RESPONSE OF POTATO YIELD AND QUALITY TO BIOCHAR AND ITS EFFECT ON SOIL PROPERTIES

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CERTIFICATE

This is to certify that thesis entitled, **"Response of potato yield and quality to biochar and its effect on soil properties"** 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 bonafide research work carried out by **Mridula Parvin,** Registration **No. 15-06484** 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.

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DEDICATED TO
MY
BELOVED PARENTS

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ABSTRACT

A field experiment was carried out at the experimental plot of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207 during the period from November, 2021 to March, 2022 in Rabi season to find out the effect of biochar on yield and quality of potato tuber. In this experiment test crop variety was Diamant. The experiment comprised of the following 9 treatments as T_1 = Control (No chemical fertilizer and biochar), T_2 = RFD (Recommended Fertilizer Dose), T_3 = RFD + Biochar @ 1 t ha^{-1}, T_4 = RFD + Biochar @ 1.5 t ha^{-1}, T_5 = RFD + Biochar @ 2 t ha^{-1}, T_6 = 75% of RFD + Biochar @ 1 t ha^{-1}, T_7 = 75% of RFD + Biochar @ 1.5 t ha^{-1}, T_8 = 75% of RFD + Biochar @ 2 t ha^{-1} and T_9 = No chemical fertilizer + Biochar @ 2 t 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 treatments. The maximum plant height (18.33, 35.28 and 56.94 cm) at 20, 40 and 60 DAP respectively) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}). 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 maximum yield of tubers (29.77 t ha^{-1}) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) and the maximum marketable yield (71.67%) was recorded from T_5 treatment (RFD + Biochar @ 2 t ha^{-1}). The fertility and quality of soil also improved to a great extent. From this study, it was found that biochar had significant positive response for improving yield and quality of potato and also fertility of the postharvest soil apprehensively due to application of biochar along with recommended inorganic fertilizers.

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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 Agriculture Organization
et al.	=	And others
DAS	=	Days after Sowing
Mg	=	Milligram
kg	=	Kilogram
SAU	=	Sher-e-Bangla Agricultural University
SRDI	=	Soil Resources Development Institute
g	=	Gram
cm	=	Centimeter
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.) is one of the most important food crops in the world. It is used as a staple food in many countries, but in Bangladesh it is mainly used as a vegetable. Potatoes range in size, shape, color, starch content, and flavor. Potato is now the fourth most important world food crop after rice, wheat, and maize (corn) because of its great yield production and high nutritive value and third most important crop of Bangladesh (FAOSTAT, 2020). This diverse and adaptable tuber has spread from its origin and its production has been increased most rapidly in the warm, humid, tropical Asian lowlands in Bangladesh during the dry season and plays a vital role in both economy and as a major food crop. 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, 49 t ha^{-1} in New Zealand, 42.48 t ha^{-1} in Denmark and 42 t ha^{-1} in Netherlands (FAOSTAT, 2020). 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).

Potato is one of the most important crops 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. Therefore, the combined 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 (Bhuiya, 1994).

Biochar is fairly an innovative term but not a new element. All over the world, biochar deposited in soil naturally through grassland and forest fires (Krull *et al.,* 2008). However, biochar is also created by charring of various organic matters, such as firewood or farm wastes under limited or no oxygen environment (Magnusson, 2015). Nowadays, biochar is produced through the process of pyrolysis where the biomass is heated to temperatures typically between 300°C and 700°C under anaerobic conditions. Although, the term biochar has come into a new common practice while the use of charcoal for improving soil health as fertility management goes back millennia (Scholz *et.al,* 2014). Hence, biochar is usually made in an eco-friendly way by recycling plant waste into fertilizer (Cui, 2015). Biochar can improve agricultural productivity, particularly in low-fertility and degraded soils where it can be especially useful to the world's poorest farmers; it reduces the losses of nutrients and agricultural chemicals in run-off; it can improve the water-holding capacity of soils; and it is producible from biomass waste (Woolf *et al.,* 2010). It has increased crop yield through various mechanisms including stimulation of beneficial soil microbes such as mycorrhizal fungi, increase of soil base saturation, increase in water holding capacity and retention of nutrients in the portion of the soil column containing roots, thus improving nutrient use efficiency (Cui, 2015).

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. Adequate N fertilization is critical for optimizing potato yield and quality Insufficient available N leads to reduced growth, reduced light interception, limited yield and early crop senescence. Different types of nutrients are essential for growth and development of potato. N is beneficial for its growth, development and protein synthesis (Westermann *et al.,* 1988).

Biochar will be most promising technology in Bangladesh in response to soil fertility and productivity. Organic matter depletion is higher due to environmental condition of our country. Biochar will be a great solution to increase stable soil organic matter. But very limited and scattered researches have been done in Bangladesh in this regard, very little work was done with biochar in potato production that's why this experiment was set up to study the effect of biochar on yield and yield contributing characters of potato (BARI Alu-7) and soil properties.

OBJECTIVES

1. To observe the effect of biochar on yield and yield contributing characters of potato (BARI Alu-7),
2. To study the efficacy of biochar on quality of potato tuber and
3. To evaluate the improvement of soil physio-chemical properties for crop production.

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 yield and yield contributing characters are still inadequate. Brief reviews of available literature pertinent to the present study have been reviewed in this chapter.

2.1 Effect of biochar

2.1.1 Introduction of biochar

Biochar is a black carbon manufactured through pyrolysis of biomasses, a process where organic material is heated under low oxygen conditions. One practice of biochar from crop residues is as soil modification whereas charcoal, made from wood, generally is used as fuel (Lehmann *et al.,* 2006). It is the high carbon materials formed from the slow pyrolysis (heating in the absence of oxygen) of biomass (Chan *et al.,* 2007). It is also defined as, a fine-grained and porous constituent, similar in its exterior to charcoal manufactured by natural burning or by the combustion of biomass under oxygen-limited conditions (Sohi *et al.,* 2009).

Biochar affects soil fertility in many ways; it can add nutrients by itself or make them more available for plant uptake by increase the decomposition of organic material or possibly, decrease decomposition rates of other organic material thereby increasing soil C concentration in the long run. Moreover, the large surface area results in increased CEC, which may check nutrient leaching and thus eutrophication (Lehmann and Joseph, 2009). A significant decrease in leaching of pragmatic fertilizers after charcoal addition. Further, enhanced plant uptake of P, K and Ca was observed (Lehmann *et al.,* 2003). By increasing CEC, applied fertilizers can be adsorbed to the surface area and thereby used more proficiently by plants (Steinbeiss *et al.,* 2009). Absorption of biochar may therefore give higher yield with the same number of fertilizers. Nutrient uptake and availability can also be exaggerated by change in pH as a result of biochar addition (Lehmann and Joseph, 2009). The total nutrient concentration in biochar can be high, however the proportion of plant accessible nutrients can vary. Depending on which kind of feedstock is being used for biochar manufacture, the proportion of available nutrients differs (Lehmann *et al.,* 2003). When biochar is produced from plant residues; the average carbon concentration in biochar to be 47.6 % (Wolf, 2008). However, Gaskin et al. (2008) showed that carbon application in biochar formed from poultry manure and pine chips can range between 40- 78 %.

In general biochar has a high C/N ratio (mean value of 67) which specifies that immobilization of nitrogen can occur when applied to soil. Because of the carbon stability it cannot easily be digested by microbes and therefore N mineralization can occur. The surface area can be settled and small pores act as refugee site for microbes to avoid grazers. 6 The dissimilarity in pore size of biochar stimulates different habitats and thus microbe diversity (Lehmann and Joseph, 2009). Biochar can be produced from many organic materials and under diverse conditions subsequent in products of varying properties (Guerrero *et al.,* 2005). It can be produced from a wide range of biomass sources, for example, woods and barks, agricultural wastes such as olive husks, corncobs and tea waste (Demirbas, 2004), greenwaste (Chan *et al.,* 2007), animal manures and other waste products (Chan *et al.,* 2008; Lima *et al.,* 2008). Biochar is a combination of char and ash with the major part (70 – 95%) carbon (C) (Brandstaka *et al.,* 2010; Luostarinen *et al.,* 2010). It can also be twisted from sewage sludge (Khan *et al.,* 2013), rice-husk (Lu *et al.,* 2014), wheat straw (Junna *et al.,* 2014) and several other materials. Biochar solicitation in soils has positive stimuli on improving soil quality and plant growth (Chan *et al.,* 2007). According to Chan et al. (2008), biochar produced from green waste by pyrolysis considerably increased soil pH, organic carbon, and exchangeable cations with a significant decrease in tensile strength at higher rates of biochar application (>50 t ha^{-1}) in alfisol soil.

Tammeorg *et al.,* (2014) evaluated 0, 5, 10, 20 and 30 t ha^{-1} of biochar with or without inorganic fertilizer or meat bone meal for two years and found biochar enriched nitrate N content, water retention capacity, soil organic carbon and K content. Biochar derived from wheat straw decreased soil bulk density and increased soil field capacity, dissolved organic carbon and available P (Alburquerque *et al.,* 2014).

2.1.2 Biochar for crop production

There are varied reactions of crops to biochar (Chan *et al.,* 2008). Van-Zwieten *et al*. (2010) tested two biochars produced from the slow pyrolysis of paper mill waste, in two agricultural soils in a glasshouse and found that they significantly increased biomass in wheat, soybean and radish in ferrosol soil but reduced wheat and radish biomass in calcaresol, amended with fertilizer in both soils. According to McClellan *et al.,* (2007), the cases where biochar leads to decreasing plant growth can be related to short-term high pH levels, volatile or mobile matter and nutrient imbalance of fresh biochar. In their study, Alburquerque *et al.,* (2013) observed that biochar with higher ash content lead to relatively higher increase in sunflower growth due to increased plant availability of nutrients.

A significant decrease in dry matter contented of radish was obtained when biochar was applied at 10 t ha^{-1} (Chan *et al.,* 2008). In a distinct experiment, there was no significant effect of biochar rates (0, 7 and 15 t s ha^{-1}) on turnip, wheat, rape and faba bean yields (Brandstaka *et al.,* 2010). Asai *et al.,* (2009) showed that biochar increased rice grain yields at sites with low P availability, which might be due to improved inundated hydraulic conductivity of the top soil, xylem sap flow of the plant and response to N and NP chemical fertilizer treatments. Limiting soil N content by biochar application in N deficient soils could be due to the high C/N ratio, hence it might reduce crop productivity provisionally (Lehmann *et al.,* 2003). However, some biochars contain significant amount of micronutrients. For example, 8 pecan-shelled biochar contained greater amount of copper (Cu), magnesium (Mg) and zinc (Zn) than the soil (Novak *et al.,* 2009).

In a single experiment, concentrations of heavy metals including Cu and Zn increased in sewage sludge biochar but those of available heavy metals decreased (Liu *et al.,* 2014). Furthermore, poultry litter biochar was also rich with considerable amounts of Zn, Cu and manganese (Mn) (Inal *et al.,* 2015). Thus, it is needed to compare its effect solely and in combination with other nutrient sources. Some authors (Verheijen *et al.,* 2009; Brandstaka *et al.,* 2010) have highlighted the need for further research on potential benefits of biochars as well as their economics. However, their interactions with other organic sources as well as microbes and release of nutrients from them are insufficiently measured. Biochar at the rates of 20 and 40 t ha^{-1} without N fertilization in a carbon poor calcareous soil of China increased maize yield by 15.8% and 7.3% while the rates with 300 kg ha^{-1} N fertilization improved the yield by 8.8% and 12.1%, respectively (Zhang *et al.,* 2012). In addition, biochar solicitation in a nutrient poor, slightly acidic loamy sand soil had little effect on wheat yield in the absence of mineral fertilization but when pragmatic with the highest rate of mineral fertilization, it produced yield 20–30 % more than mineral fertilizer alone (Alburquerque *et al.,* 2014).

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 paralleled to farmers practices (Vinh *et al.*, 2014). 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). Biochar of maple was applied at different concentrations for root elongation of pea and wheat 9 but no significant difference was observed (Borsari, 2011), possibly due to little effect of biochar in the short-term. The wood chip biochars produced at 290°C and 700°C had no effect on growth and yield of either rice or leaf beet (Lai *et al.,* 2013). A biochar significantly increased growth and yield of French bean as compared to no biochar (Saxena *et al.,* 2013). A 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 (Carter *et al.,* 2013).

A poultry-litter biochar derived from slow pyrolysis tested in cott showed that a higher level (3000 kg ha^{-1}) with urea produced better cott progression than the lower rate (1500 kg ha^{-1}) which, in turn, showed better results than the control (Coomer *et al.,* 2012). Lehmann and Joseph (2015) reported significant crop yield benefits from biochar application to soils for various crops and plants in different environments. Uzoma *et al.,* (2011) recognized a 150% and 98% increase in maize grain yield at 15 and 20 t/ha biochar application respectively to development of soil physical and chemical properties. Crane-Droesch *et al.*, (2013) reported positive crop yield response as a result of biochar submission over much of Sub-Saharan Africa, parts of South America, Southeast Asia, and southeastern North America. The observed increase in crop yields in these highly weathered and nutrient-poor soils could be explained by biochar soil changes improving 10 soil aggregation, increasing nutrients retention, and enhancing soil water holding capacity. Despite biochar's agronomic benefits, negative effects under biochar amendment on plant productivity have also been reported in peat soils whereas moderate to negative yield response could be observed in most of the leading countries in grain production.

Biochar application has been reported to increase by about 10% plant productivity (Liu *et al.,* 2013) and about 25% for aboveground biomass (Biederman and Harpole, 2013). Biochar effectiveness on plant productivity fluctuated considering variations in climate, soil properties, investigated crops, and experimental conditions (Wang *et al.,* 2014). Zhang *et al.,* (2012) investigated the result of biochar on soil quality, plant yield and the emission of greenhouse gas in a rice paddy study in China and found increase in rice yield due increased soil pH, soil organic carbon, total nitrogen and decreased soil bulk density. Improvement of plant growth and crop yields with biochar application has been reported and could be attributed to modification of soil physical properties (Glaser *et al.,* 2002). These changes in soil physical properties are due to enhancements on soil structure and water holding capacity (Zhang *et al.,* 2012) and improved crop nutrient availability (Atkinson *et al.,* 2010) via its indirect nutrient value (Lehmann and Joseph, 2015), liming effect increased surface area (Sohi *et al.,* 2009). Biochar application in combination with fertilizers sustained crop yields due to soil property improvements (Steiner *et al.,* 2008). Jeffery *et al.,* (2011) reported -28% to 39% changes in plant productivity (crop yield and above-ground biomass) following biochar modification to soils which are partly clarified by biochar’s liming effect and superior soil moisture retention, connected with increased nutrient availability to plants. For biochar source’s effects on yield response, poultry litter presented the strongest (significant) positive effect (28%), in contrast to biosolids, which were the only feedstock showing a statistically significant negative effect (-28%). Positive crop productivity occurred in acidic than in neutral soils, in sandy than in loam and silt soils.

Yamato *et al.,* (2006) explored biochar effect on crop yield and reported increase in maize, cowpea and peanut yield under fertilized surroundings due to increased soil pH, cation exchange capacity, nutrient availability and reduced exchangeable Al^{3+} content. Trupiano *et al.,* (2017) conducted a study, to test the effects of biochar amendment, compost addition, and their combination on lettuce plants grown in a soil poor in nutrients. Compost alteration had clear and positive effects on plant growth and yield and on soil chemical characteristics. However, biochar alone stimulated lettuce leaves number and total biomass, improving soil total nitrogen and phosphorus contents, as well as total carbon and enhancing related microbial communities. Combining biochar and compost, no positive synergic and combined effects were observed. It was suggested that in a soil poor in nutrients the biochar alone could be effectively used to augment soil fertility and plant growth and biomass yield.

Carter *et al.,* (2013) conducted a pot experiment over a three crop (lettuce-cabbage lettuce) cycle on the growth of transplanted lettuce (*Lactuca sativa*) and Chinese cabbage (*Brassica chinensis*). Biochar application rates to potting medium of 25, 50 and 150 g kg^{-1} were used with and without locally presented fertilizers (a mixture of compost, liquid compost and lake sediment). The biochar treatments were found to increase the final biomass, root 12 biomass, plant height and number of leaves in all the cropping cycles in comparison to no biochar treatments. The greatest biomass increase due to biochar additions (903%) was found in the soils without fertilization, rather than fertilized soils (483% with the same biochar application as in the "without fertilization" case). Over the cropping cycles the impact was reduced; a 363% increase in biomass was observed in the third lettuce cycle.

2.2 Impact of biochar on soil physio-chemical properties

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 (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 (Steiner *et al.,* 2008), biochar, unlike fresh biomass, may persist in soils for 7 years (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.,* (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.,* (2010), 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 behave as both positively and negatively charged under acidic and alkaline conditions respectively. 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, 2007). The biochars largely composed of single-ring aromatic and aliphatic C mineralize more rapidly in comparison to those composed of condensed aromatic C (Lehmann, 2007).

Lehmann (2007) 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, 2007). 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, 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, 2007).

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 Role of biochar on plant nutrients

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). 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, 2007). 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 12 % 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-N), 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 NH4-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).

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.

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 (DM) production was later analysed. 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}), 13 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 (Ding *et al.,* 2010). 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).

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.

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 shortterm. 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-cabbagelettuce 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.

2.4 Effect of biochar on potato cultivation

Farooque *et al.,* (2020) conducted a study in Atlantic Canada representative soil to cultivate potatoes with four treatments of soil amendments (T_1 = control [no added nutrients], T_2 = B [biochar], T_3 = F [synthetic fertilizer @ recommended NPK], and T_4 = B + F [biochar + recommended NPK]) under a completely randomized block design with factorial arrangements. Chemical analyses of soils were conducted for physical, hydrological, and chemical (including concentration of macro- and micro-nutrients) prior to and after the completion experiments to evaluate soil fertility and its resulting effects on crop yield. The biochar amendment improved soil micro- and macro-nutrients. Soil organic matter, pH, and cation exchange capacity (ECE) significantly increased by application of biochar. The maximum potato yield of 30,467.4 kg h^{-1} was achieved by the combined application of biochar and synthetic fertilizer as this combination resulted in the maximum net benefit in comparison with control treatment. And found that, biochar amendment of soils resembling to that of the Atlantic Canada representative soil used in this study, with a mix of recommended NPK for, can formulate a smart precision farming nutrient management technique.

A study investigated by Nzediegwu *et al.,* (2019) to find out the effects of biochar, produced from plantain peel, on the yield of potatoes (*Solanum tuberosum* L.) irrigated with wastewater in two consecutive seasons. The treatments were (i) wastewater with biochar, (ii) wastewater without biochar, and (iii) freshwater without biochar. The plant health parameters (e.g., photosynthesis rate) varied with time but were not affected by biochar amendment. Also, the total fresh tuber weights as well as the total number of tubers were similar in all treatments although the biochar showed a significant positive effect ($p < 0.05$) on the pH and the cation exchange capacity of the soil. Thus, it was concluded that application of the plantain peel biochar as soil amendment showed no significant effect on the yield of potatoes irrigated with wastewater.

CHAPTER III
MATERIALS AND METHODS

The study was carried to find out the effect of biochar on yield and yield contributing characters of potato with its effect on soil physio-chemical properties. 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, 2021 to March, 2022 in Rabi season.

3.2 Site description

Geographical location

The present research work was conducted in the Agronomy field (plot-13) of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The experimental area was situated at 23°74'N latitude and 90°33' E longitude at an altitude of 8.6 meter above the sea level.

Agro-Ecological Region

The experimental site belongs to the agro-ecological zone of “Modhupur Tract”, AEZ-28. 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. The experimental site was shown in the map of AEZ of Bangladesh in Appendix I.

Climate characteristics

Experimental site was located in the sub-tropical monsoon climatic zone, set a parted by winter during the months from November, 2021 to March, 2022. 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.

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. 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 (Appendix III).

3.3 Experimental details

Treatments and factor of the experiment;

Treatments:

T_1 = Control (No chemical fertilizer and biochar)

T_2 = RFD (Recommended Fertilizer Dose)

T_3= RFD + Biochar @ 1 t ha^{-1}

T_4 = RFD + Biochar @ 1.5 t ha^{-1}

T_5 = RFD + Biochar @ 2 t ha^{-1}

T_6 = 75% of RFD + Biochar @ 1 t ha^{-1}

T_7= 75% of RFD + Biochar @ 1.5 t ha^{-1}

T_8 = 75% of RFD + Biochar @ 2 t ha^{-1}

T_9 = No chemical fertilizer + Biochar @ 2 t ha^{-1}

RFD (Recommended Fertilizer Dose): for potato N-150 kg ha^{-1}, P-30 kg ha^{-1}, K-140 kg ha^{-1}, S-15 kg ha^{-1}, Zn-3 kg ha^{-1} and B-1 kg ha^{-1} (BARC, 2018).

Experimental design and layout

The experiment was laid out in Randomized Complete Block Design (RCBD) with three (3) replications. Total number of plots was 27 with a total size of 4.38 m^2 (2.5 m × 1.75 m) for each plot. 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 IV.

3.4 Planting materials

The seed tubers of selected potato varieties were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur. 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 Biochar collection

Biochar was collected from Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur.

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 15 November, 2021. Ploughing and cross ploughing were done with power tiller followed by laddering. Land preparation was completed on 19 November, 2021 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 N-150, P-30, K-140, S-15, Zn-3 kg ha^{-1} and B-1 kg ha^{-1} (BARC, 2018) where urea, triple super phosphate (TSP), murate of potash (MoP), gypsum, zinc sulphate and boric acid respectively. The entire amount of biochar (as per treatment), triple super phosphate, gypsum, zinc sulphate, boric acid and half of urea and full of MoP were applied as basal dose at two days before potato planting. Rest of the urea was side dressed in two equal splits at 30 and 45 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 23, 2021.

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 (5 February, 2022) 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 20, 2022 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 March 2, 2022 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

i. Number of tubers hill^{-1}
ii. Average weight of tuber (g hill^{-1})
iii. Yield of tubers kg plot^{-1}
iv. Yield of tubers t ha^{-1}

C. Quality characters

i. Tuber dry matter content
ii. Specific gravity
iii. Marketable yield (>28 mm to <55 mm)
iv. Non-marketable yield (<28 mm)
v. Seed yield (>20 mm)
vi. Non-seed yield (<20 mm)

D. Postharvest soil analysis

i. Bulk density
ii. Particle density
iii. Porosity
iv. Soil pH
v. Organic carbon (%)
vi. Organic matter (%)
vii. Available P (ppm)

A. Crop growth characters

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 90 days after planting (DAP). The height of selected plant was measured in cm with the help of a meter scale and mean was calculated.

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

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.

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

Weight of tubers hill^{-1} was measure (5 randomly selected tuber) at harvest. Tuber weight hill^{-1} was recorded by measuring all tubers from sample plant.

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

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

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

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

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℃ for 72 hours. From which the weights of tuber flesh dry matter content % were recorded, and the dry matter percentage of tuber was calculated with the following formula (Elfnesh *et al.*, 2011)

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

Tuber Specific Gravity

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

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

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 and converted to percentages (Hussain, 1995). A special type of frame (potato riddle) was used for grading of tuber.

D. 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.

Soil analysis

Soil samples were analysed for both physical and chemical characteristics viz. Bulk density, particle density, porosity, pH, organic matter and available P contents. The soil samples were analysed by the following standard methods as follows:

Bulk density, Particle density and porosity of soil

Bulk density of soil samples was measured by core sampler method. The bulk density is obtained by adding a known mass of powder to a graduated cylinder. The density is calculated as mass/volume.

Particle density was determined by volumetric flask method.

Particle density= weight of soil solid/volume of soil solid.

Porosity =100 (1- bulk density/particle density)

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.

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.

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 colour with reduction of phosphomolybdate complex and the colour intensity were measured calorimetrically at 660 nm wavelength and readings were calibrated with the standard P curve (Page *et al.*, 1982).

3.7 Statistical Analysis

The data obtained for different parameters were statistically analysed to find out the significant difference the results of different levels of biochar application on growth, yield of potato and postharvest soil properties. 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 using STATISTIX-10 statistical package by least significant difference (LSD) test 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 IV-VII.

4.1 Crop growth characters

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

Plant height due to different levels of biochar applications combined with different amount of recommended fertilizer doses was significantly influenced at different days after planting (DAP) (Figure 1). The maximum plant height (18.33, 35.28 and 56.94 cm) at 20, 40 and 60 DAP, respectively) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum plant height (9.81, 21.95 and 34.82 cm) at 20, 40 and 60 DAP, respectively) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. Plant height was significantly increased due to application of different level of biochar. Graber *et al.* (2010) emphasized that treating tomato plants by biochar positively enhanced plant height. Biochar addition to mineral fertilizers significantly increased plant growth (Schulz and Glaser, 2012).

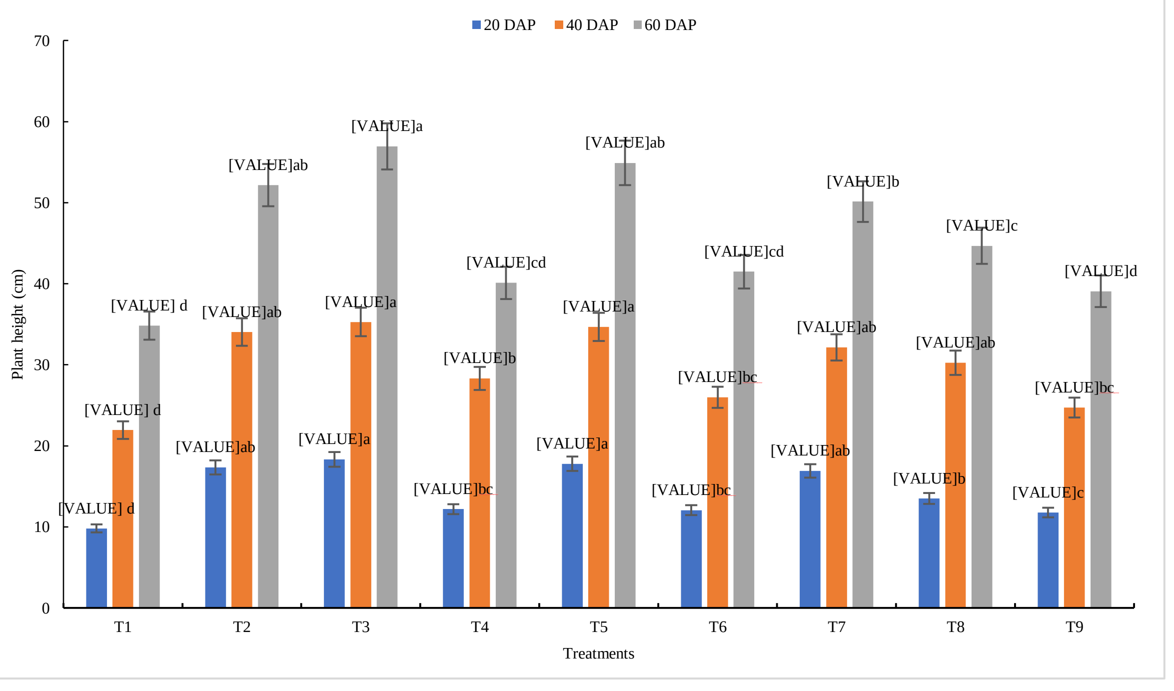

Figure 1. Effect of biochar on plant height at different days after planting on potato (BARI Alu-7)

4.1.2 Number of stem hill^{-1}

The number of stems per hill significantly increased over control (Figure 2). The maximum stem numbers hill^{-1} (7.33) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum stem numbers hill^{-1} (3.00) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. Youseef *et al.* (2017). revealed that the number of main stems significantly increased with increasing biochar application rates up to 10-12.

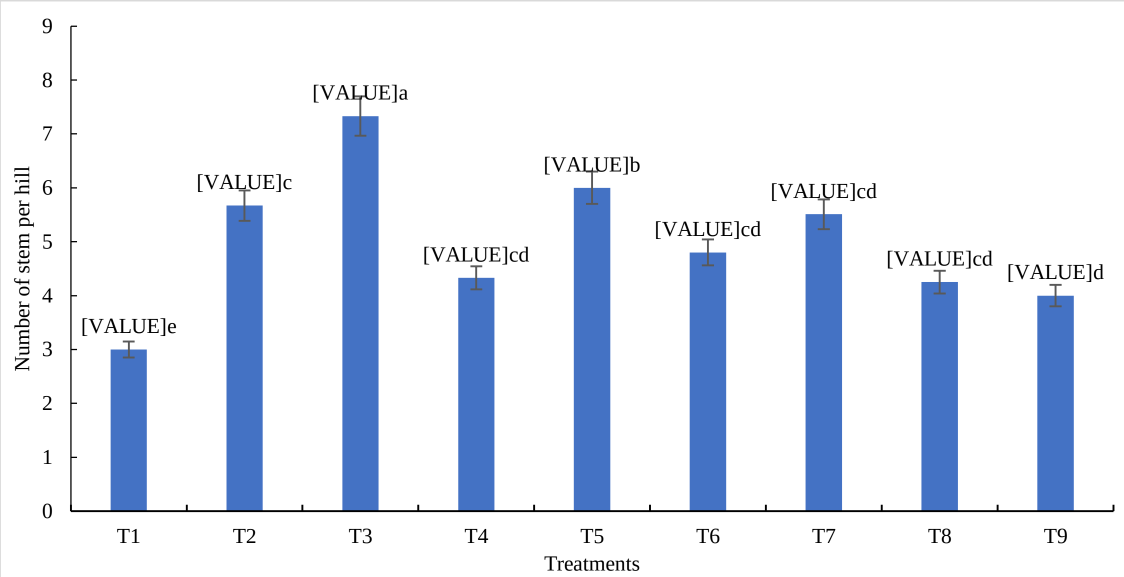

Figure 2. Effect of biochar on number of stem hill^{-1} of potato (BARI Alu-7)

[T_1 = Control (No chemical fertilizer and biochar), T_2 = RFD (Recommended Fertilizer Dose), T_3= RFD + Biochar @ 1 t ha^{-1}, T_4 = RFD + Biochar @ 1.5 t ha^{-1}, T_5 = RFD + Biochar @ 2 t ha^{-1}, T_6 = 75% of RFD + Biochar @ 1 t ha^{-1}, T_7= 75% of RFD + Biochar @ 1.5 t ha^{-1}, T_8 = 75% of RFD + Biochar @ 2 t ha^{-1}, T_9 = No chemical fertilizer + Biochar @ 2 t ha^{-1}]

4.2 Yield and yield components

4.2.1 Number of tubers hill^{-1}

The number of tubers per hill significantly increased over control (Table 1). The maximum number of tuber hill^{-1} (10.00) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum number of tuber hill^{-1} (5.17) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. Youseef *et al.* (2017) found that fertilizing with biochar positively increased number of tubers.

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

The average weight of tuber significantly increased over control (Table 1). The maximum average weight of tuber (g hill^{-1}) (61.16) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum average weight of tuber g hill^{-1}

(34.76) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. Akhtar *et al.* (2014) indicated that addition of biochar increased the soil moisture contents, which consequently improved yield of tomato fruits.

4.2.3 Yield of tubers kg plot^{-1}

The yield of tubers (kg plot^{-1}) significantly increased over control (Table 1). The maximum yield of tubers kg plot^{-1} (24.27) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum yield of tubers kg plot^{-1} (20.60) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. Nair *et al.* (2014) stated that the increases in crop yields of potato cv. Atlantic have been attributed to better water holding capacity, higher cation exchange capacity, increased nutrient retention, and the ability of biochar to reduce bulk density.

Table 1. Effect of biochar on number of tubers hill^{-1}, average weight of tubers, yield of tubers of potato (BARI Alu-7)

[In a column means having similar letter (s) are statistically similar and those having

Treatments	Number of tubers hill^{-1}	Average weight of tuber (g hill^{-1})	Yield of tubers kg plot^{-1}	Yield of tubers t ha^{-1}
T_1	5.17 e	34.76 e	20.60 c	23.67 d
T_2	9.00 ab	51.90 bc	23.95 ab	29.00 ab
T_3	10.00 a	61.16 a	24.27 a	29.77 a
T_4	7.33 bc	48.70 c	23.46 ab	27.93 bc
T_5	9.33 ab	55.15 b	24.20 a	29.60 a
T_6	7.00 c	55.50 b	23.10 ab	27.85 bc
T_7	8.67 b	48.00 cd	23.70 ab	28.46 ab
T_8	7.98 bc	43.44 d	23.86 ab	28.08 b
T_9	6.00 d	35.34 de	21.93 b	24.43 c
LSD $_{(0.05)}$	2.37	3.18	2.20	3.17
CV (%)	7.18	9.32	14.91	13.88

dissimilar letter (s) differ significantly by LSD at 0.05 level of probability.]

[T_1 = Control (No chemical fertilizer and biochar), T_2 = RFD (Recommended Fertilizer Dose), T_3= RFD + Biochar @ 1 t ha^{-1}, T_4 = RFD + Biochar @ 1.5 t ha^{-1}, T_5 = RFD + Biochar @ 2 t ha^{-1}, T_6 = 75% of RFD + Biochar @ 1 t ha^{-1}, T_7= 75% of RFD + Biochar @ 1.5 t ha^{-1}, T_8 = 75% of RFD + Biochar @ 2 t ha^{-1}, T_9 = No chemical fertilizer + Biochar @ 2 t ha^{-1}]

4.2.4 Yield of tubers t ha^{-1}

The yield of tubers t ha^{-1} significantly increased over control (Table 1). The maximum yield of tubers t ha^{-1} (29.77) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum yield of tubers t ha^{-1} (23.67) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. Akhtar *et al.* (2014) indicated that addition of biochar increased the soil moisture contents, which consequently improved yield of tomato fruits.

4.3 Quality characters

4.3.1 Tuber dry matter content

The tuber dry matter content (%) significantly increased over control (Figure 4). The maximum tuber dry matter content (21.71 %) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum tuber dry matter content (18.64 %) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. Youseef *et al.* (2017). found that the total dry weight of tubers significantly increased (15.60%) with increasing of biochar application rate for biochar applied at 3 m^3/ha.

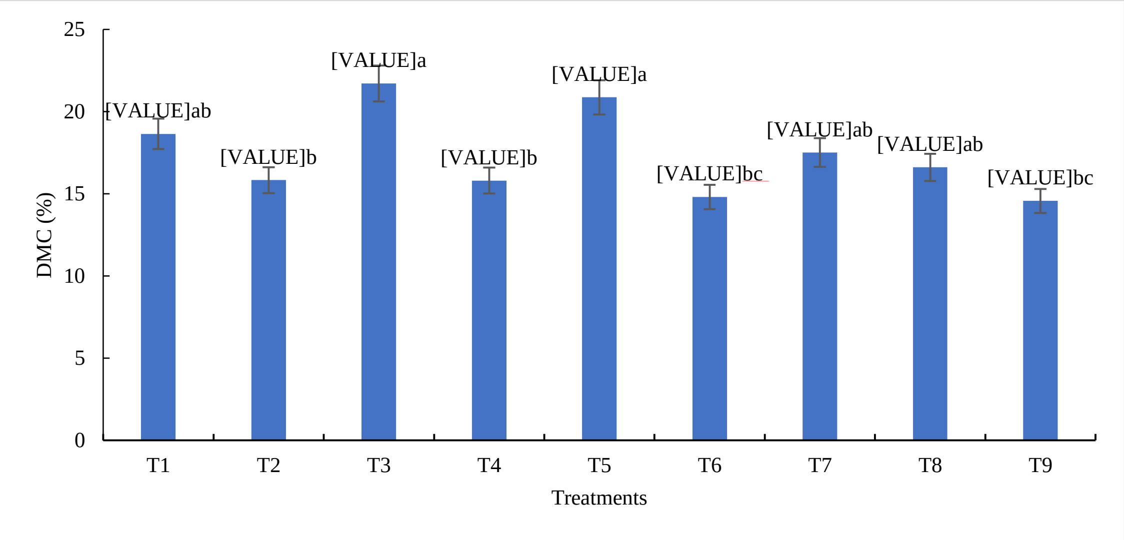

Figure 3. Effect of biochar on tuber dry matter content (%) of potato (BARI Alu-7)

[T_1 = Control (No chemical fertilizer and biochar), T_2 = RFD (Recommended Fertilizer Dose), T_3= RFD + Biochar @ 1 t ha^{-1}, T_4 = RFD + Biochar @ 1.5 t ha^{-1}, T_5 = RFD + Biochar @ 2 t ha^{-1}, T_6 = 75% of RFD + Biochar @ 1 t ha^{-1}, T_7= 75% of RFD + Biochar @ 1.5 t ha^{-1}, T_8 = 75% of RFD + Biochar @ 2 t ha^{-1}, T_9 = No chemical fertilizer + Biochar @ 2 t ha^{-1}]

4.3.2 Tuber specific gravity

The tuber specific gravity was found non-significant increased over control (Table 2). The maximum tuber specific gravity (1.10) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum tuber specific gravity (1.02) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment.

Table 2. Effect of biochar on tuber specific gravity of potato (BARI Alu-7)

Treatments	Tuber specific gravity
T_1	1.02
T_2	1.09
T_3	1.10
T_4	1.09
T_5	1.07
T_6	1.06
T_7	1.07
T_8	1.06
T_9	1.05
LSD $_{(0.05)}$	--
CV (%)	1.42

[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 (No chemical fertilizer and biochar), T_2 = RFD (Recommended Fertilizer Dose), T_3= RFD + Biochar @ 1 t ha^{-1}, T_4 = RFD + Biochar @ 1.5 t ha^{-1}, T_5 = RFD + Biochar @ 2 t ha^{-1}, T_6 = 75% of RFD + Biochar @ 1 t ha^{-1}, T_7= 75% of RFD + Biochar @ 1.5 t ha^{-1}, T_8 = 75% of RFD + Biochar @ 2 t ha^{-1}, T_9 = No chemical fertilizer + Biochar @ 2 t ha^{-1}]

4.3.3 Marketable yield (>28 mm to <55 mm)

Marketable yield (>28 mm to <55 mm) significantly increased over control (Figure 4). The maximum marketable yield (71.67%) was recorded from T_5 treatment (RFD + Biochar @ 2 t ha^{-1}) whereas, the minimum marketable yield (26.67%) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment.

4.3.4 Non-marketable yield (<28 mm)

Non-marketable yield (<28 mm) significantly decreased over control (Figure 4). The maximum non-marketable yield (49.51%) was recorded from T_1 treatment (Control: no chemical fertilizer and biochar) whereas, the minimum non-marketable yield (27.69%) was recorded from T_3 (RFD + Biochar @ 1 t ha^{-1})

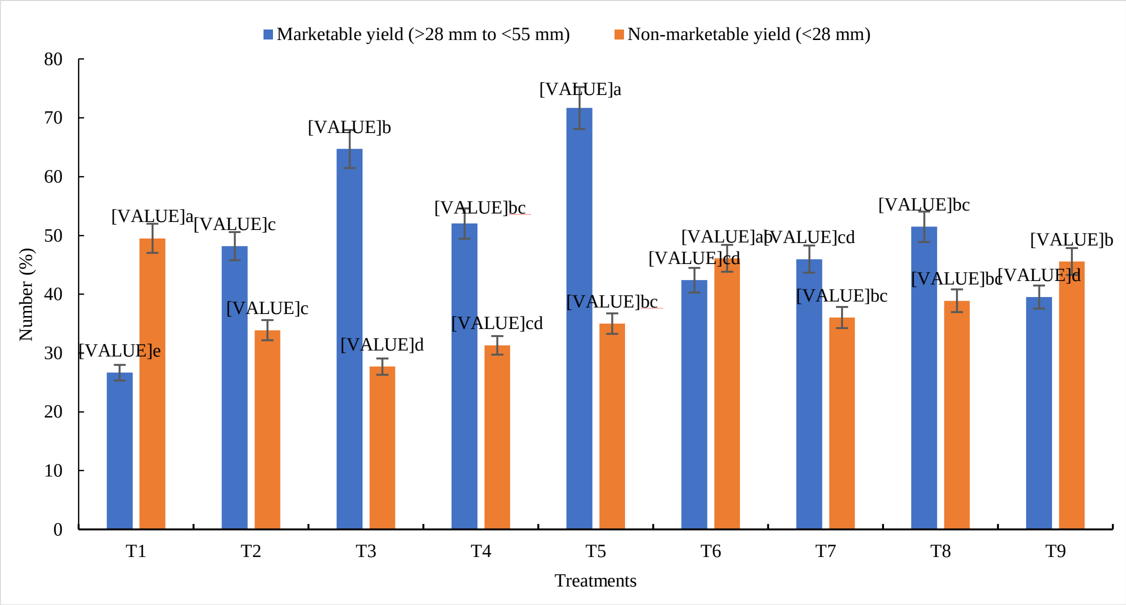

Figure 4. Effect of biochar on number (%) of marketable yield (>28 mm to <55 mm) of potato (BARI Alu-7) and non-marketable yield (<28 mm)

[T_1 = Control (No chemical fertilizer and biochar), T_2 = RFD (Recommended Fertilizer Dose), T_3= RFD + Biochar @ 1 t ha^{-1}, T_4 = RFD + Biochar @ 1.5 t ha^{-1}, T_5 = RFD + Biochar @ 2 t ha^{-1}, T_6 = 75% of RFD + Biochar @ 1 t ha^{-1}, T_7= 75% of RFD + Biochar @ 1.5 t ha^{-1}, T_8 = 75% of RFD + Biochar @ 2 t ha^{-1}, T_9 = No chemical fertilizer + Biochar @ 2 t ha^{-1}]

4.3.5 Seed yield (>20 mm)

Seed yield (>20 mm) significantly increased over control (Figure 5). The maximum seed yield (68.35%) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum seed yield (51.75%) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment.

4.3.6 Non-seed yield (<20 mm)

Non-seed yield (<20 mm) significantly decreased over control (Figure 5). The maximum non-seed yield (30.15%) was recorded from T_1 treatment Control (No chemical fertilizer and biochar) whereas, the minimum non-seed yield (16.50%) was recorded from T_3 (RFD + Biochar @ 1 t ha^{-1}) treatment.

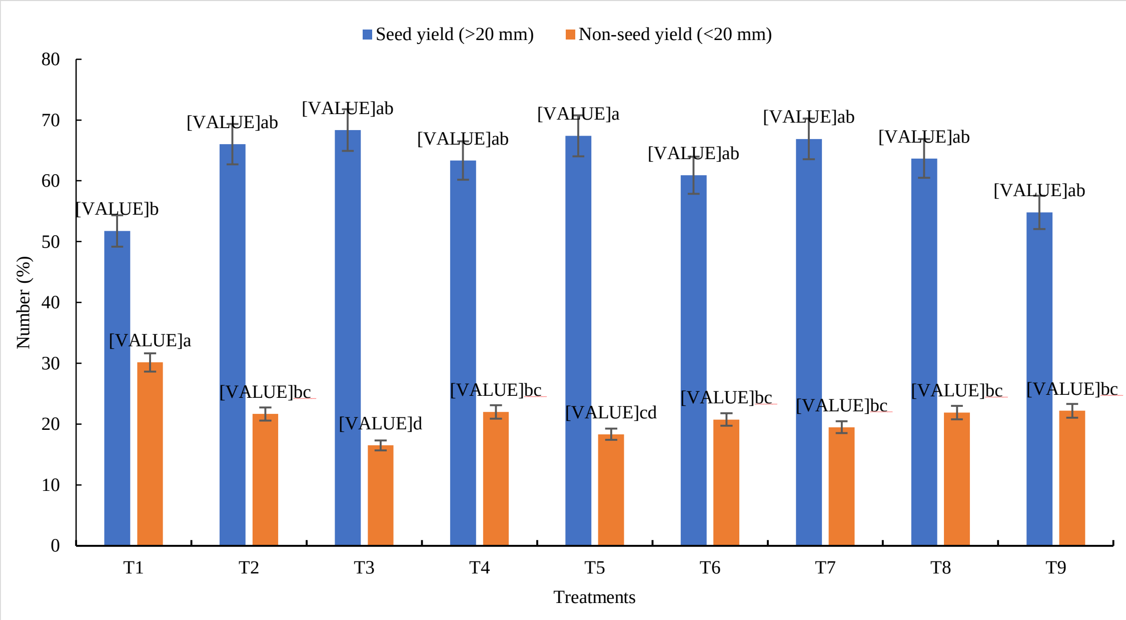

Figure 5. Effect of biochar on number (%) of seed yield and non-seed yield of potato

(BARI Alu-7)

[T_1 = Control (No chemical fertilizer and biochar), T_2 = RFD (Recommended Fertilizer Dose), T_3= RFD + Biochar @ 1 t ha^{-1}, T_4 = RFD + Biochar @ 1.5 t ha^{-1}, T_5 = RFD + Biochar @ 2 t ha^{-1}, T_6 = 75% of RFD + Biochar @ 1 t ha^{-1}, T_7= 75% of RFD + Biochar @ 1.5 t ha^{-1}, T_8 = 75% of RFD + Biochar @ 2 t ha^{-1}, T_9 = No chemical fertilizer + Biochar @ 2 t ha^{-1}]

4.4 Postharvest soil analysis

4.4.1 Soil pH

Soil pH found non-significant over control (Table 3). The maximum soil pH (6.10) was recorded from T_5 treatment (RFD + Biochar @ 2 t ha^{-1}) whereas, the minimum soil pH (6.00) was recorded from T_3 (RFD + Biochar @ 1 t ha^{-1}) treatment. The application of biochar could increase soil pH (6.0) value. Wang *et al.* (2014) found that rice husk biochar increased the tea garden soil (acid soil) pH from 3.33 to 3.63. The agricultural soil pH increased by almost 1 pH unit for biochar treatment which produced from mixed hardwood (*Quercus spp*. and *Carya spp*.) (Laird *et al.*, 2010).

4.4.2 Organic carbon (%)

Organic carbon (%) found non-significant over control (Table 3). The maximum organic carbon (0.81) was recorded from T_5 treatment (RFD + Biochar @ 2 t ha^{-1}) whereas, the minimum organic carbon (0.64) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. Increase in organic carbon (up to 69%) due to biochar application was found by Laird *et al.*, 2010.

4.4.3 Organic matter (%)

Organic matter (%) found non-significant over control (Table 3). The maximum organic matter (1.40) was recorded from T_5 treatment (RFD + Biochar @ 2 t ha^{-1}) whereas, the minimum organic matter (1.10) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment.

4.4.7 Available P (ppm)

Available phosphorus (ppm) increased over control (Table 5). The maximum phosphorus (30.04) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum phosphorus (16.00) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. Xu *et al.* (2014) showed that biochar affects P availability by interaction with other organic and inorganic components in the soil, including organic matter or other base cations in the soil.

Table 3. Effect of biochar on soil pH, organic carbon (%) and organic matter (%) of post-harvest soil

Treatments	Soil pH	Organic carbon (%)	Organic matter (%)	Available P (ppm)
T_1	6.02	0.64	1.10	16.00 c
T_2	6.01	0.72	1.25	28.51 ab
T_3	6.00	0.76	1.39	30.04 a
T_4	6.03	0.79	1.17	26.15 ab
T_5	6.10	0.81	1.40	28.90 ab
T_6	6.03	0.74	1.28	26.33 ab
T_7	6.03	0.76	1.32	27.81 ab
T_8	6.07	0.77	1.33	28.14 ab
T_9	6.07	0.80	1.15	21.33 b
$LSD_{(0.05)}$	--	--	--	5.78
CV (%)	3.59	2.08	2.61	6.93

[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 (No chemical fertilizer and biochar), T_2 = RFD (Recommended Fertilizer Dose), T_3= RFD + Biochar @ 1 t ha^{-1}, T_4 = RFD + Biochar @ 1.5 t ha^{-1}, T_5 = RFD + Biochar @ 2 t ha^{-1}, T_6 = 75% of RFD + Biochar @ 1 t ha^{-1}, T_7= 75% of RFD + Biochar @ 1.5 t ha^{-1}, T_8 = 75% of RFD + Biochar @ 2 t ha^{-1}, T_9 = Control (No chemical fertilizer) + Biochar @ 2 t ha^{-1}]

4.4.4 Bulk density (g/cc)

Bulk density (g/cc) found non-significant over control (Table 4). The maximum bulk density (1.61) was recorded from T_8 (75% of RFD + Biochar @ 2 t ha^{-1}) treatment whereas, the minimum bulk density (1.40) was recorded from T_5 (RFD + Biochar @ 2 t ha^{-1}) treatment.

4.4.5 Particle density (g/cc)

Particle density (g/cc) increased non-significantly over control (Table 4). The maximum particle density (2.62) was recorded from T_9 treatment [(Control: No chemical fertilizer) + Biochar @ 2 t ha^{-1}] whereas, the minimum particle density (2.48) was recorded from T_5 (RFD + Biochar @ 2 t ha^{-1}) treatment.

4.4.6 Porosity (%)

Porosity (%) found significant over control (Table 4). The maximum porosity (43.20) was recorded from T_5 (RFD + Biochar @ 2 t ha^{-1}) and T_3 (RFD + Biochar @ 1 t ha^{-1}) treatments. whereas, the minimum porosity (38.08) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment.

Table 4. Effect of biochar on bulk density, particle density and porosity (%) of post-harvest soil

Treatments	Bulk density (g/cc)	Particle density (g/cc)	Porosity (%)
T_1	1.61	2.60	38.08 c
T_2	1.60	2.59	38.22 bc
T_3	1.55	2.57	39.69 ab
T_4	1.50	2.56	41.41 ab
T_5	1.42	2.50	43.20 a
T_6	1.55	2.55	39.22 bc
T_7	1.50	2.51	40.24 ab
T_8	1.44	2.41	40.25 ab
T_9	1.46	2.42	39.67 b
LSD $_{(0.05)}$	---	--	3.04
CV (%)	2.18	3.59	5.07

[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 (No chemical fertilizer and biochar), T_2 = RFD (Recommended Fertilizer Dose), T_3= RFD + Biochar @ 1 t ha^{-1}, T_4 = RFD + Biochar @ 1.5 t ha^{-1}, T_5 = RFD + Biochar @ 2 t ha^{-1}, T_6 = 75% of RFD + Biochar @ 1 t ha^{-1}, T_7= 75% of RFD + Biochar @ 1.5 t ha^{-1}, T_8 = 75% of RFD + Biochar @ 2 t ha^{-1}, T_9 = Control (No chemical fertilizer) + Biochar @ 2 t 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, 2021 to March, 2022 in Rabi season to find out the effect of biochar on yield and quality of potato. In this experiment test crop variety was Diamant. The experiment comprised of the following 9 treatments as T_1 = Control (No chemical fertilizer and biochar), T_2 = RFD (Recommended Fertilizer Dose), T_3= RFD + Biochar @ 1 t ha^{-1}, T_4 = RFD + Biochar @ 1.5 t ha^{-1}, T_5 = RFD + Biochar @ 2 t ha^{-1}, T_6 = 75% of RFD + Biochar @ 1 t ha^{-1}, T_7= 75% of RFD + Biochar @ 1.5 t ha^{-1}, T_8 = 75% of RFD + Biochar @ 2 t ha^{-1}, T_9 = No chemical fertilizer + Biochar @ 2 t 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 treatments.

Plant height due to different levels of biochar applications combined with different amount of recommended fertilizer doses was significantly influenced at different days after planting (DAP). The maximum plant height (18.33, 35.28 and 56.94 cm) at 20, 40 and 60 DAP, respectively) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum plant height (9.81, 21.95 and 34.82 cm) at 20, 40 and 60 DAP, respectively) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. The maximum stem numbers $hill^{-1}$ (7.33) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum stem numbers $hill^{-1}$ (3.00) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment.

The maximum number of tuber $hill^{-1}$ (10.00) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum number of tuber $hill^{-1}$ (5.17) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. The maximum average weight of tuber (g $hill^{-1}$) (61.16) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum average weight of tuber g $hill^{-1}$ (34.76) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. The maximum yield of tubers kg $plot^{-1}$ (24.27) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum yield of tubers kg $plot^{-1}$ (20.60) was recorded from T_1 (Control:

no chemical fertilizer and biochar) treatment. The maximum yield of tubers t ha^{-1} (29.77) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum yield of tubers t ha^{-1} (23.67) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment.

The maximum tuber dry matter content (21.71 %) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum tuber dry matter content (18.64 %) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. The maximum tuber specific gravity (1.10) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum tuber specific gravity (1.02) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment.

The maximum marketable yield (71.67%) was recorded from T_5 treatment (RFD + Biochar @ 2 t ha^{-1}) whereas, the minimum marketable yield (26.67%) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. The maximum non-marketable yield (49.51%) was recorded from T_1 treatment (Control: no chemical fertilizer and biochar) whereas, the minimum non-marketable yield (27.69%) was recorded from T_3 (RFD + Biochar @ 1 t ha^{-1}). The maximum seed yield (68.35%) was recorded from T_3 treatment = RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum seed yield (51.75%) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. The maximum non-seed yield (30.15%) was recorded from T_1 treatment = Control (No chemical fertilizer and biochar) whereas, the minimum non-seed yield (16.50%) was recorded from T_3 (RFD + Biochar @ 1 t ha^{-1}).

The maximum soil pH (6.10) was recorded from T_5 treatment (RFD + Biochar @ 2 t ha^{-1}) whereas, the minimum soil pH (6.00) was recorded from T_3 (RFD + Biochar @ 1 t ha^{-1}) treatment. The application of biochar could increase soil pH (5.9) value. The maximum organic carbon (0.81) was recorded from T_5 treatment (RFD + Biochar @ 2 t ha^{-1}) whereas, the minimum organic carbon (0.64) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. The maximum organic matter (1.40) was recorded from T_5 treatment (RFD + Biochar @ 2 t ha^{-1}) whereas, the minimum organic matter (1.10) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment.

The maximum bulk density (1.61) was recorded from T_8 (75% of RFD + Biochar @ 2 t ha^{-1}) treatment whereas, the minimum bulk density (1.40) was recorded from T_5 (RFD + Biochar @ 2 t ha^{-1}) treatment. The maximum particle density (2.62) was recorded from T_9 treatment (No chemical fertilizer + Biochar @ 2 t ha^{-1}) whereas, the minimum particle density (2.48) was recorded from T_5 (RFD + Biochar @ 2 t ha^{-1}) treatment. The maximum porosity (43.20) was recorded from T_5 (RFD + Biochar @ 2 t ha^{-1}) and T_3 (RFD + Biochar @ 1 t ha^{-1}) treatments. whereas, the minimum porosity (38.08) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment. The maximum phosphorus (30.04) was recorded from T_3 treatment (RFD + Biochar @ 1 t ha^{-1}) whereas, the minimum phosphorus (16.00) was recorded from T_1 (Control: no chemical fertilizer and biochar) treatment.

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 and quality of soil also improved to a great extent.

Recommendation

1. Another experiment may be carried out with different doses of biochar for specific biochar effect.
2. Long duration experiments 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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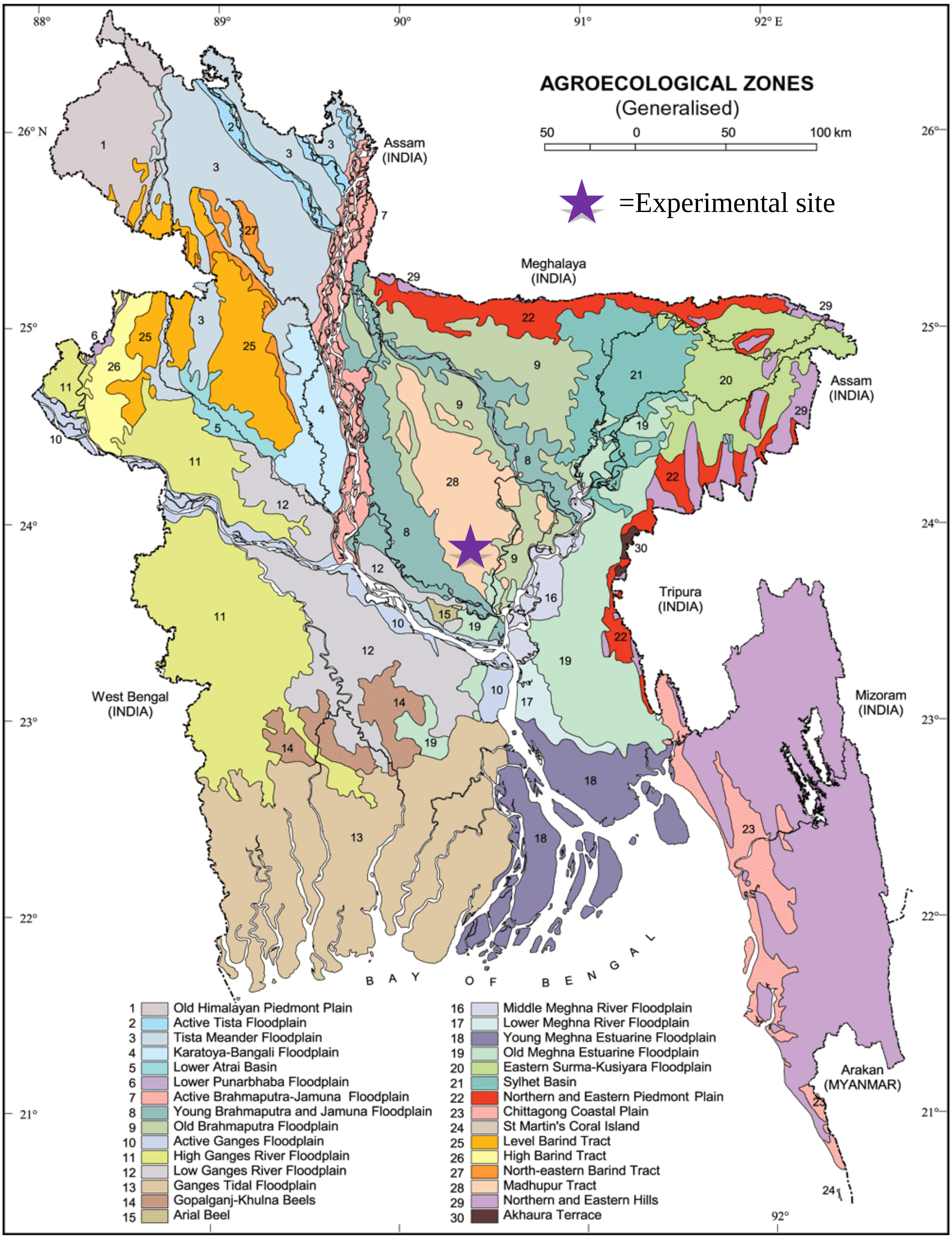
APPENDICES

Appendix I. Map showing the experimental site under study



Appendix II. Characteristics of soil of experimental site.

A. Morphological characteristics of the experimental site

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University Research field, Dhaka
General Soil Type	Shallow Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled

B. The initial physical and chemical characteristics of soil of the experimental site (0 - 15 cm depth)

Physical characteristics	
Constituents	Percent
Sand	26
Silt	45
Clay	29
Textural class	Silty clay
Chemical characteristics	
Soil characters	Value
pH	6.0
Organic carbon (%)	0.65
Organic matter (%)	1.25
Total nitrogen (%)	0.03
Available P (ppm)	20.54
Exchangeable K (me/100 g soil)	0.10

Appendix III. Monthly meteorological information during the period from November, 2020 to April, 2021

Year	Month	Air temperature (^0C)		Relative humidity (%)	Total rainfall(mm)
		Maximum	Minimum		
2020	November	28.10	11.83	58.18	47
	December	25.00	9.46	69.53	00
2021	January	25.2	12.8	69	00
	February	27.3	16.9	66	39
	March	31.7	19.2	57	23
	April	33.50	25.90	64.50	119

Meterological Centre, Agargaon, Dhaka (Climate Division)

Appendix IV. Analysis of variance on the effect of biochar on plant height and number of stem hill^{-1} at different days after planting on potato (BARI Alu-7)

Source of variation	D.F.	Mean square of plant height (cm) at			Number of stem hill^{-1}
		20 DAT	40 DAT	60 DAT	
Replications	2	8.523	0.324	0.855	0.009
Treatments (G)	8	52.384**	127.844**	167.706**	1.818**
Error	16	5.046	2.554	2.587	0.024

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix V. Analysis of variance of effect of biochar on number of tubers hill^{-1}, average weight of tubers and yield of tubers of potato (BARI Alu-7)

Source of variation	D.F.	Mean square of			
		Number of tubers hill^{-1}	Average weight of tuber (g hill^{-1})	Yield of tubers kg plot^{-1}	Yield of tubers t ha^{-1}
Replications	2	1.160	0.149	0.063	0.002
Treatments (G)	8	1012.860**	47.628**	111.698**	0.025**
Error	16	2.640	2.948	2.891	0.005

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix VI. Analysis of variance on effect of biochar on tuber quality of potato (BARI Alu-7)

Source of variation	D.F.	Mean square of					
		Tuber dry matter content (%)	Tuber specific gravity	Marketable yield (>28 mm to <55 mm)	Non-marketable yield (<28 mm)	Seed yield (>20 mm)	Non-seed yield (<20 mm)
Replications	2	12.962	2.214	0.145	0.014	1.279	1.390
Treatments (G)	8	15.641**	1.066^{NS}	448.926**	32.840**	22.697**	2.056**
Error	16	1.109	0.321	0.962	0.072	0.209	0.087

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix VII. Analysis of variance on effect of biochar on postharvest soil properties of potato (BARI Alu-7)

Source of variation	D.F.	Mean square of					
		Soil pH	Organic carbon (%)	Organic matter (%)	Bulk density (g/cc)	Particle density (g/cc)	Porosity (%)
Replications	2	7.000	3.486	0.001	4.181	0.009	0.009
Treatments (G)	8	6.717^{NS}	4.918^{NS}	0.026^{NS}	1.703^{NS}	1.818^{NS}	2.285*
Error	16	3.333	1.864	0.000	2.198	0.024	0.056

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

PLATE

Plate 1. Seed bed preparation and seed sowing.

Plate 2. Seed germination.

Plate 3. Biochar and fertilizer preparation.

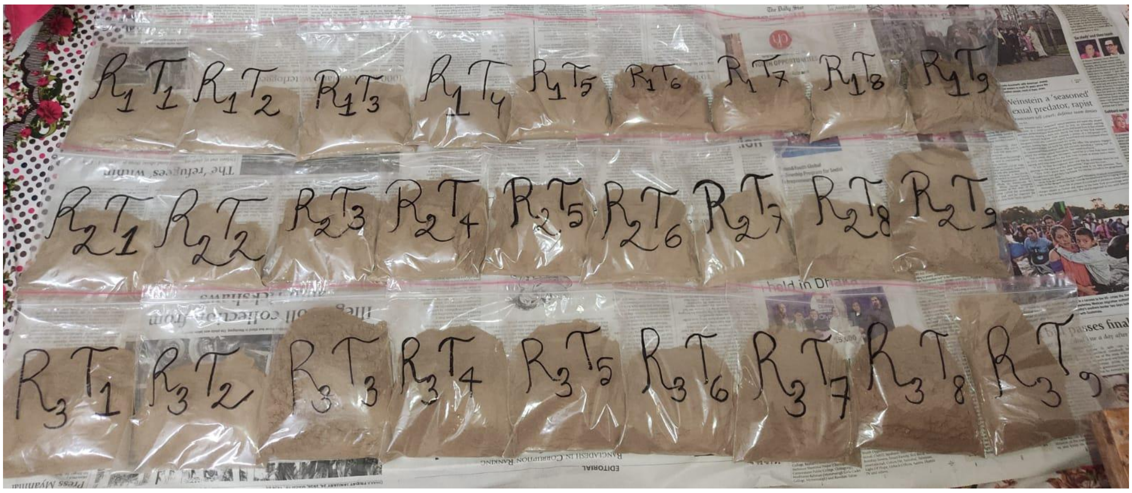


Plate 4. Soil sample collection.

Plate 5. Data collection.

Plate 6. Experimental field visit.