EFFECT OF BIOCHAR AND WATER STRESS ON THE GROWTH AND YIELD OF WHEAT

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EFFECT OF BIOCHAR AND WATER STRESS ON THE GROWTH AND YIELD OF WHEAT

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CERTIFICATE

This is to certify that the thesis entitled, ***“EFFECT OF BIOCHAR AND WATER STRESS ON THE GROWTH AND YIELD OF WHEAT*** *“submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE*** *in* ***SOIL SCIENCE,*** *embodies the result of a piece of bona fide research work carried out by* ***RAJIB KUMER HARI*** *Registration No.* ***11-04535****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 **(Syfullah Shahriar)**
Supervisor

DEDICATED TO

MY BELOVED PARENTS

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ABSTRACT

The experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University, Dhaka during the period from December 2016 to April 2017 to observe the effect of biochar and water stress on the growth and yield of wheat. In this experiment, the treatment consisted of three doses of biochar viz. BC_1= Control, BC_2= 5 ton biochar ha^{-1}, BC_3= 10 ton biochar ha^{-1} and four different water stress viz. water stress, WS_1 = regular irrigation, WS_2= skipped irrigation at crown root initiation stage, WS_3= skipped irrigation at booting stage, WS_4= skipped irrigation at heading and flowering stage. The experiment was laid out in two factors Randomized Complete Block Design (RCBD) with three replications. The collected data were statistically analyzed for evaluation of the treatment effect.Results showed that a significant variation among the treatments in respect majority of the observed parameters. The maximum plant height, Number of leaf $plant^{-1}$, leaf length, Number of effective tillers $hill^{-1}$, ear length, number of spikelets per spike, number of grain per spike, grain yield was found from biochar 5 ton biochar ha^{-1}. The highest grain yield ha^{-1} (2.79 ton) was found from biochar 5 ton biochar ha^{-1}.The maximum plant height, Number of leaf $plant^{-1}$, leaf length, Number of effective tillers $hill^{-1}$, ear length, number of spikelets per spike, number of grain per spike ,yield was attained from skipped irrigation at booting stage.The maximum yield (3.09 t ha^{-1})was obtained from skipped irrigation at bootingstage.Interaction effect of improved biochar and irrigation showed significant differences on yield. The highest yield (3.18 t ha^{-1}) was obtained from 5 ton biochar ha^{-1} with skipped irrigation at booting stage. BARI Gom 27 coupled with 5 ton biochar ha^{-1} and skipped irrigation at booting stage was found to be a promising practice for good yield.

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LIST OF ABBREVIATION AND ACRONYMS

AEZ	=	Agro-Ecological Zone
BARI	=	Bangladesh Agricultural Research Institute
BBS	=	Bangladesh Bureau of Statistics
FAO	=	Food and Agricultural Organization
N	=	Nitrogen
et al.	=	And others
TSP	=	Triple Super Phosphate
MOP	=	Muriate of Potash
RCBD	=	Randomized Complete Block Design
DAT	=	Days after Transplanting
ha^{-1}	=	Per hectare
g	=	gram (s)
kg	=	Kilogram
SAU	=	Sher-e-Bangla Agricultural University
SRDI	=	Soil Resources and Development Institute
wt	=	Weight
LSD	=	Least Significant Difference
^{0}C	=	Degree Celsius
NS	=	Not significant
Max	=	Maximum
Min	=	Minimum
%	=	Percent
NPK	=	Nitrogen, Phosphorus and Potassium
CV%	=	Percentage of Coefficient of Variance

Chapter I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important cereal crop which contains high amount of protein and carbohydrate.About two third of the total world's population consume wheat as staple food (Majumder, 1991). It supplies mainly carbohydrate (69.60%) and also protein (12%), fat (1.72%), and minerals (16.20%) (BARI, 1997). Dubin and Ginkel (1991) reported that the largest area of wheat cultivation in the warmer climates exists in the South-East Asia including Bangladesh, India and Nepal. In Bangladesh, wheat is the second most important cereal crop next to rice. It contributes to the national economy by reducing the volume of import of cereals for fulfilling the food requirements of the country (Razzaque *et al.*, 1992). Besides these, wheat and straw are also used as animal feed. Wheat straw is also used as fuel or house building materials of the poor man of Bangladesh.

An interesting option to achieve this is the application of biochar into the soil. Biochar is a fine-grained charcoal-like material produced by pyrolysis of biomass at temperatures between 300 °C and 600 °C, without limited access of air. During pyrolysis, carbonization of plant cells and chemical change produce structures that are resistant to microbial degradation. Thus, thermally converted material is approximately 1.5 to 2 orders of magnitude more stable in soil than the organic mass, which was not carbonized. Biochar in soil has a mean lifetime of several hundred to several thousands of years (Kuzyakov *et al.*, 2009). Application of biochar to soil can also be used as a method of storage (sequestration) of carbon (Amonette *et al.*, 2007).

Biochar is the solid product material produced during a process known as pyrolysis from the thermo-conversion of biomass under little or no oxygen for use in soils as an amendment (Gaskin *et al*. 2008; Lehmann and Joseph 2009). Biochar is produced from a variety of biomass residues (feedstocks) and under different pyrolytic conditions, and thus has varying nutrient contents. For example, the total nitrogen and phosphorus contents are typically higher in biochars produced from feedstocks of animal origin than those of plant origin (Chan and Xu 2009).

An understanding of the chemical changes that occur in biochar-amended soils is key in managing agricultural soils. This is particularly of importance because the application of biochar to soils as an amendment has shown a number of physico-chemical advantages and disadvantages. For example, several studies have provided encouraging evidence that biochar adds basic cations to soils, improves soil water retention, and has liming potential of acid soils (Glaser *et al*. 2002; Laird *et al*. 2010; Sohi *et al*. 2010; Van Zwieten *et al*. 2010a). However, although the liming ability of biochar has shown positive responses due to increased biomass production and yields (Lehmann *et al*. 2003; Rondon *et al*. 2007; Vaccari *et al*. 2011; Van Zwieten *et al*. 2007), negative yield responses have also been found because high soil pH values are often associated with micronutrient deficiencies (Mikan and Abrams 1995).

The addition of biochar also significantly increases the content of available water in the soil by increasing the amount of water retained in the soil (field water capacity) and allowing plants to draw the soil water content and lower it before wilting (Koide *et al.*, 2015). This is caused mainly due to increasing capillary water capacity of the soil after application of biochar. This leads to increased productivity of plant cultivation, increased microbial activity in soil, and higher levels of availability of nutrients, particularly P and K (Biedermann and Harpole, 2013). Biochar has also shown the ability to change soil biological community composition and abundance (Lehmann, 2011). Atkinson (2010) summarises mechanisms that affect the application of biochar in soils of the temperate zone.

Irrigation plays a vital role on proper growth and development of wheat. Insufficient soil moisture affects both the germination of seed and uptake of nutrients from the soil. Irrigation frequency also has a significant influence on growth and yield of wheat (Khajanij and Swivedi, 1988). These suggest that irrigation water should be supplied precisely at the peak period of crop growth, which may provide good yield of wheat. Shoot dry weight, number of grains, grain yield, biological yield and harvest index decreased to a greater extent when water stress was imposed at the anthesis stage while imposition of water stress at booting stage caused a greater reduction in plant height and number of tillers (Gupta *et al*., 2001). The lowest value corresponded to the treatment with irrigation during grain filling and under rainfed conditions (Bazza *et al*., 1999). In Bangladesh, lack of irrigation facilities was found to be a major constraint for 38% wheat growers, and 25% of the farmers of Bangladesh could not grow wheat due to this problem (Gao *et al*., 2009).

With the selection of superior variety with proper irrigation facilities, its productivity needs to be tested. Lack of irrigation facilities was found to be a major constraint for 38% wheat growers, and 25% of the farmers of Bangladesh could not grow wheat due to this problem (Ahmed and Elias, 1986). Information on the effect of biochar and water stress on the growth and wheat. So, the present piece of research work was carried out with the following objectives-

i. To observe the effect of biochar on the growth and yield of wheat.

ii. To determine the optimum combination of water stress level and biochar application for maximum growth and yield of wheat.

Chapter II

REVIEW OF LITERATURE

Wheat is an important cereal crop which attracted less concentration in respect of various agronomic aspects especially than the high yielding boro rice. Very few research works related to growth, yield and development of wheat variety due to water stress, application of irrigation and biochar performance in these relations have been carried out in our country. The research work so far done in Bangladesh is not adequate and conclusive. However, some of the important and informative works and research findings related to the water stress and effect of biochar on wheat, so far been done at home and abroad on this crop, have been reviewed in this chapter under the following heads-

2.1 Effect of biochar

The widespread problems of an escalating global human population, diminishing food reserves and climate change (carbon abatement) are a growing concern (Lehmann and Joseph 2009). It has been predicted that over the next two decades, crop yields of primary foods such as corn (maize), rice and wheat will considerably decrease as a result of warmer and drier climatic conditions particularly in semi-arid areas (Brown and Funk 2008). In addition to this, agricultural soil degradation and soil infertility are common problems (Chan and Xu 2009; Glover 2009). As a means of addressing these problems, the application of biochar to soils has been brought forward in an effort to sustainably amend low nutrient-holding soils (Laird 2008; Lehmann and Joseph 2009; Yuan *et al*. 2011b).

Biochar is pyrolyzed (charred) biomass, or also commonly known as charcoal or agrichar, produced by an exothermic process called pyrolysis (Lehmann and Joseph 2009). Pyrolysis is the combustion of organic materials in the presence of little or no oxygen, leading to the formation of carbon-rich char that is highly resistant to decomposition (Thies and Rillig 2009). As a result thereof, biochar can persist in soils and sediments for many centuries (Downie *et al*. 2011; Glaser 2007; Woods and McCann 1999), and has great potential to improve agronomic production when applied as a soil amendment (Laird *et al*. 2009).

In previous studies, soils used to investigate the agricultural properties of biochar have mostly been highly weathered soils from humid tropic regions (Glaer *et al*. 2001; Steiner *et al*. 2008; Verheijen *et al*. 2009). Only recently has research included the investigation of biochar application on the performance of infertile, acidic soils with kaolinitic clays, low cation exchange capacity (CEC), and deteriorating soil organic carbon contents (Chan *et al*. 2007; Chan and Xu 2009; Novak *et al.* 2009; Van Zwieten *et al*. 2010b). Generally, the addition of biochar to soil has been reported to have a multitude of agricultural benefits. These include a high soil sorption capacity, reduced nutrient loss by surface and groundwater runoff, and a gradual release of nutrients to the growing plant (Laird 2008).

On the contrary, a few possible negative implications have been reported to be associated with biochar. Kookana *et al*. (2011) found that these include i) additional agronomic input costs, ii) the binding and deactivation of synthetic agrochemicals due to an interaction with herbicides and nutrients, iii) the deposit and transport of hazardous contaminants due to the release of toxicants such as heavy metals present in biochar, and iv) an immediate increase in pH and electrical conductivity (EC). Furthermore, although studies have highlighted that contaminants such as organic compounds, heavy metals, and dioxins may be present in biochar, there is limited published research that proves that these contaminants are available (Smernik 2009; Verheijen *et al*. 2009).

The dark anthropogenic soils found in Brazil, also 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). Studies involving radiocarbon dating have revealed that these soils were produced up to 7000 years ago during pre-Columbian civilization. It is believed that the accumulation of charcoal in these soils is as a result of anthropogenic activities which consequently led to the formation of terra pretasoils (Glaser 2007). Although most dark earths are as a result of long-term human habitation, studies show that chemical changes in the soil are central to the darkening of these soils. These chemical changes encourage soil biotic activity and downward development, and thus resulting in melanization. While these ADE have formed over several millennia, they have not formed at a constant rate. Several studies have found that the rate of formation can fall in the range of 0.015 cm to 1.0 cm per annum. In particular, dark brown to black soils are classified as terra preta de Indio based on similarities in texture and subsoil of the underlying and immediately surrounding soil (Woods and McCann 1999).

Dutch soil scientist Wim Sombroek introduced the term terra mulatato describe the brown coloured soil which formed as a consequence of semi-intensive cultivation practiced over long periods (Woods and Denevan 2009). Both terra preta and terra mulata soils are closely associated because they are usually found nearby or embedded within greater regions of each other (Woods and McCann 1999).

2.1.1 Impact of biochar on soil chemistry

Biochar is becoming a popular alternative to organic amendments that are being applied to soils to increase and sustain soil productivity (Lehmann and Joseph 2009). This is attributed to the large amounts of highly porous black carbon found in biochar. The carboxylate groups found in black carbon provide CEC, increase the O/C ratio, and are the primary source of biochar’s high nutrient rete ntion ability (Glaser et al. 2001). In addition, biochar may aid in maintaining or increasing nutrient cycling and the stable pools of soil organic carbon (Gaskin et al. 2008). Despite biochar being able to improve and sustain soil fertility, fresh biochar shows moderately low cation retention properties relative to aged biochar (Lehmann 2007a). Therefore, there is a pertinent area of research required to determine the conditions and time period required for biochar to develop its adsorbing properties.

Leached sandy soils typically have low soil pH values, poor buffering capacities, low CEC, with values ranging from 2-8 cmolckg-1, and can have Al toxicity (Novak *et al*. 2009). The addition of biochar to highly leached, infertile soils has been shown to give an almost immediate increase in the availability of basic cations (Glaser *et al*. 2002; Liang *et al*. 2006), and a significant improvement in crop yields, particularly where nutrient resources are in short supply (Lehmann and Rondon 2006) . Over time, these additions continue to promote soil nutrient availability by giving rise to greater stabilization of organic matter and a subsequent reduction in the release of nutrients from organic matter (Glaser *et al*. 2001; Lehmann and Rondon 2006).

Several studies comparing the application of fresh biomass and biochars of the same biomass into soils with similar soil characteristics have found that primarily due to their recalcitrant nature (Baldock and Smernik 2002; Steiner et al. 2008), biochar , unlike fresh biomass, may persist in soils for hundreds of years (Cheng *et al*. 2008; Liang *et al*. 2008; Zimmerman 2010). A long term study involving frequent applications of fresh papermill waste biomass on sandy soil failed to demonstrate the long term build up of soil C (Curnoe et al. 2006). In contrast, Van Zwieten et *al*. (2010b) found that papermill biochar significantly increased total soil C in the range of 0.5 – 1.0 %. Furthermore, biochar, relative to the fresh biomass of the same biomass has proven to be effective for carbon sequestration (Vaccari *et al*. 2011), increasing soil fertility (Wang *et al*. 2009), and improving the liming potential of acid soils (Yuan *et al*. 2011b).

A major disadvantage relative to biochar regarding the direct incorporation of fresh biomass to the soil is that because soil fauna are bound to decompose the organic biomass, the fresh biomass will not remain in the soil for long periods of time (Xu et al. 2006). However, since biochar is slow to degrade in the terrestrial environment (Gaskin et al. 2008), it can be used to sequester C in the long-term (Glaser 2007). A key underlying element in the application of charred biomass to soil is that the pyrolysis conditions and feedstock directly affect nutrient availability (Gaskin et al. 2010; Glaser *et al*. 2002). Therefore, this provides evidence that it is more effective to ameliorate soils with pyrolyzed biomass relative to fresh biomass.

Depending on the biochar biomass used, basic cations such as Ca, K, Mg, and silicon (Si) can form alkaline oxides or carbonates during the pyrolysis process. Following the release of these oxides into the environment, they can react with the H+ and monomeric Al species, raise the soil pH, and decrease exchangeable acidity (Novak *et al*. 2009). Furthermore, research conducted by Novak *et al*. (2009) on pecan shell derived biochar revealed that there was a high concentration of calcium oxide (CaO) in the biochar, which neutralizes soil acidity as follows: 2Al –soil + 3CaO + 3H2O → 3Ca –soil + $2Al(OH)_3$.

The reaction describes the reduction in exchangeable acidity whereby Ca replaces the monomeric Al species on the soil exchangeable sites and generates alkalinity. Subsequently, there is an increase in soil solution pH as a result of the reduction of the readily hydrolysable monomeric Al and the subsequent formation of the neutral [Al(OH)3]0species (Sparks 2003).

When biochar has high concentrations of carbonates, it may have effective liming properties for overcoming soil acidity (Chan and Xu 2009). In a study conducted by Van Zwieten *et al.* (2010b), it was shown how the carbonates in the biochar encouraged wheat growth by overcoming the toxic effects of acidic soils. Both acidic and basic sites may coexist within micrometres of each other on biochar outer surfaces and pore particles. These sites react as both an acid and a base and are known as amphoteric sites. In particular, amphoteric sites are found on oxide surfaces, whose surface charge is dependent on solution pH. Therefore, the surfaces are respectively positively and negatively charged under acidic and alkaline conditions. In contrast, basal surfaces of layer silicates have a permanent negativel y charged site in addition to the amphoteric edge sites. Furthermore, carbonate mineral surfaces are analogous to oxide surfaces because of the presence of O in the carbonate anion (Amonette and Joseph 2009).

A corn field study evaluating the effect of the nutrient rich peanut hull biochar on soil nutrients found that soil pH decreased both times during the two growing seasons of investigation in the fertilized treatments. An unspecified nitrogen fertilizer was initially applied at 26 kg ha^{-1}, followed by a side dress application of 166 kg ha^{-1}. At the highest biochar application rate of 22 t ha^{-1}, the soil pH decreased from 6.46 to 5.61 in the 0-15 cm soil depth, and from 6.13 to 5.61 in the 15-30 cm soil depth (Gaskin *et al.* 2010). This may be attributed to the production of carboxylic functional groupscaused by the time dependent oxidation of the biochar surface (Cheng *et al.* 2006).

Biochar is synonymous with biomass derived black carbon (Lehmann *et al.* 2006; Liang *et al.* 2006), and is consequently commonly referred to as black carbon (BC). Black carbon is a solid residue that forms by the partial burning of plant materials, fossil fuels and other geological deposits. The formation of black carbon gives rise to two different products. In the first instance, volatiles re-condense to a soot-BC which is very high in graphite, while the solid residues produce a form of char-BC. Black carbon generally encompasses C forms of varying aromaticity and falls along a broad spectrum that includes charred organic materials to charcoal, soot and graphite (Schmidt and Noack 2000).

Black carbon is highly resilient given that it is able to persist in the environment for hundreds and thousands of years. This characteristic is established in the black carbon's inherent nature of being chemically and microbially stable because of its polycyclic aromatic structure. The oxidation of BC causes a continual production of carboxylic groups on the edges of the aromatic backbone and a resultant increase in its nutrient holding capacity (Glaser *et al*. 2001).

Biochar is primarily composed of both single and condensed ring aromatic C, and subsequently has a mutual high surface area per unit mass and a high surface charge density (Lehmann 2007a). The biochars largely composed of single-ring aromatic and aliphatic C mineralize more rapidly in comparison to those composed of condensed aromatic C (Lehmann 2007a). Spectra using NEXAFS reveal that aromatic and quinonic compounds are more common when aliphatic groups are lost at 400 ˚C (Keiluweit *et al*. 2010).

Lehmann (2007a) reported that biochar may be an alternative to renewable energy because it is not carbon neutral, but rather carbon negative. This implies that because biochar is formed by a carbon negative process, it may serve as a longterm terrestrial sink of carbon. The carbon egative process means that the feedstock parent material used to manufacture biochar initially withdraws organic carbon from the photosynthesis and decomposition carbon cycle pathways (Lehmann 2007b). This process is then followed by storing this organic carbon in the soil, thus causing it to accumulate over time (Glaser 2007). Relative to merely using fresh material to store C, because biochar decomposes over a long period of time, it is able to create the slow release of CO_2 into the atmosphere over an extended period, and thus reduce CO_2 emissions (Gaunt and Lehmann 2008). Therefore, because biochar is able to gain CO_2 from the atmosphere, it would circumvent from the contribution of climate change, and hence aid in reducing global warming (Lehmann 2007a).

Ideal carbon sequestration involves no negative soil effects as a result of the additional carbon input. In the case of using biochar, this means that the crop quality and yield would be enhanced, with no incidence of harmful pests and crop diseases (Vaccari et *al.* 2011). Busscher *et al*., (2010) proposed that using non-activated pecan shell derived biochar to increase soil C would improve soil physical properties. Switchgrass (Panicum virgatum) was added for this purpose. It was found that although switchgrass increased soil C, it is likely that the results will be transitory due to the rapid oxidation rate of the soils and climate.

Numerous and regular applications of biochar to soil are not necessary because biochar is not warranted as a fertilizer (Lehmann and Joseph 2009). In a pot trial carried out by Chan *et al.* (2007), a significant increase in the dry matter (DM) production of radish resulted when N fertilizer was used together with biochar. The results showed that in the presence of N fertilizer, there was a 95 to 266 % variation in yield for soils with no biochar additions, in comparison to those with the highest rate of 100 t ha^{-1}. Improved fertilizer-use efficiency, referring to crops giving rise to higher yield per unit of fertilizer applied (Chan and Xu 2009), was thus shown as a major positive attribute of the application of biochar.

Major *et al*. (2010) conducted a study whereby a field trial demonstrated that a single dolomitic lime and wood biochar application on an acidic, infertile Oxisol was sufficient to increase crop yield and nutrition uptake of crops. A maize-soybean rotation was used for the study which took place over several cropping seasons. In addition, inorganic fertilizers were equally applied to both the biochar-amended and control soils. The trial was carried over 4 years. It was found that no significant effect was observable during the first year of application. However, the maize yield gradually increased with an increase in the biochar application rate in the ensuing years. These yield increases were as a result of increases in pH and nutrient retention. It was found that there was a stark overall decline in yield in the fourth year of application due to the decreasing Ca and Mg soil stocks.

Plant nutrient uptake and availability of elements such as P, K and Ca are typically increased, while free Al in solution is decreased in solution in biochar-amended soils. This occurs as a function of biochar's high porosity and surface to volume ratio, together with an increase the in the pH of acid soils, attributed to the basic compounds found in biochar (Chan *et al*. 2007).

When comparing pyrogenic organic material such as biochar to ordinary organic matter, it was found that the chief distinguishing characteristic between the two products is that biochar has a much higher sorption affinity and ability for sorbing non polar organic compounds. These compounds refer to polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), herbicides, and pesticides. Furthermore, the pyrogenic organic material showed signs of being less reversible than other forms of organic matter, and of displaying non linear sorption isotherms. This is indicative of adsorption onto biochar surfaces. This ability for sorption is essential in controlling the fate and behaviour of organic and environmental pollutants (Smernik 2009).

Liang et al. (2006) reported that both an increase in surface oxidation and CEC are the possible reasons for the long term affects that biochar have on nutrient availability. Various studies continue to prove that the increase in soil fertility of ADE is attributed to charcoal. Lima *et al*. (2002) showed that P and Ca accumulated from bone apatite due to anthropogenic activities, while black carbon arose from charcoal (Glaser *et al*. 2001).

Plant based biochar consists of various N containing structures which include amino acids, amines, and amino sugars. When subjectedto pyrolysis, these structures get condensed and form heterocyclic N aromatic structures (Cao and Harris 2010), which may possibly not be available for plant use (Gaskin et al. 2010). Consequently, the residual N in the biochar is largely found as recalcitrant heterocyclic N rather than bio-available amine N (Cao and Harris

2010; Novak *et al*. 2009). For agronomic purposes, and to counter the potentially unavailable biochar N it has been found that there is a positive effect when biochar was applied together with the addition of a N fertilizer (Chan *et al*. 2007; Steiner *et al*. 2008), thus showing that biochar has the potential to improve the efficiency of mineral N fertilizer. In addition, biochar is suggested as being economically viable due the reduction in the amount spent on commercial mineral fertilizers (Steiner et al. 2008).

Although not fully understood, empirical research has shown that biochar alters the N dynamics in soil (Lehmann 2007a). Weathering of biochar in soil has been shown to lead to N immobilization (Singh *et al*. 2010) primarily attributed to high C contents of leaching sources (Laird *et al*. 2010; Lehmann *et al*., 2003). Also, depending on biochar feedstock, soil and contact time period, high biochar application levels between 10 and 20 % by weight have been shown to reduce NH_4^+ leaching in contrasting (Ferralsol and Anthrosol) soils (Lehmann *et al*. 2003). Furthermore, Chan *et al.* (2007) observed an increase in the uptake of N at higher levels of biochar. Since nitrogen is primarily assimilated by plants as nitrate (NO_3^-), it is imperative that its uptake be coupled with an uptake of basic cations in order to maintain electrical balance. Consequently, this is associated with a considerable increase in K uptake, and a slight Ca uptake.

The determination of soluble NH_4^+-N is typically used to assess the potential of a material to be used as a soil amendment. Consequently, in a study conducted by Cao and Harris (2010), it was determined that it was better to carbonize the dairy manure derived biochar at a low temperature of less than 200°C, than at higher temperatures. This was done to ensure that the NH_4^+-N content of the biochar was favourably used as an effective soil amendment for the nutrition of the crop. Common N functional groups for low temperature biochar were measured by X-ray photoelectron spectroscopy (XPS) and found to be pyrrolic or pyridinic amines (Amonette and Joseph 2009). Nitrate nitrogen (NO3-N) and ammonium-N are mineral forms of N, and are found in low concentrations in biochar. However, the availability and rate of mineralization of organic N found in biochar applied to soil provides an indication of the biochar's ability of being a slow release N fertilizer (Chan and Xu 2009).

In a study carried out using pecan shell derived biochar, the results indicated that although the biochar contained some N, mixing 0.5 % and 1.0 % biochar had no evident effect on the total C and total combustible nitrogen (TCN). However, adding 2 % biochar showed a considerable increase in the soil mean Total combustible nitrogen content (Novak et al. 2009), although the soil N status was not significantly improved.

Chan et al. (2007) conducted glasshouse pot trial experiments where the agronomic benefits of greenwaste biochar applied as a soil amendment were investigated. Radish was planted in an acidic hardsetting soil with a low soil organic carbon content, and its dry matter production was later analyzed. The DM production of radish using greenwastes and ammonium nitrate were investigated in the absence and presence of N fertilizer. It was found that in the absence of N fertilizer, biochar application did not at all cause an increase in the crop yield. However, increasing biochar application rates (10, 50 and 100 t ha^{-1}) resulted in significant yield increases in the presence of 100 kg ha^{-1} of N fertilizer. As the biochar used in this study had a low N content (1.3 g kg^{-1}), negligible mineral N, anda high C: N ratio of 200, its application to the soil did not contribute to any additional available N to the crop. Therefore, it was shown that biochar has the potential to improve N fertilizer use efficiency of plants (Chan *et al*. 2007; Ding *et al*. 2010; Gaskin *et al*. 2008).

Steiner *et al*. (2008) used both charcoal and compost to determine the influence of on N retention on a permeable humid tropic soil. It was found that soil charcoal amendments enhanced the efficiency of mineral N fertilizer more than the compost. Furthermore, there was a significant recovery difference of 7.2 % between the total N recovered in soils with biochar and the control. This indicated an improvement in the fertilizer usage of N, P, and K.

Soils found in tropical regions are particularly poor in plant available phosphorus resulting in P deficient environments. These soils contain sesquioxides that have the ability to strongly sorb phosphate (Turner *et al*. 2006), and thereby creating a sink on the availability of inorganic phosphorus for plants (Oberson *et al*. 2006). Sandy textured soils give biochar the potential to ameliorate P leaching in soils, therefore, it is expected that P will increase with increasing levels of biochar additions (Novak et al. 2009). In a study conducted on the response of DM production of radish using greenwastes, the biochar application increased the P concentration. It was established that significant yield increases were only found at biochar application rates greater than 50 t ha-1, and when no N fertilizer was applied. This increase was due to the high concentrations of available P found in the biochar, and because P was no longer limiting (Chan *et al*. 2007).

In a study conducted on the response of DM production of radish using greenwastes, the biochar application increased the K concentration. It was found that significant increases were only found at biochar application rates greater than 50 t $ha^{-1}$and when no N fertilizer was applied. This increase was due to the high concentrations of exchangeable K found in the biochar (Chan *et al*. 2007).

The application of biochar increased the Ca concentration in a study conducted on the response of DM production of radish using greenwastes. It was found that significant increases were only found at biochar application rates greater than 50 t $ha^{-1}$and when no N fertilizer was applied (Chan *et al*. 2007). A field trial conducted over a period of 4 years with biochar application rates of 0, 8, and 20 t ha^{-1} respectively also showed an overall increase in available Ca. Over time, the available Ca content increased from 101 % to 320 % and up to 30 cm depths. These increases further meant that there was minimal Ca leaching with biochar (Major *et al.* 2010).

In a 6 week pot trial study conducted on the response of DM production of radish using greenwastes, the various biochar application rates were relatively similar in the Mg concentrations. It was found that significant reductions were only found in the unfertilized treatments at 10 t ha^{-1} and in the fertilized treatments at 50t ha^{-1}(Chan *et al*. 2007). In contrast, (Major *et al*. 2010) found that the available Mg content increased from 64 % to 217 % over a biochar application rate of 0-20 t ha^{-1}, and over a period of 4 years.

The common S functional groups for low temperature biochar are sulfonates andsulfates (Amonette and Joseph 2009). The pecan shell biochar study conducted by Novak *et al*. (2009) showed that exchangeable S marginally decreased with an increase in the biochar concentration that was added.

Kawsar *et al*. (2015)To investigate the integrative effect of biochar, farmyard manure (FYM) and nitrogen (organic and inorganic soil amendments) in a wheat-maize cropping system, a two year study was designed to assess the interactive outcome of biochar, FYM and nitrogenous fertilizer on wheat nitrogen (N) parameters and associated soil quality parameters. Three levels of biochar (0, 25 and 50 t ha^{-1}), two levels of FYM (5 and 10 t ha^{-1}) and two levels of nitrogen fertilizer (60 and 120 kg ha-1) were used in the study. Biochar application displayed a significantly increased in wheat leaf, stem, straw and grain N content; grain and total N-uptake and grain protein content by 24, 20, 24, 56, 50, 17 and 20% respectively. Similarly, biochar application significantly increased soil total N (TN) and soil mineral N (SMN) by 63 and 40% respectively in second year. Mineral N application increased soil TN by over a half and Soil Mineral Nitrogen by a third, and grain protein content increased 16%. In contrast, nitrogen use efficiency (NUE) decreased for all amendments relative to the control. However, biochar treated plots improved NUE by 38% compared to plots without biochar.

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

Zee *et al*., (2017) performed to see if the addition of biochar, in comparison to lime and fertilizer treatments, has the potential to return key nutrients back to the soil or increase crop yield. A field study to investigate the effects of biochar on plant growth was initiated in 2011 near St. John, KS. Treatments included biochar applied at 16.6 ton/a (biochar), lime and annual applications of phosphorus and potassium fertilizer (lime+P&K), and a control. Four rates of nitrogen (N) fertilizer were applied within each treatment (0, 45, 90, and 135 lb N/a). Winter wheat was planted in 2015 and harvested in 2016. The biochar treatment had greater wheat yield and better plant growth than the control but it was similar to the lime+P&K treatment. The greater yields from the biochar and the lime+P&K were likely due to increased soil pH from the lime and biochar. Biochar appears to be an effective method of supplying phosphorus (P), potassium (K), and increasing soil pH, and there was no effect on nitrogen availability.

In this research, four different proportion of biochar was added in five different levels of saline-alkali soil for pot culture experiment by Wang and Xu (2013). The pH of the soil increases as the proportion of biochar increase in same saline-alkali level soil, while the EC decrease as the proportion of biochar increase. The germination rate of wheat seeds varies as the different of soil's saline-alkali level. Notable among these results is the germination of wheat seeds in the serious saline-alkali soil without biochar added is 0, while in 45% biochar added in serious saline-alkali soil, the germination rate get to as high as 48.9%. Also, biochar improve the growth of wheat seedling, while for mild saline alkali soil and normal soil. Biochar had no obvious effect on the growth of wheat seedling.

Abbas*et al*. (2017) studied to the effect of rice straw BC on Cd immobilization in soil and uptake by wheat in an agricultural contaminated-soil was investigated. Different levels of rice straw BC (0%, 1.5%, 3.0% and 5% w/w) were incorporated into the soil and incubated for two weeks. After this, wheat plants were grown in the amended soil until maturity. The results show that the BC treatments increased the soil and soil solution pH and silicon contents in the plant tissues and in the soil solution while decreased the bioavailable Cd in soil. The BC application increased the plant-height, spike-length, shoot and root dry mass and grain yield in a dose additive manner when compared with control treatment. As compared to control, BC application increased the photosynthetic pigments and gas exchange parameters in leaves. Biochar treatments decreased the oxidative stress while increased the activities of antioxidant enzymes in shoots compared to the control. The BC treatments decreased the Cd and Ni while increased Zn and Mn concentrations in shoots, roots, and grains of wheat compared to the control. As compared to the control, Cd concentration in wheat grains decreased by 26%, 42%, and 57% after the application of 1.5%, 3.0%, and 5.0% BC respectively. Overall, the application of rice straw BC might be effective in immobilization of metal in the soil and reducing its uptake and translocation to grains.

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

2.2. Effect of irrigation on growth and yield of wheat

Islam *et al*. (2015) carried out an experiment with four irrigation stages viz. I_0: No irrigation; I_1: Irrigation at crown root initiation (CRI) stage (18 DAS); I_2: Irrigation at preflowering stage (45 DAS) and I_3: Irrigation at both CRI and pre-flowering stage. Maximum number of tiller hill^{-1}(5.2), CGR (6.7gm-2day^{-1}), RGR (0.03gg-1day^{-1}), dry matter content (28.7%), number of spikes hill^{-1}(4.5), number of spikelets spike^{-1} (19.0), ear length (17.5), filled grains spike-1 (30.8), total grains spike^{-1}(32.9), weight of 1000-grains (47.1 g), grain yield (3.9 tha^{-1}), straw yield (4.9 t ha^{-1}), biological yield (8.8 t ha^{-1}) and harvest index (45.9%) were obtained from I_3 whereas lowest occurred in I_0. They also stated that early flowering (70.6 days), maturity (107.2 days) and minimum number of unfilled grains spike^{-1} (2.1) were also obtained from I_3.

Chouhan *et al.* (2015) observed that water saving of about 28.42% higher when drip irrigation was applied rather than the border irrigation system. They also stated that water productivity of drip irrigated wheat was 24.24% higher compared with the border irrigated wheat. But, there was a slightly reduction of 10.8% in the grain yield because of severe water deficit during the growing stages.

Mueen-ud-din *et al*. (2015) conducted an experiment that maximum grain yield (4232.5 kg ha^{-1}), no. of grains $spike^{-1}$(51), 1000 grain weight (46.5 g) were observed due to application of 3 acre inch water and highest water use efficiency of 20, 19.89 kg ha^{-1}/mm was obtained where 2 acre inch water was given.

Atikullah, *et al.* (2014) showed that maximum dry matter content (18.8g/plant), crop growth rate (CGR) (13.5 g m-2 day-1), relative growth rate (RGR) (0.024 g m^{-2} day^{-1}) were obtained from I_1 which was statistically same as I_2 whereas lowest obtained from I_0 . They also reported that 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, straw 5.7 t/ha and biological 9.1 t/ha) and harvest index were observed better in I_1

Atikulla (2013) observed that each of the 3 different dated irrigated plots showed better performance than that of the non-irrigated plot in all the parameters studied. Among the 3 different dates of irrigation, irrigation at crown root initiation stage (WS_1), recorded the highest values in all the parameters studied but it was statistically similar with irrigation at flowering (WS_2) and irrigation at grain filling stage of wheat (WS_3).

Sultana (2013) stated that increasing water stress declined the plant height, nos. of effective tillers per hill, grain yield and straw yield and maximum grain yield was obtained for the variety BARI Gam-26 that was 2.96t ha^{-1}.

Wang *et al.* (2012) reported that a significant irrigation effect was observed on grain yield, kernel numbers and straw yield. The highest levels were achieved with a high irrigation supply, although WUE generally decreased linearly with increasing seasonal irrigation rates in 2 years. The low irrigation treatment (0.6 ET) produced significantly lower grain yield (20.7 %), kernels number (9.3 %) and straw yield (12.2 %) compared to high

The field experiment was conducted by Vinod *et al.* (2011) during winter seasons to study the effect of irrigation and fertilizer management on yield and economics of simultaneous planting of winter sugarcane + wheat. The experiment was carried out in split plot design, keeping four irrigation options in main plot, viz. irrigation scheduled at 0.8 (I1), 1.0 (I2), 1.2 (I3) IW/CPE ratio and critical stages i.e. crown root initiation, tillering, late jointing, flowering, milk and dough stages of wheat (I4), and four nutrient levels, with four replications. The maximum gain of gross return (Rs 126,992.0/ha), net return (Rs 75,882.5/ha) and B:C ratio (1.49) was obtained with irrigation at physiological stages of wheat followed by irrigation at 1.2 IW/CPE ratio over the irrigation at 0.8 and 1.0 IW/CPE ratio whereas, least net returns (Rs 48,687.4/ha) and B:C ratio (1.34) was under 0.8 IW/CPE ratio.

The effect of compensation irrigation on the yield and water use efficiency of winter wheat in Henan province was studied by Wu *et al*. (2011) and found that the soil was obviously short of moisture when the irrigation was managed in the former stage, and the layer of 20-40 cm was the lowest one in all of the layers. The group dynamics, the volume of spikes per hectare and the tiller volume of single plant were improved under national compensative irrigation. The spike volume per ha, the tillers and spikes per plant were increased by 16,500-699,000, 0.12-1.16 and 0.01-0.11, respectively. For the effect of irrigation on plant height, spike length and spike grains, the combinative treatment of irrigation in the former stage and medium irrigation compensation in the latter were better. The wheat yield was increased by 2.54%-13.61% compared to control and the treatments, irrigation of 900 m3/ha at the elongation stage and of 450 m3/ha at the booting stage or separate irrigation of 900 m3/ha at the two stage were the highest.

Field trials were conducted by Malik *et al.* (2010) to estimate the effect of number of irrigations on yield of wheat crop in the semi arid area of Pakistan. The study comprised of three treatments including four irrigations (T_1) at crown root development, booting, milking and grain development; five irrigations (T_2) at crown root development, tillering, milking, grain development and dough stage and six irrigations (T_3) at crown root development, tillering, milking, grain development, dough stage and at maturity. The results revealed that the grain yield and yield contributing parameters were significantly higher when crop was irrigated with five irrigations (T_2), while 1000-grain weight, germination count m-2and number of tillers m-2were not affected significantly. The highest grain yield was recorded with five irrigations at different critical growth stages of wheat crop. The possible reason might be availability of more moisture. The results revealed that the application of irrigation at tillering stage played a vital role to increase wheat yield and contrarily the application of irrigation at maturity caused decrease in wheat yield.

Rahim *et al.* (2010) conducted under farmer's field conditions to see the effect of phosphorus application and irrigation scheduling on wheat yield and phosphorus use efficiency. Fertilizer P doses 0, 47, 81 and 111 kg P_2O_5 ha^{-1} were calculated by using adsorption isotherms and applied by broadcast and band placement. Four irrigations i.e. 0, 2, 3, 4 were applied at critical stages of wheat. Basal N: K=130:65 kg ha^{-1}were applied. Wheat grain yield increased from 1.58 Mg ha^{-1} to 3.94 Mg $ha^{-1}$with the use of P @ 81 kg P_2O_5 ha^{-1}. Band placement of P proved better over broadcast, whilst three irrigations at crown roots, booting, and grain development stages were sufficient to get maximum yield and improve phosphorus use efficiency.

Naeem *et al.* (2010) conducted a field study pertaining to the effect of different levels of irrigation on yield and yield components of wheat cultivars at Agronomic Research Area, University of Agriculture, Faisalabad. Treatments were three cultivars and five irrigation levels WS_1(irrigation at crown root stage), WS_2(irrigation at crown root +

tillering), WS_3(irrigation at crown root + tillering +booting), WS_4(irrigation at crown root + tillering + booting + anthesis), and I5(irrigation at crown root + tillering + booting + anthesis + milking). Wheat crop supplied with five irrigations at crown root + tillering + booting + earing +milking recorded the highest grain yield (5696.8 kg ha-1) which was significantly higher than all the other irrigation levels.

Field experiment was conducted by Mishra and Padmakar (2010) to study the effect of irrigation frequencies on yield and water use efficiency of wheat varieties during Rabi seasons. The I2treatment combinations comprised of four irrigation levels viz., I1(one irrigation at CRI stage), I2(two irrigations: one each at CRI and flowering stages), I3(three irrigations: one each at CRI, LT and flowering stages) and I4(four irrigations: one each at CRI + LT + LJ + ear head formation stages) along with the combination of three varieties viz., HUW-234, HD-2285 and PBW-154. Progressive increase in number of irrigations from 1 to 4 increased various yield contributing characters viz., effective tillers m^{-2}, ear length, no. of grains ear-1 and test weight while three and four irrigations were found statistically at par with each other. The highest grain yield (40.65 q ha^{-1}) was credited to I4 that 7was significantly superior over I1 and I2 but non-significant with I_3. Consumptive use of water increased while water use efficiency gradually decreased with increase in number of irrigations.

Using semi-winter wheat Yumai 49-198 as experiment material, a field experiment was conducted by Li *et al.* (2010) to investigate the leaf area index, dry matter accumulation, photosynthetic characteristics and yield of winter wheat under different irrigation stages and amounts. The results showed that, before the jointing stage, the leaf area index increased with the increase of irrigation amount. After jointing stage, all the indexes were good when the field water capacity maintained at 65%, while too much irrigation amount was unfavourable to the dry matter accumulation, especially to the photosynthetic rate of flag leaf and yield formation after anthesis.

Excessive nitrogen (N) and high irrigation in local agricultural systems are raising concern owing to water quality and water quantity in the middle reach of the Heihe River basin. Consequently, a controlled study of irrigation and N was conducted by Wang *et al.* (2009) to investigate the effects of different irrigation and N supply levels on spring wheat growth characteristics, water consumption and grain yield on recently reclaimed sandy farmlands with an accurate management system. A complete randomized block split-plot design was employed, with irrigation regimes [0.6, 0.8 and 1.0 estimated wheat evapotranspiration (ET)] and N fertilizer application rates [0, 140, 221, 300 kg/hm2] as the main-plot and split-plot respectively. Under the experimental conditions, irrigation and N had relative low effects on plant height. Water consumption was increased with irrigation, water consumption in high irrigation treatment was increased by 16.68% and 36.88% compared with intermediate irrigation treatment and low irrigation treatment, respectively. The low irrigation (378 mm during spring wheat growth), accompanied by 221 kg N/hm2 was the best management system for the relative high economic yield and high WUE in this region.

Gao *et al.* (2009) conducted a field experiment to determine the reasonable and effective water-saving irrigation schemes in wheat production, the commercial wheat cvs Shannong 15 and Yannong 21 were grown in in China and subjected to 3 water irrigation treatments: W0 (with a relative water content of 60% in the 0-140 cm soil layer at the jointing stage and 55% at anthesis), W1(75% at the jointing stage and 65% at anthesis) and W2 (75% at the jointing stage and 75% at anthesis). The highest irrigation water use efficiency was recorded in W1 and the highest grain yield and water use efficiency (WUE) were achieved in W2for both cultivars. Under the conditions of this experiment, W2 was the optimum water management treatment, which was beneficial to both of grain yield and WUE.

Sarkar *et al.* (2009) wheat with five irrigation treatments which were Io (No irrigation), I1 (17-21 DAS), I2 (17-21 DAS+50-55 DAS), I3 (17-21 DAS+50-55 DAS+75-80 DAS) and I4 (17-21 DAS+35-40 DAS+50-55 DAS+75-80 DAS).They reported that on an average 33,43,52 and 51 percent higher yield were obtained over farmer's practice at I1,I2,I3 and I4 irrigation levels, respectively.

Two field experiments with winter wheat were made by Zhao *et al.* (2009) in Hebei, China and one in Baoding in 2006-2007 and the other in Gaocheng in 2007-2008. Four irrigation treatments (W0, no irrigation; W1, irrigation at the elongation stage; W2, irrigations at the elongation and the heading-anthesis stages; and W3, irrigations at thawing, the elongation stage and the heading-anthesis stage) were combined with 3 nitrogen (N) application treatments. In 2006-2007, irrigation frequency and N application rate had considerable influences on total number of culms, which was significantly higher in W1, W2 and W3 than in W0, while no significant difference existed among W1, W2 and W3. The effects of irrigation frequency on spike number per ha and 1000-grain-weight were statically significant, and the effects of N rate on spike number per ha and grain number per spike were significant. Grain yield was the highest in W3 and the lowest in W0, and the highest in N1 and the lowest in N0.

The study was carried out by Mangan *et al*. (2008) to evaluate the performance of yield and yield components traits of wheat genotypes under water stress conditions. Four wheat varieties were screened under water stress conditions at Nuclear Institute of Agriculture (NIA) Tandojam. Different irrigation treatments (1, 2, 3 and 4) were applied during various crop growth stages. Grain yield and grain yield contributing traits of wheat varieties were significantly affected under water stress conditions. Except spike yield, Sarsabz had significantly more 1000-9 grain weight, grain yield, main spike yield and grains spike-1 as compared to other varieties over all irrigation treatments; hence more tolerant to drought. Grain yield ranged between 373 kg ha-1 in single irrigation treatment to 3931 kg ha-1 in four irrigations, whereas 1000-grain weight ranged between 28.1-41.8 in four treatments.

Ali and Amin (2007) Irrigation treatments were given as: no irrigation, control (T0); one irrigation at 21 DAS (T1); two irrigations at 21 and 45 DAS (T2); three irrigations at 21, 45 and 60 DAS (T3); and four irrigation at 21, 45,60 and 75 DAS (T4). Plant height, number of effective tillers per hill, spike length, number of spikelets per spike, filled grains per spike obtained significantly by applying irrigation at different levels. The growth, yield attributes and yield of wheat increased significantly when two irrigations were given at 21 and 45 DAS over the other treatments.

Twenty bread wheat cultivars were subjected to irrigation at 10, 20 and 30-day intervals in a field experiment conducted by Zarea and Ghodsi (2004) in Iran. Grain yield, total biomass, number of spike/m2, harvest index and 1000-kernel weight decreased with increasing irrigation intervals. Water use efficiency was highest with irrigation at 20-day intervals. When a 20 and 30-day irrigation interval were applied, grain yield, number of spike/m2, harvest index and water use efficiency were higher in cultivars C-75-14 and C-75-9.

This study was carried out by Baser *et al.* (2004) to determine the influence of water deficit on yield and yield components of winter wheat under Thrace conditions (Turkey). Four wheat genotypes were grown under five different water stress treatments. The treatments included an unstressed control (S0), water stress at the late vegetative stage (S1), at the flowering stage (S2), or at the grain formation stage (S3) and full stress (non-irrigation S4). The effects of water stress treatments on grain yield and yield components were statistically significant compared with non-stressed conditions. Grain yield under non-irrigated conditions was reduced by approximately 40%. Among the genotypes, MV-17 gave the highest grain yield.

Zhai *et al.* (2003) conducted a pot experiment with winter wheat to determine water stress on the growth, yield contributing characters and yield of wheat and they reported that water stress significantly inhibited the growth and yield of winter wheat.

Wang *et al*. (2002) conducted a pot experiment in a green house to study the effects of water deficit and irrigation at different growing stages of winter wheat and observed that water deficiency retarded plant growth. Irrigation increased yield of wheat significantly than under control condition.

Debelo *et al.* (2001) conducted a field experiment in Ethiopia on bread wheat and reported that plant height and thousand-kernel weight showed positive and strong association with grain yield, indicating considerable direct or indirect contribution to grain yield under low moisture conditions.

Gupta *et al.* (2001) reported that shoot dry weight, number of grains, grain yield, biological yield and harvest index decreased to a greater extent when water stress was imposed at the anthesis stage while imposition of water stress at booting stage caused a greater reduction in plant height and number of tillers. Among the yield attributes, number of leaves and number of tillers were positively correlated at the anthesis stage whereas leaf area and shoot dry weight significantly correlated with grain and biological yield at both the stages.

A field experiment was conducted by Ghodpage and Gawande (2001) in Akola, Maharashtra, India, during rabi to investigate the effect of scheduling irrigation (2, 3, 4, 5 and 6 irrigations) at various physiological growth stages of late-sown wheat in Morna command area. The maximum grain yield of 2488 kg/ha was obtained in 6 irrigations treatment and it was significantly superior over all other treatments. In general, there was consistent reduction in grain yield due to missing irrigation. A yield reduction of 9.88% was recorded when no irrigation at dough stage was scheduled. Further, missing irrigation at tillering and milking stages resulted in 21.94% yield reduction. It was still worse when no irrigation was scheduled at tillering, milking and dough stages, recording 29.30% yield reduction. Approximately 50% loss in grain was observed when irrigation was missed at tillering, flowering, milking and dough stages.

Chapter III

MATERIALS AND METHODS

The experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University, Dhaka during the period from December 2016 to April 2017 to observe the effect of biochar and water stress on the growth and wheat. The details of the materials and methods have been presented below:

3.1 Description of the experimental site

The research work was conducted in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The location of the site was $23^0 74^/$ N latitude and $90^0 35^/$ E longitude with an elevation of 8.2 meter from sea level.

3. 2 Soil characteristics

The soil belonged to "The Modhupur Tract", AEZ – 28 (FAO, 1988). Top soil was silty clay in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. Soil pH was 5.6 and had organic carbon 0.73%. The experimental area was flat having available irrigation and drainage system and above flood level. The selected plot was medium high land. The details have been presented in Appendix I.

3.3 Climate condition

The geographical location of the experimental site was under the subtropical climate, characterized by three distinct seasons, winter season from November to February and the pre-monsoon period or hot season from March to April and monsoon period from May to October (Edris *et al*., 1979).

3.4 Treatments of the experiment

The experiment consisted of two factors as follows:

Factor A: Biochar (3 levels):

i. BC_1= Control

ii. BC_2= 5 ton biochar ha^{-1}

iii. BC_3= 10 ton biochar ha^{-1}

Factor B : water stress (4 levels)

i. WS_1 = regular irrigation

ii. WS_2= skipped irrigation at crown root initiation stage

iii. WS_3= skipped irrigation at booting stage

iv. WS_4= skipped irrigation at heading and flowering stage

3.5 Experimental design and layout

The two factors experiment was laid out following Randomized Complete Block Design (RCBD) with three replications. An area was divided into three equal blocks. Each block was divided into 12 plots where 12 treatment were allotted at random. Thus there were 36 unit plots altogether in the experiment. The size of each plot was 2m×1.5 m. The distance between two blocks and two plots were kept 0.5 m and 0.5 m respectively.

3.6 Growing of crops

3.6.1 Seed collection

The seeds of wheat variety of BARI Gom 27 for this experiment were collected from Bangladesh Agricultural Research Institute (BARI), Joydevpur, Gazipur**.**

3.6.2 Preparation of the main field

The plot selected for the experiment was opened in the third week of December 2008 with a power tiller, and was exposed to the sun for a week after which the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain a good tilth. Weeds and stubbles were removed and finally a desirable tilth of soil was obtained for sowing of seeds.

3.6.3 Application of fertilizers and manure

The fertilizers N, P, K and S in the form of Urea, TSP, MP and Gypsum, respectively were applied. The entire amount of TSP, MP and Gypsum, 2/3rd of urea were applied during the final preparation of land. Rest of urea was top dressed after first irrigation (BARI, 2006). The doses and method of application of fertilizers are shown in below.

Fertilizers	Dose (ha)	Application (%)	
		Basal	1st installment
Urea	220 kg	66.66	33.33
TSP	180 kg	100	--
MP	50 kg	100	--
Gypsum	120 kg	100	--
Cowdung	10 ton	100	--

3.6.4 After care

After the emergence of seedlings, various intercultural operations such as irrigation and drainage, weeding, top dressing of fertilizer and plant protection measure were accomplished for better growth and development of the wheat seedlings as per the recommendation of BARI (2006).

3.6.4.1 Irrigation and drainage

Irrigation was provided in this experiment. As per treatment

3.6.4.2 Weeding

Weedings were done to keep the plots free from weeds which ultimately ensured better growth and development of wheat seedlings. The newly emerged weeds were uprooted carefully at tillering (30 DAS) and panicle initiation stage (55 DAS) manually.

3.6.4.3 Plant protection

The crop was attacked by different kinds of insects during the growing period. Triel-20 ml was applied on 5 January and sumithion-40 ml/20 litre of water was applied on 25 January as plant protection measure.

3.7 Harvesting, threshing and cleaning

The crop was harvested depending upon the maturity of plant manually from each plot through the first week of April, 2017. The harvested crop of each plot was bundled separately, properly tagged and brought to threshing floor. Enough care was taken during threshing and cleaning period of wheatgrain. Fresh weight of wheat grain and straw were recorded in m^{-2} in plot wise. The grains were cleaned and weighted. The weight was adjusted to a moisture content of 14%. The straw was sun dried and the yields of wheat grain and straw m^{-2} were recorded and converted to t ha^{-1}.

3.8 Data collection

3.8.1 Plant height

The height of plant was recorded in centimeter (cm) at 20, 30, 40, 50, 70 DAS (Days after sowing) and at harvest. Data were recorded as the average of 10 plants selected at random from the inner rows of each plot. The height was measured from the ground level to the tip of the plant.

3.8.2 Number of leaves per plant

The total number of leaves per plant was counted as the number of leaves from 10 randomly selected plants from each plot and average value was recorded.

3.8.3 Leaf length

The length of leaf was measred by using a meter scale. The measurement was taken from base to tip of the leaf . average length of leaves was taken from five random selected plants. Average was expressed in centimeter (cm).

3.8.4 Number of effective tillers/plant

The total number of effective tillers plant^{-1} was counted as the number of panicle bearing plant^{-1}. Data on effective tillers plant^{-1} were counted from 10 selected hills at harvest and average value was recorded.

3.8.5 Ear length

The length of ear was measured with a meter scale from 10 selected panicles and the average value was recorded.

3.8.6 Number of spikelet per spike

The total number of spikelets per spike was counted as the number of spikelets from 10 randomly selected spikes from each plot and average value was recorded.

3.8.7 Number of filled grain per spike

The number of fertile florets per spike was counted as the number of fertile floret from 10 randomly selected spikes in each plot and average value was recorded.

3.8.8 Grain yield per hectare

Grains obtained from m^{-2} were converted into t ha^{-1} grain weight.

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

Straw yield was determined from the central 1 m^2 of each plot. After threshing, the samples were oven dried to a constant weight and finally converted to t ha^{-1}.

3.9 Statistical Analysis

The data obtained for different characters were statistically analyzed to observe the significant difference among the genotypes in response to growth and yield of late sown wheat. The mean values of all the characters were calculated and analysis of variance was performed. The significance of the difference among the treatment means was estimated by the Duncan Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER 4

RESULTS AND DISCUSSION

This chapter comprised with presentation and discussion of the results obtained from the study to observe the growth and yield performance of selected wheat genotypes at variable irrigation management have been presented in Table and Figure.

4.1 Plant height

Plant height varied significantly influenced by three different doses of biochar (Fig. 1). The tallest plant height (77.87 cm) was obtained from BC_2 (5 t biochar ha^{-1}) and the shortest plant height (72.53cm)recordedfrom control treatment. However,

Plant height of wheat showed statistically significant variation due to amount of irrigation (Figure 2). The tallest plant (79.39cm) was recorded from WS_3 (skipped irrigation at booting sage), which was statistically similar with WS_4 (skipped irrigation at heading and flowering sage) while the shortest plant (71.34cm) was observed from WS_1(regular irrigation)Providing 2 irrigations at crown root initiation stage and pre flowering stage ensured the optimum vegetative growth of the wheat and the ultimate results were the longest plant. Zhai *et al*. (2003) reported that water stress significantly inhibited the growth and yield of winter wheat. Gupta *et al.* (2001) reported that when water stress was imposed at booting stage caused a greater reduction in plant height. Islam (1997) reported that plant height increased with increasing number of irrigations.

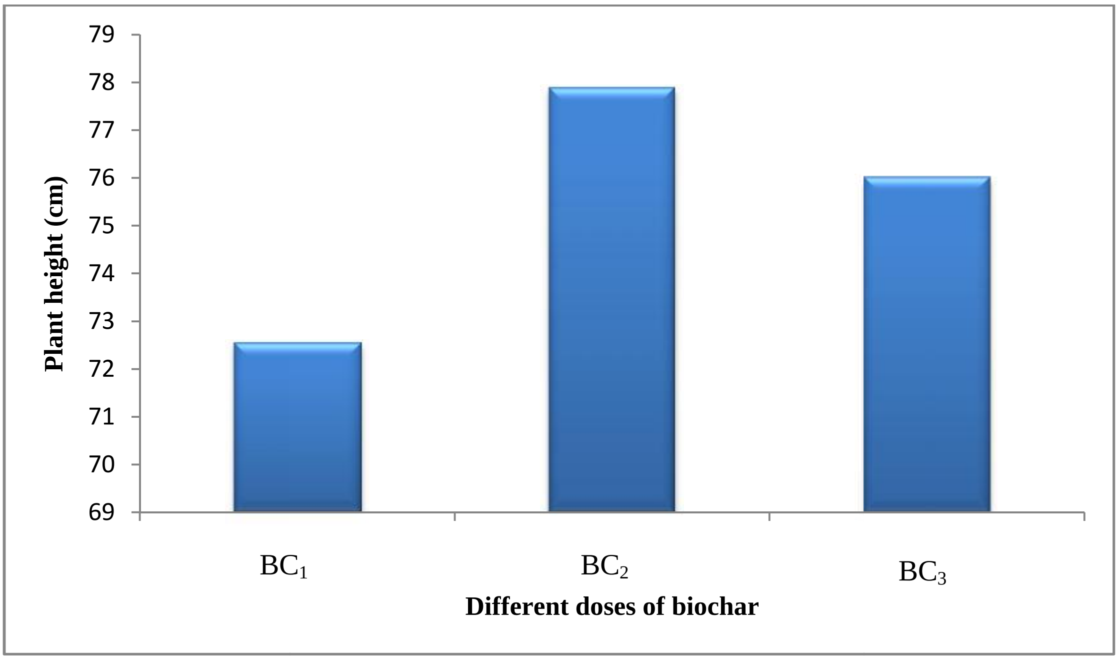

Fig. 1. Effect of different doses of biochar on plant height of wheat

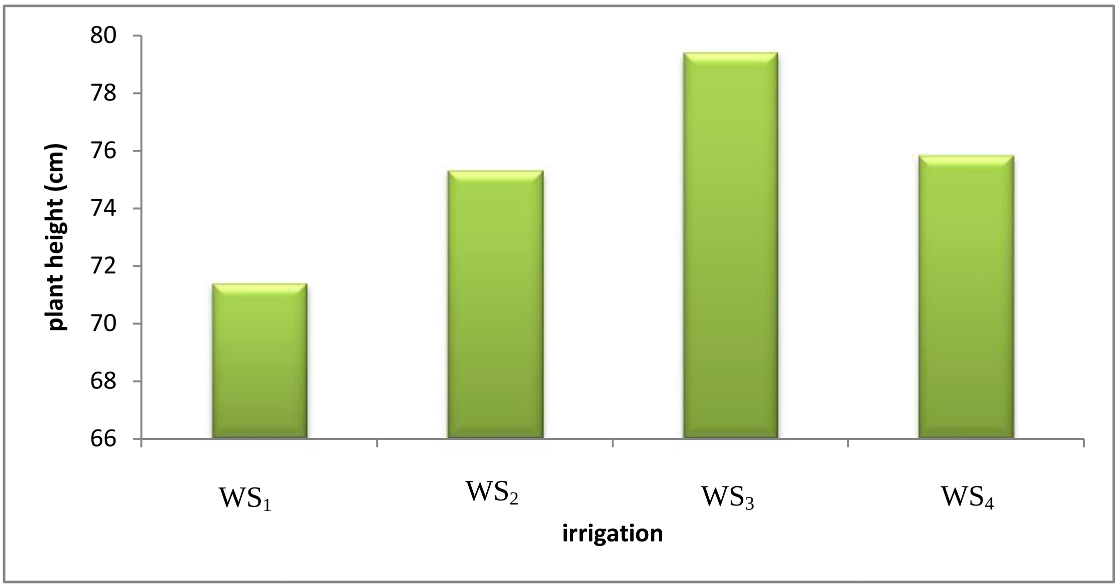

Fig. 2. Effect of irrigation on plant height of wheat

Interaction effect of biochar and different amount of irrigation showed significant differences on plant height of wheat (Table 1). The highestplant heightwas 81.80cm obtained from BC_2WS_3 treatment combination. The shortest plant height (66.27) obtained from BC_1WS_1treatment combination.

4.2 Number of leaf plant^{-1}

Number of leaf plant^{-1} of wheat was not varied significantly due to biochar (Fig. 3). The BC_2 treatment produced the highest Number of leaf plant^{-1} **(**4.92) and the lowest Number of leaf plant^{-1} (3.83) was observed in BC_1 treatment.

Different levels of irrigation varied significantly in terms of Number of leaf plant^{-1} of wheat (Figure 4). The highest Number of leaf plant^{-1} (5.89) was recorded from WS_3, while the corresponding lowest Number of leaf plant^{-1} (3.11) was observed in WS_1, which was statistically similar with WS_4 treatment.

Interaction effect of biochar and irrigation showed significant differences on Number of leaf plant^{-1} of wheat (Table 2). The maximumnumber of leaf plant^{-1} (6.67) was observed from BC_2WS_3 treatment combination. The minimum number of leaf plant^{-1}(2.67) were recorded from BC_1WS_1 treatment combination, which was statistically similar with BC_1WS_2,BC_1WS_4, BC_2WS_1, BC_2WS_4, BC_3WS_1treatment combinations.

Table 1. Combined effect of biochar and irrigation on plant height, number of leaf per plant, length of leaf of wheat

Treatment	Plant height (cm)		Number of leaf per plant		Length of leaf (cm)	
BC_1WS_1	66.27	f	2.67	d	10.16	e
BC_1WS_2	72.73	e	3.67	d	11.00	cde
BC_1WS_3	77.03	bcd	5.33	bc	12.18	bc
BC_1WS_4	74.10	cde	3.67	d	11.49	cd
BC_2WS_1	74.00	cde	3.67	d	11.11	cde
BC_2WS_2	77.70	bcd	5.33	abc	11.61	bcd
BC_2WS_3	81.80	a	6.67	a	13.52	a
BC_2WS_4	77.97	abc	4.00	d	11.88	bc
BC_3WS_1	73.77	de	3.00	d	10.49	de
BC_3WS_2	75.47	bcde	3.67	d	11.20	cde
BC_3WS_3	79.33	ab	5.67	ab	12.70	ab
BC_3WS_4	75.43	bcde	4.00	cd	11.62	bcd
LSD $_{(0.05)}$	3.66		1.27		1.06	
CV (%)	5.86		7.46		5.40	

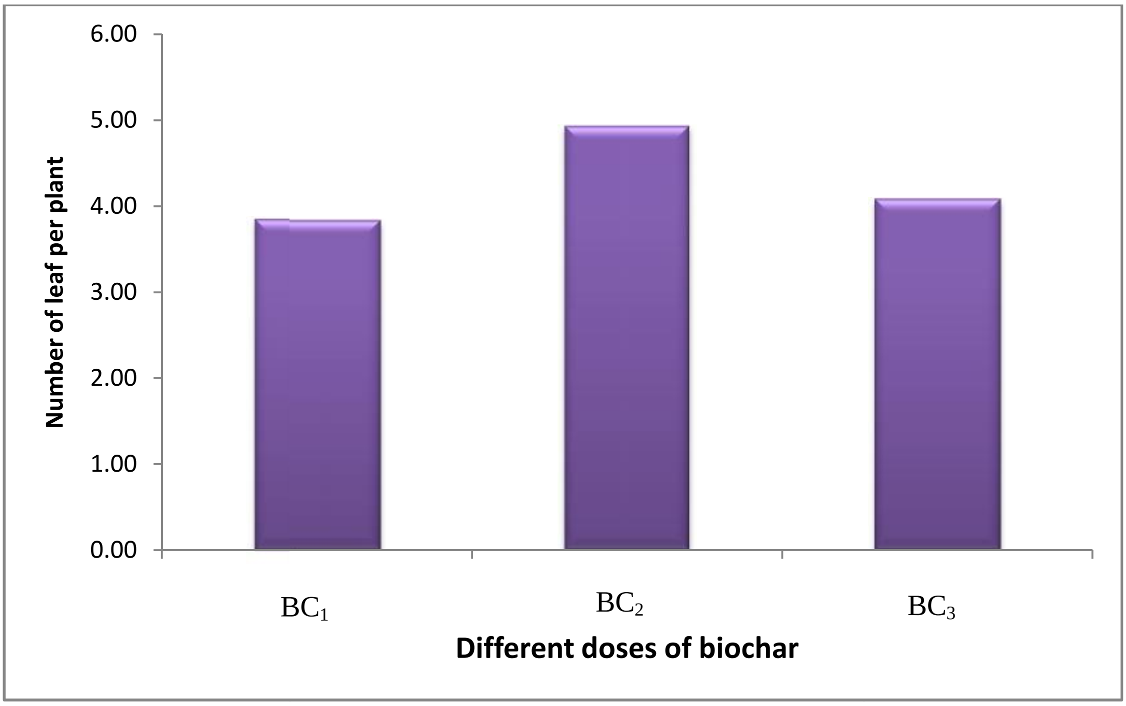

Fig. 3 Effect of different doses of biochar on number of leaf per plant of wheat

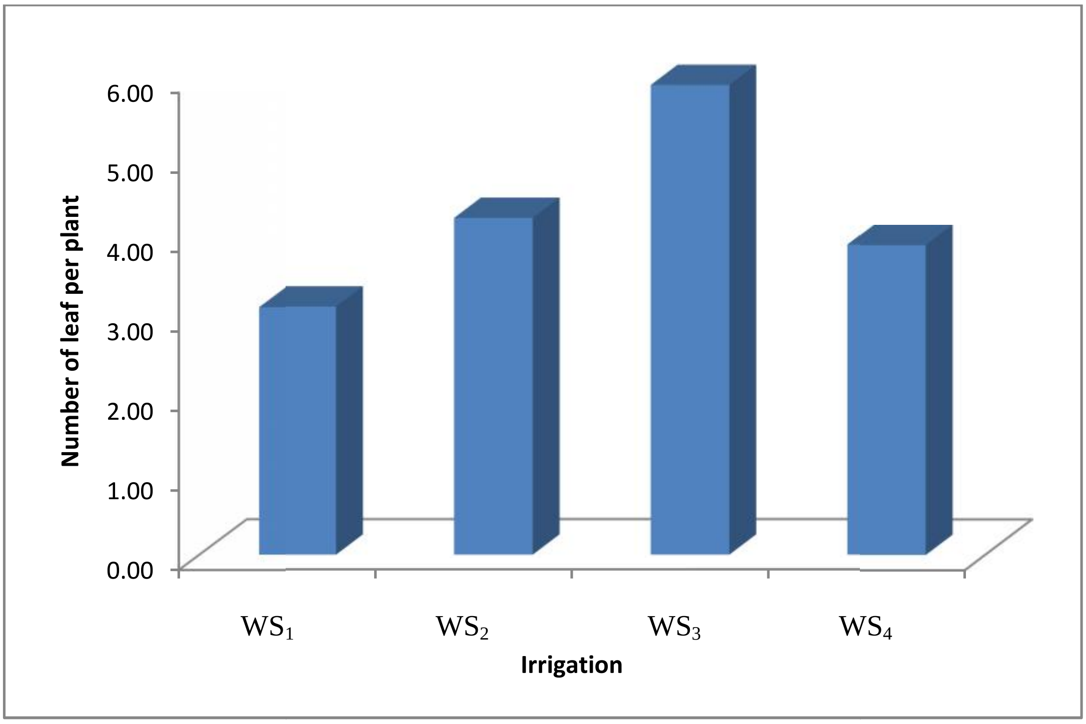

Fig. 4 Effect of irrigation on number of leaf per plant of wheat

4.3. Leaf length (cm)

Insignificant variation was observed on leaf length (cm) due to different level of biochar. From the experiment with that three types of biochar, BC_2 given the largest leaf length (12.03 cm) and the BC_1 was given the lowest leaf length (11.20 cm) (fig.5).

Different irrigation application has a statistically significant variation on leaf length.The WS_3 treatment was given the maximum leaf length (12.80 cm) and the WS_1 given the lowest leaf length (10.58 cm) (Fig. 6).

Interaction effect of biochar and irrigation showed significant differences on leaf length. Results showed that the highest leaf length (13.52 cm) was obtained from BC_2WS_3 (5 ton biochar ha^{-1} with skipped irrigation at booting sage). On the other hand the lowest leaf length (10.16 cm) was observed at BC_1WS_1 (Control with regular irrigation) (Table 1).

4.4 Number of effective tillers hill^{-1}

Number of effective tillers hill^{-1}of wheat was not varied significantly due to biochar (Table 2). The maximum number of effective tillers hill^{-1} **(**7.42) was produced from BC_2 treatment and the minimumt number of effective tillers hill^{-1}(4.83) was observed in BC_1 treatment.

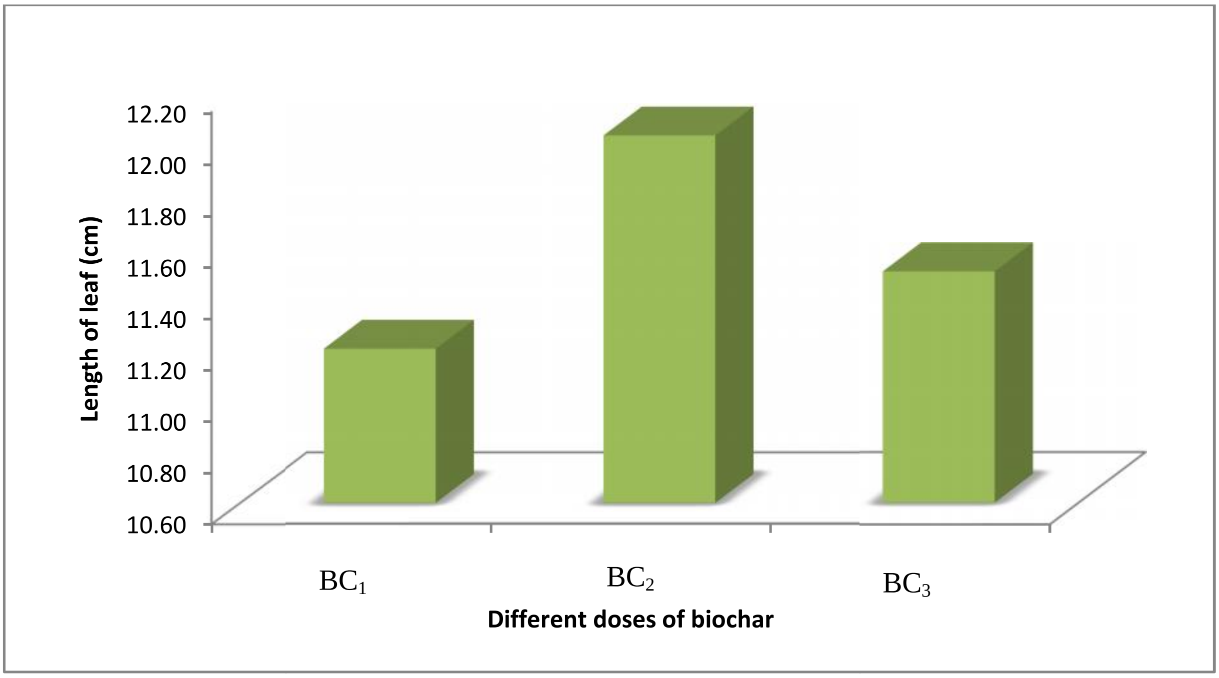

Fig. 5 Effect of different doses of biochar on length of leaf per plant of wheat

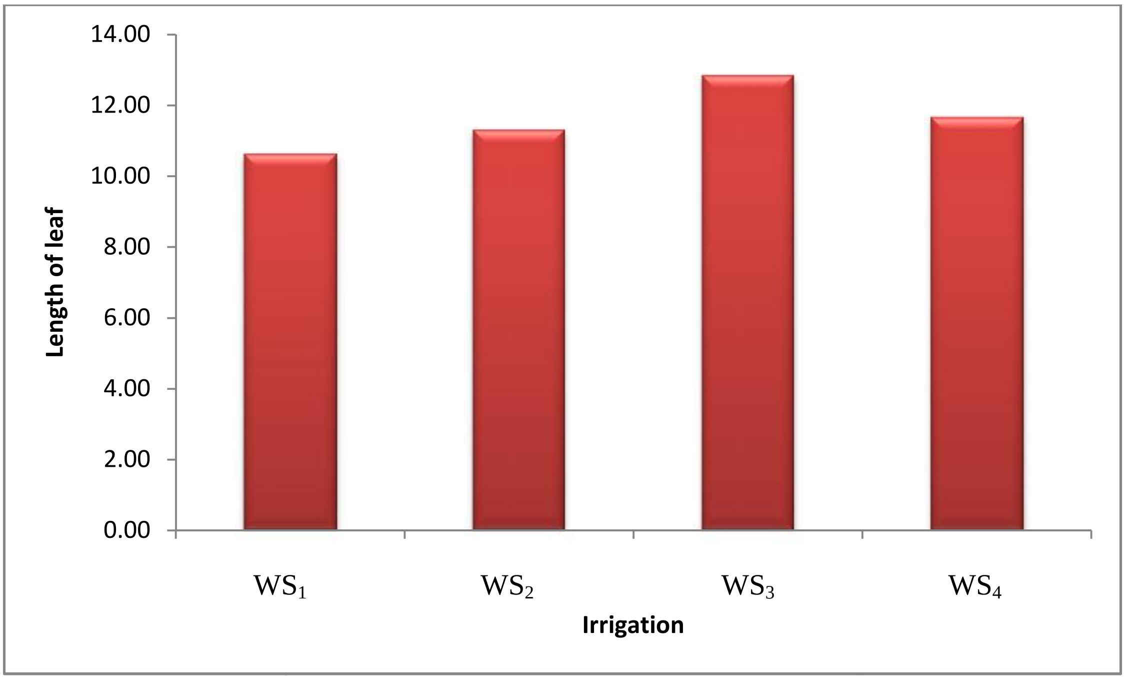

Fig. 6 Effect of irrigation on length of leaf per plant of wheat

Different levels of irrigation varied significantly in terms of number of effective tillers hill^{-1} of wheat at harvest under the present trial (Table 3). The highest number of effective tillers hill^{-1}(7.44) was recorded from WS_3treatment, while the corresponding lowest number of effective tillers hill^{-1}(5.11) was observed in W_1 treatment, which was statistically similar with WS_4 treatment. Application of 2 irrigations at crown root initiation stage and pre flowering stage ensured the optimum vegetative growth of the wheat with highest number of tillers hill^{-1} as referred by Meena *et al*, (1998). Gupta *et al.* (2001) reported that when water stress was imposed at the booting stage caused a greater reduction in number of tillers.

Biochar andirrigation showed significant differences on number of effective tillers hill^{-1} of wheat due to interaction effect (Table 4). The highest number of effective tillers hill^{-1}(9.00) were observed from Bc_3Ws_3 treatment combination, while the corresponding lowest number of effective tillers hill^{-1} (3.67) as were recorded from BC_1WS_1 treatment combination.

4.5. Ear length (cm)

Insignificant variation was observed on ear length (cm) at applied three types of biochar. From the experiment with three types of biochar that the 5 ton biochar ha^{-1} BC_3 (13.12 cm) given the largest ear length and control (BC_1) (12.73 cm) was given the lowest ear length (Table 2).

Table 2. Effect of biochar on Number of effective tiller,Ear length and Number of spike per spikeletof wheat

Treatment	Number of effective tiller	Ear length (cm)	Number of spike per spikelet
BC_1	4.83 a	12.73 a	14.25 b
BC_2	7.42 a	13.12 a	16.17 a
BC_3	6.17 a	12.88 a	15.25 ab
LSD $_{(0.05)}$	2.68	0.42	1.78
CV (%)	12.65	3.64	5.32

Table 3. Effect of irrigation on Number of effective tiller,Ear length and Number of spike per spikeletof wheat

Treatment	Number of effective tiller	Ear length (cm)	Number of spike per spikelet
WS_1	5.11 b	11.81 c	13.33 c
WS_2	6.44 ab	13.12 ab	15.56 ab
WS_3	7.44 a	13.87 a	16.89 a
WS_4	5.56 b	12.84 b	15.11 b
LSD $_{(0.05)}$	1.81	1.00	1.76
CV (%)	12.65	3.64	5.32

Table 4. Interaction effect of biochar and irrigation on number of effective tiller,ear length and number of spike per spikelet of wheat

Treatment	Number of effective tiller		Ear length (cm)		Number of spike per spikelet	
BC_1WS_1	3.67	f	11.57	d	11.67	g
BC_1WS_2	5.67	cde	12.97	b	15.67	bcd
BC_1WS_3	5.67	cde	13.41	ab	16.00	bc
BC_1WS_4	4.33	ef	12.98	b	13.67	f
BC_2WS_1	6.67	bcd	12.07	cd	14.33	def
BC_2WS_2	7.00	bc	13.40	ab	15.67	bcd
BC_2WS_3	9.00	a	14.15	a	17.67	a
BC_2WS_4	7.00	bc	12.84	bc	17.00	ab
BC_3WS_1	5.00	ef	11.78	d	14.00	ef
BC_3WS_2	6.67	bcd	12.98	b	15.33	cde
BC_3WS_3	7.67	b	14.03	a	17.00	ab
BC_3WS_4	5.33	de	12.72	bc	14.67	cdef
$LSD_{(0.05)}$	1.32		0.80		1.37	
CV (%)	12.65		3.64		5.32	

Different irrigation application have a statistically significant variation on ear length as irrigated condition (WS_3) was given the maximum result (13.87 cm) and regular irrigated condition (WS_1) given the lowest spike length (11.81 cm) (Table 3). Pal and Upasani (2007) also observed that irrigation effect on spike length (cm) of wheat and applied different irrigation treatment at same way and found effect of irrigation on spike length (cm).

Interaction effect biochar and irrigation showed significant differences on earlength. Results showed that the highest spike length was obtained from BC_2WS_3(14.15 cm), which was statistically similar with BC_3WS_3 treatment combination. On the other hand the lowest spike length was observed at BC_1WS_1 treatment combination (11.57 cm) (Table4).

4.6 Number of spikelets spike^{-1}

Significant variation was observed in case of number of spikelets spike^{-1} with different dose of biochar application (Table 3). It was observed that that the highest number of spikelets spike^{-1} (16.17) was obtained with 5 ton biochar application per hectare. On the other hand the lowest number of spikelets spike-1 (14.25) was obtained with no biochar application.

Number of spikelets spike^{-1} at harvest was significantly influenced by different irrigation treatments (Table 3). It was observed that the highest number of spikelets spike-1 at harvest (16.89) was obtained with skipped irrigation at booting sage. On the other hand the lowest number of spikelets spike^{-1} (13.33) at harvest was shown by regular irrigation. It was also observed that one irrigation showed intermediate results compared to all other treatments. This finding was supported by the findings of Ali and Amin (2007).

The interaction effect between different doses of biochar and irrigation was significant for the number of spikelets spike^{-1} at harvest (Table 4). It was observed that the highest number of spikelets spike^{-1} at harvest (17.67) was obtained from 5 ton biochar ha^{-1}withskipped irrigation at booting sage. On the other hand the lowest number of spikelets spike^{-1} (11.67) was obtained fromControl with regular irrigation (BC_1WS_1) treatment combination at harvest. The results obtained from all other treatments were significantly different compared to the highest and lowest number of spikelets spike-1 at harvest. This was similar to that of Maqsood *et al*., (2007).

4.7. Grain spike^{-1}

Insignificant variation was observed on grain spike^{-1} at these applied three types of doses of biochar. The 5 ton biochar ha^{-1} (BC_3) given the maximum number of grain spike^{-1}(15.92) and control (BC_1) was given the lowest number of grain spike^{-1}(14.42) (Table 5).

Different irrigation application have a statistically significant variation on grain spike^{-1} as three irrigation condition (WS_3) was given the maximum result (16.67), and non irrigated condition (WS_1) given the lowest grain spike^{-1} (14.00) (Table 6). Sarkar *et al.* (2010) also observed that irrigation have a significatint effect on grain spike^{-1}.

Table 5. Effect of variety on yield and yield of wheat

Treatment	Number of filled grain per spike	Grain yield (t ha^{-1})	Straw Yield (t ha^{-1})
BC_1	14.42 a	2.44 b	2.82 a
BC_2	15.92 a	2.79 a	2.92 a
BC_3	15.17 a	2.68 ab	2.90 a
LSD $_{(0.05)}$	3.88	0.33	0.11
CV (%)	7.87	8.44	7.23

Table 6. Effect of irrigation on yield and yield of wheat

Treatment	Number of filled grain per spike	Grain yield (t ha^{-1})	Straw Yield (t ha^{-1})
WS_1	14.00 b	2.20 c	2.56 b
WS_2	15.33 ab	2.51 bc	2.83 ab
WS_3	16.67 a	3.09 a	3.19 a
WS_4	14.67 b	2.75 ab	2.92 ab
LSD $_{(0.05)}$	1.84	0.44	0.60
CV (%)	7.87	8.44	7.23

Interaction effect of improved wheat biochar and irrigation showed significant differences on grain spike^{-1}. Results showed that the highest grain spike^{-1} was obtained from BC_2WS_3 treatment combination (17.33). On the other hand the lowest grain spike^{-1} was observed at BC_1WS_1treatment combination(13.00)(Table 7).

4.8. Yield (t ha^{-1})

Different doses of biocharshowed significant difference for grain weight hectare^{-1} (Table 5). The highest grain weight hectare^{-1} (2.79 ton) was found from biochar5 ton biochar ha^{-1} (WS_3), whereas the lowest (2.44 ton) was observed from control.

Significant difference was observed for yield for different irrigation application. The irrigation (WS_3) was given the maximum yield (3.09 t ha^{-1}), which was statistically identicaland regular irrigation condition (WS_1) given the lowest yield (2.20t ha^{-1}) (Table 6). Sarkar *et al.* (2010), Baser *et al*. (2004) reported that grain yield under non-irrigated conditions was reduced by approximately 40%. Bazza *et al.* (1999) reported that one water application during the tillering stage allowed the yield to be lower only than that of the treatment with three irrigations but Meena *et al.* (1998) reported that wheat grain yield was the highest with 2 irrigations (2.57 ton/ha in 1993 and 2.64 ton/ha) at flowering and/or crown root initiation stages.

Table 7. Interaction effect of variety and irrigation on yield and yield of wheat

Treatment	Number of filled grain per spike		Grain yield ($t\ ha^{-1}$)		Straw Yield ($t\ ha^{-1}$)	
BC_1WS_1	13.00	f	1.95	e	2.44	f
BC_1WS_2	14.67	cdef	2.05	de	2.63	def
BC_1WS_3	15.67	abcde	3.06	ab	3.29	a
BC_1WS_4	14.33	cdef	2.70	bc	2.90	abcde
BC_2WS_1	14.00	def	2.43	cd	2.59	ef
BC_2WS_2	16.33	abc	2.67	bc	2.87	bcde
BC_2WS_3	17.33	a	3.18	a	3.17	ab
BC_2WS_4	16.00	abcd	2.88	ab	3.04	abc
BC_3WS_1	15.00	bcdef	2.22	de	2.65	cdef
BC_3WS_2	15.00	bcdef	2.81	abc	2.99	abcd
BC_3WS_3	17.00	ab	3.03	ab	3.11	ab
BC_3WS_4	13.67	ef	2.66	bc	2.83	bcdef
$LSD_{(0.05)}$	2.02		0.37		0.35	
CV (%)	7.87		8.44		7.23	

Interaction effect of improved wheat biochar and irrigation showed significant differences on yield (t ha^{-1}). Results showed that the highest yield (3.18t ha^{-1}) was obtained from BC_2WS_3 treatment combination. On the other hand the lowest yield (1.95t ha^{-1}) was observed at BC_1WS_1 treatment combination(Table7).

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

Applied three types of biochar have not significant variation on straw yield (t ha^{-1}) (Table 5). The maximum straw yield (2.92t ha^{-1}) was obtained from Bc_2 treatmentand the Bc_1treatment was given the lowest straw yield (2.82t ha^{-1}).

Different irrigation application has a statistically significant variation on straw yield (t ha^{-1}) of wheat (Table 6). The Ws_3 treatment for straw yield (3.19 t ha^{-1}) was given the maximum result and non irrigated condition (W_0) given the lowest (2.56 t ha^{-1}). Similler results were found by Ali and Amin (2004) through his experiment.

Interaction effect of biochar and irrigation showed significant differences on straw yield (Table 7). The highest straw yield (3.29t ha^{-1}) was obtained from BC_1WS_3 treatment combination. On the other hand the lowest straw yield (02.44t ha^{-1}) was observed at BC_1WS_1 treatment combination.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University, Dhaka during the period from December 2016 to April 2017 to observe the effect of biochar and water stress on the growth and wheat. In this experiment, the treatment consisted of three doses of biochar viz. BC_1= Control, BC_2= 5 ton biochar ha^{-1}, BC_3= 10 ton biochar ha^{-1} and four different water stress viz. water stress, WS_1 = regular irrigation, WS_2= skipped irrigation at crown root initiation stage, WS_3= skipped irrigation at booting stage, WS_4= skipped irrigation at heading and flowering stage. The experiment was laid out in two factors Randomized Complete Block Design (RCBD) with three replications. The collected data were statistically analyzed for evaluation of the treatment effect.Results showed that a significant variation among the treatments in respect majority of the observed parameters.

Plant height varied significantly influenced by three different doses of biochar, The tallest plant height (77.87 cm) was obtained from BC_2 (5 t biochar ha^{-1}). Plant height of wheat showed statistically significant variation due to amount of irrigation. The tallest plant (79.39 cm) was recorded from WS_3 (skipped irrigation at booting stage). Interaction effect of biochar and different amount of irrigation showed significant differences on plant height of wheat. The highest plant height was 81.80 cm obtained from BC_2WS_3 treatment combination.

Number of leaf plant^{-1} of wheat was not varied significantly due to biochar. The B_2 treatment produced the highest Number of leaf plant^{-1} **(**4.92). Different levels of irrigation varied significantly in terms of Number of leaf plant^{-1} of wheat (Figure 3). The highest Number of leaf plant^{-1} (5.89) was recorded from WS_3. Interaction effect of biochar and irrigation showed significant differences on Number of leaf plant^{-1} of wheat. The maximum number of leaf plant^{-1} (6.67) was observed from BC_2WS_3 treatment.

Insignificant variation was observed on leaf length) due to different level of biochar. The BC_2 gave the largest leaf length (12.03 cm). Different irrigation application has a statistically significant variation on leaf length. The WS_3 treatment was given the maximum leaf length (12.80 cm). The highest leaf length (13.52 cm) was obtained from BC_2WS_3 treatment combination(5 ton biochar ha^{-1} with skipped irrigation at booting sage).

Number of effective tillers hill^{-1}of wheat was not varied significantly due to biochar. The maximum number of effective tillers hill^{-1} **(**7.42) was produced from BC_2 treatment. Different levels of irrigation varied significantly in terms of number of effective tillers hill^{-1} of wheat at harvest under the present trial. The highest number of effective tillers hill^{-1} (7.44) was recorded from Ws_3 treatment. The highest number of effective tillers hill^{-1} (9.00) was observed from BC_3WS_3 treatment combination.

The largest ear length (13.12 cm) was produced form 5 ton biochar ha^{-1}. The maximum ear length (13.87 cm) was produced from WS_3 treatment. Interaction effect biochar and irrigation showed significant differences on ear length. The highest spike length was obtained from BC_2WS_3 treatment combination (14.15 cm).

Significant variation was observed in case of number of spikelets per spike with different dose of biochar application. The highest number of spikelets per spike(16.17) was obtained with 5 ton biochar application per hectare. Number of spikelets per spike at harvest was significantly influenced by different irrigation treatments. The highest number of spikelets per spike at harvest (16.89) was obtained with skipped irrigation at booting sage. The interaction effect between different doses of biochar and irrigation was significant for the number of spikelets per spike at harvest. It was observed that the highest number of spikelets per spike at harvest (17.67) was obtained from 5 ton biochar $ha^{-1}$with skipped irrigation at booting sage.

Insignificant variation was observed on grain $spike^{-1}$ at these applied three types of doses of biochar. The 5 ton biochar ha^{-1} (BC_3) was given the maximum number of grain per spike (15.92). Different irrigation application has a statistically significant variation on grain per spike as three irrigation condition (WS_3) was given the maximum result (16.67). Interaction effect of improved wheat biochar and irrigation showed significant differences on grain per spike. The highest grain $spike^{-1}$ was obtained from BC_2WS_3 treatment combination (17.33).

Different dose of biochar showed significant difference for grain weight hectare^{-1}. The highest grain weight hectare^{-1} (2.79 ton) was found from biochar 5 ton biochar ha^{-1} (BC_2), whereas the lowest (2.44 ton) was observed from control. The irrigation (WS_3) was given the maximum yield (3.09 t ha^{-1}) and regular irrigation condition (WS_1) given the lowest yield (2.20 t ha^{-1}). The highest yield (3.18 t ha^{-1}) was obtained from BC_2WS_3 treatment combination. On the other hand the lowest yield (1.95 t ha^{-1}) was observed at BC_1WS_1 treatment combination..

The maximum straw yield (2.92 t ha^{-1}) was obtained from BC_2 treatment. The maximum straw yield (3.19 t ha^{-1}) was produced from WS_3 treatment. The highest straw yield (3.29 t ha^{-1}) was obtained from BC_1WS_3 treatment combination.

In conclusion it could be suggested that BARI Gom 27 coupled with 5 ton biochar ha^{-1} and skipped irrigation at booting sage was found to be a promising practice for good yield.

Considering the situation of the present experiment, further studies in the following areas may be suggested:

1. Such study is needed in different agro-ecological zones (AEZ) of Bangladesh for regional compliance and other performance.

2. Another experiment may be carried out with different doses of biochar for specific biochar effect.

3. Another experiment may be carried out with different levels of irrigation for specific water deficit.

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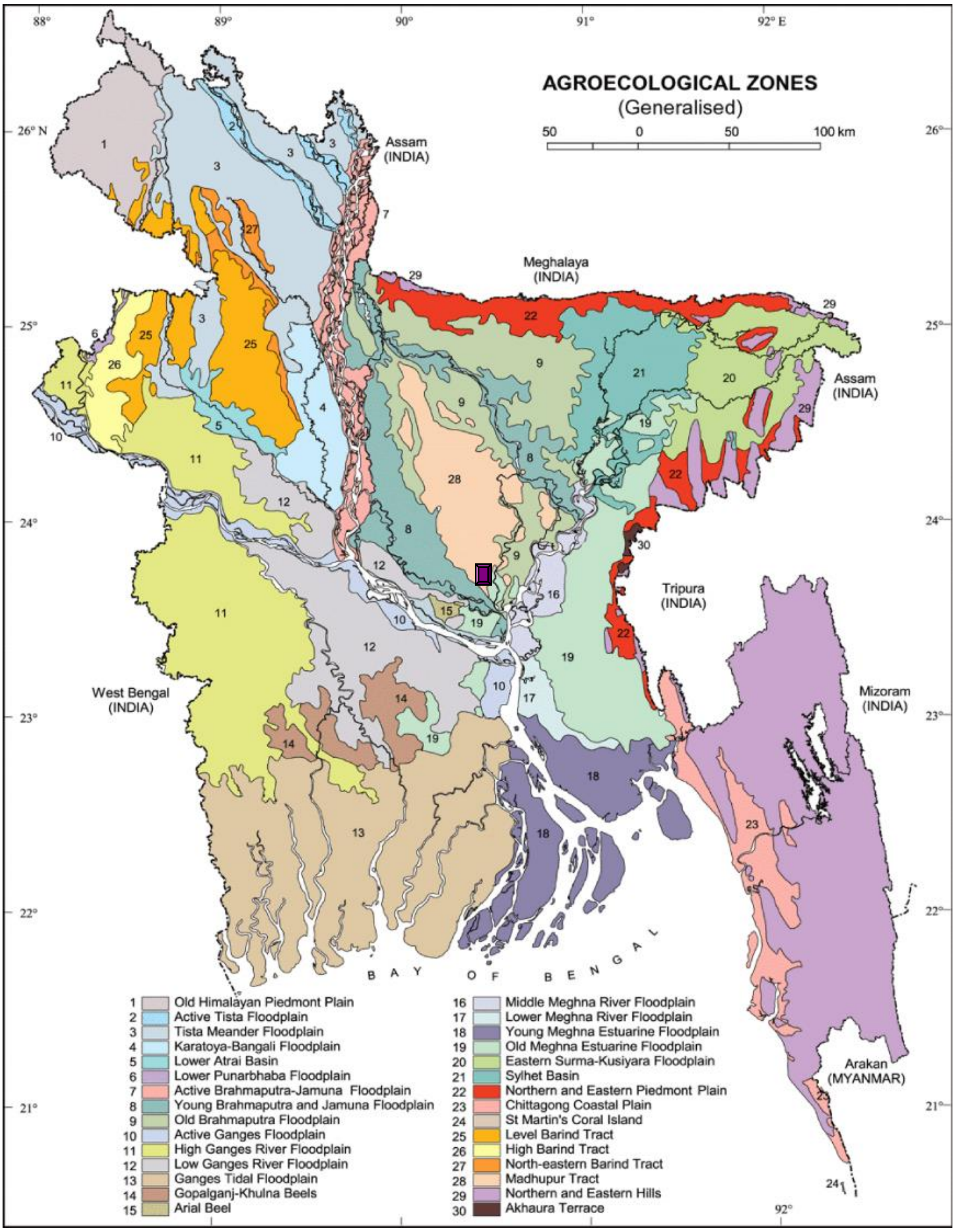
APPENDIES

Appendix I: Map showing the experimental sites under study



The experimental site under study

Appendix II: **Soil characteristics of experimental farm of Sher-e-Bangla Agricultural University are analyzed by soil Resources Development Institute (SRDI), Farmgate, Dhaka.**

A. Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Farm, SAU, Dhaka
AEZ	Modhupur tract (28)
General soil type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping pattern	**N/A**

Source: SRDI

B. Physical and chemical properties of the initial soil

Characteristics	Value
Practical size analysis	
Sand (%)	16
Silt (%)	56
Clay (%)	28
Silt + Clay (%)	84
Textural class	Silty clay loam
pH	5.56
Organic matter (%)	1.26
Total N (%)	0.02
Available P (µgm/gm soil)	20.64
Available K (meq/100gm soil)	0.13
Available S (µgm/gm soil)	9.40