EFFECT OF BIOCHAR ON GROWTH, YIELD AND QUALITY OF POTATO

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CERTIFICATE

This is to certify that the thesis entitled ***"Effect of Biochar on Growth, Yield And Quality Of Potato"*** submitted to the Department of Soil Science, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **Master Of Science In Soil Science,** embodies the results of a piece of bona fide research work carried out by **Afrina Ali**, Registration No. **11-04666** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that any help or source of information, received during the course of this investigation has been duly acknowledged.

Dated:

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Dedicated To

My Beloved Parents

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ABSTRACT

The present experiment was carried out in the research field of Sher-e-Bangla Agricultural University (SAU), Sher-e-Bangla Nagar, Dhaka-1207 during the period from November, 2016 to March, 2017 in Rabi season. The objective was to observe the effect of biochar on the yield and quality of potato and to find out the optimum dose of biochar along with inorganic fertilizer. The experiment comprised of 8 treatments as T_1 = Control, T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 5 ton ha^{-1}; T_4 = RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔ of RFD + Biochar @ 5 tonha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7 = ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The tested variety was BARI ALU-7 (Daimant). Data were recorded on different yield attributes, growth and quality of potato and nutrient status of postharvest soil. 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 was recorded from RFD + Biochar @ 10 ton ha^{-1} treatment. The highest number of stem hill^{-1}, number of tubers hill^{-1}, weight of tubers g hill^{-1} was found from biochar 5 ton biochar ha^{-1} treatment. The maximum yield of tubers (34.10 ton ha^{-1}) was produced from RFD + Biochar @ 5 ton ha^{-1} treatment. The minimum yield of tubers (16.60 t ha^{-1}) was produced from control treatment. The maximum data of quality parameters like % dry matter content (23.41), specific gravity (1.065) was also recorded in RFD + Biochar @ 5 ton ha^{-1} treatment. From postharvest soil analysis, the highest organic carbon (0.89%), organic matter (1.52%) was recorded in ½ of RFD + Biochar @ 10 ton ha^{-1} treatment. From this study, it may be concluded that biochar had significant positive response for the improving growth, yield and quality of potato and also fertility of the postharvest soil was improved apprehensively due to application of biochar along with inorganic fertilizers.

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LIST OF ABBREVIATION AND ACRONYMS

AEZ	=	Agro-Ecological Zone
BARI	=	Bangladesh Agricultural Research Institute
HRC	=	Horticulture Research Centre
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

Potato (*Solanum tuberosum* L.) popularly known as alu 'The king of vegetable', is a tuber crop belongs to the family Solanaceae. It originated in the central Andean area of South America (Keeps, 1979). It is the 4th world crop after wheat, rice and maize. Bangladesh is the 8th potato producing country in the world. In Bangladesh, it ranks 2nd after rice in production (FAOSTAT, 2016). The total area under potato crop, national average yield and total production in Bangladesh are 475488 hectares, 19.925 t ha^{-1} and 9474098 metric tons, respectively (BBS, 2016). It is a staple diet in European countries and its utilization both in processed and fresh food form is increasing considerably in Asian countries (Brown, 2005).

Potato has acquired great importance in rural economy in Bangladesh. It is not only a cash crop but also an alternative food crop against rice and wheat. Bangladesh has a great agro-ecological potential of growing potato. The area and production of potato in Bangladesh has been increased during the last decades but the yield per unit area remains more or less static. The yield is very low in comparison to that of the other leading potato growing countries of the world, 49.02 t ha^{-1} in USA, 48.99 t ha^{-1} in New Zealand, 42.48 t ha^{-1} in Denmark and 41.99 t ha^{-1} in Netherlands (FAO STAT, 2016). The reasons responsible for such a low yield of potato in Bangladesh are use of imbalanced fertilizer, low organic matter content in soil, improper management of soil, inadequate use of manure and organic matter etc. Further, use of imbalanced dose of chemical fertilizer by farmers has also deteriorated soil health and soil organic carbon which is a threat to soil sustainability (Sujatha *et al.*, 2014). Available reports indicated that potato production in Bangladesh can be increased by improving cultural practices among those optimization of manure and fertilizer are important which influences the yield of potato (Divis and Barta, 2001).

Potato is undoubtedly one of the most important crop which requires both organic and mineral fertilizer for higher yield. Continuous use of inorganic fertilizer in crop cultivation is causing health hazards and creating problems to the environment including the pollution of air, water and soil. The use of chemical fertilizer is badly affecting the texture and structure of the soil, decreasing soil organic matter and hampering soil microorganism activity (Brady, 1990). The organic matter of most of the soils of Bangladesh is below 2% as compared to an ideal minimum value 4% (Bhuiya, 1994).

The price of inorganic fertilizers is increasing day by day. So the combine application of inorganic and organic fertilizers, usually termed integrated nutrient management, is widely recognized as a way of increasing yield and or improving productivity of the soil sustainability. Integrated use of chemical fertilizers and some of organic source such as cowdung, vermicompost, farm yard manure (FYM), biochar that can increase the effectiveness of fertilizers, yield of potato and also may improve soil physical properties.

Biochar is the solid product of pyrolysis, which is to be used for environmental management and increase crop production. Biochar is a solid material obtained from thermochemical conversion of biomass in an oxygen limited environment. Biochar application to soils can potentially aid mitigation of climate change by sequestering carbon (C). (Yamato *et al*., 2006) revealed that biochar can lead to changes in physical and chemical properties of the soil that resulted in the increased nutrient availability in the soil and increase plant root colonization by mycorrhizal fungi. In addition, biochar may reduce emissions of other greenhouse gases from soil such as nitrous oxide (N_2O) methane (CH_4) (Rondon *et al.*, 2005). Biochar addition can improve plant productivity directly because of its nutrient content and release characteristics, or indirectly, through improved nutrient retention. Biochar additions to agricultural soil have been reported to climate gas emission, as well as improve soil fertility and crop productivity (Lehmann *et al*., 2003).

Biochar application changes different soil physical properties, aggregate structure, increase soil C:N ratio. Biochar reduces soil bulk density, increase soil porosity, cation exchange capacity, soil pH, nutrient availability, increase C content, trap CO_2 gas within soil. Biochar mitigate climate change through slower return of terrestrial organic C as CO_2 gas to the atmosphere. Biochar reduces leaching loss which is main problem for N fertilizer by retain water into soil. Biochar has been described as a possible means to improve soil fertility as well as other ecosystem services and sequester carbon (C) to mitigate climate change (Sohi *et al.,* 2010). The observed effects on soil fertility have been explained mainly by a pH increase in acid soils (Van Zwieten *et al.*, 2010[a]) or improved nutrient retention through cation adsorption (Liang *et al.*, 2006).

Biochar enhance N availability into the soil, reduce leaching loss of N by retaining water. Mineralization of N could be enhanced by application of biochar produced from slow pyrolysis rather than fast pyrolysis (Bruun *et al.*, 2012). Nitrogen is of vital importance for plant growth due to being a part of amino acid, protein and chlorophyll molecule. Potato needs large amount of nitrogen. Therefore, adequate N fertilization is critical for optimizing potato yield and quality (Westermann *et al.,* 1988). Insufficient available N leads to reduced growth, reduced light interception, limited yield and early crop senescence. Different types of nutrient are essential for growth and development of potato. N is beneficial for its growth, development and protein synthesis.

Several studies take places on biochar upon vegetables. The yield of tomato fruit was significantly higher in beds with charcoal than without charcoal (Yilangai *et al.*, 2014). Biochar application increased vegetable yields by 4.7-25.5% as compared to farmers' practices (Vinh *et al.*, 2014). Very little work was done with biochar in potato production that's why this experiment was set up study to the effect of biochar on growth, yield and quality of potato.

OBJECTIVES

- To observe the effect of biochar on growth, yield and quality of potato.
- To find out the optimum dose of biochar along with inorganic fertilizer.

CHAPTER II

REVIEW OF LITERATURE

Potato is the most important tuber crop in the world as well as in Bangladesh. Numerous experiments have been conducted throughout the world on potato crop but information regarding the effect of biochar on the on growth, yield and quality parameters are still inadequate. Brief reviews of available literature pertinent to the present study in home and abroad have been reviewed in this chapter.

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). 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).

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), and has great potential to improve agronomic production when applied as a soil amendment.

In previous studies, soils used to investigate the agricultural properties of biochar have mostly been highly weathered soils from humid tropic regions (Verheijen *et al*., 2009). Only recently research has 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). 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 through 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 but there is a 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).

2.2 Impact of biochar on soil chemistry

Brandstaka *et al*., (2010) listed the general effects of biochar on soil. It is beneficial for sequestration of carbon, improvement of cation exchange capacity, durability of soil aggregates, microbial activity, bioenergy production and water retention capacity; reduction of nitrous oxide and methane emissions from soils, leaching, soil erosion and need of fertilization and thereby enhancement of soil fertility and crop yields.

Leached sandy soils typically have low soil pH values, poor buffering capacities, low CEC, with values ranging from 2-8 c mol kg^{-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 (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 (Zimmerman 2010a). 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.*, (2010) 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*., 2011).

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 micro meters 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 negatively 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).

Nelson *et al*., (2011) reported that the biochar produced from corn cobs increased nitrate N in the first ten days of crop growth and thereafter it decreased; while it decreased P content when biochar was applied solely and increased it after addition of nitrogenouse phosphate fertilizer. This finding indicates the use of biochar combined with application of other sources of fertilizers could be beneficial for improving plant growth and soil nutrient status.

The pyrolysis method could play an important role in soil properties. For example, mineralization of N could be enhanced by application of biochar produced from slow pyrolysis rather than fast pyrolysis (Bruun *et al*., 2012).

Yao *et al*., (2012) indicated that there are varied responses of soils to biochar for the leaching of nutrients and the sorption of nutrients on biochar.

Quilliam *et al*., (2012) conducted a three-year field experiment, there was no difference between biochar added and not-added soil but reapplication of biochar after three years significantly increased available P, exchangeable K and calcium, dissolved organic carbon, soil moisture and electrical conductivity.

Biochar is synonymous with biomass derived black carbon (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).

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 2007b). 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 long term terrestrial sink of carbon. The carbon negative 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 2006). 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.

2.3 Effect on plant growth

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 observed 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.

2.4 The effect of biochar on plant nutrients and non-essential elements availability

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 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 nonlinear 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 subjected to 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 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 to 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 primarily attributed to high C contents of leaching sources (Laird *et al*. 2010). 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 NH4+ 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 (NO_3-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).

Chan *et al*., (2007) conducted glasshouse pot trial experiments where the agronomic benefits of green waste biochar applied as a soil amendment were investigated. Radish was planted in an acidic hard setting soil with a low soil organic carbon content, and its dry matter production was later analyzed. The DM production of radish using green wastes 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, and a 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 green wastes, 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 green wastes, 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 green wastes. 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 green wastes, 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 50 t 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 and sulfates (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.

Yilangai *et al*., (2014) observed that the yield of tomato fruit was significantly higher in beds with charcoal than without charcoal.

Vinh *et al*., (2014) told that biochar application increased vegetable yields by 4.7-25.5% as compared to farmers' practices.

In another work, biochar did not increase annual yield of winter wheat and summer maize but the cumulative yield over four growing season was significantly increased in a calcareous soil (Liang *et al*., 2014).

Borsari (2011) revealed that biochar of maple was tested at different concentrations for root elongation of pea and wheat but no significant difference was observed possibly due to little effect of biochar in the short-term.

Saxena *et al*., 2013) showed that biochar significantly increased growth and yield of french bean as compared to no biochar.

Carter *et al*., (2013) observer that rice-husk biochar tested in lettuce-cabbage-lettuce cycle increased final biomass, root biomass, plant height and number of leaves in comparison to no biochar treatments.

Hottle (2013) showed that an oak biochar derived from a slow pyrolysis process was tested for four years at 0 t ha^{-1}, 5 t ha^{-1} and 25 t ha^{-1} with 100% and 50% of N fertilizer on a maize -soybean rotation in an alfisol soil, result in an overall positive trend in total above-ground biomass and grain yield.

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).

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.

CHAPTER III

MATERIALS AND METHODS

The study was carried to find out the effect of biochar on growth, yield and quality of potato. This chapter presents a brief description about experimental period, site description, soil and climatic condition of the experimental area, crop or planting materials, treatments, experimental design and layout, crop growing procedure, intercultural operations, data collection and statistical analysis. The details of experiments and methods are described below-

3.1 Experimental period

The experiment was conducted during the period from November, 2016 to March, 2017 in Rabi season.

3.2 Site description

3.2.1 Geographical location

The present research work was conducted in the farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The experimental area was situated at $23^{0}74'$N latitude and $90^{0}33'$E longitude at an altitude of 8.6 meter above the sea level.

3.2.2 Agro-Ecological Region

The experimental site belongs to the agro-ecological zone of “Modhupur Tract”, AEZ-28 (Anon., 1988b). This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract (Anon., 1988b). The experimental site was shown in the map of AEZ of Bangladesh in Appendix I.

3.2.3 Climate characteristics

Experimental site was located in the sub-tropical monsoon climatic zone, set aparted by winter during the months from November, 2016 to March, 2017.

Plenty of sunshine and moderately low temperature prevails during experimental period, which is suitable for potato growing in Bangladesh. The weather data during the study period at the experimental site are shown in Appendix II.

3.2.4 Soil characteristic

The soil of the experimental site belongs to the general soil type, Shallow Red Brown Terrace Soils under Tejgaon Series. Top soils were clay loam in texture, olive–gray with common fine to medium distinct dark yellowish brown mottles. Soil pH was 5.6 and had organic matter 1.3%. The experimental area was flat having available irrigation and drainage system and above flood level. Soil samples from 0–15 cm depths were collected from experimental field. The properties studied included pH, organic matter, total N, available P and exchangeable K. The morphological, physical and chemical characteristics of initial soil are presented in Tables A and B

Table A: Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Experimental Filed, 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

Table B: Physical and chemical characteristics of the initial soil (0-15 cm depth)

Characteristics	Value
Mechanical fractions:	
% Sand (2.0-0.02 mm)	26
% Silt (0.02-0.002 mm)	43
% Clay (<0.002 mm)	30
Textural class	Clay loam
pH	5.6
Organic carbon	0.76
Organic matter (%)	1.3
Total N (%)	0.06
Available P (ppm)	18.49
Exchangeable K (me/100g soil)	0.10
Available S (ppm)	15.6

Table C: Properties of Biochar

Organic carbon (%)	1.053
Organic matter (%)	1.82

3.3 Experimental details

3.3.1 Treatments and factor of the experiment

Treatments:

T_1 = Control

T_2 = RFD (Recommended Fertilizer Dose)

T_3= RFD + Biochar @ 5 tonha^{-1}

T_4 = RFD + Biochar @ 10 tonha^{-1}

T_5 = ⅔of RFD + Biochar @ 5 tonha^{-1}

T_6 = ⅔ of RFD + Biochar @ 10 tonha^{-1}

T_7= ½ of RFD + Biochar @ 5 tonha^{-1}

T_8 = ½ of RFD + Biochar @ 10 tonha^{-1}

RFD (Recommended Fertilizer Dose): for potato N_{150}, P_{30}, K_{140}, S_{15}, Zn_3 kg ha^{-1} (FRG, 2012).

3.3.2 Experimental design and layout

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. An area of 18.5 m × 18 m was divided into 3 blocks. The size of the each unit plot was (5.0 m × 1.75 m) or 8.75 m^2. The space between two blocks and two plots were 1.0 m and 0.5 m, respectively. The layout of the experiment is shown in appendix III.

3.4 Planting materials

The seed tubers of selected potato varieties were collected from Bangladesh Agricultural Development Corporation (BADC) office, Nokla , Sherpur.In this experiment BARI ALU -7 (Diamant) was used which was developed in 1993 by the Bangladesh Agricultural Research Institute. It is recommended for rabi season. It requires about 90-95 days completing its life cycle with an average yield of around 25-35 t ha^{-1}.

3.5 Collecting biochar

Biochar was collected from CCDB (Christian Commission for Development in Bangladesh), Shivaloy, Manikgonj.

3.6 Crop management

3.6.1 Preparation of seed

Collected seed tubers were kept in room temperature to facilitate sprouting. Finally sprouted potato tubers were used as a planting material.

3.6.2 Land preparation

The experimental land was opened with a power tiller on 17 November, 2016. Ploughing and cross ploughing were done with power tiller followed by laddering. Land preparation was completed on 24 November, 2016 making soil adequate tilth. The soil was treated with Furadan 5G @10 kg ha^{-1} when the plot was finally ploughed to protect the young plant from the attack of cut worm.

3.6.3 Fertilizer application

The crop was fertilized as per recommendation of FRG, 2012. The N, P, K, S, Zn were used as urea, triple super phosphate (TSP), murate of potash (MoP), gypsum and zinc sulphate respectively.

Fertilizers	Dose (Kg ha^{-1})
N	150
P	30
K	140
S	15
Zn	3

Source: FRG, 2012

The entire amount of biochar (as per treatment), triple super phosphate, gypsum, zinc sulphate and half of urea and MoP were applied as basal dose at 2 days before potato planting. Rest of the urea and MoP were side dressed in two equal splits at 35 and 50 days after planting (DAP) during first and second earthing up.

3.6.4 Planting of seed tuber

The well sprouted healthy and uniform sized potato tubers were planted according to treatment and a whole potato was used for one hill. Plant spacing was maintained 60 cm×25 cm. Seed potatoes were planted in such a way that potato does not go much under soil or does not remain in shallow. On an average, potatoes were planted at 4-5 cm depth in soil on November 26, 2016.

3.6.5 Intercultural operations

3.6.5.1 Weeding

Weeding was necessary to keep the plant free from weeds. The newly emerged weeds were uprooted carefully in the entire field after complete emergence of sprouts and afterwards when necessary.

3.6.5.2 Irrigation

Frequency of watering was done upon moisture status of soil retained as requirement of plants. Excess water was not given, because it always harmful for potato plant.

3.6.5.3 Earthing up

Earthing up process was done in the plot at two times, during crop growing period. First was done at 35 DAP and second was at 50 DAP.

3.6.5.4 Plant protection measures

Dithane M-45 was applied at 30 DAP as a preventive measure for controlling fungal infection. Ridomil (0.25%) was sprayed at 45 DAP to protect the crop from the attack of late blight.

3.6.5.5 Haulm cutting

Haulm cutting was done at February 19, 2017 when 40-50% plants showed senescence and the tops started drying. After haulm cutting the tubers were kept under the soil for 7 days for skin hardening.

3.6.5.6 Harvesting of potatoes

Harvesting of potato was done on February 26, 2017 at 7 days after haulm cutting. The potatoes of each treatment were separately harvested, bagged and tagged and brought to the laboratory. Harvesting was done manually by hand.

3.6.6 Recording of data

The following data were collected during the experimentation.

A. Crop growth characters

i. Plant height at different days after planting (cm)

ii. Number of stem $hill^{-1}$

B. Yield and yield components

iii. Number of tubers $hill^{-1}$

iv. Average weight of tuber $hill^{-1}$ (g)

v. Yield of tubers kg $plot^{-1}$

vi. Yield of tubers t ha^{-1}

C. Quality characters

vii. Tuber matter content

viii. Specific gravity

ix. Grading of tubers according to size and diameter (%by number)

D. Postharvest soil analysis

x. Soil pH

xi. Organic carbon (%)

xii. Organic matter (%)

xiii. Total N (%)

xiv. Available P (ppm)

xv. Exchangeable K (me/100 g soil)

A. Crop growth characters

i. Plant height (cm)

Plant height refers to the length of the plant from ground level to the tip of the tallest stem. It was measured at 30, 45, 60 and 75 days after planting (DAP). The height of selected plant was measured in cm with the help of a meter scale and mean was calculated.

ii. Number of stems hill^{-1}

Number of stems hill^{-1} was counted at the time of haulm cutting. Stem numbers hill^{-1} was recorded by counting all stem from each plot.

B. Yield and yield components

iii. Number of tubers hill^{-1}

Number of tubers hill^{-1} was counted at harvest. Tuber numbers hill^{-1} was recorded by counting all tubers from sample plant.

vi. Average weight of tubers (g hill^{-1})

Weight of tubers hill^{-1} was measure at harvest. Tuber weight hill^{-1} was recorded by measuring all tubers from sample plant.

Average weight of tubers (gm hill^{-1}) = Weight of tubers gm hill^{-1} ÷ No. of tubers hill^{-1}

v. Yield of tuber (kg plot^{-1})

Tuber yield was recorded on the basis of total harvested tuber plot^{-1}.

vi. Yield of tubers (t ha^{-1})

Tuber yield was recorded on the basis of total harvested tuber plot^{-1} and was expressed in terms of t ha^{-1}.

C. Quality characters

vii. Tuber dry matter content (%)

The samples of tuber were collected from each treatment. After peel off the tubers the samples were dried in oven at 72^{0}C for 72 hours. From which the weights of tuber flesh dry matter content % were recorded. From which the dry matter percentage of tuber was calculated with the following formula (Elfinesh *et al.,* 2011)

Dry matter content (%) = (Dry weight ÷ Fresh weight) × 100

viii. Specific Gravity

It was measured by using the following formula (Gould, 1995)

Specific gravity = Weight in air ÷ (Weight in air ─ Weight in water)

ix. Grading of tuber according to size and diameter (% by number)

Tubers harvested from each treatment were graded by number on the basis of diameter into the >55 mm, 45-55 mm, 28-55 mm ,<28 mm ,>20 gm, <20 gm and converted to percentages (Hussain, 1995). A special type of frame (potato riddle) was used for grading of tuber.

3.6.7 Post harvest soil sampling

After harvest of crop, soil samples were collected from each plot at a depth of 0 to 15 cm. Soil samples of each plot was air-dried, crushed and passed through a two mm (10 meshes) sieve. The soil samples were kept in plastic container to determine the physical and chemical properties of soil.

3.6.7.1 Soil analysis

Soil samples were analyzed for both physical and chemical characteristics viz. pH, organic matter, total N, available P and Exchangeable K contents. The soil samples were analyzed by the following standard methods as follows:

3.6.7.1 Soil pH

Soil pH was measured with the help of a glass electrode pH meter, the soil water ratio being maintained at 1: 2.5 as described by Page *et al.*, 1982.

3.6.7.2 Organic matter

Organic carbon in soil sample was determined by wet oxidation method (Page *et al.*, 1982). The underlying principle was used to oxidize the organic matter with an excess of 1N $K_2Cr_2O_7$ in presence of conc. H_2SO_4 and conc. H_3PO_4 and to titrate the excess $K_2Cr_2O_7$ solution with 1N $FeSO_4$. To obtain the content of organic matter was calculated by multiplying the percent organic carbon by 1.724 (Van Bemmelen factor) and the results were expressed in percentage.

3.6.7.3 Total nitrogen

Total N content of soil were determined followed by the Micro Kjeldahl method. One gram of oven dry ground soil sample was taken into micro Kjeldahl flask to which 1.1 gm catalyst mixture (K_2SO_4: $CuSO_4$. $5H_2O$: Se in the ratio of 100:10:1), and 6 ml H_2SO_4 were added. The flasks were swirled and heated 200^0c and added 3 ml H_2O_2 and then heating at 360^0c was continued until the digest was clear and colorless. After cooling, the content was taken into 100 ml volumetric flask and the volume was made up to the mark with distilled water. A reagent blank was prepared in a similar manner. These digests were used for nitrogen determination (Page *et al.*, 1982). Then 20 ml digest solution was transferred into the distillation flask, Then 10 ml of H_3BO_3 indicator solution was taken into a 250 ml conical flask which is marked to indicate a volume of 50 ml and placed the flask under the condenser outlet of the distillation apparatus so that the delivery end dipped in the acid. Add sufficient amount of 10N-NaOH solutions in the container connecting with distillation apparatus. Water runs through the condenser of distillation apparatus was checked. Operating switch of the distillation apparatus collected the distillate. The conical flask was removed by washing the delivery outlet of the distillation apparatus with distilled water. Finally the distillates were titrated with standard 0.01 N H_2SO_4 until the color changes from green to pink. The amount of N was calculated using the following formula:

$$\% \text{ N} = (\text{T-B}) \times \text{N} \times 0.014 \times 100/\text{W}$$

Where,

T = Sample titration (ml) value of standard H_2SO_4

B = Blank titration (ml) value of standard H_2SO_4

N = Strength of H_2SO_4

W = Sample weight in gram

3.6.7.4 Available phosphorus

Available P was extracted from the soil with 0.5 M $NaHCO_3$ solutions, pH 8.5 (Olsen *et al.,* 1954). Phosphorus in the extract was then determined by developing blue color with reduction of phosphomolybdate complex and the color intensity were measured colorimetrically at 660 nm wavelength and readings were calibrated with the standard P curve (Page *et al*., 1982).

3.6.7.5 Exchangeable potassium

Exchangeable K was determined by 1N NH_4OAc (pH 7) extraction methods and by using flame photometer and calibrated with a standard curve (Page *et al*., 1982).

3.7 Statistical Analysis

The data obtained for different parameters were statistically analyzed to find out the significant difference the results of different levels of biochar application on growth, yield and yield contributing characters of potato. The mean values of all the characters were calculated and analysis of variance was performed by the 'F' (variance ratio) test. The significance of the difference among the treatment means was estimated by Duncan's Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV
RESULTS AND DISCUSSION

The experiment was conducted to find out the effect of biochar on growth, yield and quality of potato. The results obtained from the study have been presented, discussed and compared in this chapter through table(s) and figures. The analysis of variance of data in respect of all the parameters has been shown in Appendix V-XII. The results have been presented and discussed with the help of table and graphs and possible interpretations given under the following headings.

4.1 Crop growth characters

4.1.1. Plant height (cm)

Plant height due to different levels of biochar applications was significantly influenced at days after planting (DAP) (Fig. 1 and table 1). The maximum plant height (28.12, 43.31, 58.29 and 61.38 cm at 30, 45, 60 and 75 DAP, respectively) was recorded from T_4 treatment whereas, the minimum plant height (17.67, 26.17, 36.88 and 43.50 cm at 30, 45, 60 and 75 DAP, respectively) was recorded from T_1 treatment.

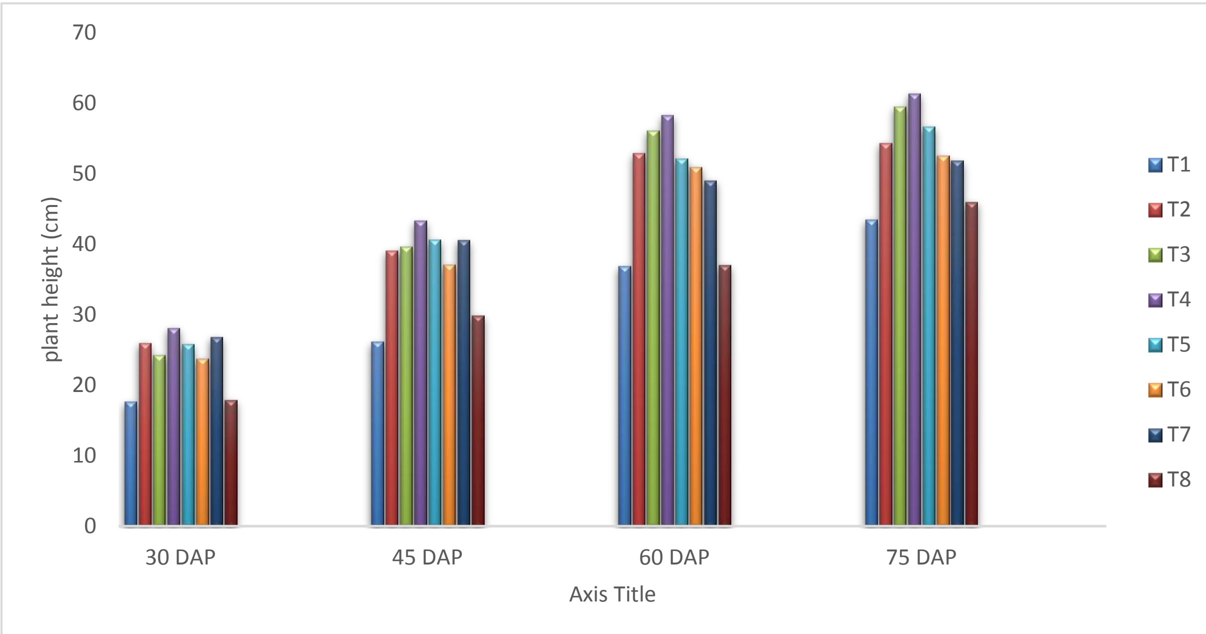

Figure 1. Effect of Biochar on Plant height at different days after planting

(LSD$_{0.05}$= 2.18, 1.40, 1.40, 1.28 and 1.50 at 30, 45, 60 and 75 DAP, respectively)

T_1= Control; T_2 = RFD (Recommended Fertilizer Dose); T_3= RFD + Biochar @ 5 ton ha^{-1}; T_4= RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7= ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}

4.1.2 Number of stem hill^{-1}

The number of stems per hill at haulm cutting stage significantly increased only over control (Figure 2 and table 1). The maximum stem numbers hill^{-1} (6.00) was obtained from T_3 treatment which was statistically identical with T_4 (5.33) treatment and whereas, the minimum (2.67) was obtained from T_1 treatment.

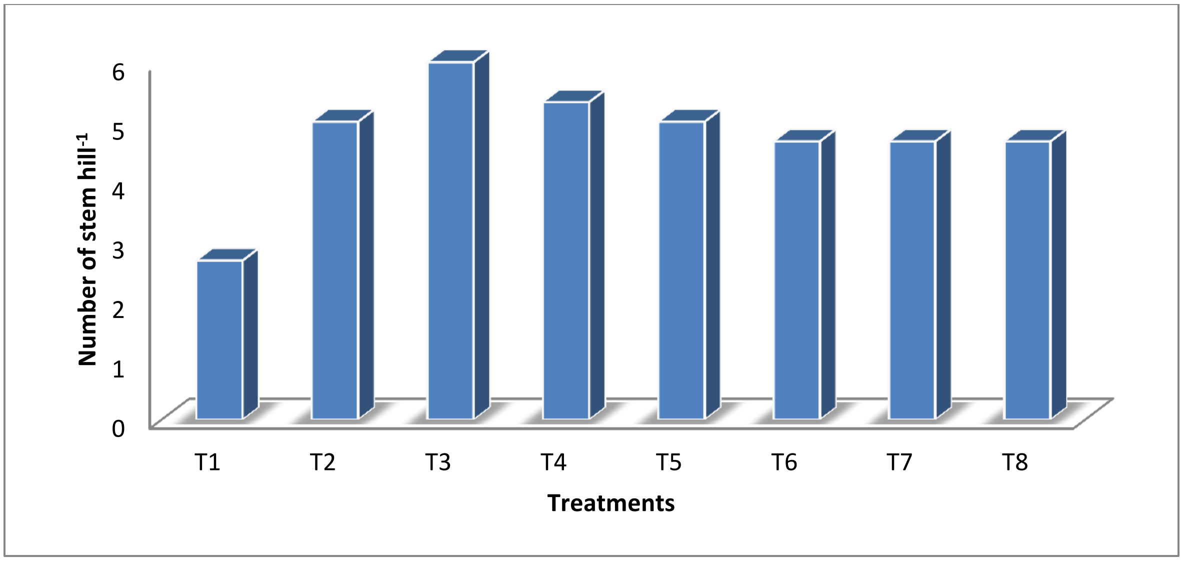

Figure 2. Effect of Biochar on Number of stem hill^{-1} ($LSD_{0.05}$= 2.38)

T_1= Control; T_2 = RFD (Recommended Fertilizer Dose); T_3= RFD + Biochar @ 5 ton ha^{-1}**;** T_4= RFD + Biochar @ 10 ton ha^{-1}**;** T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}**;** T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}**;** T_7= ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8= ½ of RFD + Biochar @ 10 ton ha^{-1}.

Table 1. Effect of biochar on Plant height at different days after planting and Number of stem hill^{-1}

Treatment	Plant height (cm)								Number of stem hill^{-1}	
	30 DAP		**45 DAP**		**60 DAP**		**75 DAP**			
T_1	17.67	c	26.17	f	36.88	f	43.50	g	2.67	b
T_2	26.01	ab	39.08	c	52.95	c	54.38	d	5.00	ab
T_3	24.27	b	39.64	bc	56.10	b	59.53	b	6.00	a
T_4	28.12	a	43.31	a	58.29	a	61.38	a	5.33	a
T_5	25.87	ab	40.65	b	52.18	cd	56.72	c	5.00	ab
T_6	23.77	b	37.11	d	50.95	d	52.55	e	4.67	ab
T_7	26.84	a	40.57	b	49.07	e	51.86	e	4.66	ab
T_8	17.91	c	29.91	e	37.05	f	46.02	f	4.67	ab
$LSD_{(0.05)}$	2.18		1.40		1.40		1.28		2.38	
CV (%)	8.25		7.34		6.45		8.34		17.42	

In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by LSD at 0.05 level of probability.

T_1= Control; T_2 = RFD (Recommended Fertilizer Dose); T_3= RFD + Biochar @ 5 ton ha^{-1}; T_4= RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7 = ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}.

4.2 Yield and yield components

4.2.1 Number of tubers $hill^{-1}$

Number of tubers $hill^{-1}$ significantly influenced by the different levels of biochar applications (Fig. 3 and Table 2). The maximum number of tubers $hill^{-1}$ (9.35) was produced from T_3 (RFD + Biochar @ 5 ton ha^{-1}) treatment, which was statistically identical with T_4 (8.98) and statistically similar with T_2 (8.33), T_7 (8.48) and T_8 (8.57) treatments, whereas the minimum (6.52) was produced from control.

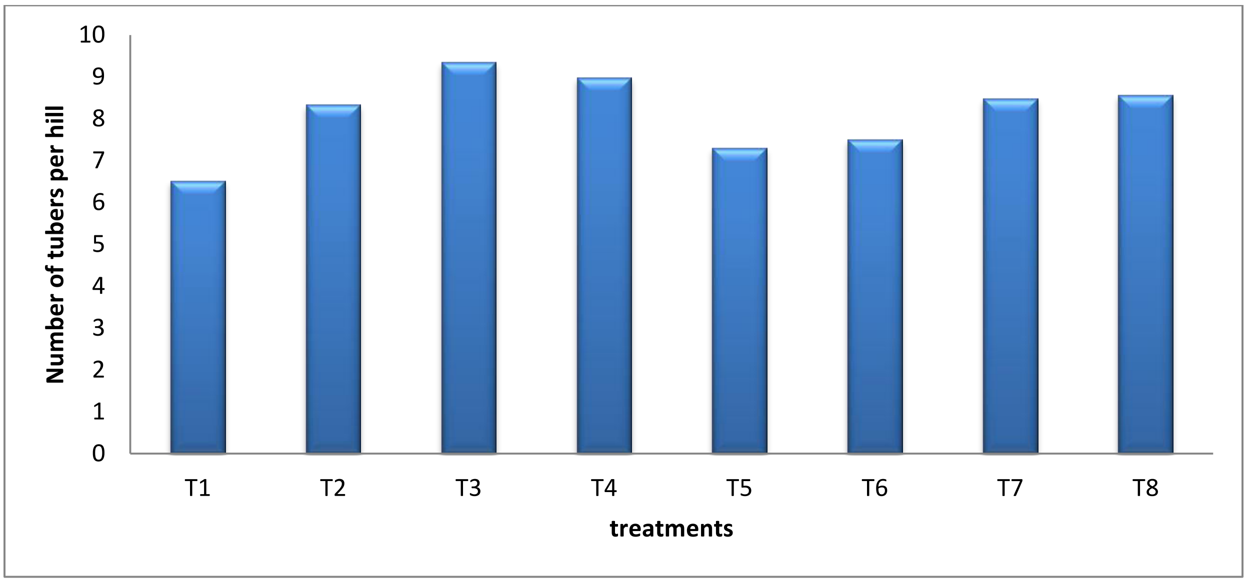

Figure 3 : Effect of Biochar on Number of tubers per hill

T_1 = Control; T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 5 ton ha^{-1}; T_4= RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7 = ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}

4.2.2 Average weight of tubers (g $hill^{-1}$)

Weight of tubers $hill^{-1}$ significantly varied among the different levels of biochar applications (Fig. 3 and Table 2). The maximum weight of tubers g $hill^{-1}$ (56.1) was observed from T_3 (RFD + Biochar @ 5 ton ha^{-1}) which was statistically similar with T_2 (52.88), T_4 (51.89), T_6 (50.10), T_7 (51.90), T_8 (52.73) treatments while the minimum weight of tubers g $hill^{-1}$ (41.187) was observed from T_1 (Control) treatment.

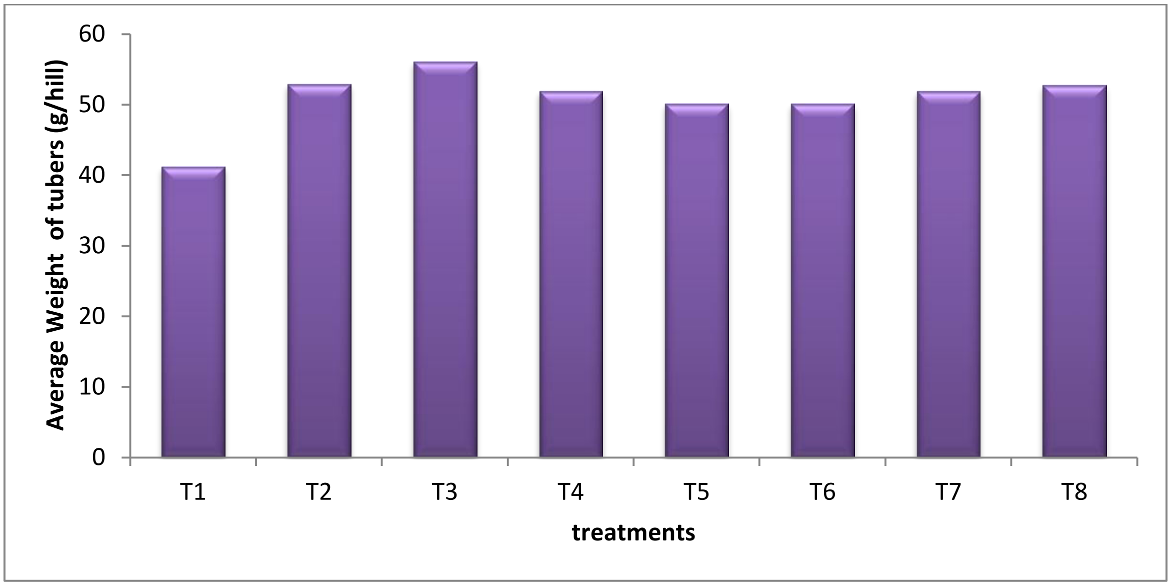

Figure 4 : Effect of Biochar on Average Weight of tubers (g $hill^{-1}$)

T_1= Control; T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 5 ton ha^{-1}; T_4= RFD + Biochar @ 10 ton ha^{-1};T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7= ½ of RFD + Biochar @ 5 ton ha^{-1};T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}

4.2.3 Yield of tuber (kg $plot^{-1}$)

Application of biochar in combination with chemical fertilizer had significant effect on the yield of tuber kg per plot (Table 2 and Fig. 4). The highest tuber yield kg $plot^{-1}$ (29.84) was obtained from T_3 (RFD + Biochar @ 5 ton ha^{-1}) treatment, and the lowest tuber yield kg $plot^{-1}$ (14.492) was obtained from T_1 (control) treatment.

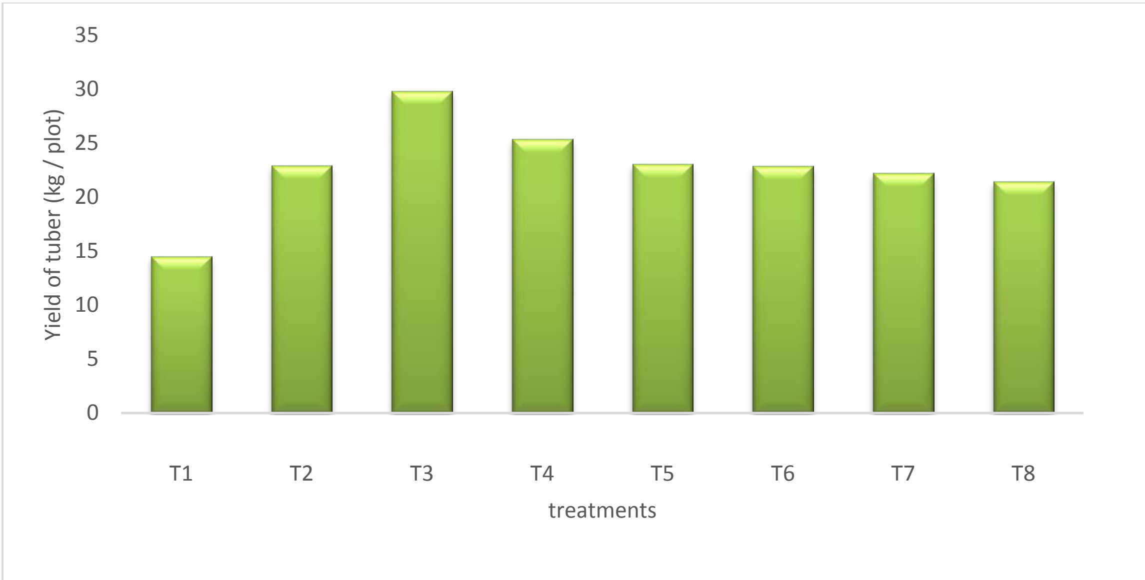

Figure 5 : Effect of Biochar on Yield of tubers (kg plot^{-1})

T_1 = Control; T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 5 ton ha^{-1}; T_4 = RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7= ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}.

4.2.4 Yield of tubers ton ha^{-1}

The tuber yield of potato increased significantly due to application of biochar in combination with chemical fertilizers (Table 2 and fig. 5) The highest tuber yield (34.10t ha^{-1}) was obtained from T_3 (RFD + Biochar @ 5 ton ha^{-1}) treatment, which was followed by T_4(28.99 t ha^{-1}) and lowest tuber yield kg plot^{-1} (16.60t ha^{-1}) was obtained from T_1 (control) treatment. Higher dose of biochar (10 t ha^{-1}) along with similar dose of RFD reduced the tuber yield significantly.

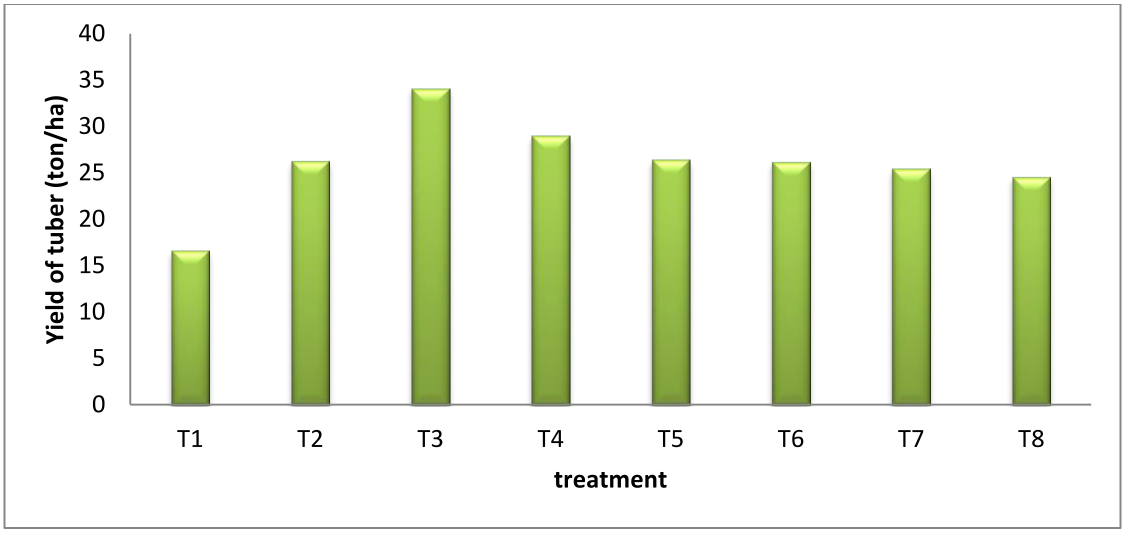

Figure 6: Effect of Biochar on Yield of tubers (ton ha^{-1})

T_1 = Control; T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 5 ton ha^{-1}; T_4 = RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7 = ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}

Table 2 : Effect of Biochar on Number of tubers $hill^{-1}$, Average weight of tubers (g $hill^{-1}$), Yield of tubers (kg $plot^{-1}$), Yield of tubers (t ha^{-1})

Treatment	Number of tubers per hill	Average Weight of tubers (gm $hill^{-1}$)	Yield of tuber (kg $plot^{-1}$)	Yield of tuber (ton ha^{-1})
T_1	6.52 c	41.19 c	14.49 d	16.60 d
T_2	8.33 ab	52.88 ab	22.95 bc	26.25 bc
T_3	9.35 a	56.10 a	29.84 a	34.10 a
T_4	8.98 a	51.89 ab	25.38 b	28.99 b
T_5	7.30 bc	50.10 b	23.07 bc	26.39 bc
T_6	7.50 bc	50.10 ab	22.89 bc	26.14 bc
T_7	8.48 ab	51.90 ab	22.25 bc	25.43 bc
T_8	8.57 ab	52.73 ab	21.48 **c**	24.55 c
LSD $_{0.05)}$	1.38	5.98	3.62	4.14
CV (%)	9.68	6.67	9.08	9.07

In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by LSD at 0.05 level of probability.

T_1= Control; T_2 = RFD (Recommended Fertilizer Dose); T_3= RFD + Biochar @ 5 ton ha^{-1}; T_4= RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7 = ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}

4.3. Quality characters

4.3.1. Tuber dry matter content (%)

Dry matter content (%) of tubers significantly influenced different levels of biochar application. The higher tuber dry matter content (23.41%) was recorded from T_3 (RFD + Biochar @ 5 ton ha^{-1}) treatment and the lower tuber dry matter content (17.90%) was recorded from T_1 (control) treatment (Table 3 and fig. 6).

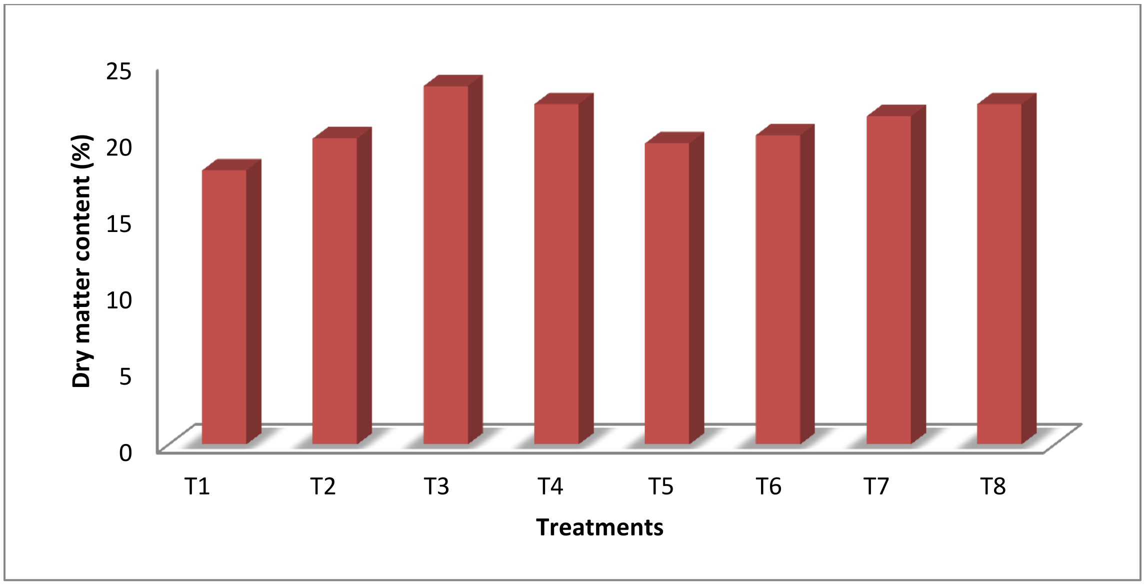

Figure 7 : Effect of Biochar on Tuber dry matter content (%)

T_1= Control; T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 5 ton ha^{-1}; T_4= RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7= ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}

4.3.2 Specific Gravity

Specific gravity of tuber varied significantly with different levels of biochar application (Table 3 and fig. 7). The highest specific gravity of tuber was recorded (1.07) from T_3treatment, which was statistically similar with T_2 (1.05), T_4 (1.06) treatments while, the minimum was found from T_1 (1.03) treatment.

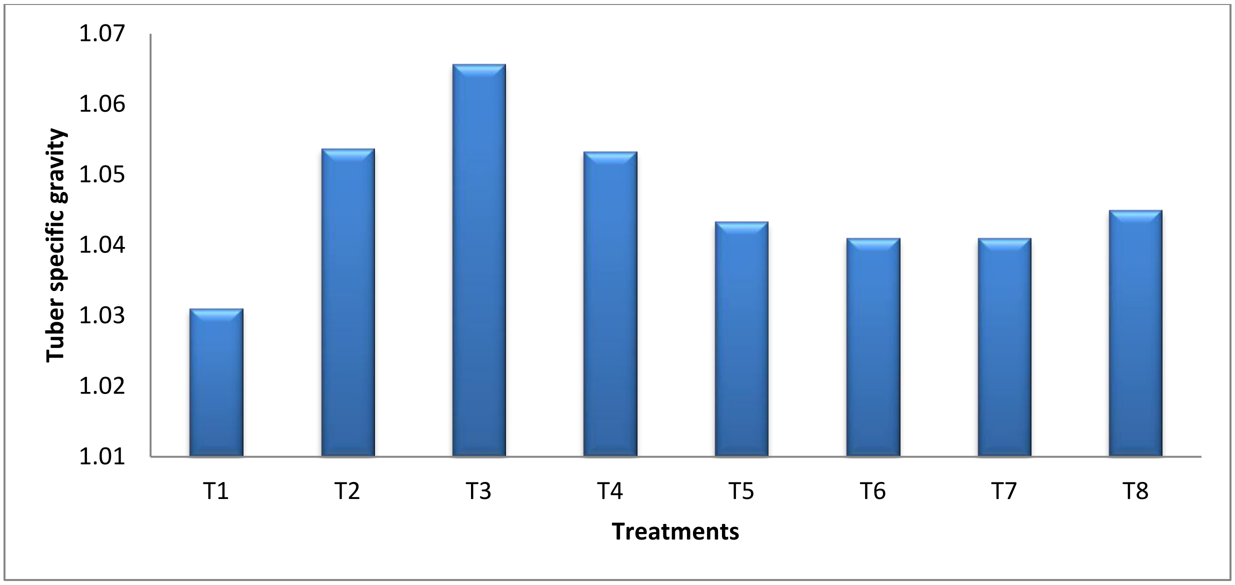

Figure 8 : Effect of Biochar on Specific gravity on tuber

T_1 = Control; T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 5 ton ha^{-1}; T_4 = RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7 = ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}

Table 3 : Effect of Biochar on Tuber dry matter content (%) and Tuber specific gravity

Treatment	Tuber dry matter content (%)	Tuber specific gravity
T_1	17.90 d	1.03 c
T_2	19.99 cd	1.05 ab
T_3	23.41 a	1.07 a
T_4	22.23 ab	1.06 ab
T_5	19.67 cd	1.04 bc
T_6	20.20 bc	1.04 bc
T_7	21.43 abc	1.04 bc
T_8	22.23 abc	1.05 bc
LSD $_{(0.05)}$	2.22	0.02
CV (%)	3.69	0.63

In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by LSD at 0.05 level of probability.

T_1 = Control; T_2 = RFD (Recommended Fertilizer Dose); T_3= RFD + Biochar @ 5 ton ha^{-1}; T_4= RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7 = ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}

4.3.3 Grading of tuber according to size (% by number)

On the basis of weight tubers have been graded into marketable tuber (>20g) and non-marketable tuber (<20g). The results indicate that there was significant difference in the treatments in respect of production of different grades of tubers. The highest (40.7%) non marketable tuber (<20 gm) was produced from T_1 = control treatment and the lowest (24.3) non marketable tuber (<20 gm) was produced from T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}. The maximum (70.667%) marketable tuber (>20 gm) was produced from T_8 (½ of RFD + Biochar @ 10 ton ha^{-1}) treatment while the minimum (59.3%) marketable tuber was produced from T_1 (control) treatment (table 4 and Fig. 8).

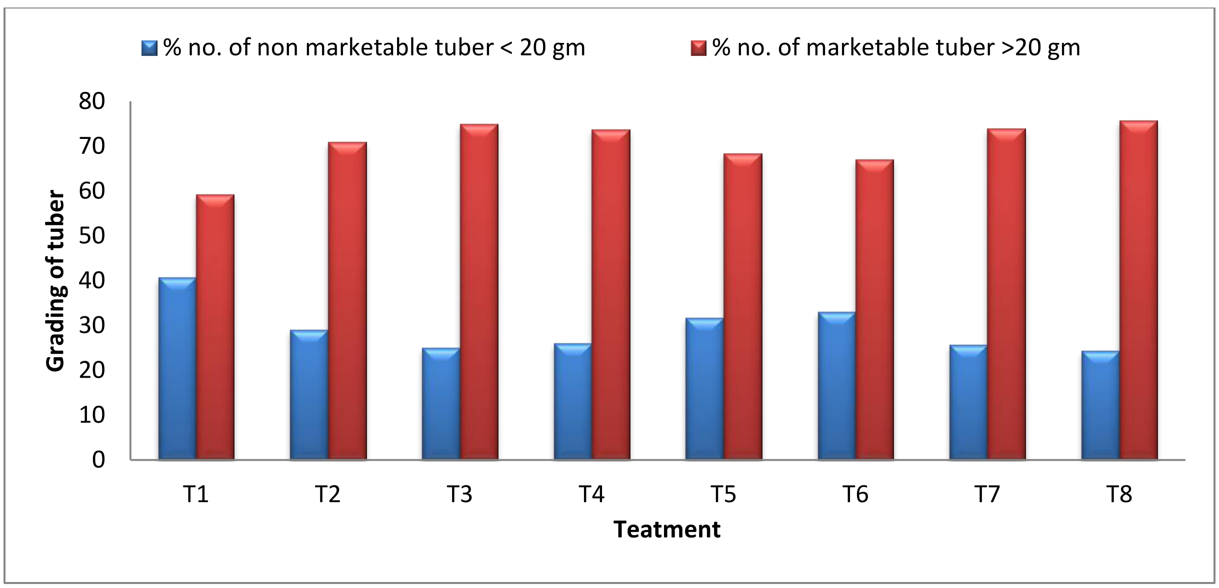

Figure 9. Effect of biochar on Grading of tuber according to size (% by number)

T_1 = Control; T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 5 ton ha^{-1}; T_4= RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7 = ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}.

Table 4. Effect of biochar on Grading of tuber (% by number)

Treatments	% No. of non marketable tuber < 20 gm		% No. of marketable tuber >20 gm	
T_1	40.70	a	59.30	d
T_2	29.00	bcd	71.00	abc
T_3	25.00	cd	75.00	ab
T_4	26.00	bcd	73.70	abc
T_5	31.70	bc	68.30	bc
T_6	33.00	b	67.00	c
T_7	25.70	cd	74.00	abc
T_8	24.30	d	75.70	a
CV(%)	13.54		5.88	
$LSD_{(0.05)}$	6.97		7.26	

In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by LSD at 0.05 level of probability.

T_1= Control; T_2 = RFD (Recommended Fertilizer Dose); T_3= RFD + Biochar @ 5 ton ha^{-1}; T_4 = RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7 = ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8= ½ of RFD + Biochar @ 10 ton ha^{-1}

4.3.4 Grading of tubers on the basis of diameter (% by number)

On the basis of size in diameter tubers have been graded into seed tuber 28 – 55 mm, non seed tuber <28 mm and >55 mm, Tuber yield for chips 45-55 mm. The results indicate that there was significant difference in different levels of biochar application in respect of production of different grades of tubers (Fig. 9 and Table 5). The maximum no. of non seed tuber <28mm (34.6), >55 mm (16.3), seed tuber 28-55 mm (70.7) and % no. of Tuber yield for chips 45-55 mm (23.3) was obtained fromT_1, T_5, T_2 and T_3 treatments respectively. The minimum no. of non seed tuber <28mm (15.0), >55 mm (11.00), seed tuber 28-55 mm (54.6) and% no. of tuber yield for chips 45-55 mm (13.6) was obtained fromT_8, T_8, T_1 and T_1treatments respectively.

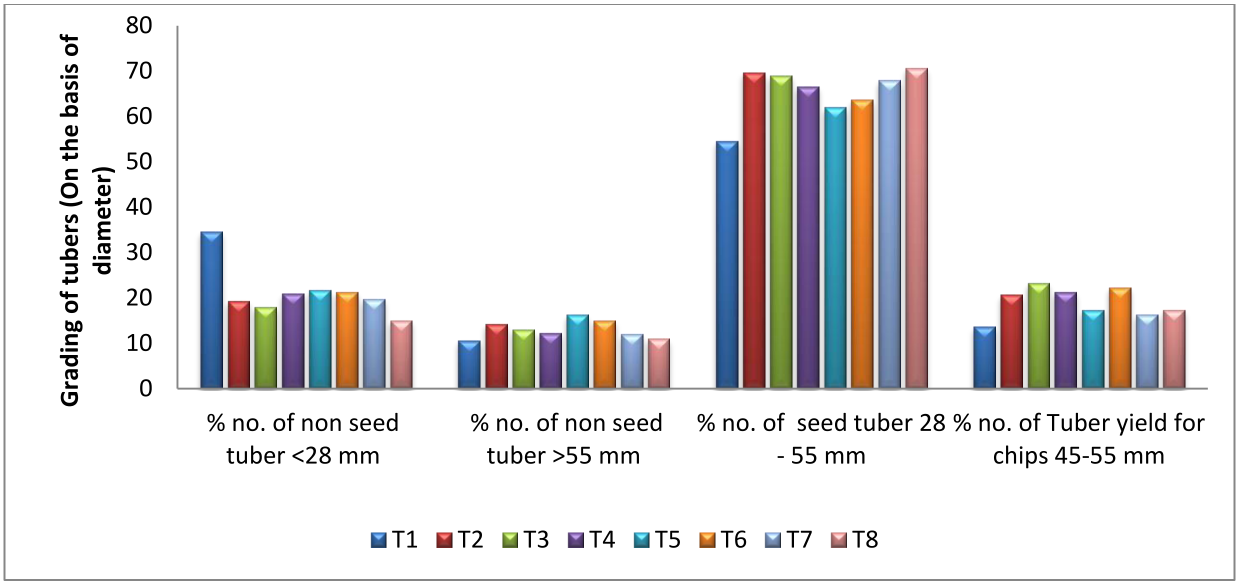

Figure 10. Effect of biochar on Grading of tuber on the basis of diameter (% by number

T_1= Control; T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 5 ton ha^{-1}**;** T_4 = RFD + Biochar @ 10 ton ha^{-1}**;** T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}**;** T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}**;** T_7= ½ of RFD + Biochar @ 5 ton ha^{-1};T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}

Table 5. Effect of biochar on Grading of tuber on the basis of diameter (% by number)

Treatments	% No. of non seed tuber <28 mm	and >55 mm	% No. of seed tuber 28 - 55 mm	% No. of Tuber yield for chips 45-55 mm
T_1	34.6 a	10.6 b	54.6 c	13.6 c
T_2	19.3 b	14.3 ab	69.7 a	20.7 ab
T_3	18.0 b	13.0 ab	69.0 ab	23.3 a
T_4	21.0 b	12.3 ab	66.6 ab	21.3 ab
T_5	21.7 b	16.3 a	62.0 bc	17.3 abc
T_6	21.3 b	15.0 ab	63.7 ab	22.3 ab
T_7	19.7 b	12.0 ab	68.0 ab	16.3 bc
T_8	15.0 b	11.0 b	70.7 a	17.3 abc
CV(%)	18.19	19.65	6.55	20.35
$LSD_{0.05\%}$	11.174	4.5155	7.5140	6.7864

In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by LSD at 0.05 level of probability.

($LSD_{0.05}$= 11.174, 4.5155, 7.5140 and 6.7864 respectively)

T_1= Control; T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 5 ton ha^{-1}; T_4 = RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7 = ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}

4.2 Post Harvest Soil Analysis

4.2.1 Soil pH

The highest soil pH (5.91) was recorded in T_3 (RFD + Biochar @ 5 ton ha^{-1}) which is statistically identical with other treatments that's why soil pH has no significant differences with other treatments (Table 6).

4.2.2 Organic carbon

The highest organic carbon (0.89%) was recorded in T_8 treatment which was statistically similar with T_3 (0.87%), T_4 (0.85%), T_5 (0.81%), T_7 (0.83%) treatments, while the lowest organic carbon (0.78%) was recorded from T_1 which was also statistically identical with T_2 0.78%) treatment (Table 6).

4.2.3 Organic matter

A significant variation in the organic matter was found from biochar. The highest organic matter (1.52%) was recorded in T_8 treatment which was statistically identical with T_3 (1.50%) treatment and also statistically similar with T_4 (1.46 %), T_5 (1.40%), T_6 (1.38%), T_7 (1.43%) treatments while the lowest organic matter (1.33%) was recorded in T_1which was statistically identical with T_2 (1.33%) treatment (Table 6).

4.2.4 Total Nitrogen

Total nitrogen was not significantly influenced by different treatment. The highest total nitrogen (0.087%) was recorded in T_4 treatment which was statistically identical with other treatments. The lowest was recorded from control treatment (Table 6).

4.2.5 Available phosphorus

The different treatment showed significantly variation in the Available phosphorus**.** The highest available phosphorus (29.67 ppm) was recorded from T_3 while the lowest available phosphorus (17.5 ppm) was recorded from T_1 treatment (Table 6).

4.2.6 Exchangeable potassium

Exchangeable potassium was significantly influenced by different treatment. The highest exchangeable potassium (0.45%) was recorded in T_3 treatment which was statistically identical with T_4 (0.42) and T_6 (0.40) treatments and statistically similar with T_2 (0.21), T_5 (0.37), T_7 (0.26), T_8 (0.29) treatments while the lowest exchangeable potassium (0.18%) was recorded in T_1 treatment. (Table 6)

Table 6: Effect of Biochar on of Postharvest Soil Properties

Treatment	Soil pH	Organic carbon	Organic matter	Total N (%)	Available P (ppm)	Exchangeable K (me/100 gm soil)
T_1	5.30	0.78 c	1.33 b	0.050 a	17.50 h	0.18 d
T_2	5.70	0.78 c	1.33 b	0.063 a	21.81 g	0.21 cd
T_3	5.91	0.87 ab	1.50 a	0.083 a	29.67 a	0.45 a
T_4	5.87	0.85 abc	1.46 ab	0.087 a	28.49 b	0.42 a
T_5	5.65	0.81 abc	1.40 ab	0.068 a	25.34 d	0.37 ab
T_6	5.74	0.80 bc	1.38 ab	0.072 a	27.00 c	0.40 a
T_7	5.52	0.83 abc	1.43 ab	0.075 a	22.55 f	0.26 cd
T_8	5.83	0.89 a	1.52 a	0.078 a	24.30 e	0.29 bc
$LSD_{(0.05)}$	NS	0.08	0.14	0.055	0.11	0.10
CV (%)	4.35	6.25	7.48	3.570	4.58	8.36

In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by LSD at 0.05 level of probability.

($LSD_{0.05}$= 0.02, 0.08, 0.14, 0.055, 0.11 and 0.10 respectively)

T_1= Control; T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 5 ton ha^{-1}; T_4 = RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 ton ha^{-1}; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7= ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}

CHAPTER V

SUMMARY AND CONCLUSION

The field experiment was conducted at the experimental plot of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207 during the period from November, 2016 to March, 2017 in Rabi season to find out the effect of biochar on growth, yield and quality of potato. In this experiment test crop variety is Diamant. The experiment comprised of the following 8 treatments as T_1= Control, T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 5 ton ha^{-1}; T_4 = RFD + Biochar @ 10 ton ha^{-1}; T_5 = ⅔of RFD + Biochar @ 5 $tonha^{-1}$; T_6 = ⅔ of RFD + Biochar @ 10 ton ha^{-1}; T_7 = ½ of RFD + Biochar @ 5 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 10 ton ha^{-1}. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Data were recorded on different yield attributes, yield and quality of potato and nutrient status of postharvest soil and significant variation was recorded for different treatment.

Plant height due to different levels of biochar applications was significantly influenced at days after planting (DAP). The maximum plant height (28.12, 43.31, 58.29 and 61.38 cm at 30, 45, 60 and 75 DAP, respectively) was recorded from T_4 treatment. The minimum plant height (17.67, 26.17, 36.88 and 43.50 cm at 30, 45, 60 and 75 DAP, respectively) was recorded from T_1 treatment.

All parameter significantly varied among the different levels of biochar application. The maximum stem numbers $hill^{-1}$ (6.00) was obtained from T_3 treatment. The maximum number of tubers $hill^{-1}$ (9.35) was produced from RFD + Biochar @ 5 ton ha^{-1}application. The maximum weight of tubers g $hill^{-1}$ (56.1) was observed from T_3 (RFD + Biochar @ 5 ton ha^{-1}) treatment. The highest tuber yield kg $plot^{-1}$ (29.84) was obtained from T_3. The maximum yield of tubers (34.10 t ha^{-1}) was produced from T_3 treatment where RFD with 5 ton per ha^{-1} biochar was applied. The minimum yield of tubers (16.60 t ha^{-1}) was produced from T_1 (Control) treatment.

Significantly higher dry matter content and specific gravity was also recorded from T_3 treatment declined with reduced dose of chemical fertilizer was applied with higher or lower dose of biochar. The maximum data of quality parameters like % dry matter content (23.41), specific gravity (1.065) was recorded in T_3 treatment and the lowest (17.90), (1.031) was recorded in T_1 treatment respectively.

In case of grading of tuber (% by number) the maximum no. of non marketable tuber (<20 gm) (40.7) was recorded from T_1 treatment while the minimum (24.3) was recorded in T_8 treatment. The highest no. of marketable tuber (>20 gm) (75.7) was observed in T_8 treatment while the lowest (59.3) was recorded from T_1 treatment. On the basis of size in diameter tubers have been graded into seed tuber 28 – 55 mm, non seed tuber <28 mm and >55 mm, Tuber yield for chips 45-55 mm. The maximum no. of non seed tuber <28mm (34.6), >55 mm (16.3), seed tuber 28-55 mm (70.7) and % no. of Tuber yield for chips 45-55 mm (23.3) was obtained fromT_1, T_5, T_2 and T_3 treatments respectively. The minimum no. of non seed tuber <28mm (15.0), >55 mm (11.00), seed tuber 28-55 mm (54.6) and % no. of Tuber yield for chips 45-55 mm (13.6) was obtained fromT_8, T_8, T_1 and T_1 treatments respectively.

Application of biochar in presence of chemical fertilizers resulted in improvement of postharvest soil fertility interring of organic matter, total N, available P and S and also exchangeable K contents. The soil pH or also tended to increase where biochar was applied. Biochar had some significant effect on soil properties. The highest soil pH (5.91) was recorded in T_3 treatment. The highest organic carbon (0.89) was recorded in T_8 treatment. The highest organic matter (1.52) was recorded in T_8 treatment. The maximum total nitrogen (0.0865) was recorded in T_4 treatment. The maximum available phosphorus (29.67 ppm) was recorded from T_3 treatment. The highest exchangeable potassium (me/100g soil) (o.45%) was recorded in T_3 treatment.

Conclusion

Biochar appeared to be a potential source of organic amendment, Tuber yield and quality of potato significantly increased when biochar was applied in combination with inorganic fertilizers. The fertility of soil also improved to a great extent. Thus biochar could be a alternate source of organic manure in Bangladesh agriculture. However, further studies are suggested to explore the real benefit of bio-char inters of yield sustainability and regenerations of soil fertility.

Recommendation

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. Long durated experimentation with bio-char is suggested to know its residual values and also to find out the nutrient composition of biochar derived from different sources of organic manures.

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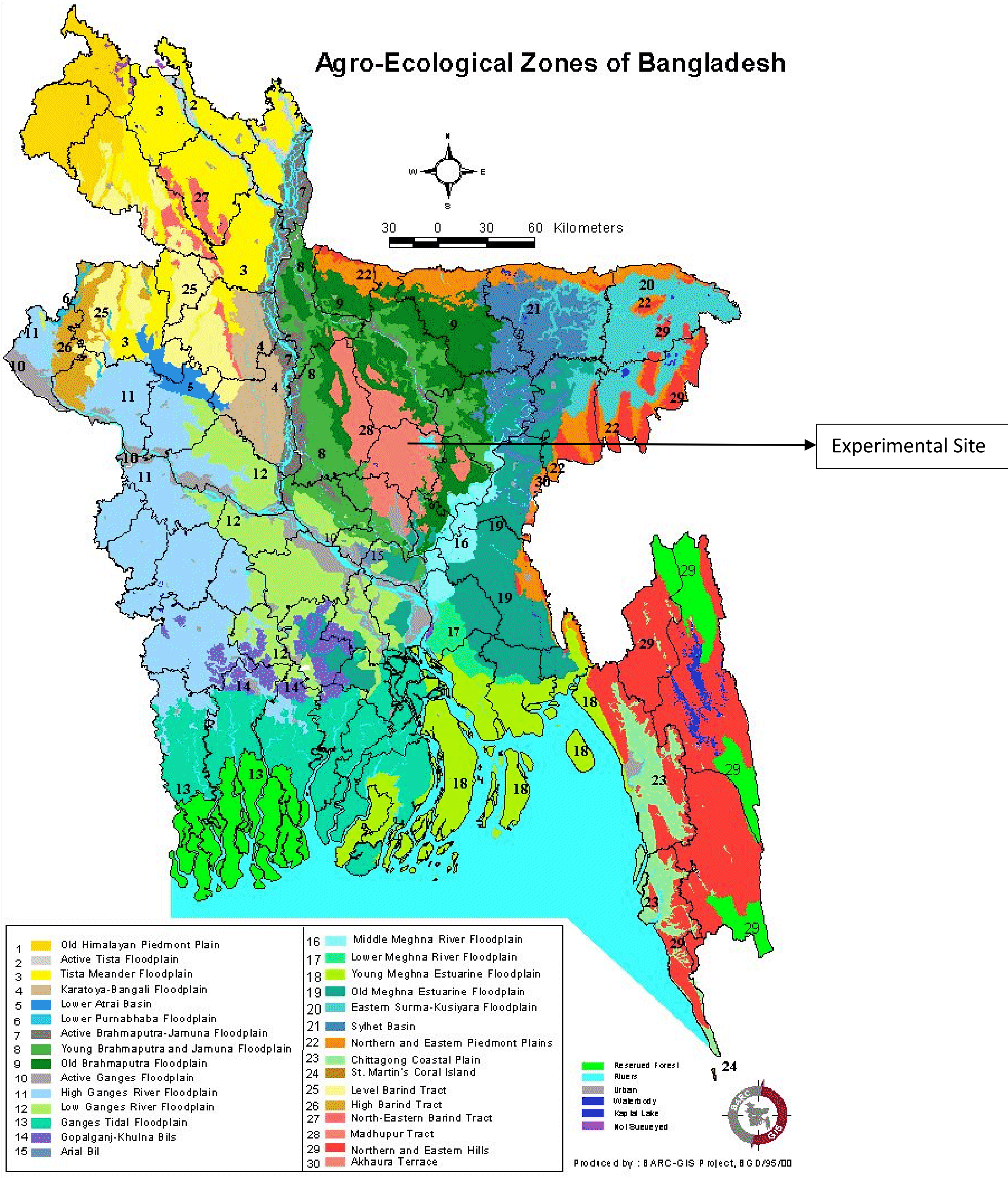
APPENDICES

Appendix I. Map showing the experimental sites under study

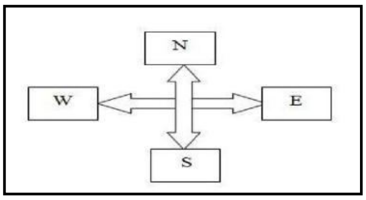


Appendix II. Monthly average of air temperature, relative humidity and total rainfall of the experimental site during the period from November, 2016 to February, 2017.

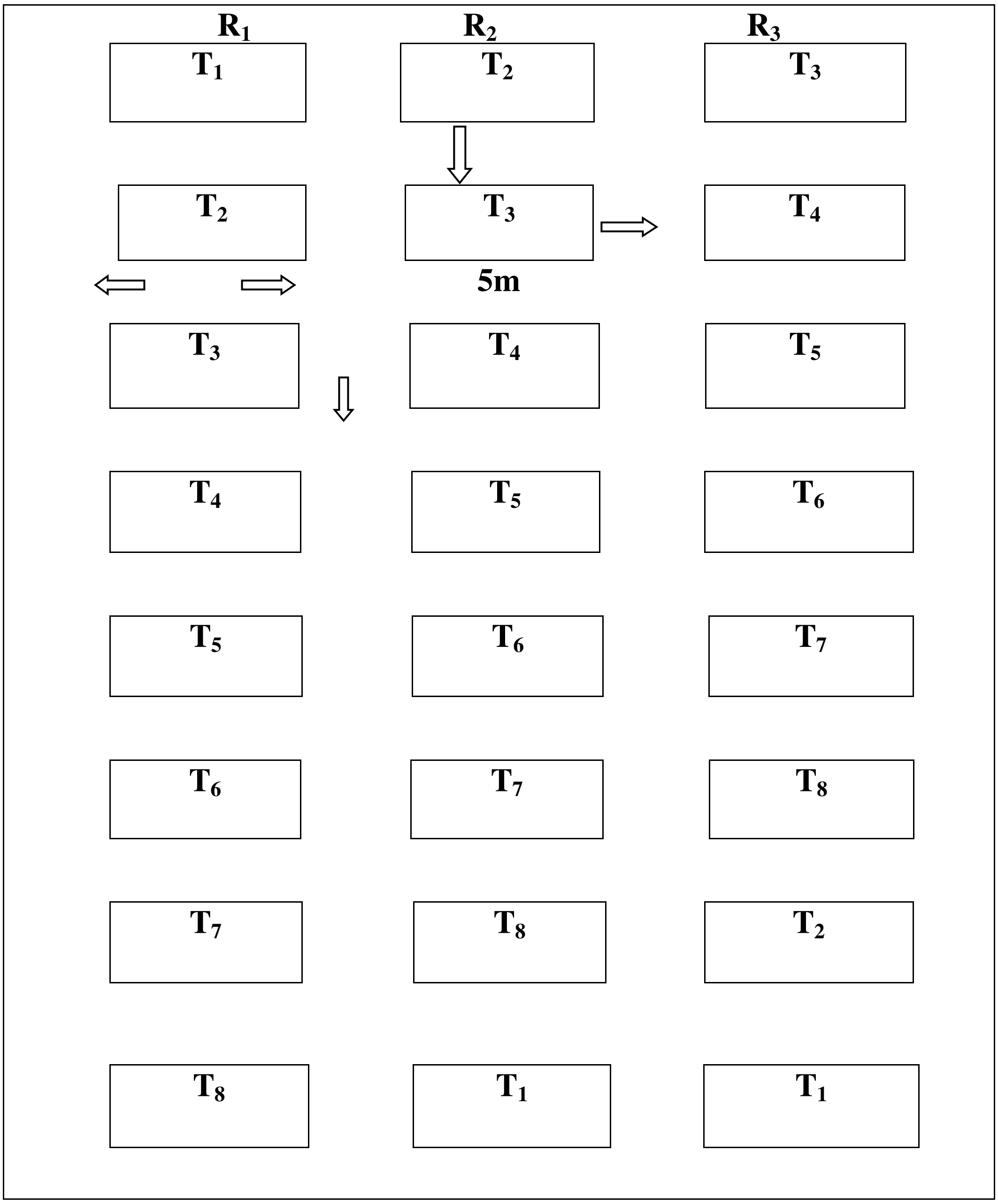
Months	Air temperature (^0C)		Relative humidity (%)	Total rainfall (mm)
	Maximum	Minimum		
November	29.74	19.15	67.21	66
December	23.92	14.50	75.58	5
January	24.55	12.20	64.39	12
February	28.60	17.5	48.16	30
March	29.3	18.38	45.17	50

Source: Bangladesh Meteorological Dept. (Climate & weather division) Agargoan, Dhaka – 1216

APPENDIX III: Layout of the experimental plot



Plot size: 5 m × 1.75 m (8.75 m^2)
Plot to plot distance: 0.5 m
Block to block distance: 1.0 m



Appendix IV: Analysis of variance of the data on Plant height (cm) and No. of stem per hill of potato as influenced by biochar

Sources of Variation	Degrees of freedom	Mean Square					
		Plant height					No. of stem per hill
		30 DAP	45 DAP	60 DAP	75 DAP	90 DAP	
Replication	2	12.542	10.135	10.135	10.135	10.135	0.875
Factor A	7	46.938	104.85	195.25	115.09	158.38	2.7381
Error	14	1.542	0.635	0.635	0.635	0.635	0.6845

Appendix V: Analysis of variance of the data on yield and yield contributing character of potato as influenced by biochar

Sources of Variation	Degrees of freedom	Mean Square			
		No. of tuber / hill	Average Weight of tuber (g)/ hill	Tuber yield (kg / plot)	Tuber yield (ton/ha)
Replication	2	2.6838	1.0547	9.2413	12.011
Factor A	7	0.619	56.911	54.597	70.945
Error	14	27.9	11.647	4.2816	5.5829

Appendix VI: Analysis of variance of the data on Grading of tuber of potato as influenced by biochar

Sources of Variation	Degrees of freedom	Mean Square			
		% no. of marketable tuber >20 gm	% no. of non marketable tuber < 20 gm	% no. of Tuber yield for chips 45-55 mm	% no. 0f seed tuber 28 - 55 mm
Replication	2	12.011	9.292	0.875	0.2917
Factor A	7	70.945	101.14	90.476	93.024
Error	14	5.583	15.054	17.208	15.863

Appendix VII: Analysis of variance of the data on Grading of tuber of potato as influenced by biochar

Sources of Variation	Degrees of freedom	Mean Square			
		% Dry matter content	Specific gravity	% no. 0f non seed tuber <28 mm	% no. 0f non seed tuber >55 mm
Replication	2	26.542	2.7917	0.1107	12.125
Factor A	7	33.946	84.375	9.0173	11.613
Error	14	15.018	18.411	0.5918	6.6488

Appendix VIII: Analysis of variance of the data on Postharvest Soil properties influenced by biochar

Sources of Variation	Degrees of freedom	Mean Square					
		Soil pH	Organic carbon	Organic matter	Total N (%)	Available P (ppm)	Exchangeable K (me/100g soil)
Replication	2	0.5	0.02	0.02	0.003	8.82	0.02
Factor A	7	0.122	0.005	0.016	0.002	46.984	0.031
Error	14	0	0	0.001	0	0	0