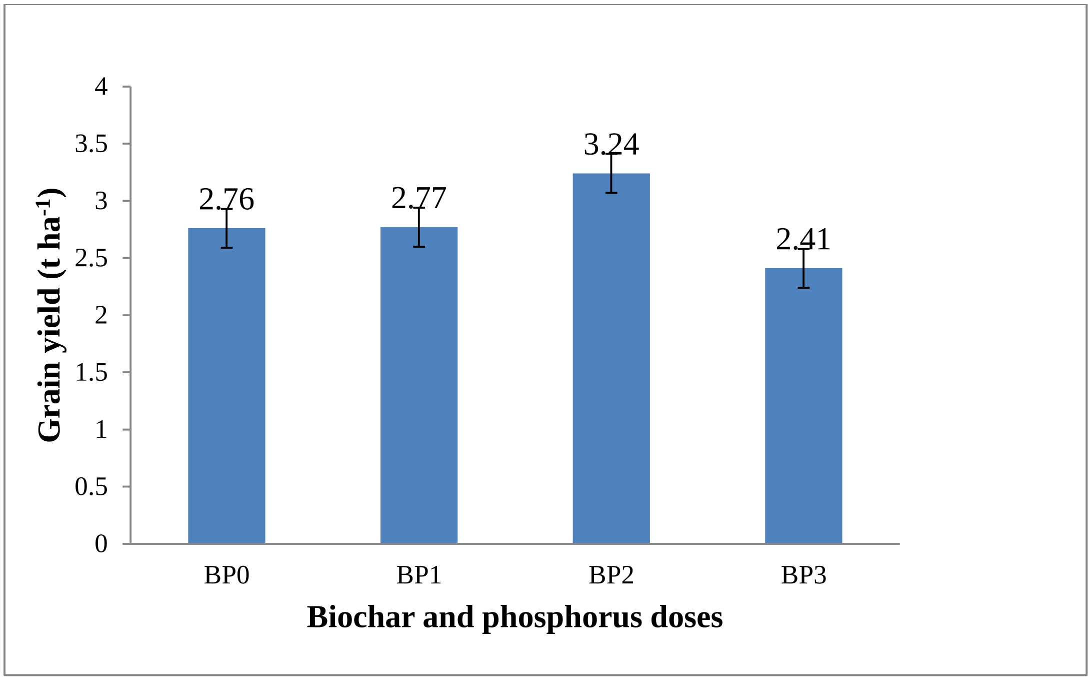


I_0 = Control, I_1 = At Crown Root Initiation (CRI), I_2 = At CRI +Flower Initiation (FI) stage,I_3 =At CRI+FI+ Grain Filling (GF) stage

Figure 14. Effect of different irrigation regime on grain yield of wheat ($LSD_{0.05}$=0.17).

4.2.6.2 Effect of biochar and phosphorus

Variation in doses of biochar and phosphorus had shown influence on grain yield of wheat (Fig. 15 and Appendix 4). Plots treated with treatment BP_2 (5 ton Biochar +15 kg Phosphorus ha^{-1}) had given highest grain yield (3.24 t ha^{-1}) whereas lowest grain yield (2.41 t ha^{-1}) was obtained from treatment BP_3 (20 kg Phosphorus ha^{-1}). Grain yields (2.76 t ha^{-1} and 2.77 t ha^{-1}) obtained from treatment BP_0 and BP_1 are statistically similar. Alburquerque *et al*., (2013); Asai, (2009) and Novak *et al*., (2009) worked on biochar and different mineral fertilizes which showed significant result.



BP_0= 5 ton Biochar ha^{-1}, BP_1 =5 ton Biochar + 20 kg Phosphorus ha^{-1}, BP_2=5 ton Biochar +15 kg Phosphorus ha^{-1}, BP_3 =20 kg Phosphorus ha^{-1}

Figure 15. Effect of biochar and phosphorus on grain yield (t ha^{-1}) of wheat ($LSD_{0.05}$=0.14).

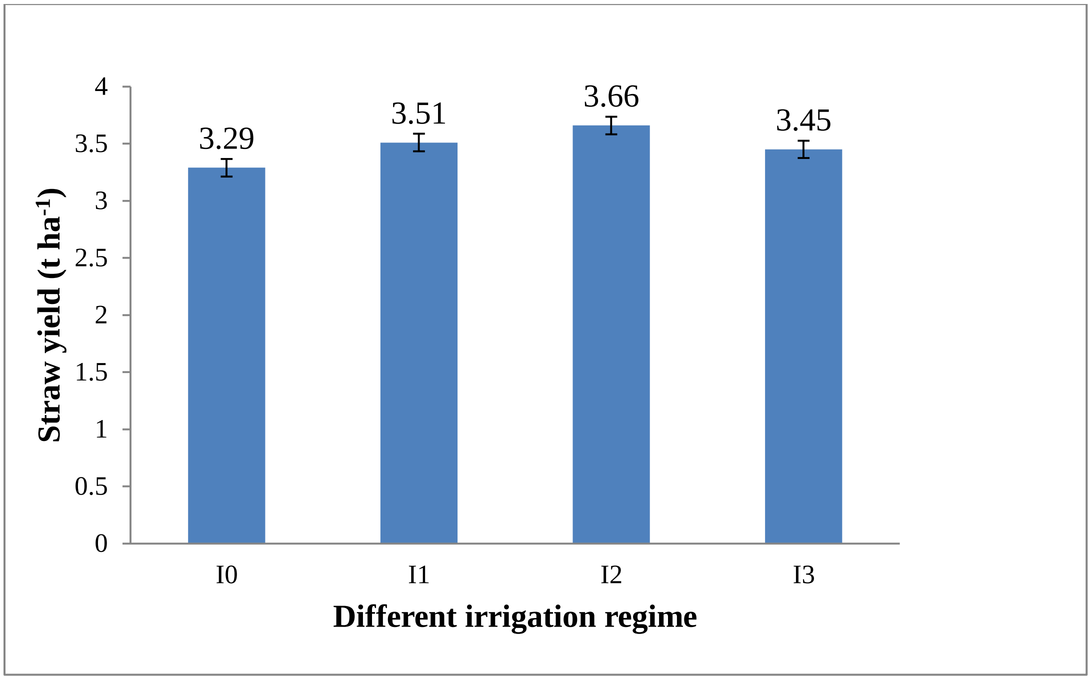
4.2.6.3 Interaction effect of irrigation with biochar and phosphorus

Interaction between different irrigation regime with biochar and phosphorus had significant influence on grain yield of wheat (Table 10). Maximum grain yield (3.67 t ha^{-1}) was recorded in treatment I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}). Minimum grain yield (2.06 t ha^{-1}) was observed in treatment I_0BP_3 (Control Irrigation and 20 kg biochar ha^{-1}). Gebremedhin *et al*., (2015) and Lehmann *et al*., (2003) observed that biochar improves nutrient availability in soil during crop production.

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

4.2.7.1 Effect of irrigation

In case of straw yield of wheat different irrigation regime had shown statistically not significant variation (Fig. 16 and Appendix 3). Highest straw yield (3.66 t ha^{-1}) was obtained from treatment I_2 (Irrigation at CRI +FI stage) which is statistically similar to I_1. Lowest straw yield (3.29 t ha^{-1}) was obtained in treatment I_0 (Control).

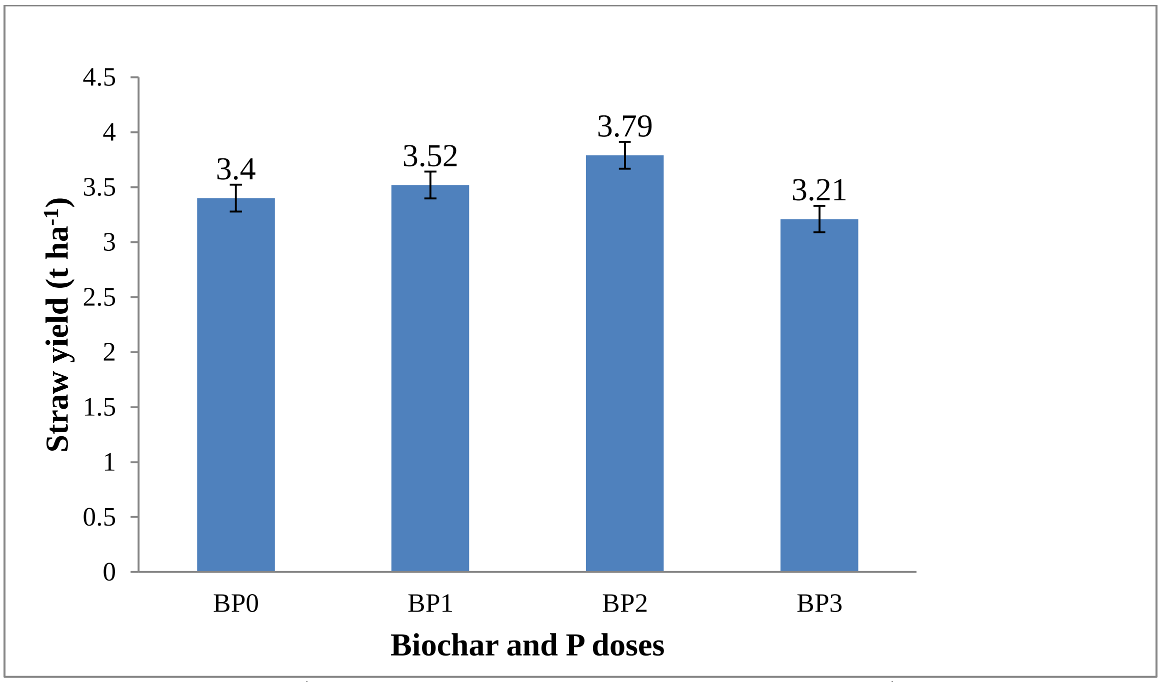


I_0 = Control, I_1 = At Crown Root Initiation (CRI), I_2 = At CRI +Flower Initiation (FI) stage, I_3 =At CRI+FI+ Grain Filling (GF) stage

Figure 16. Effect of different irrigation regime on straw yield of wheat ($LSD_{0.05}$=0.18).

4.2.7.2 Effect of biochar and phosphorus

Different doses of biochar and phosphorus had shown significant influence on straw yield of wheat (Fig. 17 and Appendix 4). Highest straw weight (3.79 t ha^{-1}) was recorded in treatment BP_2 (5 ton Biochar +15 kg Phosphorus ha^{-1}) whereas lowest straw weight (3.21 t ha^{-1}) was recorded in treatment BP_3 (20 kg Phosphorus ha^{-1}). Straw weights (3.40 t ha^{-1} and 3.52 t ha^{-1} respectively) obtained from treatment BP_0 and BP_1 are statistically similar. Zhanga *et al*., (2020) stated that application of biochar increases straw biomass of rice.



BP_0= 5 ton Biochar ha^{-1}, BP_1 =5 ton Biochar + 20 kg Phosphorus ha^{-1}, BP_2=5 ton Biochar +15 kg Phosphorus ha^{-1}, BP_3 =20 kg Phosphorus ha^{-1}

Figure 17. Effect of biochar and phosphorus on straw yield of wheat ($LSD_{0.05}$=0.17).

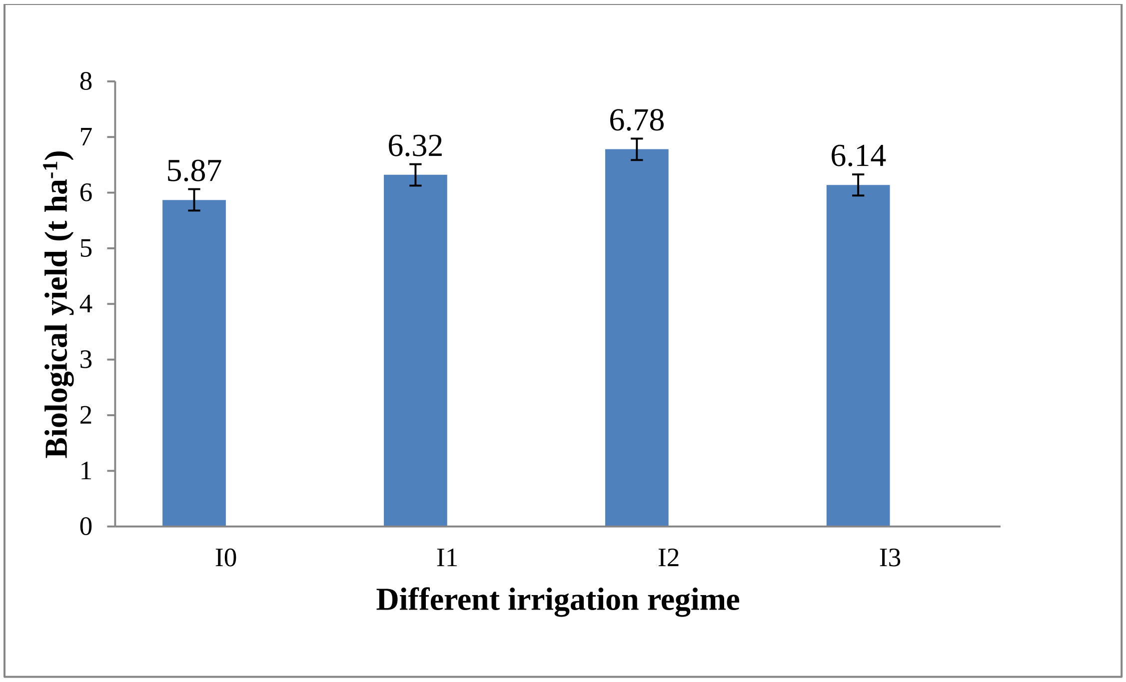
4.2.7.3 Interaction effect of irrigation with biochar and phosphorus

Combined effect of irrigation with biochar and phosphorus had shown not significant variation in straw yield of wheat (Table 10). Highest straw yield (4.03 t ha^{-1}) was recorded in treatment I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}) which is statistically similar to yields (3.84 and 3.83 t ha^{-1}) obtained from treatments I_1BP_2 (Irrigation at CRI+FI and 5 ton Biochar+ 20 kg P ha^{-1}) and I_2BP_1 (Irrigation at CRI +FI stage and 5 ton Biochar + 20 kg Phosphorus ha^{-1}) respectively. On the other hand lowest straw yield (2.91 t ha^{-1}) was recorded in treatment I_0BP_3 (Control Irrigation and 20 kg biochar ha^{-1}). Gebremedhin *et al*., (2015) experimented on irrigation and biochar and found significant result.

4.2.8 Biological yield (t ha^{-1})

4.2.8.1 Effect of irrigation

Significant variation was observed when different irrigation was applied (Fig. 18 and Appendix 3). Highest yield (6.78t ha^{-1}) was recorded in treatment I_2 (Irrigation at CRI +FI stage) whereas lowest yield (5.87 t ha^{-1}) was recorded in treatment I_0 (Control). Yields (6.14 and 6.32 t ha^{-1}) obtained from treatment I_1 and I_3 are statistically similar. Ranjita *et al*., (2007) found that irrigation significantly affect crop yield.

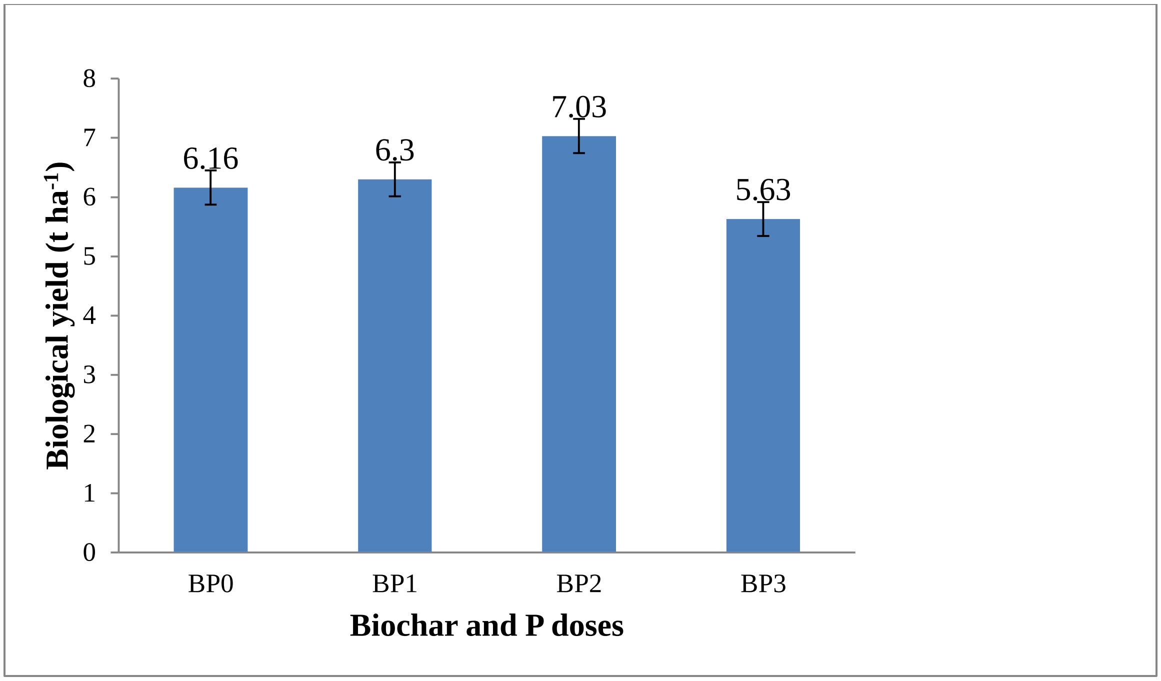


I_0 = Control, I_1 = At Crown Root Initiation (CRI), I_2 = At CRI +Flower Initiation (FI) stage, I_3 =At CRI+FI+ Grain Filling (GF) stage

Figure 18. Effect of irrigation on biological yield of wheat ($LSD_{0.05}$=0.30).

4.2.8.2 Effect of biochar and phosphorus

Different doses of biochar and phosphorus had shown significant effect on biological yield of wheat (Fig. 19 and Appendix 4). Highest yield (7.03 t ha^{-1}) was recorded in treatment BP_2 (5 ton Biochar +15 kg Phosphorus ha^{-1}) and lowest yield (5.63 t ha^{-1}) was recorded in treatment BP_3 (20 kg Phosphorus ha^{-1}). Yields (6.16 and 6.30 t ha^{-1} respectively) obtained from treatment BP_0 and BP_1 are statistically similar.



BP_0= 5 ton Biochar ha^{-1}, BP_1 =5 ton Biochar + 20 kg Phosphorus ha^{-1}, BP_2=5 ton Biochar +15 kg Phosphorus ha^{-1}, BP_3 =20 kg Phosphorus ha^{-1}

Figure 19. Effect of biochar and phosphorus on biological yield of wheat ($LSD_{0.05}$=0.30).

4.2.8.3 Interaction effect of irrigation with biochar and phosphorus

In case of interaction of irrigation with biochar and phosphorus not significant variation was observed (Table 10). Highest yield 7.71 t ha^{-1}) was recorded in treatment I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}) .On the other hand lowest yield (4.97 t ha^{-1}) was recorded in treatment I_0BP_3 (Control Irrigation and 20 kg biochar ha^{-1}).

Table 10. Interaction effect of irrigation with biochar and phosphorus doses on 1000 grain weight (g), grain yield, straw yield (t/ha), biological yield (t/ha) and H.I. (%)

Treatment	1000 grain (g)	Grain yield t/ha	Straw yield t/ha	Biological yield t/ha	H.I.
I_0BP_0	45.73 cd	2.64 ef	3.33 c-e	5.97 ef	44.24 b-e
I_0BP_1	45.37 d-f	2.50 ef	3.29 de	5.83 ef	43.48 c-f
I_0BP_2	45.84 b-d	3.04 bc	3.65 bc	6.69 b-d	45.51 b
I_0BP_3	44.50 g	2.06 g	2.91 f	4.97 g	41.53 g
I_1BP_0	45.93 b-d	2.81 c-e	3.52 b-e	6.34 d-e	44.34 b-e
I_1BP_1	46.00 b-d	2.72 d-f	3.37 c-e	6.09 d-f	44.72 b-d
I_1BP_2	46.67 b	3.23 b	3.84 ab	7.08 b	45.65 b
I_1BP_3	45.23 ef	2.45 f	3.32 c-e	5.77 f	42.39 e-g
I_2BP_0	46.50 bc	2.96 b-d	3.48 c-e	6.45 c-d	45.96 b
I_2BP_1	46.42 bc	3.19 b	3.83 ab	7.03 bc	45.46 bc
I_2BP_2	47.87 a	3.67 a	4.03 a	7.71 a	47.75 a
I_2BP_3	45.37 d-f	2.64 ef	3.30 c-e	5.95 ef	44.44 b-d
I_3BP_0	45.88 b-d	2.61 ef	3.27 e	5,88 ef	44.36 b-e
I_3BP_1	45.93 b-d	2.63 ef	3.61 b-e	6.24 d-f	42.21 fg
I_3BP_2	46.64 b	3.00 b-d	3.63 b-d	6.63 b-d	45.28 bc
I_3BP_3	44.77 f	2.51 ef	3.31 c-e	5.82 f	43.10 d-g
CV%	0.94	6.31	6.00	5.84	2.14
$LSD_{(0.05)}$	0.82	0.30	0.35	0.61	1.9
Level of significance	NS	NS	NS	NS	NS

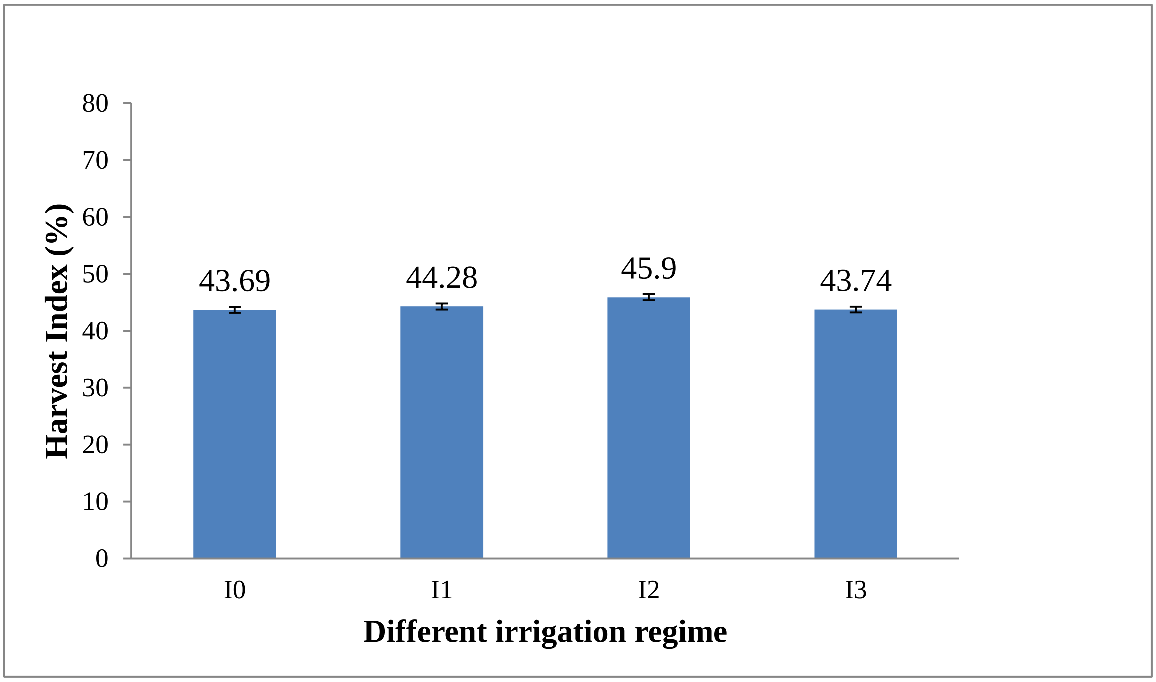
* indicates 5% level of significance and NS indicates not significant

I_0BP_0=Control and 5 t ha^{-1} biochar, I_0BP_1=Control and 5 t ha^{-1} biochar + 20 kg ha^{-1} P, I_0BP_2= Control and 5 t ha^{-1} biochar + 15 kg ha^{-1} P, I_0BP_3= Control and 20 kg ha^{-1} P,I_1BP_0= Irrigation at CRI and 5 t ha^{-1} biochar,I_1BP_1= Irrigation at CRI and 5 t ha^{-1} biochar + 20 kg ha^{-1} P,I_1BP_2 = Irrigation at CRI and 5 t ha^{-1} biochar + 15 kg ha^{-1} P,I_1BP_3= Irrigation at CRI and 20 kg ha^{-1} P,I_2BP_0= Irrigation at CRI+FI and 5 t ha^{-1} biochar, I_2BP_1= Irrigation at CRI+FI and 5 t ha^{-1} biochar + 20 kg ha^{-1} P, I_2BP_2= Irrigation at CRI+FI and 5 t ha^{-1} biochar + 15 kg ha^{-1} P, I_2BP_3= Irrigation at CRI and 20 kg ha^{-1} P, I_2BP_3= Irrigation at CRI+FI and 20 kg ha^{-1} P, I_3BP_0= Irrigation at CRI+FI+GF and 5 t ha^{-1} biochar, I_3BP_1= Irrigation at CRI+FI+GF and 5 t ha^{-1} biochar + 20 kg ha^{-1} P, I_3BP_2= Irrigation at CRI+FI+GF and 5 t ha^{-1} biochar + 15 kg ha^{-1} P, I_3BP_3= Irrigation at CRI+FI+GF and 20 kg ha^{-1} P.

4.2.9 Harvest index (%)

4.2.9.1 Effect of irrigation

Harvest Index of wheat was not significantly influenced by different irrigation regime (Fig. 20). Highest Harvest Index (45.90 %) was recorded in treatment I_2 (Irrigation at CRI +FI stage). Lowest Harvest Index (43.69 %) was recorded in treatment I_0 (Control) which is statistically similar to (43.74% and 44.28 %) obtained from treatment I_1 and I_3 respectively. Atikullah et al., (2014) also observed different irrigation level significantly influenced Harvest index of wheat.

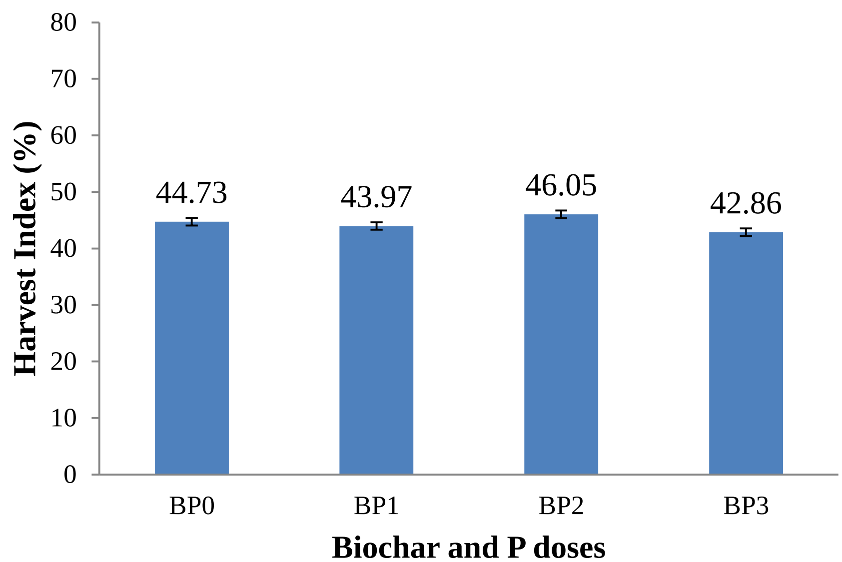


I_0 = Control, I_1 = At Crown Root Initiation (CRI), I_2 = At CRI +Flower Initiation (FI) stage, I_3 =At CRI+FI+ Grain Filling (GF) stage

Figure 20. Effect if irrigation on Harvest Index (%) ($LSD_{0.05}$=1.44).

4.2.9.2 Effect of biochar and phosphorus

Harvest Index of wheat was not significantly influenced by different biochar and phosphorus doses (Fig. 21). Highest Harvest Index (46.05%) was recorded in treatment BP_2 (5 ton Biochar +15 kg Phosphorus ha^{-1}) and lowest (42.86%) one was recorded in treatment BP_3 (20 kg Phosphorus ha^{-1}). Harvest Index of treatment BP_0 and BP_1 are statistically similar.



BP_0= 5 ton Biochar ha^{-1}, BP_1 =5 ton Biochar + 20 kg Phosphorus ha^{-1}, BP_2=5 ton Biochar +15 kg Phosphorus ha^{-1}, BP_3 =20 kg Phosphorus ha^{-1}

Figure 21. Effect of biochar and phosphorus on Harvest Index of wheat ($LSD_{0.05}$=0.80).

4.2.9.3 Interaction effect of irrigation with biochar and phosphorus

In case of interaction of irrigation with biochar and phosphorus not significant variation was recorded for Harvest Index of wheat (Table 10). Highest Harvest Index (47.75%)

was recorded in treatment I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}). On the other hand lowest harvest index (41.53 %) was recorded in treatment I_3BP_3 (Irrigation at CRI+FI+ GF stage and 20 kg biochar ha^{-1}) which is statistically similar to treatments I_0BP_1, I_0BP_3 and I_1BP_3 respectively.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University, during the period from November 2019 to March 2020 to observe the effect of biochar and phosphorus under different irrigation regime on growth and yield of wheat. This experiment consisted of four different irrigation regimes viz. I_0=control, I_1=Irrigation at Crown Root Initiation (CRI) stage, I_2= Irrigation at CRI+ Flowering (FI) stage, I_3= Irrigation at CRI+ FI+ Grain filling (GF) stage and four different doses of biochar and phosphorus combination BP_0= 5 ton biochar ha^{-1} , BP_1= 5 ton biochar + 20 kg phosphorus ha^{-1} , BP_2= 5 ton biochar + 15kg phosphorus ha^{-1}, BP_3= 20 kg phosphorus ha^{-1} . The experiment was laid out in two factor split plot design along with three replications. There were 48 unit plots of size $2m^2 \times 1m^2$ i.e. $2m^2$ and 16 different treatments were applied. The collected data ware statistically analyzed in order to evaluate the effect of those treatments.

Plant height varied significantly due to different amount of irrigation. The tallest plant height (94.00cm) was recorded in treatment I_2 (irrigation at CRI+ FI) at 80DAS which was similar in case of 20 DAS, 40 DAS, 60 DAS and at harvest. Plant height was significantly influenced by different doses of biochar and phosphorus. The tallest plant (95.34 cm) was obtained from treatment BP_2 (5 ton biochar+ 15 kg phosphorus ha^{-1}). Interaction of irrigation with biochar and phosphorus showed insignificantly variation in case of plant height. The tallest plant height (100.16 cm) was recorded in treatment I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}) at harvest.

Number of tiller per plant was significantly influenced by different level of irrigations. Maximum number of tiller (4.70) was observed in treatment I_2. Different doses of biochar and phosphorus showed significant variations for number of tiller. Highest number of tiller (4.93) was recorded in case of treatment BP_2. Interaction effect of biochar and phosphorus with irrigation was significantly varied for number of tiller per plant where maximum tiller (5.64) was recorded in treatment I_2BP_2.

Leaf length was significantly influenced by application of different doses of biochar and phosphorus. Highest leaf length (15.41 cm) was recorded in treatment BP_2 (5 ton biochar +15 kg phosphorus ha^{-1}). Different level of irrigation showed significant variation in case of leaf length. Longest leaf (14.79cm) was observed in treatment I_2 having irrigation at CRI and FI stage. Interaction effect of irrigation with biochar and phosphorus was insignificantly influenced. Highest leaf length (16.02 cm) was observed in treatment I_2BP_2 (Irrigation at CRI +FI stage and 5 ton biochar +15 kg phosphorus ha^{-1}).

Ear number per plant was significantly influenced by different level of irrigation. Maximum number of ear $plant^{-1}$ (4.17) was recorded in treatment I_2. Different doses of biochar and phosphorus showed significant effect on ear $plant^{-1}$ of wheat. Highest number of ear $plant^{-1}$ (4.48) was observed in treatment BP_2. Interaction of irrigation with biochar and phosphorus doses was insignificantly varied from each other. Maximum number of ear $plant^{-1}$ (5.36) was recorded in treatment I_2BP_2.

In case of spike length of wheat, different irrigation regime showed significant influences. Longest spike length (13.06 cm) was measured in treatment I_2. For different doses of biochar and phosphorus spike length was having significant variation. Highest spike (13.66 cm) was observed in treatment BP_2. While in case of interaction effect of irrigation with biochar and phosphorus spike length of wheat was significantly influenced. Longest spike length (14.86 cm) was recorded in treatment I_2BP_2.

Significant variation was observed in case of spikelet spike^{-1} due to different level of irrigation. Highest number of spikelet spike^{-1} (15.21) was recorded in treatment I_2. In case of different doses of biochar and phosphorus, statistically significant variation was observed for spikelet spike^{-1}. Highest spikelet spike^{-1}(16.45) was obtained from treatment BP_2. In case of interaction among irrigation and different doses of biochar and phosphorus significant variation was observed. Highest number of spikelet spike^{-1} (17.76) was recorded in treatment I_2BP_2.

Different irrigation regime showed significant variations in case of grain per spike of wheat. Maximum number of grain (44.86) from a single spike was obtained from treatment I_2. Similarly different doses of biochar and phosphorus also had significant influence on grain spike^{-1}. Highest number of grain per spike (44.72) was recorded in treatment BP_2. In case of interaction effect of irrigation with biochar and phosphorus the result was not significantly varied. Maximum number of grain spike^{-1} (50.77) was recorded in treatment I_2BP_2.

In case 1000 grain weight effect of different irrigation regime was significantly varied. Maximum grain weight (46.54 g) was recorded in treatment I_2. Different doses of biochar and phosphorus showed statistically significant variation for weight of 1000 grain. Highest grain weight (46.75 g) was recorded in treatment BP_2. Insignificant variation was observed for 1000 grain weight in case of interaction between irrigation and biochar-phosphorus doses. Highest 1000 grain weight was recorded in treatment I_2BP_2.

Grain yield was significantly influenced by different irrigation regime. Maximum grain yield (3.12 t ha^{-1}) was obtained in treatment I_2. Different doses of biochar and phosphorus had shown significant influence on grain yield. Highest grain yield (3.24 t ha^{-1}) was recorded in treatment BP_2. Significant variation was present in case of interaction among different irrigation and biochar and phosphorus doses maximum grain yield (3.67t ha^{-1}) was obtained from treatment I_2BP_2.

Straw yield showed significant result when different irrigation was applied, giving highest straw yield (3.66 t ha^{-1}) in treatment I_2. Different doses of biochar and phosphorus also showed significant result for straw yield. Highest straw yield (3.79 t ha^{-1}) was recorded from treatment BP_2. In case of interaction effect of irrigation with biochar and phosphorus, insignificant variation was observed. Maximum straw yield (4.03 t ha^{-1}) was recorded in treatment I_2BP_2.

Different irrigation regime showed significant result in case of biological yield of wheat. Highest yield (6.78 t ha^{-1}) was recorded in treatment I_2. Application of biochar and phosphorus had significant influence on total yield. Maximum yield (7.03 t ha^{-1}) was recorded in treatment BP_2. Insignificant variation was observed when irrigation and doses of biochar and phosphorus combination was applied. Highest yield (7.71 t ha^{-1}) was obtained from treatment I_2BP_2.

Insignificant variation was observed for different irrigation regime in case of harvest index. Maximum Harvest Index (45.90%) was recorded in treatment I_2. In case of different doses of biochar and phosphorus result of Harvest Index was insignificantly varied. Highest Harvest Index (46.05%) was recorded in treatment BP_2. Statistically insignificant variation was observed in case of result showing Harvest Index where highest H.I. (47.75%) was recorded in treatment I_2BP_2.

From the above discussion it may be concluded that application of biochar reduces the requirement of phosphorus fertilizer without affecting grain yield. Treatment I_2BP_2 was proved to be optimum management to harvest optimum yield of wheat. To reach a specific conclusion and recommendation the study needs further investigation under different Agro Ecological Zones (AEZ) of Bangladesh.

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APPENDICES

Appendix 1. Effect of irrigation on spike and grain after harvest

Treatment	No of spike $hill^{-1}$	Spike length (cm)	Spikelet $spike^{-1}$	Grains $spike^{-1}$
I_0	3.11 c	11.94 c	13.18 d	36.37 b
I_1	3.63 bc	12.72 ab	14.59 b	38.93 b
I_2	4.18 a	13.06 a	15.21 a	44.87 a
I_3	3.67 ab	12.41 bc	14.22 c	38.46 b
CV%	14.71	4.43	2.18	6.70
LSD	0.54	0.56	0.31	2.65
Level of significance	**	**	**	**

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

I_0 = Control, **I_1** = At Crown Root Initiation (CRI), **I_2** = At CRI +Flower Initiation (FI) stage, **I_3** =At CRI+FI+ Grain Filling (GF) stage

Appendix 2. Effect of biochar and phosphorus on spike and grain after harvest

Treatment	No of spike $hill^{-1}$	Spike length (cm)	Spikelet $spike^{-1}$	Grains $spike^{-1}$
BP_0	3.68 b	12.63 b	14.55 b	40.09 b
BP_1	3.81 b	13.03 b	13.55 c	38.24 c
BP_2	4.49 a	13.66 a	16.46 a	44.73 a
BP_3	2.61 c	10.83 c	12.65 d	35.65 d
CV%	13.97	4.48	3.01	4.93
LSD	0.43	0.47	0.36	1.65
Level of significance	**	**	**	**

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

BP_0= 5 ton Biochar ha^{-1}, **BP_1** =5 ton Biochar + 20 kg Phosphorus ha^{-1}, **BP_2**=5 ton Biochar +15 kg Phosphorus ha^{-1}, **BP_3** =20 kg Phosphorus ha^{-1}

Appendix 3. Effect of irrigation on grain and straw yield

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)
I_0	2.57 c	3.29 c	5.87 c
I_1	2.80 bc	3.51 ab	6.32 b
I_2	3.12 a	3.66 a	6.78 a
I_3	2.69 b	3.45 bc	6.14 bc
CV%	6.2	5.24	4.83
LSD	0.17	0.18	0.30
Level of significance	**	*	**

** indicated 1% level of significance

I_0 = Control, **I_1** = At Crown Root Initiation (CRI), **I_2** = At CRI +Flower Initiation (FI) stage, **I_3** =At CRI+FI+ Grain Filling (GF) stage

Appendix 4. Effect of biochar and phosphorus doses on grain and straw yield

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)
BP_0	2.76 b	3.40 b	6.16 b
BP_1	2.77 b	3.52 b	6.30 b
BP_2	3.24 a	3.79 a	7.03 a
BP_3	2.41 c	3.21 c	5.63 c
CV%	6.31	6.00	5.84
LSD	0.14	0.17	0.30
Level of significance	**	**	*

** indicated 1% level of significance

BP_0= 5 ton Biochar ha^{-1}, **BP_1** =5 ton Biochar + 20 kg Phosphorus ha^{-1}, **BP_2**=5 ton Biochar +15 kg Phosphorus ha^{-1}, **BP_3** =20 kg Phosphorus ha^{-1}

Appendix 5. ANOVA Table for Plant height at 20 DAS

Source	DF	SS	MS	F	P
Rep	2	14.770	7.3851		
I	3	79.530	26.5101	19.37 **	0.0017
Error Rep*I	6	8.214	1.3689		
BP	3	140.812	46.9373	25.43 **	0.0000
I*BP	9	28.226	3.1362	1.70 ^{NS}	0.1442
Error Rep*I*BP	24	44.306	1.8461		
Total	47	315.858			
Grand Mean	27.438				
CV(Rep*I)	4.26				
CV(Rep*I*BP)	4.95				

Appendix 6. ANOVA Table for Plant height at 40 DAS

Source	DF	SS	MS	F	P
Rep	2	102.909	51.4544		
I	3	79.004	26.3347	16.93 **	0.0025
Error Rep*I	6	9.334	1.5556		
BP	3	98.922	32.9741	15.97 **	0.0000
I*BP	9	14.065	1.5628	0.76 ^{NS}	0.6555
Error Rep*I*BP	24	49.554	2.0647		
Total	47	353.788			
Grand Mean	47.896				
CV(Rep*I)	2.60				
CV(Rep*I*BP)	3.00				

Appendix 7. ANOVA Table for Plant height at 60 DAS

Source	DF	SS	MS	F	P
Rep	2	10.704	5.3521		
I	3	66.542	22.1808	6.82 *	0.0233
Error Rep*I	6	19.522	3.2537		
BP	3	113.396	37.7988	21.50 **	0.0000
I*BP	9	50.341	5.5934	3.18**	0.0113
Error Rep*I*BP	24	42.196	1.7582		
Total	47	302.702			
Grand Mean	74.246				
CV(Rep*I)	2.43				
CV(Rep*I*BP)	1.79				

Appendix 8. ANOVA Table for Plant height at 80 DAS

Source	DF	SS	MS	F	P
Rep	2	11.143	5.5714		
I	3	95.812	31.9373	13.27 **	0.0047
Error Rep*I	6	14.444	2.4073		
BP	3	236.811	78.9371	22.53 **	0.0000
I*BP	9	56.146	6.2384	1.78 NS	0.1272
Error Rep*I*BP	23	80.593	3.5040		
Total	47				
Grand Mean	88.144				
CV(Rep*I)	1.76				
CV(Rep*I*BP)	2.12				

Appendix 9. ANOVA Table for Plant height at harvest

Source	DF	SS	MS	F	P
Rep	2	0.685	0.343		
I	3	132.480	44.160	10.74 **	0.0079
Error Rep*I	6	24.664	4.111		
BP	3	311.790	103.930	28.46 **	0.0000
I*BP	9	57.280	6.364	1.74 NS	0.1335
Error Rep*I*BP	24	87.640	3.652		
Total	47	614.539			
Grand Mean	91.633				
CV(Rep*I)	2.21				
CV(Rep*I*BP)	2.09				

Appendix 10. ANOVA Table for No of tiller hill^{-1} at 20 DAS

Source	DF	SS	MS	F	P
Rep	2	0.19813	0.09907		
I	3	0.46056	0.15352	8.24 **	0.0151
Error Rep*I	6	0.11178	0.01863		
BP	3	1.65654	0.55218	37.16 **	0.0000
I*BP	9	0.18760	0.02084	1.40 NS	0.2417
Error Rep*I*BP	24	0.35665	0.01486		
Total	47	2.97126			
Grand Mean	1.3564				
CV(Rep*I)	10.06				
CV(Rep*I*BP)	8.99				

Appendix 11. ANOVA Table for No of tiller hill^{-1} at 40 DAS

Source	DF	SS	MS	F	P
Rep	2	2.9626	1.48128		
I	3	2.3294	0.77647	6.36 *	0.0271
Error Rep*I	6	0.7328	0.12213		
BP	3	5.1279	1.70931	21.23 **	0.0000
I*BP	9	1.4624	0.16249	2.02 ^{NS}	0.0821
Error Rep*I*BP	24	1.9327	0.08053		
Total	47	14.5478			
Grand Mean	2.7650				
CV(Rep*I)	12.64				
CV(Rep*I*BP)	10.26				

Appendix 12. ANOVA Table for No of tiller hill^{-1} at 60 DAS

Source	DF	SS	MS	F	P
Rep	2	0.8556	0.42781		
I	3	7.8462	2.61540	7.61 **	0.0181
Error Rep*I	6	2.0609	0.34348		
BP	3	18.4758	6.15862	38.72 **	0.0000
I*BP	9	3.8016	0.42240	2.66 *	0.0271
Error Rep*I*BP	24	3.8173	0.15905		
Total	47	36.8574			
Grand Mean	3.8623				
CV(Rep*I)	15.17				
CV(Rep*I*BP)	10.33				

Appendix 13. ANOVA Table for No of tiller hill^{-1} at 80 DAS

Source	DF	SS	MS	F	P
Rep	2	0.6830	0.34151		
I	3	7.6260	2.54201	6.49 *	0.0259
Error Rep*I	6	2.3489	0.39148		
BP	3	17.3224	5.77414	28.90 **	0.0000
I*BP	9	3.8614	0.42904	2.15 ^{NS}	0.0653
Error Rep*I*BP	24	4.7946	0.19978		
Total	47	36.6364			
Grand Mean	4.1442				
CV(Rep*I)	15.10				
CV(Rep*I*BP)	10.79				

Appendix 14. ANOVA Table for Leaf length (60 DAS)

Source	DF	SS	MS	F	P
Rep	2	8.561	4.2805		
I	3	21.657	7.2189	15.82 **	0.0030
Error Rep*I	6	2.738	0.4564		
BP	3	49.525	16.5084	34.67 **	0.0000
I*BP	9	7.020	0.7801	1.64 ^{NS}	0.1605
Error Rep*I*BP	24	11.429	0.4762		
Total	47	100.930			
Grand Mean	13.945				
CV(Rep*I)	4.84				
CV(Rep*I*BP)	4.95				

Appendix 15. ANOVA Table for ear hill^{-1}

Source	DF	SS	MS	F	P
Rep	2	0.1592	0.07958		
I	3	6.7627	2.25424	7.84**	0.0169
Error Rep*I	6	1.7258	0.28763		
BP	3	21.7916	7.26387	28.03 **	0.0000
I*BP	9	3.6905	0.41005	1.58 ^{NS}	0.1770
Error Rep*I*BP	24	6.2202	0.25917		
Total	47	40.3499			
Grand Mean	3.6460				
CV(Rep*I)	14.71				
CV(Rep*I*BP)	13.96				

Appendix 16. ANOVA Table for spike length (cm)

Source	DF	SS	MS	F	P
Rep	2	5.3928	2.6964		
I	3	8.1906	2.7302	8.84 **	0.0127
Error Rep*I	6	1.8530	0.3088		
BP	3	53.3227	17.7742	56.48 **	0.0000
I*BP	9	12.0737	1.3415	4.26 **	0.0021
Error Rep*I*BP	24	7.5528	0.3147		
Total	47	88.3856			
Grand Mean	12.534				
CV(Rep*I)	4.43				
CV(Rep*I*BP)	4.48				

Appendix 17. ANOVA Table for Spikelet spike^{-1}

Source	DF	SS	MS	F	P
Rep	2	3.006	1.5032		
I	3	26.207	8.7357	89.64 **	0.0000
Error Rep*I	6	0.585	0.0975		
BP	3	95.851	31.9503	172.58 **	0.0000
I*BP	9	5.246	0.5829	3.15 **	0.0119
Error Rep*I*BP	24	4.443	0.1851		
Total	47	135.338			
Grand Mean	14.303				
CV(Rep*I)	2.18				
CV(Rep*I*BP)	3.01				

Appendix 18. ANOVA Table for No of grains spike^{-1}

Source	DF	SS	MS	F	P
Rep	2	57.90	28.949		
I	3	478.92	159.639	22.63 **	0.0011
Error Rep*I	6	42.32	7.053		
BP	3	526.48	175.494	45.86 **	0.0000
I*BP	9	37.84	4.204	1.10 ^{NS}	0.4001
Error Rep*I*BP	24	91.83	3.826		
Total	47	1235.29			
Grand Mean	39.657				
CV(Rep*I)	6.70				
CV(Rep*I*BP)	4.93				

Appendix 19. ANOVA Table for 1000-grain weight (g)

Source	DF	SS	MS	F	P
Rep	2	3.4055	1.70275		
I	3	8.4922	2.83073	17.83 **	0.0022
Error Rep*I	6	0.9524	0.15873		
BP	3	19.3510	6.45034	34.40 **	0.0000
I*BP	9	1.9206	0.21340	1.14 ^{NS}	0.3773
Error Rep*I*BP	23	4.3125	0.18750		
Total	47				
Grand Mean	45.907				
CV(Rep*I)	0.87				
CV(Rep*I*BP)	0.94				

Appendix 20. ANOVA Table for Grain yield (t ha^{-1})

Source	DF	SS	MS	F	P
Rep	2	0.42580	0.21290		
I	3	1.99491	0.66497	22.08 **	0.0012
Error Rep*I	6	0.18066	0.03011		
BP	3	4.10636	1.36879	43.86**	0.0000
I*BP	9	0.41487	0.04610	1.48 ^{NS}	0.2126
Error Rep*I*BP	24	0.74900	0.03121		
Total	47	7.87160			
Grand Mean	2.7985				
CV(Rep*I)	6.20				
CV(Rep*I*BP)	6.31				

Appendix 21. ANOVA Table for Straw yield (t ha^{-1})

Source	DF	SS	MS	F	P
Rep	2	0.33485	0.16743		
I	3	0.83111	0.27704	8.31*	0.0148
Error Rep*I	6	0.20005	0.03334		
BP	3	2.11941	0.70647	16.17**	0.0000
I*BP	9	0.53112	0.05901	1.35 ^{NS}	0.2640
Error Rep*I*BP	24	1.04850	0.04369		
Total	47	5.06503			
Grand Mean	3.4831				
CV(Rep*I)	5.24				
CV(Rep*I*BP)	6.00				

Appendix 22. ANOVA Table for Biological yield (t ha^{-1})

Source	DF	SS	MS	F	P
Rep	2	1.3891	0.69456		
I	3	5.3081	1.76938	19.21**	0.0018
Error Rep*I	6	0.5526	0.09210		
BP	3	12.0071	4.00236	29.77*	0.0000
I*BP	9	1.7106	0.19006	1.41 ^{NS}	0.2372
Error Rep*I*BP	24	3.2272	0.13446		
Total	47	24.1947			
Grand Mean	6.2817				
CV(Rep*I)	4.83				
CV(Rep*I*BP)	5.84				

Appendix 23. ANOVA Table for Harvest Index (%)

Source	**DF**	**SS**	**MS**	**F**	**P**
Rep	2	11.013	5.5065		
I	3	38.550	12.8501	6.12*	0.0295
Error Rep*I	6	12.594	2.0990		
BP	3	64.431	21.4771	23.70**	0.0000
I*BP	9	11.313	1.2570	1.39 ^{NS}	0.2481
Error Rep*I*BP	24	21.747	0.9061		
Total	47	159.649			
Grand Mean	44.406				
CV(Rep*I)	3.26				
CV(Rep*I*BP)	2.14				

Appendix 24. Agro Ecological Zone (AEZ) of Bangladesh