EFFECT OF BIOCHAR ON YIELD AND QUALITY OF POTATO TUBER

MD. OMAR ALI MOLLICK

DEPARTMENT OF SOIL SCIENCE

SHER-E-BANGLA AGRICULTURAL UNIVERSITY

DHAKA -1207

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EFFECT OF BIOCHAR ON YIELD AND QUALITY OF POTATO TUBER

BY

MD. OMAR ALI MOLLICK

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Approved by:

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

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

Prof. Dr. Saikat Chowdhury
Chairman
Examination Committee
Department of Soil Science
Sher-e-Bangla Agricultural University, Dhaka-1207

DEDICATED

TO

MY BELOVED PARENTS

DEPARTMENT OF SOIL SCIENCE
Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207

CERTIFICATE

This is to certify that the thesis entitled "***Effect of Biochar on Yield and Quality of Potato Tuber***" 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 **Md. Omar Ali Mollick**, Registration No. **11-04674** 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.

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Dhaka, Bangladesh

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

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The Author

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ABSTRACT

The present experiment was conducted in the research field of Sher-e-Bangla Agricultural University (SAU), Sher-e-Bangla Nagar, Dhaka-1207, Bangladesh during the period from November, 2017 to March, 2018 in rabi season. The objective was to observe the effect of biochar on the yield and quality of potato tuber and to find out the optimum dose of biochar along with inorganic fertilizer for achieving the maximum yield of potato. The experiment consist of 9 treatments as T_1 = Control (no chemical fertilizer and biochar), T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 ton ha^{-1}; T_4 = RFD + Biochar @ 5.0 ton ha^{-1}; T_5 = RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 ton ha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 ton ha^{-1};T_9 = Biochar @ 10 tonha^{-1}. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The tested variety was BARI Alu-7 (Diamant). Data were collected on different yield attributes, growth and quality of potato and postharvest soil analysis. A significant variation among the treatments in respect of majority of the parameters was observed. The maximum plant height was recorded from RFD + Biochar @ 7.5 ton ha^{-1} treatment. The highest number of stem hill^{-1} and number of tubers hill^{-1} were recorded from T_6 treatment. The maximum weight of tubers (0.51 kg hill^{-1}) and yield of tubers (35.76 ton ha^{-1}) were produced from T_5 treatment. The minimum yield of tubers (14.51t ha^{-1}) was produced from control treatment. The maximum data of quality parameters like % dry matter content (25.41), specific gravity (1.12) were also recorded in T_5 treatment. From postharvest soil analysis, the highest organic carbon (0.98%), organic matter (1.69%) was recorded in biochar @ 10 ton ha^{-1} treatment. From this study, it may be concluded that biochar had significant positive effect on yield and quality of potato and postharvest soil was improved considerably due to application of biochar along with inorganic fertilizers.

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LIST OF ABBREVIATION AND ELABORATION

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
DAP	=	Days After Planting
Ha^{-1}	=	Per hectare
g	=	gram(s)
Kg	=	Kilogram
SAU	=	Sher-e-Bangla Agricultural University
SRDI	=	Soil Resources Development Institute
wt	=	Weight
LSD	=	Least Significant Difference
^0C	=	Degree Celsius
NS	=	Not significant
MAX	=	Maximum
Min	=	Minimum
%	=	Percent
NPK	=	Nitrogen, Phosphorus and Potassium
CV%	=	Percentage of Coefficient of Variance

CHAPTER I

INTRODUCTION

‘The king of vegetable’ Potato (*Solanum tuberosum* L.) popularly known as ‘alu’ is a tuber crop under the family Solanaceae. South America is known to be native of Potato. In 1537, the Spaniards first came into contact with Potato in one of the villages of Andes. In Europe, Potato was introduced from 1580 A.D. to 1585 A.D. in Spain, Portugal, Italy, France, Belgium and Germany. In India it was introduced by the Portuguese sailors during early 17th century and its cultivation was spread to North India during the British period (Rajalakshmi, P. and George, L., 2018). In the world, it is the 4th crop after wheat, rice and maize. Bangladesh is the 7th potato producing country in the world. In Bangladesh, it ranks 2nd after rice in production (FAOSTAT, 2019). The total area under potato crop, national average yield and total production in Bangladesh are 4.75 lakh hectares, 19.925 t ha^{-1} and 94.74 lakh 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, 2008).

Potato has attained impressive significance in rural economy in Bangladesh. It is not only a cash crop but also a substitute food crop against rice and wheat. The area and production of potato in Bangladesh has been improved during the last decades but the yield per unit area remains more or less stagnant. In contrast 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, the yield is very low in Bangladesh (FAO STAT, 2016). Imbalanced fertilizer, low organic matter content in soil, inappropriate management of soil, insufficient use of manure and organic matter are accountable for such a low yield of potato in Bangladesh. Adverse effects on soil health and soil quality arise from nutrient imbalance in soil, excessive fertilization, soil pollution and soil loss processes that are increasingly becoming common in developing countries (Maikhuri, R. K. and Rao, K. S., 2012). Available reports indicated that potato production in Bangladesh can be increased by improving cultural practices among which optimization of manure and fertilizer, planting time, spacing and use of optimal sized seed are important which influences the yield of potato (Pulok *et al*., 2016).

Potato is undeniably 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 resulting health hazards and generating problems to the environment including the pollution of air, water and soil. Use of mineral fertilizers constantly lead to decline soil chemical and physical properties, biological activities and thus, overall, the total soil health. Due to this, nutrients supplied exclusively through chemical sources, though enhance yield initially, and lead to unsustainable productivity over the years (Tadesse *et al*., 2013). The organic matter of most of the soils of Bangladesh is below 2% as compared to an ideal minimum value 4% (Bhuiya, 1994).

Day by day the price of inorganic fertilizers is increasing. The best remedy for soil fertility management is, therefore, a combination of both mineral and organic fertilizers, where the mineral fertilizer provides readily available nutrients and the organic fertilizer mainly increases soil organic matter and improves soil structure and buffering capacity of the soil.

Biochar is the solid, carbon-rich material obtained by pyrolysis using different biomasses. It has been widely documented in previous studies that, the crop growth and yield can be increased by using biochar (Rawat, *et al.*, 2019). Biochar, a solid porous material obtained from the carbonization of biomass under low or no oxygen conditions, has been proposed as a climate change mitigation tool because it is expected to sequester carbon (C) for centuries and to reduce greenhouse gas (GHG) emissions from soils (Brassard *et al.*,2016). Biochar addition will change the chemical and physical properties of soil and thus influence roots and mycorrhizal fungi that resulted in the increased nutrient availability in the soil and increase plant root colonization by mycorrhizal fungi (Koide, R. T., 2017). In addition, biochar may reduce emissions of other greenhouse gases from soil such as nitrous oxide (N_2O), methane (CH_4) (Van Zwieten *et al.*, 2015). Biochar addition can improve plant productivity directly or indirectly, through improved nutrient retention and release characteristics. Biochar additions to agricultural soil have been reported to reduce gas emission, as well as biochar has been shown to improve soil fertility, to promote plant growth, to increase crop yield, and to reduce contaminations (Ding *et al.*, 2003).

Biochar reduces soil bulk density, increase soil porosity, cation exchange capacity, soil pH, nutrient availability, increase C content and 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 increasing retention of water into soil. Biochar has been described as a possible means to improve soil fertility 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.*, 2010a) or improved nutrient retention through cation adsorption (Liang *et al.*, 2006).

Biochar application could reduce the risks of soil compaction. In general, biochar reduces soil bulk density and tensile strength (the soil's resistance to rupture) and increases porosity. The consistent decrease in tensile strength indicates that biochar-amended soils can be more friable and less compactible than soils without biochar. Biochar also improves soil consistency and reduces cohesiveness. Biochar application generally improves soil's structural quality. Biochar can improve soil aggregation and increase the proportion of water-stable aggregates. This can result in increased porosity and water infiltration, and reduced the risks of water erosion (Hansen *et al*., 2015).

Biochar application can alter water transmission characteristics in the soil. Biochar seems to have little or no effect on water repellency, but biochar strongly alters saturated hydraulic conductivity. Biochar application reduces saturated water flow in coarse-textured soils and increases it in fine-textured soils. Biochar appears to have the most consistent effect on water retention of all soil physical properties. About 90% of the recent biochar studies report increased water retention. The increase in plant-available water with biochar can have important applications for soil water management, particularly in water limited regions.

Biochar enrich N availability into the soil, decrease leaching loss of N by holding water. Biochar promotes the nitrogen use efficiency and biochar can markedly reduce NO_3^--N leaching losses from soil (Liu *et al*., 2017). Mineralization of N could be improved by use of biochar produced from slow pyrolysis rather than fast pyrolysis (Bruun *et al.*, 2012). Being a part of amino acid, protein and chlorophyll molecule, nitrogen is of vital significance for plant growth. Potato require great amount of nitrogen. Therefore, sufficient N fertilization is critical for improving potato productivity and quality. Potato tuber yield is strongly influenced by N and nitrogen rates positively influenced the number of tubers (Mokrani *et al*., 2018).

A number of studies take places on biochar upon vegetables. Application of biochar increased vegetable yields by 4.725 % 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 to study the effect of biochar on yield and quality of potato.

OBJECTIVES

. To observe the effect of biochar on yield and yield contributing factors of potato

. To study the efficacy of biochar on quality of potato tuber

. To find out the optimum dose of biochar along with inorganic fertilizer for achieving the maximum yield of potato

CHAPTER II

REVIEW OF LITERATURE

Potato is the most significant tuber crop in the world as well as in Bangladesh. Several experiments have been directed all over 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 relevant to the present study in home and abroad have been reviewed in this chapter.

2.1 Effect of biochar

Rapid industrial development and human activities have caused a degradation of soil quality and fertility. There is increasing interest in recovering low fertility soils to progress crop yield and sustainability. Biochar, a carbonaceous material intentionally produced from biomass, is widely used as an amendment to improve soil fertility by retaining nutrients and potentially enhancing nutrient bioavailability (El-Naggar *et al.*, 2019). But, biochar is not a simple carbon material with uniform properties, so appropriate biochar selection must consider soil type and target crop. In this respect, many recent studies have evaluated several modification methods to maximize the effectiveness of biochar such as optimizing the pyrolysis process, mixing with other soil amendments, composting with other additives, activating by physicochemical processes and coating with other organic materials (Sun *et al.*, 2014).

The extensive problems of an ever-increasing global human population, shrinking food reserves and climate change (carbon abatement) are a growing concern (Lehmann and Joseph, 2009). It has been projected that over the next two decades, crop yields of principal foods such as corn (maize), rice and wheat will significantly decline as a result of warmer and drier climatic conditions predominantly 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 use of biochar to soil has been brought forward in an effort to sustainably amend low nutrient-holding soils (Laird, 2008).

Biochar is a stable carbon-rich by-product synthesized through pyrolysis /carbonization of plant- and animal-based biomass (Ahmad *et al.*, 2014). Carbonization is a slow pyrolysis process in which biomass is converted into a highly carbonaceous, charcoal-like material. Typically, carbonization consists of heating the biomass in an oxygen-free or oxygen-limited environment, and reaction conditions are tailored to maximize the production of char (Ronsse *et al.*, 2015). Application of biochar to agriculture may have a significant effect on reducing global warming through the reduction of greenhouse gas (GHG) emissions and the sequestering of atmospheric carbon into soil. At the same time, biochar can help improve soil health and fertility and enhance agricultural productivity (Qambrani *et al.*, 2017).

Biochars vary widely in pH, surface area, nutrient concentration, porosity, and metal binding capacity due to the assortment of feedstock materials and thermal conversion conditions under which it is formed (Novak *et al.*, 2016). The wide variety of chemical and physical characteristics have resulted in biochar being used as an amendment to rebuild soil health, improve crop yields, increase soil water storage, and restore soils/spoils impacted by mining (Yargicoglu *et al.*, 2015). In spite of the mixed crop yield reports, biochar have properties that can improve soil health characteristics, by increasing carbon (C) sequestration and nutrient and water retention. Biochars also have the ability to bind enteric microbes and enhance metal binding in soils impacted by mining. In this review, we present examples of both effective and ineffective uses of biochar to improve soil health for agricultural functions and reclamation of degraded mine spoils.

Mukherjee and Lal (2013), reported that biochar's physical properties like large surface area and presence of micro pores contribute to the adsorptive properties of biochar and potentially alters the soil's surface area, pore size distribution, bulk density, water holding capacity and penetration resistance.

In earlier studies, soils used to study the agricultural properties of biochar have mostly been highly weathered soils from humid tropic regions (Verheijen *et al.*, 2009). Only recent research has involved 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 stated to have a multitude of agricultural benefits. These include a high soil sorption capacity, reduced nutrient loss through surface and groundwater runoff, and a regular release of nutrients to the growing plant (Laird, 2008).

Nelissen *et al.*, (2015) established a field trial to inspect the influence of biochar application to a temperate agricultural soil on soil chemical, physical and biological properties, and on crop growth and nutrient uptake under field conditions. The biochar applied was produced from a mixture of hard and softwood at 480 °C. The biochar dose was 0 (control) or 20 t ha^{-1} (on dry weight basis). Over two years, biochar addition to soil did not affect soil chemical properties, except for organic carbon content and C: N ratios. Effects on bulk density, porosity and soil water retention curves were non-consistent over time, possibly due to interaction with tillage operations. Biochar increased soil water content, although mostly not significantly. Soil temperature, as measured at a soil depth interval of

8–20 cm, was not changed by biochar addition. Furthermore, biochar addition to soil did only slightly influence soil microbiological community structure during the first year after biochar application. Hence, it was not surprising that biochar addition did not affect crop yield, N or P uptake during the first two years after biochar application.

Laird *et al*., (2010) elucidate that biochar amended soils retained more water at gravity drained equilibrium (up to 15%), had greater water retention at − 1 and −5 bars soil water matric potential, (13 and 10% greater, respectively), larger specific surface areas (up to 18%), higher cation exchange capacities (up to 20%), and pH values (up to 1 pH unit) relative to the un-amended controls. No effect of biochar on saturated hydraulic conductivity was detected. The biochar amendments significantly increased total N (up to 7%), organic C (up to 69%), and Mehlich III extractable P, K, Mg and Ca but had no effect on Mehlich III extractable S, Cu, and Zn.

Regardless of positive aspects, a few possible negative implications have been reported to be associated with biochar. The release of particulate from biochar is cause for concern because of the potentially harmful effects on health and the implications in terms of reduction of its mitigation potential (Genesio *et al*., 2016). Indeed, the production and post-production processes (packaging, storage, transport, and field application) can cause substantial losses of biochar, whose extent and destiny depends on many factors. A segment of the smallest biochar particles can be gone by percolation, runoff, and lateral migration or transported by turbulence into the atmosphere (Spokas *et al*., 2014). Anthropogenic Black Carbon aerosols (BCa), due to their shortwave absorption properties, are known to have both a direct and indirect climate warming effect, the release of particulate matter from biochar can lead to the formation of BCa, potentially reversing the efficacy of biochar for climate change mitigation (Bond *et al.*, 2013).

Kookana *et al.*, (2011) found some negative impact associated with biochar these include i) further agronomic input costs, ii) the binding and deactivation of synthetic agrochemicals due to relations with herbicides and nutrients, iii) the deposit and transport of dangerous contaminants due to the release of toxicants such as heavy metals present in biochar, and iv) an unexpected increase in pH and electrical conductivity (EC). Although studies have emphasized that contaminants such as organic compounds, heavy metals, and dioxins may be present in biochar but there is a inadequate published research that proves that these contaminants are available (Smernik, 2009; Verheijen *et al.*, 2009).

Anthropogenic amazonian dark earths (ADE) high fertile soils found in Brazil are mostly created between 500 and 2500 years ago by pre-Columbian populations called terra peta de Indio (Souza *et al.*,2017). These rich black earths are highly fertile and produce large crop yields despite the fact that the surrounding soils are infertile (Renner, 2007). 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 peta 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

Jien *et al*., (2013) showed the general effects of biochar on soil. It increases in soil pH, cation exchange capacity, base cation percentage and microbial biomass carbon (MBC). Compared with the control (i.e., no biochar), biochar application decreased bulk density, increased saturated potassium (K_{sat}) and increased the mean weight diameter (MWD) of soil aggregates. Incorporating biochar into the soil significantly reduced soil loss compared with the control.

A study was conducted including four rice-husk biochar rates (0%, 0.1%, 0.5% and 1%) to understand the effects on selected soil properties of two Alfisols (sand and sandy loam). Substantial changes in soil properties together with increases in pH, cation exchange capacity (CEC), organic carbon, water retention at field capacity and saturated hydraulic conductivity, and reduction in bulk density, were observed at higher rates of biochar (0.5% and 1%). Biochar showed a potential for amending acidity, especially in slightly acidic sandy soil. Soil aggregation and water flow improved markedly in sandy loam soil over sandy soil. Further, CEC and water retention of sandy soil had noticeable effects compared with sandy loam soil (Gamage *et al*., 2016).

The chemical properties of acidic soil such as soil pH, electrical conductivity (EC), cation exchange capacity (CEC) and exchangeable acidity are affected by biochar addition were investigated to determine the liming potential of biochars. By incubating acidic soil of pH < 4.80 with biochars for 165 days was studied. The biochars were produced from two biomass feedstocks such as corn stover (*Zea mays L*.) and switchgrass (*Panicum virgatum L*.) using microwave pyrolysis (at 650°C). Corn stover biochar, switchgrass biochar, and lime (calcium carbonate) were applied at four rates (0, 52, 104, and 156 Mg ha^{-1}) to acidic soil. Amendment type, application rate, and their interaction had significant effects ($p < 0.05$) on soil pH, EC, and CEC of acidic soil. Exchangeable acidity was significantly affected by amendment type. Application of corn stover biochar had shown a relatively larger increase in soil pH than switchgrass biochar at all application rates. The ameliorating effect of biochars on chemical properties of acidic soil was consistent with their chemical composition (Chintala *et al*., 2014).

Abbruzzini *et al*., (2017) incubated different soils in laboratory for 100 days with assorted doses of various amendments and found that soil pH, available P and exchangeable base contents increased with biochar added to sandy soil. Mineral N decreased with biochar addition to all soils. In contrary to this Liu and Zhang (2012), found that the application of alkaline biochar did not increase the soil pH but instead produced a decreasing pH trend, especially with higher biochar application rates. The decrease in soil pH was more significant at the 10 cm to 20 cm layer than in the 0 cm to 10 cm layer. Acidic materials produced by the oxidation of biochar and organic matters may have caused the pH decrease. The high soil cation exchange capacity caused by the biochar application might restrict the soil salinization process to some extent. The biochar prepared using a low temperature pyrolysis method from nine plant materials including non-leguminous straw from canola, wheat, corn, rice and rice hull and leguminous straw from soybean, peanut, faba bean and mung bean increased soil pH during incubation of the soil with all nine biochar samples added at 10 g kg^{-1} (Yuan and Xu, 2011).

Biochar application generally increases soil CEC, which improves plant nutrient availability and is thus beneficial for plant growth (Atkinson *et al*. 2010).The increase in soil CEC resulting from biochar applications can be explained via two possible mechanisms. First, biochar adsorbs soil organic matter and other compounds, and this capacity increases with the degree of biochar oxidation. Adsorption to biochar increases charge density, and consequently increases soil CEC (Lee *et al*., 2010). Second, biochar gradually oxidizes after its application to soil, and as a consequence, aromatic rings are replaced by COO− functional groups, and the overall surface negative charge increases on the biochar, thereby enhancing soil CEC (Mao *et al*. 2012).

Rudong *et al*. (2015). observed that biochar positively affect the soil acidity by reducing exchangeable Al^{3+} and exchangeable acidity as well as increasing pH and exchangeable bases. However, the effect declined to a certain extent when biochar went short term aging without soils.

Wrobel-Tobiszewska *et al*. (2016). found that high rates of biochar application (50–100 t ha^{-1}) increased soil pH from 4.0 to 4.8 in a Eucalyptus forestry plantation. Further, Rhoades *et al*. (2017) reported that the joint application of biochar (application rate of 20 t ha^{-1}) and mulch (application rate of 37 t ha^{-1}) increased soil pH from 5.7 to 6.4 in a pine (*Pinus contorta*) forest. There are two probable mechanism responsible for the observed rises in soil pH as a result of biochar application. First, biochar is alkaline and contains mineral carbonates with an abundance of basic-charged groups (Yuan and Xu, 2011). Thus, the observed increase in soil pH may be simply due to the addition of alkaline material. Alternatively, biochar application decreases the exchangeable aluminum content of soils through binding Al^{3+} ion by oxygenated functional groups on its surface, thereby increasing the abundance of soil exchangeable base cations, increasing soil base saturation, and ultimately resulting in a soil pH increase (Yuan and Xu, 2011; Dai *et al*., 2017).

Laird *et al*. (2010) showed that soil organic carbon content in a soil increased with the addition of biochar after adding 0, 5, 10, and 20 g kg^{-1} biochar to soils. Wang *et al*. (2014) showed that biochar application at a rate of 5 t ha^{-1} significantly increased soil organic carbon storage in a Chinese chestnut plantation, but addition of bamboo leaf with an equivalent amount of organic carbon did not have a comparable effect. Potentially, the primary reason for these observations is that the carbon present in biochar is stable and difficult to decompose in soil environments, thus contributing to the recalcitrant soil carbon pool (Lorenz and Lal, 2014).

Leached sandy soils typically have little 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).

Hass *et al*. (2011). reported that biochar effect on soil pH was process- and rate-dependent. Biochar increased soil pH from 4.8 to 6.6 at the high application rate (40 g kg^{-1}), but was less effective than Ag Lime. Biochar produced at 350°C without activation had the least effect on soil pH. Biochar increased soil Mehlich-3 extractable micro- and macronutrients. On the basis of unit element applied, increase in pyrolysis temperature and biochar activation decreased availability of K, P, and S compared to non-activated biochar produced at 350°C. Activated biochars reduced ABDTPA extractable Al and Cd more than AgLime. Biochar did not increase NO^{3-} in leachate, but increased dissolved organic carbon, total N and P, PO_4^{3-}, SO_4^{2-}, and K at high application rate (40 g kg^{-1}).

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, 2010). A long term study involving frequent applications of fresh paper mill waste biomass on sandy soil failed to demonstrate the long term buildup of soil C (Curnoe *et al.*, 2006). In contrast, Van Zwieten *et al.*, (2010) found that paper mill 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 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 nitrogenous 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).

Cheng *et al.,* (2018) showed that the effects of biochar on nutrient leaching and retention in sandy clay loam soil vary with the biochar properties, which are affected by pyrolytic temperature. Enhancing pyrolytic temperatures reduce nutrient leaching and improve the fertilizer use efficiency.

Zheng *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.

A three-year field experiment conducted, 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 (Quilliam *et al*., 2012).

Biochar is identical 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 mainly 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 biochar mostly 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

Several and regular applications of biochar to soil are not required because biochar is not justified as a fertilizer (Lehmann and Joseph 2009). In a pot trial carried out by Chan et al., (2007), a substantial 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.

Carter *et al*. (2013) led a pot experiment over a three crop (lettuce-cabbage-lettuce) cycle in Cambodia to assess the effect of rice-husk char (potentially biochar) application on the growth of transplanted lettuce (*Lactuca sativa*) and Chinese cabbage (*Brassica chinensis*). The biochar was the by-product of a rice-husk gasification unit and contained 28.7% carbon (C) by mass. Biochar application rates to potting medium of 25, 50 and 150 g were used with and without locally available fertilizers (a mixture of compost, liquid compost and lake sediment). The rice-husk biochar used was slightly alkaline (pH 7.79), increased the pH of the soil, and contained elevated levels of some trace metals and exchangeable cations (K, Ca and Mg) in comparison to the soil. The biochar treatments were found to increase the final biomass, root 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.

Demirbas *et al*., (2017) directed an experiment to examine the impact of the biochar applications [0%, 0.5%, 1%, 2%, 3%, 4% and 5% (v/v)] in different doses under the conditions with and without incubation on the yield of the chickpea plant (*Cicer Arietinum* L.) and nutrient concentrations. The study was carried out with three replications according to the experimental pattern of randomized blocks in the plastic pots with the capability of 3 kg in the greenhouse conditions. 60 days before the plantation of the herbs to the pots with incubation biochar was applied. After harvesting of plants the dry matter production and nutrient concentrations was determined. The results showed that the application that increases the dry matter production of the chickpea plant most is the application of 3% biochar dose in the conditions with incubation (10.02 g pot^{-1}). In addition; the biochar applications decreased the uptake of other nutrient except for K and Zn in both the conditions with and without incubation. While 3% biochar application under the conditions with incubation and 4% biochar application without incubation had the most significant impact on the Zn concentration of the chickpea plant respectively with 67.2 mg Zn kg^{-1} and 60.5 mg Zn kg^{-1}, 2% biochar application had the most significant impact on the K concentration of the chickpea with respectively 2.81% K and 2.37% K under the conditions both with and without incubation.

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.

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

In a study, a suitable concentration of cassava stem biochar produced at 350 °C was evaluated for green bean (*Vigna radiata* L.) growth from germination to seed production in pots over 8 weeks. The soil fertility was improved with increasing biochar concentration. The soil fertility and plant growth were significantly enhanced at 5% (w/w) biochar, while 10% (w/w) biochar significantly enhanced bean growth and bean pod production. The increased biochar concentration in the soil significantly increased the soil total nitrogen and extractable potassium (K) levels but did not affect the amount of available phosphorous. Biochar at 10% (w/w) significantly induced the accumulation of K in the stems, leaves, nut shells, and roots but not in nut seeds. Moreover, biochar not only increased the K concentration in soil but also increased the plant nutrient use efficiency of K, which is important for plant growth (Prapagdee and Tawinteung, 2017). Albuquerque *et al*., (2013) carried out a study to investigate the effects of two types of biochar from agricultural wastes typical of Southern Spain: wheat straw and olive tree pruning, combined with different mineral fertilization levels on the growth and yield of wheat (*Triticum durum* L. cv. Vitron). Durum wheat was pot-grown for 2 months in a growth chamber on a soil collected from an agricultural field near Córdoba, Southern Spain. Soil properties and plant growth variables were studied in order to assess the agronomic efficiency of biochar. Results showed that biochar addition to a nutrient poor, slightly acidic loamy sand soil had little effect on wheat yield in the absence of mineral fertilization. However, at the peak mineral fertilizer rate, addition of biochar led to about 20–30 % rise in grain yield compared with the use of the mineral fertilizer alone. Both biochar acted as a source of available P, which led to positive effects on crop production. In contrast, the addition of biochar resulted in decreases in available N and Mn which was related to the own nature of biochar: low available nitrogen content, high adsorption capacity, and low mineralization rate for N; and alkaline pH and high carbonate content for Mn .

Biochar is a good soil amendment that is proven by many studies. With its high Cation Exchange Capacity (CEC), it was assumed that biochar can be used as the carrier of nitrogen plant nutrient. Utomo *et al*., (2017) conducted an experiment in a greenhouse with the treatment of enriched biochar (2 enriched materials and 2 types of biochar feedstuffs), and the rice was planted on several soil acidity to explore the effect of nitrogen enriched biochar on the growth of rice (*Oryza sativa* L.). There was 21 treatments combination which organized in a Fully Randomized Design with 3 replications. Rice growth, rice yield, and some soil chemical properties, i.e. soil organic carbon and nitrogen content, soil pH, and Cation Exchange Capacity were measured. The experimental results showed that biochar was a good carrier for nitrogen plant nutrition. The growth and yield of rice planted in enriched biochar soil was as good as the rice growing in urea treated soil, even it had a higher yield and the fertilizer efficiency was amplified by nitrogen enriched biochar.

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

Biochar application is thought to increase the inorganic nutrient content and bioavailability since biochar itself also contains various inorganic constituents (Biederman and Harpole, 2013). Biochar produced from wood waste materials generally contains high levels of soluble potassium and variable concentrations of phosphorus and calcium (Page-Dumroese *et al*. 2015).

Sackett *et al*. (2015) showed that bioavailable potassium concentrations significantly increased in the initial period (2–6 weeks) after maple biochar application at a rate of 5 t ha^{-1} in a northern hardwood forest soil, while the concentrations of available calcium and magnesium increased 9 to 12 months following application.

In addition, Gundale *et al*. (2016). reported that biochar application at a rate of 10 t ha^{-1} in a boreal forest increased the soil's net N mineralization rate and NH_4^+ concentration after two growing seasons. Other studies have shown that biochar application increased other nutrient concentrations including silica, boron, and molybdenum (Kloss *et al*. 2014; Liu *et al*. 2014).

Kloss et al. (2014) found that biochar application (3%) in a greenhouse pot experiment significantly increased boron and molybdenum availability for three different soil types (Planosol, Cambisol, and Chernozem).

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 behavior of organic and environmental pollutants (Smernik, 2009).

Maria *et al*. (2017). conducted an experiment to determine the effects of amending soil with five different percentages of biochar (0, 5, 10, 20, and 35% w/w) on the phenomena of P sorption and desorption. The effect of soil/ biochar contact treatments on P availability was also examined. Phosphorus sorption was lower in the soils containing biochar compared to normal soil. The accumulated desorption quantity after eight consecutive extractions was 85% higher when 35% biochar was added to the soil than soil alone. Moreover, the application of 35% biochar increased the concentration of soluble P up to 38% after 30 days of incubation. Based on these results, we deduced that biochar induces changes in P retention soil properties that may be beneficial for agricultural soils.

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 (Amazonian Dark Earth) is attributed to charcoal. 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).

Gao *et al.,* (2017) studied to the effects of biochar and biochar-based fertilizer on the peanuts content of nutrient absorption and yield. The results indicated that applying biochar-based fertilizer can improve nitrogen, phosphorus and potassium absorbed dose. In comparison with the lower level of carbon treatment, the higher one nitrogen absorbed dose was obviously rise by 14.62%. In application of biochar-based fertilizer and chemical fertilizer can improve phosphorus absorption significantly compared with carbon alone applied. The potassium absorption content of biochar-based fertilizer (BBF) treatment was the most and increased by 28.39% and 17.47% in comparison with NPK treatment and C15 treatment, respectively. Peanut yield was the highest when biochar-based fertilizer was used. It stretched to 3494 kg/hm^2 and higher than application of the same level of carbon and nutrient treatment by 16.8%, 9.80%, respectively. 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 NH_4^+ leaching in contrasting (Ferralsol and Anthrosol) soils (Lehmann *et al*., 2003). Furthermore, Chan *et al*., (2007) observed an increase in the uptake of N at higher levels of biochar. Since nitrogen is primarily assimilated by plants as nitrate (NO_3^-), it is imperative that its uptake be coupled with an uptake of basic cations in order to maintain electrical balance. Consequently, this is associated with a considerable increase in K uptake, and a slight Ca uptake.

The determination of soluble NH_4-N is typically used to assess the potential of a material to be used as a soil amendment. Consequently, in a study conducted by CaO and Harris, (2010). it was determined that it was better to carbonize the dairy manure derived biochar at a low temperature of less than 200°C, than at higher temperatures. This was done to ensure that the NH_4-N content of the biochar was favorably 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 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) studied to investigate the effect of charcoal(biochar) and crop veil on the growth of tomato (*Lycopersicum esculentus* Mill) and showed that stem growth was very significantly higher in tomatoes grown on beds treated with charcoal and covered with veil than traditional beds without charcoal and veil covering. Fruit yield in tomato plant was also considerably higher on beds with charcoal than beds without charcoal.

Application of biochar for rice in the first year has increased the plant nutrient uptake (NPK) for rice. If lonely application of 2.5t biochar/ha for rice, grain yields were reduced by 24.7% in spring and 17.9% in summer rice. In comparison with NPK treatment, rice yields were increased by 5.9-22.3% in treatments with biochar and by 26.3- 34.2% in treatments of compost mixed with 5% biochar. Application of biochar for vegetables increased the yields by 4.7-25.5%, compared with farmer practices in both sites (Vinh *et al*., 2014).

In another work, the annual yield of either winter wheat or summer maize was not improved significantly after biochar application, whereas the cumulative yield over the first 4 growing seasons was significantly increased. Biochar could be used in calcareous soils without yield loss or significant impacts on nutrient availability (Liang *et al*., 2014).

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

Saxena *et al*. (2013). concluded that biochar considerably increased growth and yield of french bean as compared to no biochar. Both biochar and the bioinoculant have the potential to enhance the overall growth of the French beans, hence can be used for sustainable agriculture.

Hottle (2013). revealed that an oak biochar 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. Biochar did tend to increase above-ground biomass and grain yield in both maize and soybeans with the highest biochar treatment (25 t ha^{-1}) having the greatest benefit. The results were only significant in the second year, however, although a general positive trend was found in both the first and second year. In the third year, there was a significant drought which resulted in poor stand germination and highly heterogeneous results over all plots.

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 favored the formation of the root system in the treated part of the container under both drought and irrigation modes. In drought mode there was lower production of CO_2, lower overall length and surface of the roots of winter wheat compared to variants in irrigation mode. The application of biochar and activated carbon, therefore, supported the colonization of roots by mycorrhiza in general. The Scientific merit of this paper was to investigate the possibility of mitigating the effects of a long-term drought on winter wheat through the application of biochar or the application of activated carbon (Svoboda Zdenek *et al*., 2017).

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.

BC application increased potato growth, photosynthesis, and yield under salt stress while it decreased the Na^+ and increased the K^+ content in the xylem (Akhtar *et al*. 2015a). Similarly, it has been reported that BC was more effective in reducing Cd uptake by wheat plants compared to other organic amendments (Yousaf *et al*., 2016). The BC in combination with plant growth-promoting bacteria increased maize growth and biomass and decreased the Na^+ and increased the K^+ content in xylem sap of maize (Akhtar *et al*., 2015b).

The BC application enlarged 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 declined 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, after the application of 1.5%, 3.0%, and 5.0% BC respectively, Cd concentration in wheat grains decreased by 26%, 42%, and 57%. 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 (Abbas *et al.*, 2018).

A 1-year incubation experiment was carried out to investigate the effect of biochar produced from bamboo and rice straw (at temperatures ≥500 °C) on the heavy metal (Cd, Cu, Pb, and Zn) extractability and enzyme activity (urease, catalase, and acid phosphatase) in a contaminated sandy loam paddy soil. Three rates (0, 1, and 5 %) and two mesh sizes (<0.25 and <1 mm) of biochar applications were investigated. The physicochemical properties, extractable heavy metals, available phosphorus, and enzyme activity of soil samples were analyzed. The results demonstrated that rice straw biochar significantly ($P < 0.05$) increased the pH, electrical conductivity, and cation exchange capacity of the soil, especially at the 5 % application rate. Both bamboo and rice straw biochar significantly ($P < 0.05$) decreased the concentration of $CaCl_2$-extractable heavy metals as biochar application rate increased. The heavy metal extractability was significantly ($P < 0.01$) correlated with pH, water-soluble organic carbon, and available phosphorus in soil. The 5 % application rate of fine rice straw biochar resulted in the greatest reductions of extractable Cu and Zn, 97.3 and 62.2 %, respectively. Both bamboo and rice straw biochar were more effective at decreasing extractable Cu and Pb than removing extractable Cd and Zn from the soil. (Yang *et al.*, 2016).

CHAPTER III

MATERIALS AND METHODS

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 carried out during the period from November, 2017 to March, 2018 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-1207.The experimental area was located 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 separated 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 situated at the sub-tropical monsoon climatic zone, set imparted by winter during the months from November, 2017 to March, 2018. Abundantly 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 is the general soil type, Shallow Red Brown Terrace Soils under Tejgaon Series. Top soils were clay loam in texture. Soil pH was 5.9 and had organic matter 1.24%. 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 pH, organic matter, total N, available P, available S and exchangeable K of soil were studied. The morphological, physical and chemical characteristics of initial soil are show in Appendix-III.

3.3 Experimental details

3.3.1 Treatments and factor of the experiment Treatments:

T_1 = Control (no chemical fertilizer & biochar)

T_2 = RFD (Recommended Fertilizer Dose)

T_3 = RFD + Biochar @ 2.5 ton ha^{-1}

T_4 = RFD + Biochar @ 5.0 ton ha^{-1}

T_5 = RFD + Biochar @ 7.5 ton ha^{-1}

T_6 = $^1/_2$ of RFD + Biochar @ 2.5 ton ha^{-1}

T_7 = ½ of RFD + Biochar @ 5.0 ton ha^{-1}

T_8 = ½ of RFD + Biochar @ 7.5 ton ha^{-1}

T_9 = Biochar @ 10 ton ha^{-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. The research area was divided into 3 blocks. The size of the each unit plot was (2.5 m × 1.65 m) or 4.125 m^2. The space between two blocks and two plots were 0.5 m and 0.75 m, respectively. The layout of the experiment is shown in appendix IV.

3.4 Planting materials

The seed tubers of selected potato variety was collected from Bangladesh Agricultural Development Corporation (BADC) office, Gabtali, Dhaka-1207. BARI Alu -7 (Diamant) was used in this experiment which was developed in 1993 by the Bangladesh Agricultural Research Institute (BARI). It is proposed for rabi season. Life cycle of potato is about 90-95 days and average yield is 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 10 November, 2017. Ploughing and cross ploughing were done with power tiller followed by laddering. Land preparation was completed on 15 November, 2017 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), muriate of potash (MoP), gypsum and zinc sulphate respectively. The entire amount of biochar (as per treatment), triple super phosphate, gypsum, zinc sulphate 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 tubers were planted in a raised soil bed with no mulch application. The well sprouted healthy and uniform sized potato tubers were planted according to treatment and one fourth of a potato was used for one hill. Plant spacing was maintained 40 cm × 20 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 19, 2017.

3.6.5 Intercultural operations

3.6.5.1 Weeding

Weeding was required 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. Weeding was done at per requirement.

3.6.5.2 Irrigation

Application of irrigation water to potato field was done by using surface irrigation method. 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

The soil was mounted around the stems to increase productivity and improve the quality of the tubers by protecting them from exposure to the sun. Earthing up process was done in the plot at two times, during crop growing period. First was done at 30 DAP and second was at 45 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 25, 2018 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 02, 2018 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

1. Plant height at harvest (cm)
2. Number of stem hill^{-1}

B. Yield and yield components

3. Number of tubers hill^{-1}
4. Average weight of tuber hill^{-1} (g)

5. Yield of tubers kg plot^{-1}

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

C. Quality characters

7. Tuber dry matter content

8. Specific gravity

9. Grading of tubers according to size and diameter

D. Postharvest soil analysis

10. Soil pH

11. Organic carbon (%)

12. Organic matter (%)

13. Total N (%)

14. Available P (ppm)

15. Exchangeable K (cmol/kg soil)

16. Available S (ppm)

A. Crop growth characters

1. Plant height (cm)

Plant height refers to the length of the plant from ground level to the tip of the stem. It was measured at the time of harvesting. The height of 10 selected plant was measured in cm with the help of a meter scale and mean was calculated.

2. 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 stem from 10 hill of each plot and average was calculated.

B. Yield and yield components

3. Number of tubers hill^{-1}

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

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

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

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

6. 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

7. Tuber dry matter content (%)

The tubers 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:

Dry matter content (%) = (Dry weight ÷ Fresh weight) × 100 (Elfinesh *et al.*, 2011)

8. Specific Gravity

The specific gravity was measured for one sample per treatment. Tubers were randomly taken from each plot and washed with water, following which they were first weighed in air and then in water. The specific gravity of the tubers was then calculated using the following equation (Mohammed, 2016):

Specific gravity = (weight in air)/(weight in air– weight in water)

9. Grading of tuber according to size and diameter

Harvested tubers from each treatment were graded by weight and number on the basis of size and diameter into the >20 gm, <20 gm, >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.

3.6.7 Post harvest soil sampling

Soil samples were collected after harvest of crop from each plot at a depth of 0 -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 properties of soil.

D. Postharvest soil analysis

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

10. 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.

11. 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 $FeSO_4$. Percentage of organic carbon is determined from the following:

$$\% \text{ Organic carbon} = \frac{(B-T) \times N}{w} \times 0.003 \times 1.3 \times 100$$

Where, B = $FeSO_4.7H_2O$ required in blank titration

T = $FeSO_4.7H_2O$ required in actual titration

N = Strength of $FeSO_4.7H_2O$ solution

w = weight of soil taken

1.3 = conventional recovery factor

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.

12. Total nitrogen (%)

Micro Kjeldahl method was used to determine the total N content of soil. One gram of finely powdered soil was taken into micro Kjeldahl flask to which 1.1 gm catalyst mixture (K_2SO_4:$CuSO_4.5H_2O$:Se = 100:10:1) and 10 ml H_2SO_4 were added. The flasks were swirled and 3 ml of 10% H_2O_2 to destroy organic matter 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. Sufficient amount of 10N-NaOH solutions was added 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:

$$\% N = (T-B) \times N \times 0.014 \times D \times 100/W$$

Where, T = Soil 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 = Oven dry weight of sample (g)

D = dilution factor

13. Available phosphorus

Available Phosphorus of soil was determined by ascorbic acid blue color method. Available P was extracted from the soil with 0.5 M $NaHCO_3$ solutions, pH 8.5 (Olsen *et al*., 1984). Phosphorus in the extract was then determined by developing blue color with reduction of phospho-molybdate 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).

14. 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).

15. Available Sulphur

Available Sulphur was determined by $CaCl_2$ extraction method and by using spectrophotometer at a wave length 420nm and calibrated with a standard curve (Page *et al*., 1982).

3.7 Statistical Analysis

The data obtained for different parameters were statistically analyzed by using statistix10 software to find out the significant difference among 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. The significance of the difference among the treatment means was estimated by Least Significant Difference 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 gained from the study have been presented, discussed and compared in this chapter through table (s) and figures. 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 was significantly influenced due to application of different levels of biochar (Figure 1 and table 1). The maximum plant height 63.23 cm at harvesting which was recorded from T_5 treatment whereas, the minimum plant height 40.23 cm was recorded from T_1 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).

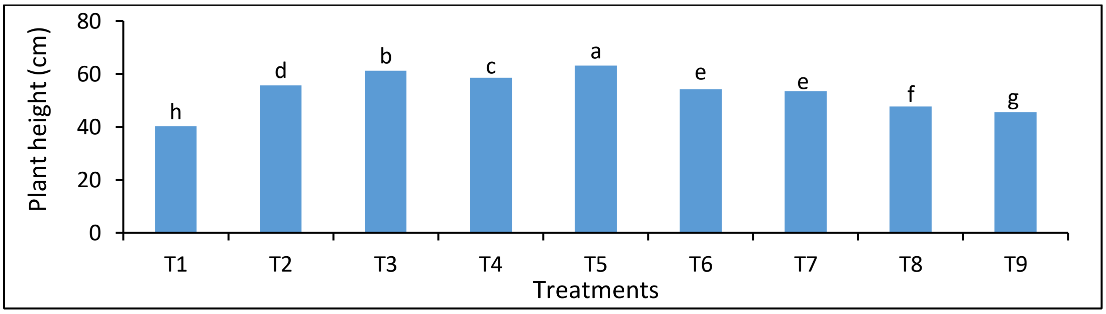


Figure 1. Effect of biochar on plant height at different days after

T_1 = Control (no chemical and biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-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} (5.17) was obtained from T_6 treatment which was statistically similar with T_3, T_4, T_5, T_6, T_7, T_8, T_9 treatment whereas, the minimum (4.00) was obtained from T_1 treatment. Youseef *et al*. (2017). revealed that the number of main stems significantly increased with increasing biochar application rates up to 12 m^3 /ha.

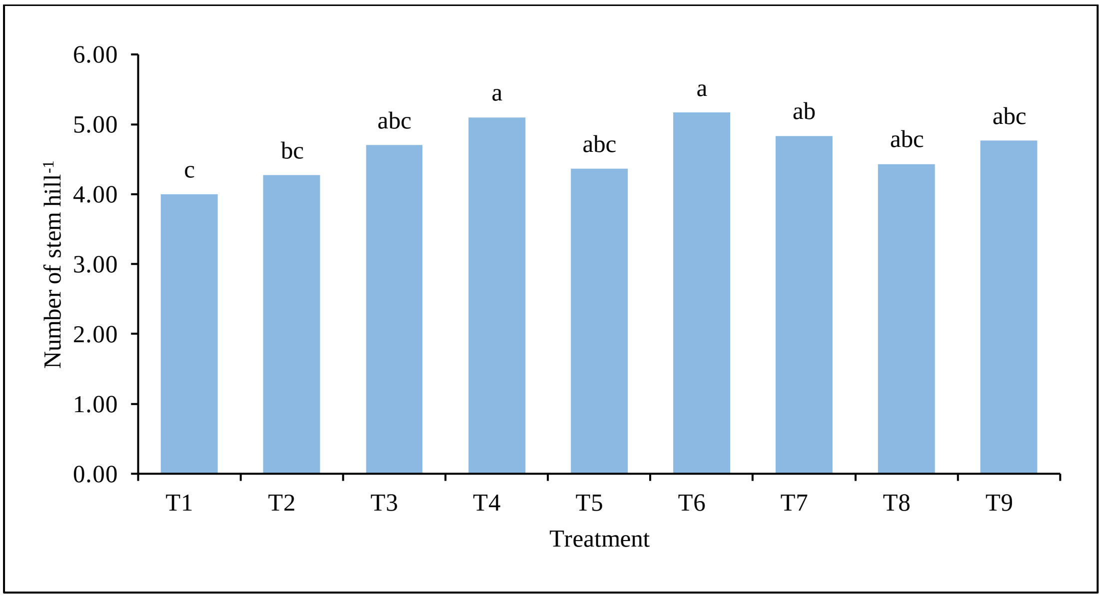


Figure 2. Effect of biochar on number of stem hill^{-1}

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

Table 1. Effect of biochar on Plant height at harvesting and Number of stem hill^{-1}

Treatment	Plant height (cm)	Number of stem hill^{-1}
T_1	40.23 h	4.00 c
T_2	55.73 d	4.27 bc
T_3	61.26 b	4.70 abc
T_4	58.45 c	5.10 a
T_5	63.23 a	4.37 abc
T_6	54.28 e	5.17 a
T_7	53.59 e	4.83 ab
T_8	47.75 f	4.43 abc
T_9	45.55 g	4.77 abc
$LSD_{(0.05)}$	1.24	0.82
CV (%)	1.34	10.22

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 and biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

4.2 Yield and yield components

4.2.1 Number of tubers hill^{-1}

Number of tubers hill^{-1} significantly increased by the different levels of biochar applications (Figure 3 and Table 2). The maximum number of tubers hill^{-1} (8.37) was produced from T_6 ($^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}) treatment, which was statistically similar with T_2 (7.27), T_3 (7.62), T_4 (7.60) and T_5 (8.00) treatments, whereas the minimum (5.52) was produced from control treatment. Youseef *et al.* (2017) found that fertilizing with biochar positively increased number of tubers.

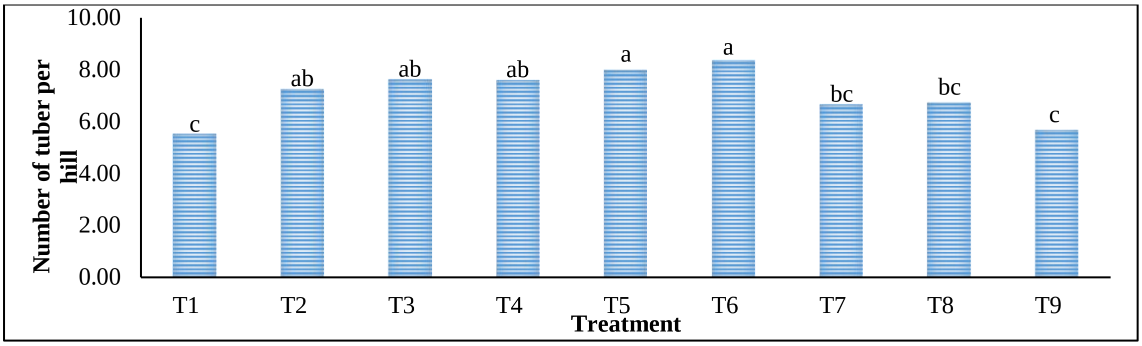


Figure 3: Effect of Biochar on Number of tubers per hill

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

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

Weight of tubers hill^{-1} significantly varied among the different levels of biochar applications (Figure 3 and Table 2). The maximum weight of tubers kg hill^{-1} (0.51) was observed from T_5 (RFD + Biochar @ 7.5 tonha^{-1}) which was statistically similar with T_2 (0.41), T_3 (0.50), T_4 (0.49), T_6 (0.34), and T_8 (0.41) treatments while the minimum weight of tubers kg hill^{-1} (0.11) was observed from T_1 (Control) treatment.

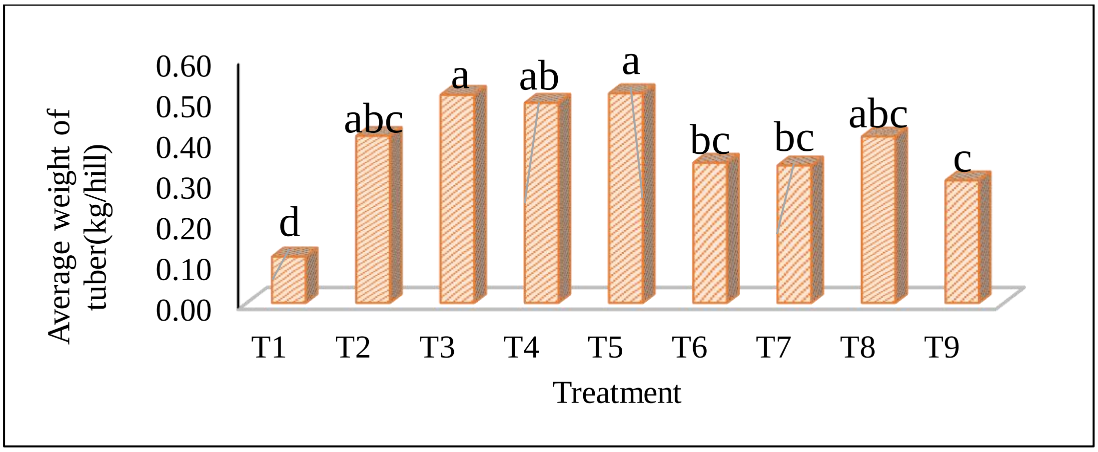


Figure 4: Effect of biochar on average weight of tubers (kg hill^{-1})

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

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

Biochar application in combination with chemical fertilizer had significant effect on the yield of tuber per plot (Table 2 and Fig. 4). The highest tuber yield plot^{-1} (14.75 kg) was obtained from T_5 (RFD + Biochar @ 7.5 ton ha^{-1}) treatment which was statistically similar with T_3 and T_4 treatments while the lowest tuber yield plot^{-1} (5.98 kg) was obtained from T_1 (control) treatment. Akhtar *et al*. (2014) indicated that addition of biochar increased the soil moisture contents, which consequently improved yield of tomato fruits.

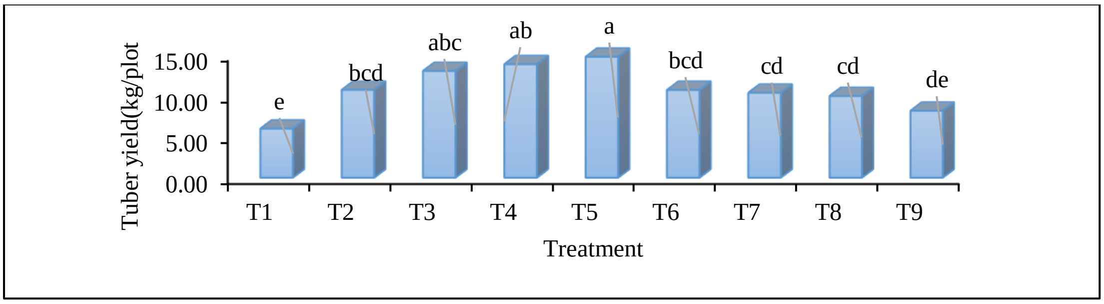


Figure 5: Effect of Biochar on Yield of tubers (kg plot^{-1})

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-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 figure 5). The highest tuber yield (35.76 t ha^{-1}) was obtained from T_5 (RFD + Biochar @ 7.5 ton ha^{-1}) treatment, which was followed by T_4 (33.56 t ha^{-1}) and lowest tuber yield kg plot^{-1} (14.51t ha^{-1}) was obtained from T_1 (control) 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.

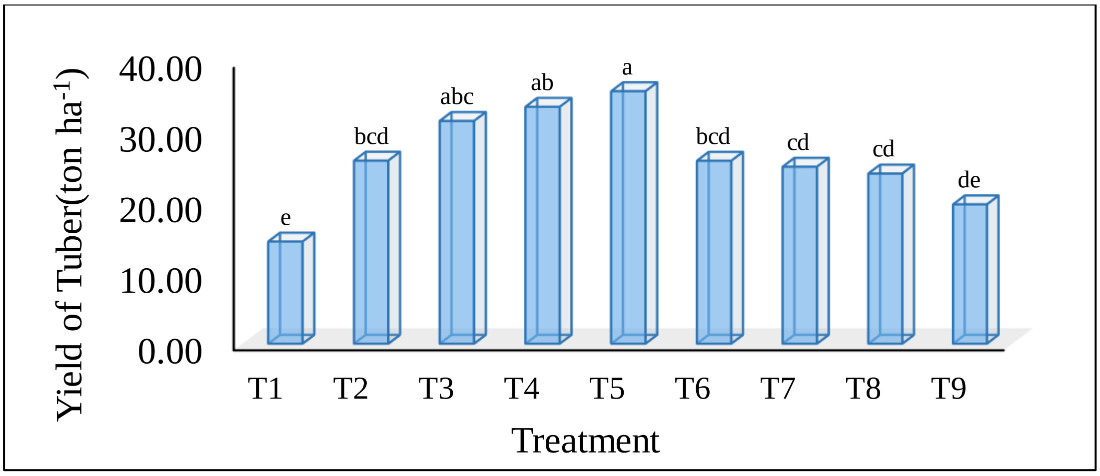


Figure 6: Effect of Biochar on Yield of tubers (ton ha^{-1})

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

Table 2: Effect of Biochar on yield attributes of potato

Treatment	Number of tubers per hill	Average Weight of tubers (kg hill^{-1})	Yield of tuber (kg plot^{-1})	Yield of tuber (ton ha^{-1})
T_1	5.52c	0.11 d	5.98 e	14.51 e
T_2	7.27 ab	0.41 abc	10.71 bcd	25.96 bcd
T_3	7.62 ab	0.50 a	13. 02 abc	31.56 abc
T_4	7.60 ab	0.49 ab	13.84 ab	33.56 ab
T_5	8.00 a	0.51 a	14.75 a	35.76 a
T_6	8.37 a	0.34 abc	10.70 bcd	25.94 bcd
T_7	6.67 bc	0.34 bc	10.35 cd	25.10 cd
T_8	6.63 bc	0.41 abc	9.96 cd	24.14 cd
T_9	5.67 c	0.30 c	8.16 de	19.78 de
LSD $_{(0.05)}$	3.39	0.17	3.20	7.75
CV (%)	27.61	26.40	17.06	17.06

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 & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

4.3. Quality characters

4.3.1. Tuber dry matter content (%)

Dry matter content (%) of tubers significantly increased by different levels of biochar application. The higher percent of tuber dry matter content (25.33%) was recorded from T_5 (RFD + Biochar @ 7.5 ton ha^{-1}) treatment which was statistically similar with T_4 (22.67) and T_6 (23.33) treatment. The lower percent of tuber dry matter content (15.00%) was recorded from T_1 (control) treatment (Table 3 and figure 7). 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.

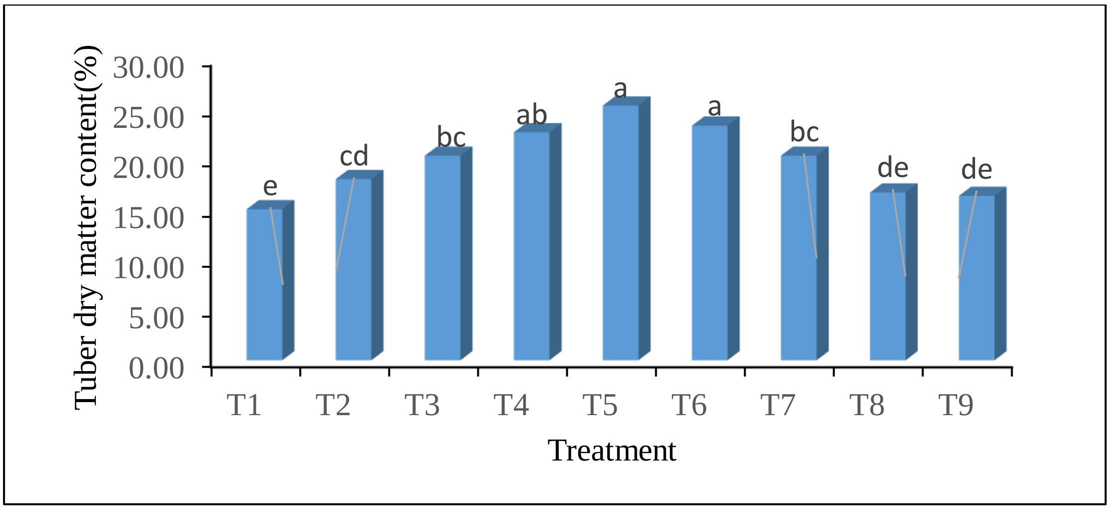


Figure 7: Effect of Biochar on Tuber dry matter content (%)

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 $tonha^{-1}$; T_4 = RFD + Biochar @ 5.0 $tonha^{-1}$; T_5 = RFD + Biochar @ 7.5 $tonha^{-1}$; T_6 = 1/2 of RFD + Biochar @ 2.5 $tonha^{-1}$; T_7 = ½ of RFD + Biochar @ 5.0 $tonha^{-1}$; T_8 = ½ of RFD + Biochar @ 7.5 $tonha^{-1}$;T_9 = Biochar @ 10 $tonha^{-1}$.

4.3.2 Specific Gravity

Specific gravity of tuber varied significantly with different levels of biochar application (Table 3 and figure 8). The highest specific gravity (1.12) of tuber was recorded from T_5 (RFD + Biochar @ 7.5 ton ha^{-1}) treatment and the minimum was found from T_1 (1.03) treatment.

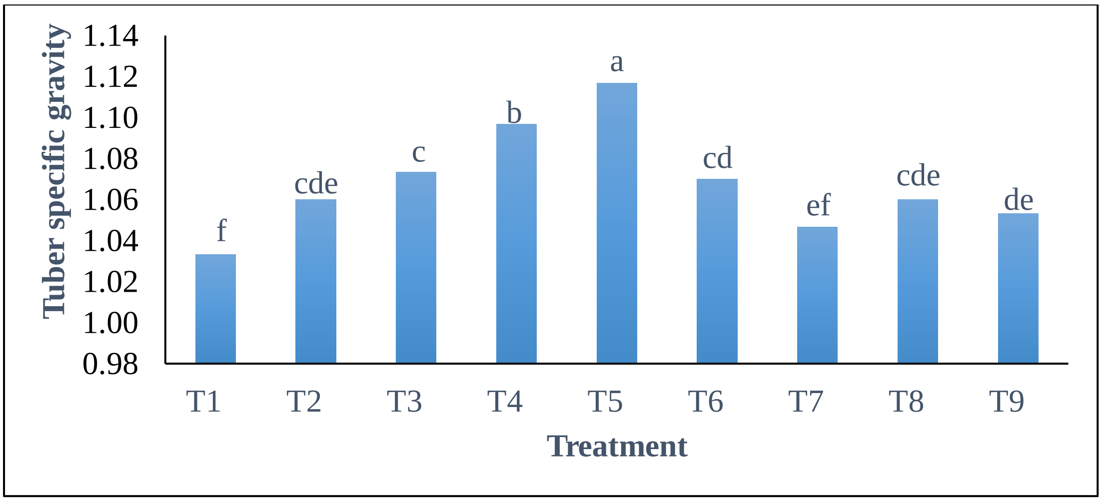


Figure 8: Effect of Biochar on Specific gravity on tuber

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-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	15.00 e	1.03 f
T_2	18.00 cd	1.06 cde
T_3	20.33 bc	1.07 c
T_4	22.67 ab	1.10 b
T_5	25.33 a	1.12 a
T_6	23.33 a	1.07 cd
T_7	20.33 bc	1.05 ef
T_8	16.67 de	1.06 cde
T_9	16.33 de	1.05 de
LSD $_{(0.05)}$	2.74	0.02
CV (%)	7.99	0.97

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 & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

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

Based on 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 percentage (31.86%) of non-marketable tuber (<20 gm) was produced from T_1 = control treatment and the lowest percentage (23.55%) of non-marketable tuber (<20 gm) was produced from T_5 (RFD + Biochar @ 7.5 ton ha^{-1}) treatment. The maximum percentage (76.45%) of marketable tuber (>20 gm) was produced from T_5 (RFD + Biochar @ 7.5 ton ha^{-1}) treatment while the minimum percentage (68.14%) of marketable tuber was produced from T_1 treatment.

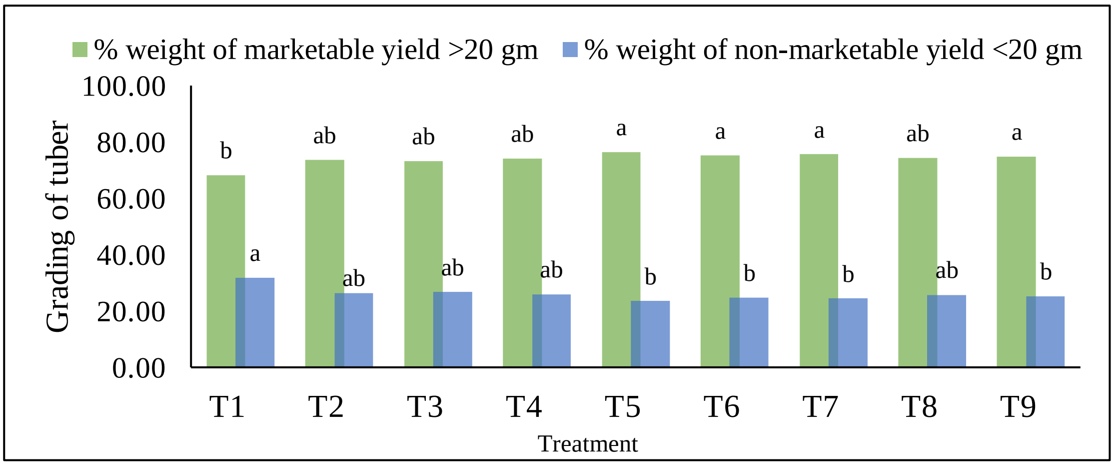


Figure 9. Effect of biochar on Grading of tuber according to size (% by weight)

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 $tonha^{-1}$; T_4 = RFD + Biochar @ 5.0 $tonha^{-1}$; T_5 = $^{1}/_{2}$ of RFD + Biochar @ 7.5 $tonha^{-1}$; T_6 = $^{1}/_{2}$ of RFD + Biochar @ 2.5 $tonha^{-1}$; T_7 = ½ of RFD + Biochar @ 5.0 $tonha^{-1}$; T_8 = ½ of RFD + Biochar @ 7.5 $tonha^{-1}$;T_9 = Biochar @ 10 $tonha^{-1}$.

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

Depending on weight, tubers have been graded into marketable tuber (>20g) and non-marketable tuber (<20g). Significant difference in the treatments in respect of production of different grades of tubers was observed. The highest percentage (49.29%) of non-marketable tuber number (<20 gm) was produced from T_8 (½ of RFD+ Biochar @ 7.5 tonha^{-1}) treatment and the lowest percentage (30.28%) of non-marketable tuber number (<20 gm) was produced from T_5 (RFD + Biochar @ 7.5 ton ha^{-1}) treatment. The maximum percentage (69.72%) of marketable tuber number (>20 gm) was produced from T_6 (1/2 of RFD + Biochar @ 2.5 ton ha^{-1}) treatment while the minimum percentage (50.71%) of marketable tuber was produced from T_8 treatment.

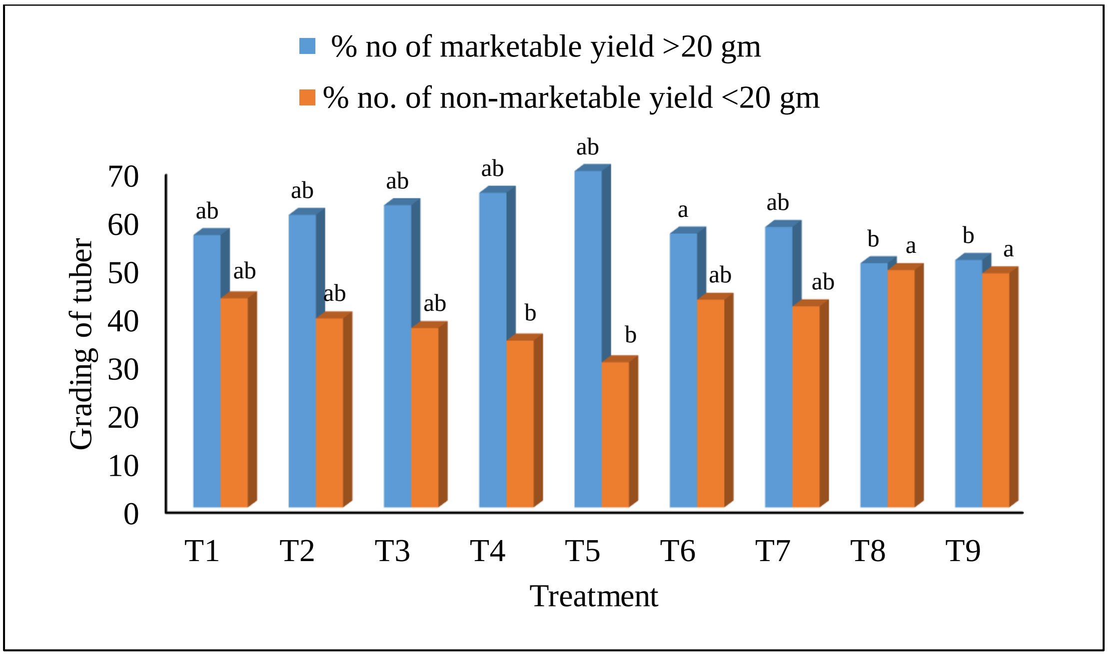


Figure 10. Effect of biochar on Grading of tuber according to size (% by number)

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

Table 4. Effect of biochar on grading of tuber (% by weight and % by number)

Treatment	Weight of non -marketable yield <20 gm (%)	Weight of marketable yield >20 gm (%)	No. of non-marketable yield < 20 gm (%)	No. of marketable yield > 20 gm (%)
T_1	31.86 a	68.14 b	43.48 ab	56.52 ab
T_2	26.38 ab	73.62 ab	39.33 ab	60.67 ab
T_3	26.75 ab	73.25 ab	37.34 ab	60.67 ab
T_4	25.96 ab	74.04 ab	34.76 b	62.67 ab
T_5	23.55 b	76.45 a	30.28 b	65.25 ab
T_6	24.79 b	75.22 a	43.17 ab	69.72 a
T_7	24.41 b	75.59 a	41.81 ab	58.19 ab
T_8	25.70 ab	74.30 ab	49.29 a	50.71 b
T_9	25.56 b	74.74 a	48.62 a	51.38 b
LSD $_{(0.05)}$	6.18	6.18	17.48	17.48
CV (%)	14.48	4.74	27.90	15.83

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 & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

4.3.5 Grading of tubers on the basis of diameter (% by weight)

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. The results indicate that there was significant difference in different levels of biochar application in respect of production of different grades of tubers (Figure 9 and Table 5). The maximum weight percentage of non-seed tuber <28 mm and >55 mm (56.88%) obtained from T_5 treatment and minimum percentage of non-seed tuber (33.59%) obtained from T_9 treatment. The maximum weight percentage of seed tuber (66.4%) between 28 mm to 55mm and minimum weight percentage of seed tuber (43.12%) were obtained T_9 and T_5 treatments respectively.

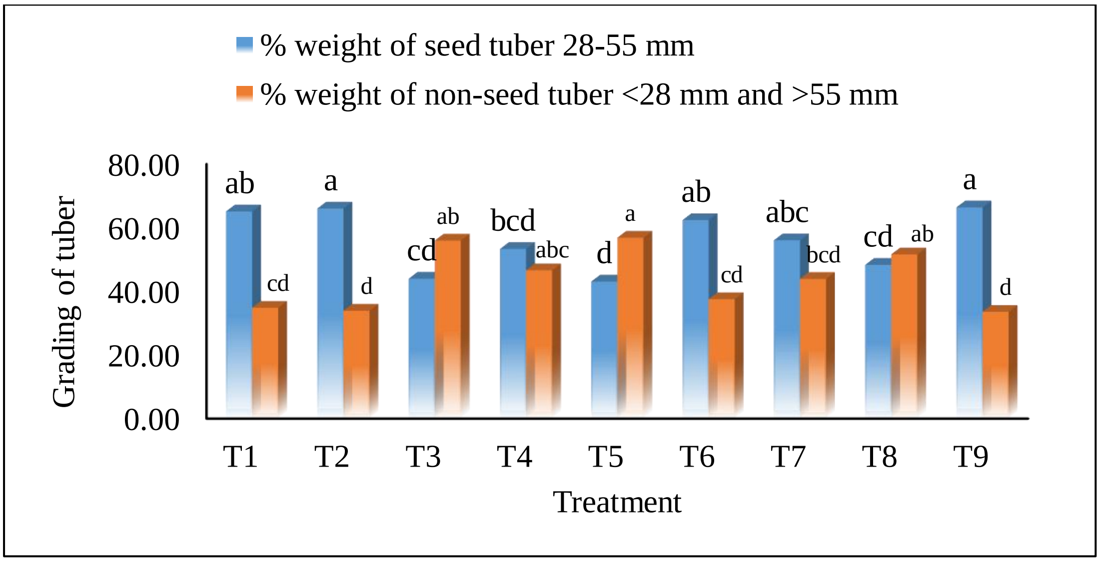


Figure 11. Effect of biochar on Grading of tuber according to diameter (% by weight)

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

4.3.6 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. 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 number percentage of non-seed tuber <28 mm and >55 mm (59.40%) obtained from T_5 treatment and minimum number percentage of non-seed tuber (41.91%) obtained from T_2 treatment. The maximum number percentage of seed tuber (58.09%) between 28 mm to 55 mm and minimum number percentage of seed tuber (40.60%) were obtained from T_2 and T_5 treatments respectively.

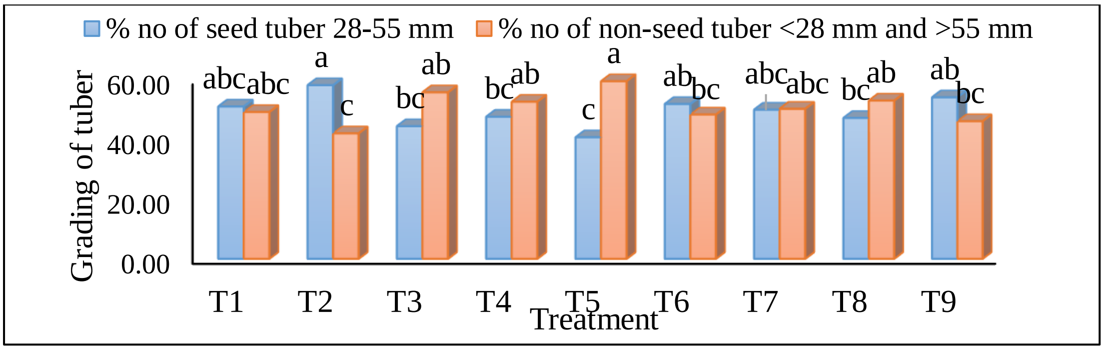


Figure 12. Effect of biochar on Grading of tuber according to diameter (% by number)

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

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

Treatment	% weight of non-seed tuber <28 mm and >55 mm	% weight of seed tuber 28 - 55 mm	% no. of non-seed tuber<28mm and >55 mm	% no. of seed tuber 28 - 55 mm
T_1	34.87cd	65.14ab	49.08 abc	50.92 abc
T_2	33.94 d	66.06a	41.91 c	58.09 a
T_3	55.99 ab	44.01 cd	55.68 ab	44.32 bc
T_4	46.65 abc	53.35 bcd	52.51 ab	47.49 bc
T_5	56.88 a	43.12 d	59.40 a	40.60 c
T_6	37.58 cd	62.42 ab	48.23 bc	51.77 ab
T_7	43.93 bcd	56.07 abc	50.14 abc	49.86 abc
T_8	51.65 ab	48.36 cd	52.91 ab	47.09 bc
T_9	33.59 d	66.41 a	45.99 bc	54.01 ab
LSD $_{(0.05)}$	12.55	12.55	10.38	10.38
CV (%)	16.51	12.92	11.84	12.15

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 & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

4.3.7 Grading of tubers on the basis of diameter (% by weight)

On the basis of size in diameter tubers have been graded into tuber for chips 45 – 55 mm, non-chips tuber <45 mm and >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 (Figure 9 and Table 5). The maximum weight percentage of tuber for non-chips (45.63%) obtained from T_9 and minimum weight percentage of. non-chips tuber (20.06%) obtained from T_5. The maximum weight percentage of tuber for chips (79.94%) and minimum weight percentage of chips tuber (54.37%) were obtained from $T_5$and T_9 respectively.

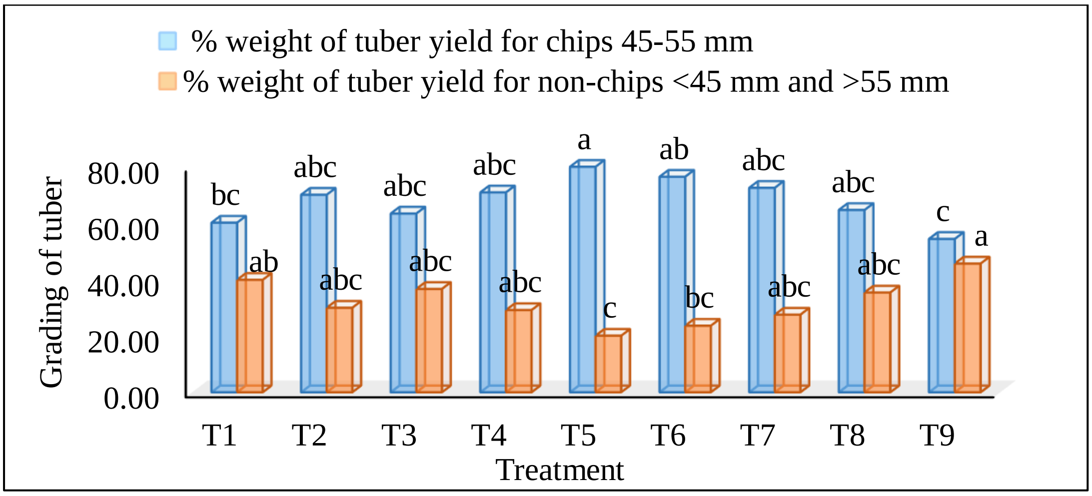


Figure 13. Effect of biochar on Grading of tuber according to diameter (% by weight)

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

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

On the basis of size in diameter tubers have been graded into tuber for chips 45 – 55 mm, non-chips tuber <45 mm and >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 (Figure 9 and Table 5). The maximum no. percentage of tuber for non-chips (67.51%) obtained from T_1 and minimum no. percentage of non-chips tuber (34.39%) obtained from T_9. The maximum no. percentage of tuber for chips (65.61%) and minimum no. percentage of chips tuber (32.49%) were obtained from T_9 and T_1 respectively.

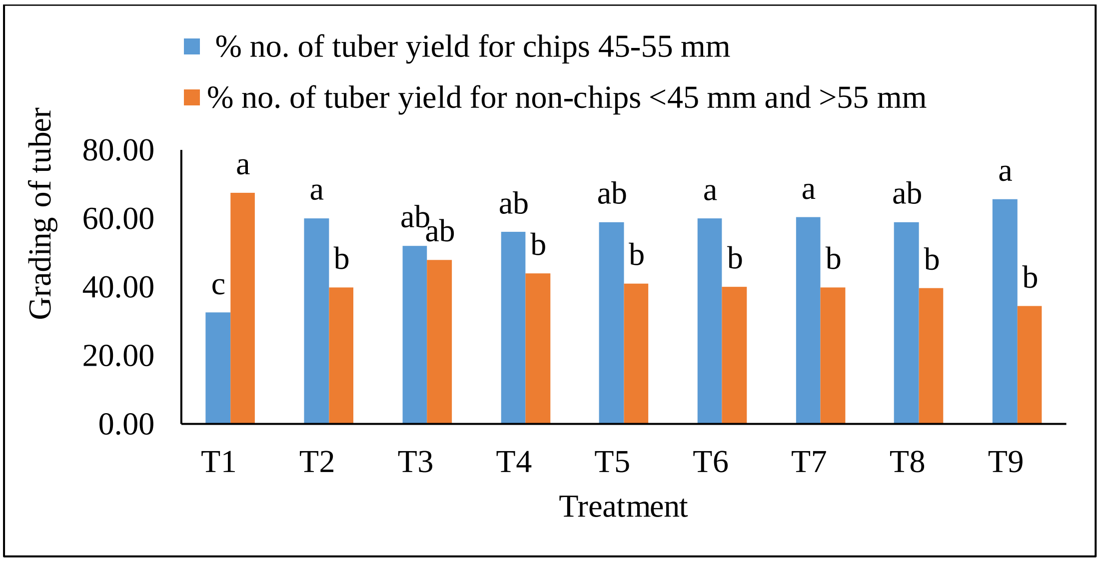


Figure 14. Effect of biochar on Grading of tuber according to diameter (% by number)

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

Table 6. Effect of biochar on grading of tuber on the basis of diameter (% by weight and % by number)

Treatment	% weight of tuber yield for non-chips <45mm and >55 mm	% weight of tuber yield for chips 45-55 mm	% no. of tuber yield for non-chips <45mm and >55 mm	% no. of tuber yield for chips 45-55 mm
T_1	39.87 ab	60.13 bc	67.51 a	32.49 c
T_2	29.97 abc	70.04 abc	39.90 ab	60.10 a
T_3	36.63 abc	63.37 abc	47.95 ab	52.05 ab
T_4	29.14 abc	70.86abc	43.97 b	56.03 ab
T_5	20.06 c	79.94 a	41.05 b	58.95 ab
T_6	23.59 bc	76.41 ab	40.03 b	59.97a
T_7	27.52 abc	72.48abc	39.90 b	60.33 a
T_8	35.37 abc	64.63 abc	39.67 b	58.95 ab
T_9	45.63 a	54.37 c	34.39 b	65.61 a
$LSD_{(0.05)}$	18.87	18.87	26.00	26.00
CV (%)	34.10	16.03	25.81	35.93

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 & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

4.4 Effect of biochar on post harvest soil properties

4.4.1 Soil pH

Application of different levels of biochar, soil pH was not significantly influenced (figure 14 and table 7).The highest soil pH (6.16) was recorded in T_6 ($^1/_2$ of RFD + Biochar @ 2.5 ton ha^{-1}) while the lowest soil pH was found from T_1 treatment. The application of biochar could increase soil pH 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).

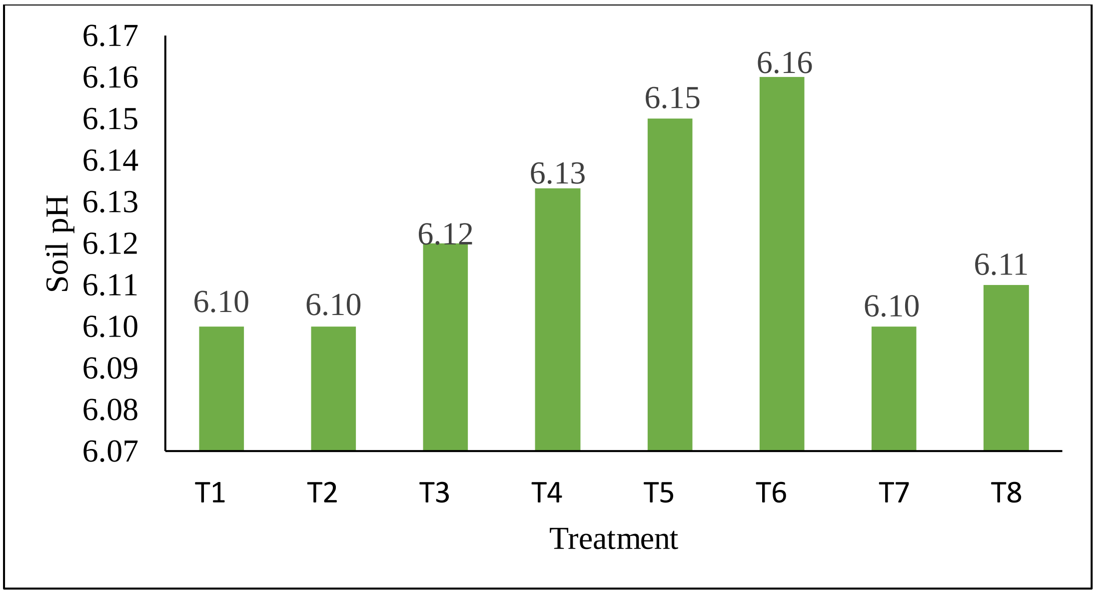


Figure 15. Effect of biochar on soil pH

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

4.4.2 Organic carbon

Soil organic carbon found due to biochar application from different treatment was statistically significant. The highest organic carbon (0.84%) was recorded in T_4 (RFD + Biochar @ 5.0 tonha^{-1}) treatment which was statistically similar with T_3 (0.82%), T_5 (0.82%), T_6 (0.84%), T_7 (0.84%), T_8 (0.83%), T_9 (0.84%) treatments, while the lowest organic carbon (0.77%) was recorded from T_1 treatment (figure 15 and table 7). Increase in organic C (up to 69%) due to biochar application was found by Laird *et al*., 2010.

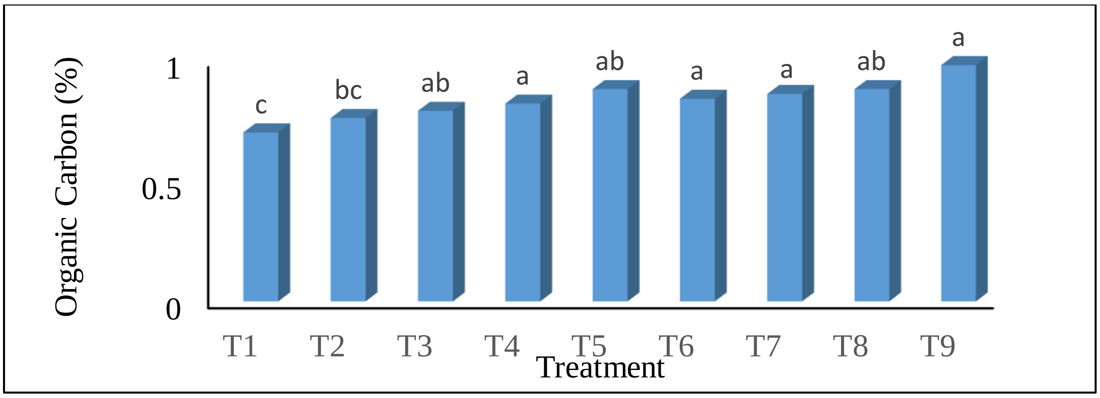


Figure 16. Effect of biochar on organic carbon

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

4.4.3 Organic matter

A significant variation in the organic matter was found from biochar application at different doses. The highest organic matter (1.51%) was recorded in T_9 (Biochar @ 10 tonha^{-1}) treatment which was statistically similar with T_8 (1.45%) treatment while the lowest organic matter (1.30%) was recorded in T_1 (Control) treatment.

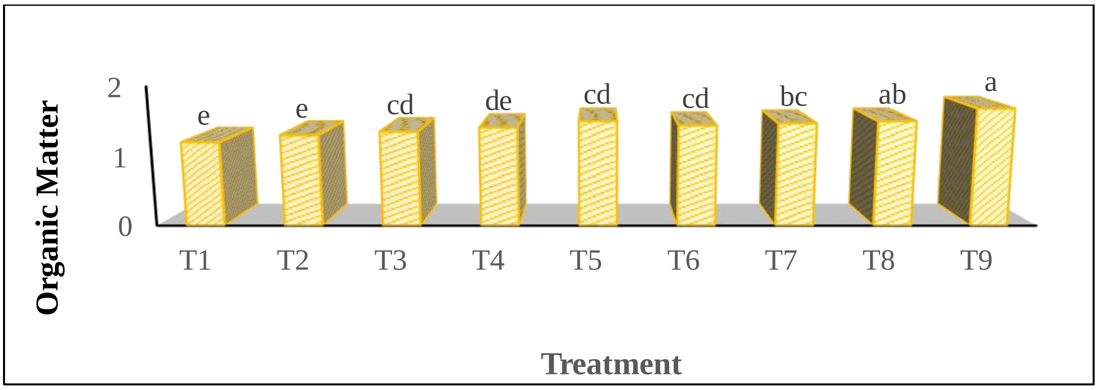


Figure 17. Effect of biochar on organic matter

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

4.4.4 Total Nitrogen

Different doses of biochar application significantly influenced the total nitrogen (%) content of soil. The maximum total nitrogen (0.089%) was recorded in T_5 (RFD + Biochar @ 7.5 tonha^{-1}) treatment and minimum was recorded from control treatment (figure 17 and table 7). Liard *et al*. (2010) found that the biochar amendments significantly increased total N (up to 7%).

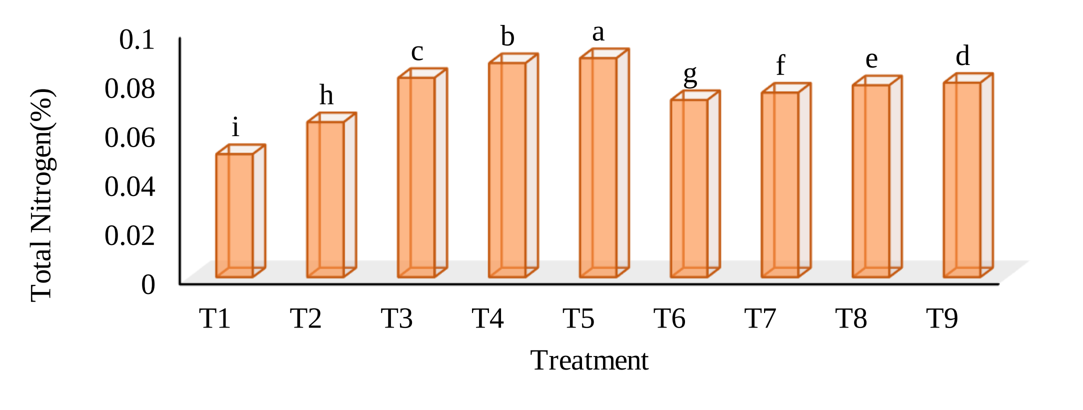


Figure 18. Effect of biochar on total nitrogen (%)

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

4.4.5 Available phosphorus

The different treatment showed significantly variation in the Available phosphorus. The highest available phosphorus (28.7 ppm) was recorded from T_4 (RFD + Biochar @ 5.0 tonha^{-1}) which was statistically similar with T_5 (27.3 ppm), T_6 (27.0 ppm), T_9 (26.3 ppm) while the lowest available phosphorus (17.5 ppm) was recorded from T_1 treatment (figure 17 and Table 7). Xu *et al*. (2014) showed that biochar affect P availability by interaction with other organic and inorganic components in the soil, including organic matter or other base cations in the soil.

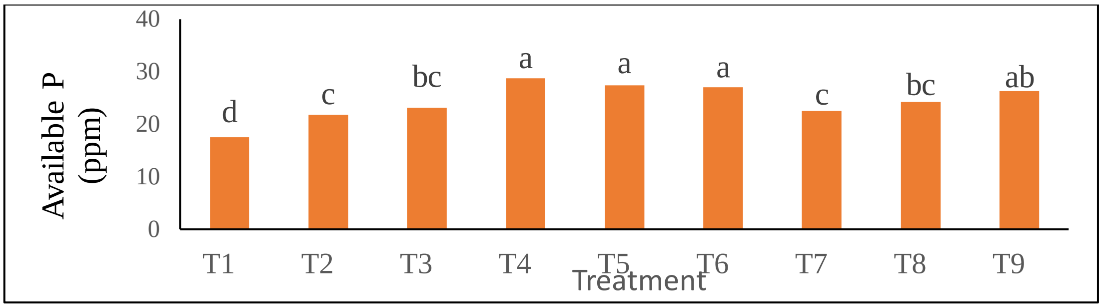


Figure 19. Effect of biochar on available phosphorus (ppm)

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

4.4.6 Exchangeable potassium

Exchangeable potassium was significantly influenced by different treatment. The highest exchangeable potassium (0.24 cmol/kg soil) was recorded in T_5 treatment while the lowest exchangeable potassium (0.15 cmol/kg soil) was recorded in T_1 treatment (figure 18 and Table 7). Wang *et al*. (2014) indicated that the amounts of the extractable K increased by biochar addition and they found that the K content of soil increased from 0.11 to o.83 cmol kg^{-1} soil.

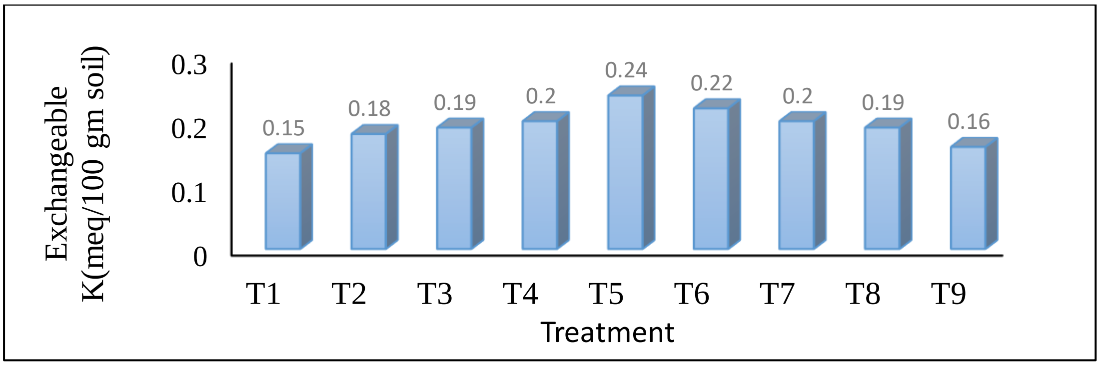


Figure 20. Effect of biochar on exchangeable K (cmol/kg soil)

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

4.4.7. Available Sulphur

Application of different level of biochar significantly influenced the available Sulphur (ppm) in soil (figure 19 and table 7). The maximum available Sulphur (26.66 ppm) found from T_5 (RFD + Biochar @ 7.5 ton ha^{-1}) treatment while the minimum (16.50 ppm) was found from T_1 treatment. This result was disagreed by Liard *et al*., 2010. They found that extractable S decreased with increasing levels of biochar.

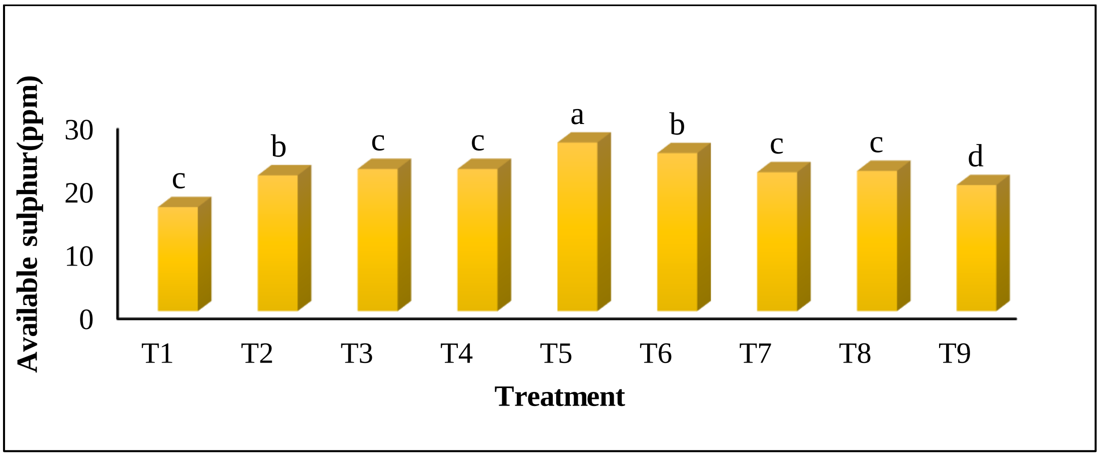


Figure 21. Effect of biochar on available Sulphur (ppm)

T_1 = Control (no chemical & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

Table 7: Effect of biochar on of postharvest soil properties

Treat-ment	Soil pH	Organic carbon (%)	Organic matter (%)	Total N (%)	Availab-le P (ppm)	Exchange able K (cmol/kg soil)	Availabl-e Sulphur (ppm)
T_1	6.0	0.70 f	1.21 f	0.05 i	17.5 d	0.15 f	16.50 c
T_2	6.10	0.76 e	1.31 e	0.063 h	21.8 c	0.18 d	21.50 c
T_3	6.12	0.79 de	1.36 de	0.081 c	23.2 bc	0.19 c	22.50 c
T_4	6.13	0.82 cd	1.42 cd	0.087 b	28.7 a	0.20 c	22.50 c
T_5	6.15	0.88 b	1.51 b	0.089 a	27.3 a	0.24 a	26.66 a
T_6	6.20	0.84 c	1.45 c	0.072 g	27.0 a	0.22 b	25.00 b
T_7	6.10	0.86 bc	1.48 bc	0.075 f	22.5 c	0.20 c	22.00 c
T_8	6.11	0.88 b	1.51 b	0.078 e	24.3 bc	0.19 c	22.20 c
T_9	6.12	0.98 a	1.69 a	0.079 d	26.3 ab	0.16 e	19.97 d
$LSD_{(0.05)}$	NS	0.05	0.06	0.04	0.66	0.02	0.88
CV (%)	3.09	5.47	5.43	5.79	4.88	6.02	4.54

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 & biochar); T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 tonha^{-1}; T_4 = RFD + Biochar @ 5.0 tonha^{-1}; T_5 = $^1/_2$ of RFD + Biochar @ 7.5 tonha^{-1}; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 tonha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 tonha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 tonha^{-1};T_9 = Biochar @ 10 tonha^{-1}.

CHAPTER V

SUMMARY AND CONCLUSION

The field experiment was conducted in the research field of Sher-e-Bangla Agricultural University (SAU), Sher-e-Bangla Nagar, Dhaka-1207 during the period from November, 2017 to March, 2018 in Rabi season. The objective was to observe the effect of biochar on the yield and quality of potato tuber and to find out the optimum dose of biochar along with inorganic fertilizer for achieving the maximum yield of potato. The experiment consist of 9 treatments as T_1 = Control(no biochar and chemical fertilizer), T_2 = RFD (Recommended Fertilizer Dose); T_3 = RFD + Biochar @ 2.5 ton ha^{-1}; T_4 = RFD + Biochar @ 5.0 ton ha^{-1}; T_5 = RFD + Biochar @ 7.5 $tonha^{-1}$; T_6 = $^1/_2$ of RFD + Biochar @ 2.5 ton ha^{-1}; T_7 = ½ of RFD + Biochar @ 5.0 ton ha^{-1}; T_8 = ½ of RFD + Biochar @ 7.5 ton ha^{-1};T_9= Biochar @ 10 $tonha^{-1}$. 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 collected on different yield attributes, growth and quality of potato and nutrient status of postharvest soil and significant variation was recorded for different treatment. Plant height was significantly influenced due to application of different levels of biochar. The maximum plant height 63.23 cm was recorded from T_5 treatment whereas, the minimum plant height 40.23 cm was recorded fromT_1 treatment.

All parameter significantly varied among the different levels of biochar application. The maximum no. of stem numbers $hill^{-1}$ (5.17) was found from ½ of RFD + Biochar @ 5 ton ha^{-1} application. The maximum number of tubers $hill^{-1}$ (8.37) was obtained from treatment. The maximum weight of tubers kg $hill^{-1}$ (0.51) was observed from T_5 (RFD + Biochar @ 7.5 $tonha^{-1}$) treatment. The highest tuber yield kg $plot^{-1}$ (14.75) was obtained from T_5 (RFD + Biochar @ 7.5 ton ha^{-1}) treatment. The highest tuber yield

(35.76 t ha^{-1}) was obtained from T_5 (RFD + Biochar @ 7.5 ton ha^{-1}) treatment, which was followed by T_4 (33.56 t ha^{-1}) and lowest tuber yield kg $plot^{-1}$ (14.51t ha^{-1}) was obtained from T_1 (control) treatment.

Significantly maximum dry matter content and specific gravity was also recorded from T_5 treatment dropped with reduced dose of chemical fertilizer was applied with higher or lower dose of biochar. The higher data of quality parameters like % dry matter content (25.33), specific gravity (1.12) was recorded in T_5 treatment and the lowest (15.00), (1.03) was recorded in T_1 treatment respectively.

The highest (31.86%) non marketable tuber (<20 gm) was produced from T_1 (control) treatment and the lowest (23.55 %) non marketable tuber (<20 gm) was produced from T_5 (RFD + Biochar @ 7.5 ton ha^{-1}) treatment. The maximum (76.45%) marketable tuber (>20 gm) was produced from T_5 (RFD + Biochar @ 7.5 ton ha^{-1}) treatment while the minimum (68.14%) marketable tuber was produced from T_1 treatment. On the basis of size in diameter the maximum weight of non-seed tuber <28 mm and >55 mm (56.88%) obtained from T_5 and minimum non-seed tuber (33.59%) obtained from T_9 treatment. The maximum weight of seed tuber (66.4%) between 28 mm to 55mm and minimum weight of seed tuber (43.12%) were obtained T_9 and T_5 treatment respectively. The maximum weight of tuber for non-chips (45.63%) obtained from T_9 and minimum weight of. non-chips tuber (20.06%) obtained from T_5 treatment. The maximum weight of tuber for chips (79.94%) and minimum weight of chips tuber (54.37%) were obtained from T_5 and T_9 treatment respectively.

Application of biochar in combination with chemical fertilizers resulted in enhancement of postharvest soil fertility interring of organic matter, total N, available P and S and also exchangeable K contents. Biochar had some significant influence on soil properties. The highest soil pH (6.20) was recorded in T_6 treatment. The highest organic carbon (0.98 %) was recorded in T_4 treatment. The highest organic matter (1.69 %) was recorded in T_8 treatment. The highest total nitrogen (0.089%) was recorded in T_5 treatment. The highest available phosphorus (28.7 ppm) was recorded from T_4 treatment. The maximum exchangeable potassium (0.48 cmol/kg) was obtained in T_5 treatment. The maximum available Sulphur found from T_5 (RFD + Biochar @ 7.5 ton ha^{-1}) treatment.

Conclusion

Biochar is great source of carbon and it has several properties by which biochar can improve the soil health and also increase the production level. It is 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 an alternate source of organic manure in Bangladesh agriculture. As our land decreasing and population increasing we need to produce more food with keeping the soil health in a good condition. In this sense this amender can be a great asset for agriculture.

Recommendations

1. Biochar improves soil health and its application to the soil at the rate of 7.5 t ha^{-1} along with recommended dose of chemical fertilizers bring up the potato yield and its quality to the maximum level.
2. It is suggested to know the long term residual effects of biochar through experimentation to find out the nutrient composition of biochar derived from different sources of organic manures.
3. Such study is needed in different agro-ecological zones (AEZ) of Bangladesh for regional amenability and other performance.

REFERENCES

Abbas, T., Rizwan, M., Ali, S., Adrees, M., Zia-ur-Rehman, M., Qayyum, M. F., and Murtaza, G. (2018). Effect of biochar on alleviation of cadmium toxicity in wheat (*Triticum aestivum* L.) grown on Cd-contaminated saline soil. *Environ. Sci. Pollut. R.* **25**(26): 25668-25680.

Abbas, T., Rizwan, M., Ali, S., Zia-ur-Rehman, M., Qayyum, M.F., Abbas, F. and Ok, Y.S. (2017). Effect of biochar on cadmium bioavailability and uptake in wheat (*Triticum aestivum* L.) grown in a soil with aged contamination. *Ecotox. Environ. Safe*. **140**: 37-47.

Abbruzzini, T.F., Moreira, M.Z., de Camargo, P.B., Conz, R.F., and Cerri, C. E.P. (2017). Increasing rates of biochar application to soil induce stronger negative priming effect on soil organic carbon decomposition. *Agr. Res*. **6**(4):389-398.

Ahmad, M., Rajapaksha, A.U., Lim, J.E., Zhang, M., Bolan, N., Mohan, D., and Ok, Y.S. (2014). Biochar as a sorbent for contaminant management in soil and water: a review. *Chemosphere.* **99**: 19-33.

Akhtar, S.S., Andersen, M.N. and Liu, F. (2015a). Biochar mitigates salinity stress in potato. *J. Agron. Crop Sci*. **201**: 368–378.

Akhtar, S.S., Andersen, M.N., and Liu, F. (2015b). Residual effects of biochar on improving growth, physiology and yield of wheat under salt stress. *Agr. Water Manage.* **158**:61–68.

Akhtar, S.S., Li, G., Andersen, M.N. and Liu, F. (2014) Biochar enhances yield andquality of tomato under reduced irrigation. *Agr. Water Manage*. **138**: 37- 44.

Albuquerque, J.A., Salazar, P., Barrón, V., Torrent, J., del Campillo, M.D.C., Gallardo, A., and Villar, R. (2013). Enhanced wheat yield by biochar addition under different mineral fertilization levels. *Agron. Sustain. Dev*. **33**(3): 475-484.

Amonette, J.E. and Joseph, S. (2009). Characteristics of biochar: Micro-chemical properties. In Biochar for environmental management: science and technology. Eds. J Lehmann and S Joseph. pp 33-52. Earthscan.

Anonymons (1988b). Land resoureces Appraisal of Bangladesh for agricultural development. Report no.2. Agroecological Regions of Bangladesh, UNDP and FAO: 472-496.

Atkinson, C.J., Fitzgerald, J.D., and Hipps, N.A. (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. *Plant Soil.* **337**: 1–18.

Baldock, J.A. and Smernik, R.J. (2002). Chemical composition and bioavailability of thermally altered *Pinus restnosa* (red pine) wood. *Org. Geochem.* **33**: 1093-1109.

BBS (Bangladesh Bureau of Statistics). 2016. Agricultural Statistics Yearbook 2016.

Bhuiyan, N.I. (1994). Crop production trend and need of sustainability in agriculture. A paper presented in a three-day workshop on "Integrated Nutrient Management for Sustainable Agriculture" held at SRS1, June 26-28.

Biederman, L.A. and Harpole, W.S. (2013). Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. *GCB Bioenergy* **5**: 202–214.

Bond, T.C., Doherty, S.J., Fahey, D.W., Forster, P.M., Berntsen, T., De Angelo, B.J., and Kinne, S. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. *J. Geophys. Res. Atmos*. **118**(11): 5380-5552.

Borsari, B. (2011). 'A Preliminary Study of the Effect of Biochar from Maple (*Acer* spp.) on Root Growth of Selected Agronomic Crops', in International Symposium on Growing Media, Composting and Substrate Analysis 1013, pp. 117-22.

Brassard, P., Godbout, S., and Raghavan, V. (2016). Soil biochar amendment as a climate change mitigation tool: key parameters and mechanisms involved. *J. environ. manage*. **181**: 484-497.

Brown, M.E. and Funk, C.C. (2008). Food Security Under Climate Change, *Science.* **319**: 580-581.

Bruun, E.W., Ambus, P., Egsgaard, H. and Hauggaard-Nielsen, H. (2012). "Effects of slow and fast pyrolysis biochar on soil C and N turnover dynamics." *Soil Biol. and Biochem.* **46**: 73-9.

Busscher, W.J., Novak, J.M., Evans, D.E., Watts, D.W., Niandou, M.A.S. and Ahmedna, M. (2010). Influence of Pecan Biochar on Physical Properties of a Norfolk Loamy Sand. *Soil Sci.***175:** 10-14.

Cao, X., and Harris, W. (2010). Properties of dairy-manure-derived biochar pertinent to its potential use in remediation. *Bio-resource technol*. **101**(14): 5222-5228.

Carter, S., Shackley, S., Sohi, S., Suy, T., and Haefele, S. (2013). The impact of biochar application on soil properties and plant growth of pot grown lettuce (*Lactuca sativa*) and cabbage (*Brassica chinensis*). *J. Agron*. **3**(2): 404-418.

Chan, K.Y. and Xu, Z. (2009). Biochar: Nutrient properties and their enhancement. In Biochar for environmental management: *sci. and technol*. Eds. J Lehmann and S Joseph. pp 67-84.

Chan, K.Y., Van Zwieten, L., Meszaros, I., Downie, A. and Joseph, S. (2007). Agronomic values of green-waste biochar as a soil amendment. *Aust. J. Soil Res*. **45**: 629-634.

Cheng, H., Jones, D.L., Hill, P., Bastami, M.S., and Tu, C.L. (2018). Influence of biochar produced from different pyrolysis temperature on nutrient retention and leaching. *Arch. Agron. Soil Sci.* **64**(6): 850-859.

Chintala, R., Mollinedo, J., Schumacher, T.E., Malo, D.D. and Julson, J.L. (2014). Effect of biochar on chemical properties of acidic soil. *Arch. Agron. Soil Sci.* **60**(3): 393-404.

Curnoe, W.E., Irving, D.C., Dow, C.B., Velema, G. and Une, A. (2006). Effect of spring application of a paper mill soil conditioner on corn yield. *Agron. J*. **98**: 423-429.

Dai, Z.M., Zhang, X.J., Tang, C., Muhammad, N., Wu, J.J., Brookes, P.C. and Xu, J.M. (2017). Potential role of biochars in decreasing soil acidification: a critical review. *Sci. Total Environ*. **581–582**: 601–611.

Demirbas, A., Karakoy, T., Durukan, H., and Erdem, H. (2017). The Impacts of the Biochar Addition in Different Doses on Yield and Nutrient Uptake of the Chickpea Plant (*Cicer Arietinum* L.) under the Conditions With and Without Incubation. *Fresen. Environ. Bull.* **26**: 8328-8336.

Ding, Y., Liu, Y., Liu, S., Li, Z., Tan, X., Huang, X., and Zheng, B. (2016). Biochar to improve soil fertility. A review. *Agron. Sustain. Dev.* **36**(2): 36.

Elfresh, F., Tekalign T. and Solomon, W. (2011). Processing Quality of improved potato (Solanum tuberosum L.) cultivars as influenced by growing environment and Blancing. *Afr. J. Food Sci*. **5**(6):324-332.

El-Naggar, A., Lee, S.S., Rinklebe, J., Farooq, M., Song, H., Sarmah, A.K. and Ok, Y.S. (2019). Biochar application to low fertility soils: A review of current status, and future prospects. *Geoderma*. **337**: 536-554.

FAOSTAT (FAO, Statistics Division). 2016. Statistical Database. Food and Agricultural Organization of the United Nations, Rome, Italy.

FAOSTAT (FAO, Statistics Division). 2019. Statistical Database. Food and Agricultural Organization of the United Nations, Rome, Italy.

FRG (Fertilizer Recommendation guide, 2012).

Gamage, D.V., Mapa, R.B., Dharmakeerthi, R.S., and Biswas, A. (2016). Effect of rice-husk biochar on selected soil properties in tropical Alfisols. *Soil Res*. **54**(3): 302-310.

Gao, M., Yang, J., Du, Z., Mu, J., and Zhang, Y. (2017). Impact of application of biochar and biochar-based fertilizer on peanuts nutrient absorption and yield. In 2017 5th International Conference on Machinery, Materials and Computing Technology (ICMMCT 2017).

Gaskin, J.W., Speir, R.A., Harris, K., Das, K.C., Lee, R.D., Morris, L.A., and Fisher, D.S. (2010). Effect of peanut hull and pine chip biochar on soil nutrients, corn nutrient status, and yield. *Agron. J.* **102**(2): 623-633.

Genesio, L., Vaccari, F.P., and Miglietta, F. (2016). Black carbon aerosol from biochar threats its negative emission potential. *Glob. Change Biol*. **22**(7): 2313-2314.

Glaser, B. (2007). Prehistorically modified soils of central Amazonia: a model for sustainable agriculture in the twenty-first century. Philosophical Transactions: *Biol. Sci.* **362**: 187-196.

Glaser, B., Haumaier, L., Guggenberger, G. and Zech, W. (2001). The 'Terra Preta' phenomenon: a model for sustainable agriculture in the humid tropics. *Nature wisent's caftan.* **88**: 37-41.

Gomez, K.A. and Gomez, A.A. (1984). Statistical Procedure for Agricultural Research (2nd edn.). Int. Rice Res. Inst., A Willey Int. Sci., pp. 28-192.

Graber, E.R., Harel, Y.M., Kolton, M., Cytryn, E., Silber, A., David, D.R. and Elad, Y. (2010). Biochar impact on development and productivity of pepper and tomato grown in fertigated soilless media. *Plant soil*. **337**(1-2): 481-496.

Gundale, M.J., Nilsson, M.C., Pluchon, N. and Wardle, D.A. (2016). The effect of biochar management on soil and plant community properties in a boreal forest. *GCB Bioenergy*. **8**: 777–789.

Hansen, V., Muller-Stover, D., Ahrenfeldt, J., Holm, J.K., Henriksen, U. B., and Hauggaard-Nielsen, H. (2015). Gasification biochar as a valuable by-product for carbon sequestration and soil amendment. *Biomass Bioenerg.* **72**: 300-308.

Hass, A., J.M. Gonzalez, I.M., Lima, H.W., Godwin, J.J., Halvorson. and D.G. Boyer. (2012). Chicken manure biochar as liming and nutrient source for acid Appalachian soil. *J. Environ. Qual*. **41**: 1096-106.

Hottle, R.D. (2013). Quantifying the impact of biochar on plant productivity and changes to soil physical and chemical properties on a maize soybean rotation in the US (Doctoral dissertation, The Ohio State University).

Hussain, M.M. (1995). Seed production and storage technology (In Bangla). Pub. Meer Imtiaz Hussain. 27/1, Uttar Pirer Bugh, Mirpur, Dhaka. pp: 147-219.

Jien, S.H., and Wang, C.S. (2013). Effects of biochar on soil properties and erosion potential in a highly weathered soil. *Catena*. **110**: 225-233.

Keiluweit, M., Nico, P.S., Johnson, M.G. and Kleber, M. (2010). Dynamic Molecular Structure of Plant Biomass-Derived Black Carbon (Biochar). *Environ. Sci. Technol.* **44**: 1247-1253.

Kloss, S., Zehetner, F., Oburger, E., Buecker, J., Kitzler, B., Wenzel, W.W., Wimmer, B. and Soja, G. (2014). Trace element concentrations in leachates and mustard plant tissue (*Sinapis alba* L.) after biochar application to temperate soils. *Sci. Total Environ*. **481**: 498–508.

Koide, R.T. (2017). Biochar—Arbuscular Mycorrhiza Interaction in Temperate. Soils. In Mycorrhizal Mediation of Soil (pp. 461-477).

Kookana, R.S., Sarmah, A.K., Van Zwieten, L., Krull, E. and Singh, B. (2011). Biochar application to soil: agronomic and environmental benefits and unintended consequences. *Adv. agron.* **112**: 103-143.

Laird, D.A. (2008). The charcoal vision: A win-win-win scenario for simultaneously producing bioenergy, permantly sequestering carbon, while improving soil and water quality. *Agron. J*. **100**: 178-181.

Laird, D.A., Fleming, P., Davis, D.D., Horton, R., Wang, B.Q., Karlen, D.L. (2010). Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma*. **158**(3-4): 443–449.

Lee, J.W., Kidder, M., Evans, B.R., Paik, S., Buchanan, A.C., Garten, C.T. and Brown, R.C. (2010). Characterization of biochars produced from corn Stover's for soil amendment. *Environ. Sci. Technol*. **44**: 7970–7974.

Lehmann, J. (2007a). Bio-energy in the black. *Front. Ecol. Environ*. **5**: 381-387.

Lehmann, J. (2007b). A handful of carbon', Nature, vol. 447, no. 7141, pp. 1434.

Lehmann, J. and Joseph, S. (2009). Biochar for environmental management: an introduction. In Biochar for Environmental Management: Sci. and Technol. Eds. J Lehmann and S Joseph. pp 1-12. Earthscan, London, UK.

Lehmann, J. and Rondon, M. (2006). Bio-char soil management in highly weathered soils in the humid tropics. In Biological approaches to sustainable soil systems. Eds. N. Uphoff, A.S. Ball, E. Fernandes, H. Herren, O. Husson, M. Laing, C. Palm, J. Pretty, P. Sanchez, N. Sanginga and J. Thies. pp 517-530. CRC Press Taylor and Francis Group, Boca Raton.

Lehmann, J., da Silva, J.P., Steiner, C., Nehls, T., Zech, W. and Glaser, B. (2003). Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. *Plant soil*. **249**(2): 343-357.

Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O'Neill, B., Skjemstad, J.O., Thies, J., Luiz, F.J., Petersen, J. and Neves, E. G. (2006). Black Carbon Increases Cation Exchange Capacity in Soils. *Soil Sci. Soc. America J* .**70**: 1719-1730.

Liang, F., Li, G.T., Lin, Q.M., and Zhao, X.R. (2014). Crop yield and soil properties in the first 3 years after biochar application to a calcareous soil. *J. Integr. Agr*. **13**(3): 525-532.

Liu, X.H. and Zhang, X.C. (2012). Effect of Biochar on pH of Alkaline Soils in the Loess Plateau: Results from Incubation Experiments. *Int. J. Agric. Biol*. **14**(5).

Liu, X.Y., Li, L.Q., Bian, R.J., Chen, D., Qu, J.J., Wanjiru Kibue, G., Pan, G.X., Zhang, X.H., Zheng, J.W. and Zheng, J.F. (2014). Effect of biochar amendment on soil-silicon availability and rice uptake. *J. Plant Nutr. Soil Sc*. **177**: 91–96.

Liu, Z., He, T., Cao, T., Yang, T., Meng, J., and Chen, W. (2017). Effects of biochar application on nitrogen leaching, ammonia volatilization and nitrogen use efficiency in two distinct soils. *J. Soil Sci. Plant Nut.* **17**(2): 515-528.

Lorenz, K. and Lal, R. (2014). Biochar application to soil for climate change mitigation by soil organic carbon sequestration. *J. Plant Nutr. Soil Sc.* **177**: 651–670.

Maikhuri, R.K., and Rao, K.S. (2012). Soil quality and soil health: A review. *Int. J. Ecol. and Environ. Sci*. **38**(1): 19-37.

Major, J., Rondon, M., Molina, D., Riha, S.J. and Lehmann, J. (2010). Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and soil*. **333**(1-2): 117-128.

Mao, J.D., Johnson, R.L., Lehmann, J., Olk, D.C., Neves, E.G., Thompson, M.L. and Schmidt-Rohr, K. (2012). Abundant and stable char residues in soils: implications for soil fertility and carbon sequestration. *Environ. Sci. Technol.* **46**: 9571–9576.

Maria, J., Martínez, C., Julio Cesar Espana, A. and Jose De Jesus Diaz, V. (2017). Effect of *Eucalyptus globullus* biochar addition on the availability of phosphorus in acidic soil. *Agron. Colombiana*. **35**(1): 75-81.

Mohammed, W. (2016). Specific gravity, dry matter content, and starch content of potato (*Solanum tuberosum* L.) varieties cultivated in Eastern Ethiopia. *East African J. Sci*. **10**(2): 87-102.

Mokrani, K., Hamdi, K. and Tarchoun, N. (2018). Potato (*Solanum Tuberosum* L.) Response to Nitrogen, Phosphorus and Potassium Fertilization Rates. *Commun. Soil Sci. Plant Ana*. **49**(11): 1314-1330.

Mukherjee, A. and Lal, R. (2013). Biochar Impacts on Soil Physical Properties and Greenhouse Gas Emissions. *J. Agron*. **3**: 313-339.

Nair, A., Kruse, R.A., Tillman, J.L. and Lawson, V. (2014). Biochar application in potato production. Iowa State Res. Farm Progress Rep., 2027. (http:// lib.dr.iastate.edu/farms reports/2027; Last accessed Dec. 16th 2017).

Nelissen, V., Ruysschaert, G., Manka’Abusi, D., D’Hose, T., De Beuf, K., Al-Barri, B. and Boeckx, P. (2015). Impact of a woody biochar on properties of a sandy loam soil and spring barley during a two-year field experiment. *Eur. J. Agron*. **62**: 65-78.

Nelson, N.O., Agudelo, S.C. Yuan, W and Gan, J. (2011). Nitrogen and phosphorus availability in biochar amended soil. *Soil Sci.* **176**(5): 218-226.

Novak, J.M., Busscher. W.J., Laird, D.L., Ahmedna, M., Watts, D.W. and Niandou, M.A.S. (2009). Impact of biochar amendment on fertility of a southeastern Coastal Plain soil. *Soil Sci*. **174**: 105-112.

Novak, J.M., Ippolito, J.A., Lentz, R.D., Spokas, K.A., Bolster, C.H., Sistani, K. and Johnson, M.G. (2016). Soil health, crop productivity, microbial transport, and mine spoil response to biochars. *Bioenerg. Res*. **9**(2):454-464.

Oberson, A., Bünemann, E.K., Friesen, D.K., Rao, I.M., Smithson, P.C., Turner, B.L. and Frossard, E. (2006). Improving phosphorus fertility in tropical soils through biological interventions. In Biological approaches to sustainable soil systems. Eds. N. Uphoff, A.S. Ball, E. Fernandes, H. Herren, O. Husson, M. Laing, C. Palm Pretty, P. Sanchez, N. Sanginga and J. Thies. pp 531-546. CRC Press: Taylor and Francis Group.

Olsen, S.R., Cole, C.V., Watanable, F.S. and Dean L.A. (1984). Estimation of available phosphorus in soils by extraction with sodium bicarbonate, U.S. Dept. Agric.Circ:929.

Page, A.L., Miller, R.H. and Keeney, D.R. (1982). Methods of analysis part 2, chemical and microbiological properties 2nd Ed. Soil science socity of American Inc. Madson, Wisconsion, USA: 403-430.

Page-Dumroese, D.S., Coleman, M., Thomas, S.C. (2015). Opportunities and uses of biochar on forest sites in North America. In: Bruckman, V.J., Varol, E.A., Uzun, B.B. and Liu, J. (eds.) Biochar: a regional supply chain approach in view of mitigating climate change. Cambridge University Press, Cambridge.

Prapagdee, S. and Tawinteung, N. (2017). Effects of biochar on enhanced nutrient use efficiency of green bean, *Vigna radiata* L. *Environ. Sci. Pollut. R.* **24**(10): 9460-9467.

Pulok, M.A.I., Roy, T.S. and Nazmul, M. (2016). Grading of Potato Tuber as Influenced by Potassium Level and Mulch Materials. *Focus Sci.* **2**(4).

Qambrani, N.A., Rahman, M.M., Won, S., Shim, S. and Ra, C. (2017). Biochar properties and eco-friendly applications for climate change mitigation, waste management, and wastewater treatment: A review. *Renew. Sust. Energ. Rev*. **79**: 255-273.

Quilliam, R.S., Marsden, K.A., Gertler, C., Rousk, J., DeLuca, T.H. and Jones, D.L. (2012). 'Nutrient dynamics, microbial growth and weed emergence in biochar amended soil are influenced by time since application and reapplication rate', Agriculture, Ecosystems and Environment, vol. 158, pp. 192-9.

Rajalakshmi, P., and George, L. (2018).Forecasting for the Potato production in India by using ARIMA Models. *Int. J*. **6**(2).

Rawat, J., Saxena, J., and Sanwal, P. (2019). Biochar: A Sustainable Approach for Improving Plant Growth and Soil Properties. In Biochar-An Imperative Amendment for Soil and the Environment. Intech-Open.

Renner R. (2007). Rethinking biochar. *Environ. Sci. Technol*. **41**: 5932-5933.

Rhoades, C.C., Minatre, K.L., Pierson, D.N., Fegel, T.S., Cotrufo, M.F., and Kelly, E.F. (2017). Examining the potential of forest residue-based amendments for post-wildfire rehabilitation in Colorado, USA. *Scientifica*, 2017.

Ronsse, F., Nachenius, R.W., and Prins, W. (2015). Carbonization of Biomass. In Recent Advances in Thermo-Chemical Conversion of Biomass. pp. 293-324).

Rudong, Z., Coles, N., Kong, Z. and Wu, J. (2015). Effects of aged and fresh biochars on soil acidity under different incubation conditions. *Soil Till. Res*. **146**: 133-138.

Sackett, T.E., Basiliko, N., Noyce, G.L., Winsborough, C., Schurman, J., Ikeda, C. and Thomas, S.C. (2015). Soil and greenhouse gas responses to biochar additions in a temperate hardwood forest. *GCB Bioenergy* **7**: 1062–1074.

Saxena, J., Rana, G. and Pandey, M. (2013). 'Impact of addition of biochar along with *Bacillus* sp. On growth and yield of French beans. *Sci. Hort.*, vol. 162, pp. 351-6.

Schmidt, M.W.I. and Noack, A.G. (2000). Black carbon in soils and sediments: Analysis, distribution, implications, and current challenges. *Global Biogeochem. Cy*. **14**: 777-793.

Schulz, H. and Glaser, B. (2012) Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment. *J. Plant Nut. Soil Sci*. **175**: 410 - 422.

Smernik, R.J. (2009). Biochar and sorption of organic compounds. In Biochar for environmental management: science and technology. Eds. J. Lehmann and S. Joseph. pp 289-300. Earthscan.

Sohi, S.P., Krull, E., Lopez-Capel, E. and Bol, R. (2010). A review of biochar and its use and function in soil. *Adv. Agron.* **105**: 47-82.

Souza, N.B., Junqueira, A.B., Struik, P.C., Stomph, T., and Clement, C.R. (2017). The role of fertile anthropogenic soils in the conservation of native and exotic agrobiodiversity in Amazonian home gardens. *Agroforest. Syst.* 1-12.

Spokas, K.A., Novak, J.M., Masiello, C.A., Johnson, M.G., Colosky, E.C., Ippolito, J.A. and Trigo, C. (2014). Physical disintegration of biochar: an overlooked process. *Environ. Sci. Tech. Let.* **1**(8): 326-332.

Steiner, C., Glaser, B., Teixeira, W.G., Lehmann. J., Blum, W.E.H. and Zech, W. (2008). Nitrogen retention and plant uptake on a highly weathered central Amazonian Ferralsol amended with compost and charcoal. *J. Plant Nutr. Soil Sci.* **171**: 893-899.

Sun, Y., Gao, B., Yao, Y., Fang, J., Zhang, M., Zhou, Y. and Yang, L. (2014). Effects of feedstock type, production method, and pyrolysis temperature on biochar and hydrochar properties. *Chem. Eng. J.* **240**: 574-578.

Svoboda, Z., Zahora, J. and Dvorackova, H. (2017). Effects of Biochar Application on Winter Wheat (*Triticum Aestivum* L.) Roots Under Long- term Drought Conditions. *Acta Universitatis Agric. et Silviculturae Mendelianae Brunensis*. **65**(5): 1615–1622.

Tadesse, T., Dechassa N., Bayu, W. and Gebeyehu, S. (2013). Effects of farmyard manure and inorganic fertilizer application on soil physico-chemical properties and nutrient balance in rain-fed lowland rice ecosystem. *American J. Plant Sci.* **4**: 309.

Turner, B.L. (2006). Organic phosphorus in Madagascan rice soils. *Geoderma*. **136**(1-2): 279-288.

Utomo, W.H., Islami, T., Wisnubroto, E. and Soelistyari, H.T. (2017). Biochar as a carrier for Nitrogen plant Nutrition: 3. Effect of Enriched Biochar on Rice *(Oryza sativa* L.) Yield and Soil Qualities. *Int. J. Appl. Eng. Res.* **12**(20): 10426-10432.

Vaccari, F.P., Baronti, S., Lugata, E., Genesio, L., Castaldi, S., Fornasier, F. and Miglietta, F. (2011). Biochar as a strategy to sequester carbon and increase yield in durum wheat. *Eur. J. Agron*. **34**: 231-238.

Van Zwieten, L., Kimber, S., Morris, S., Downie, A., Berger, E., Rust, J. and Scheer, C. (2010). 'Influence of biochars on flux of N_2O and CO_2 from Ferrosol', *Soil Res*. **48**(7): 555-68.

Van Zwieten, L., Kammann, C., Cayuela, M.L., Singh, B.P., Joseph, S., Kimber, S. and Spokas, K. (2015). Biochar effects on nitrous oxide and methane emissions from soil. Biochar for environmental management: science and technology. 2nd ed. London, New York: Earthscan Books Ltd, 489-520.

Verheijen F.G.A., Jeffery, S., Bastos, A.C., Vander, V.M. and Diafas, I. (2009). Biochar Application to Soils - A Critical Scientific Review of Effects on Soil Properties, Processes and Functions. p. 149pp, Luxembourg.

Vinh, N.C., Hien, N.V., Anh, M.T.L., Lehmann, J. and Joseph, S. (2014). Biochar treatment and its effects on rice and vegetable yields in mountainous areas of northern Vietnam. *Int. J. Agric. Soil Sci*. **2**(1): 5-13.

Wang, C., Tu, Q., Dong, D., Strong, P.J., Wang, H., Sun, B. and Wu, W. (2014). Spectroscopic evidence for biochar amendment promoting humic acid synthesis and intensifying humification during composting. *J. Hazard Mater.* **280**: 409–416.

Wang, Y., Yin, R. and Liu, R. (2014). Characterization of biochar from fast pyrolysis and its effect on chemical properties of the tea garden soil. *J. Anal. Appl. Pyrol*. **110**: 375-381.

Wang, N., Li, J.Y. and Xu, R.K. (2009). Use of various agricultural by-products to study the pH effects in an acid tea garden soil. *Soil Use Manage*. **25**: 128-132.

Woods, W.I. and McCann, J.M. (1999). The anthropogenic origin and persistence of Amazonian dark earths. The yearbook of the conference of Latin American geographers. **25**: 7-14.

Wrobel-Tobiszewska, A., Boersma, M., Adams, P., Singh, B., Franks, S. and Sargison, J.E. (2016). Biochar for eucalyptus forestry plantations. *Acta Hortic.* **1108**: 55–62.

Xu, G., Sun, J., Shao, H. and Chang, S.X. (2014). Biochar had effects on phosphorus sorption and desorption in three soils with differing acidity. *Ecol. Engin*. **62**: 54-60.

Yang, X., Liu, J., McGrouther, K., Huang, H., Lu, K., Guo, X. and Wang, H. (2016). Effect of biochar on the extractability of heavy metals (Cd, Cu, Pb, and Zn) and enzyme activity in soil. *Environ. Sci. Pollut. R.* **23**(2): 974-984.

Yargicoglu, E.N., Sadasivam, B.Y., Reddy, K.R. and Spokas, K. (2015). Physical and chemical characterization of waste wood derived biochars. *Waste Manage.* **36**: 256-268.

Yilangai, R.M., Manu, A.S., Pineau, W., Mailumo, S.S., and Okeke-Agulu, K.I. (2014). The effect of biochar and crop veil on growth and yield of Tomato (Lycopersicum esculentus Mill) in Jos, North central Nigeria. *Curr. Agric. Res. J.* **2**(1): 37-42.

Yousaf, B., Liu, G., Wang, R., Rehman, M.Z., Rizwan, M.S., Imtiaz, M., Murtaza, G. and Shakoor, A. (2016). Investigating the potential influence of biochar and traditional organic amendments on the bioavailability and transfer of Cd in the soil–plant system. *Environ. Earth Sci.* **75**:1–10.

Youseef, M.E.A., Al-Easily, I.A.S. and Nawar, D.A. (2017). Impact of Biochar Addition on Productivity and Tubers Quality of Some Potato Cultivars Under Sandy Soil Conditions.

Yu, J.Q., Lee, K.S. and Matsui, Y. (1993). Effect of the addition of activated charcoal to the nutrient solution on the growth of tomato in hydroponic culture. *Soil Sci. Plant Nutr.* **39**(1): 13-22.

Yuan J.H. and R.K. Xu. (2011). The amelioration effects of low temperature biochar generated from nine crop residues on an acidic Ultisol. *Soil Use Manage.* **27**: 110–115.

Yuan, J.H., Xu, R.K., Qian, W. and Wang, R.H. (2011). Comparison of the ameliorating effects on an acidic ultisol between four crop straws and their biochars. *J. Soil Sediment.* **11**: 741–750.

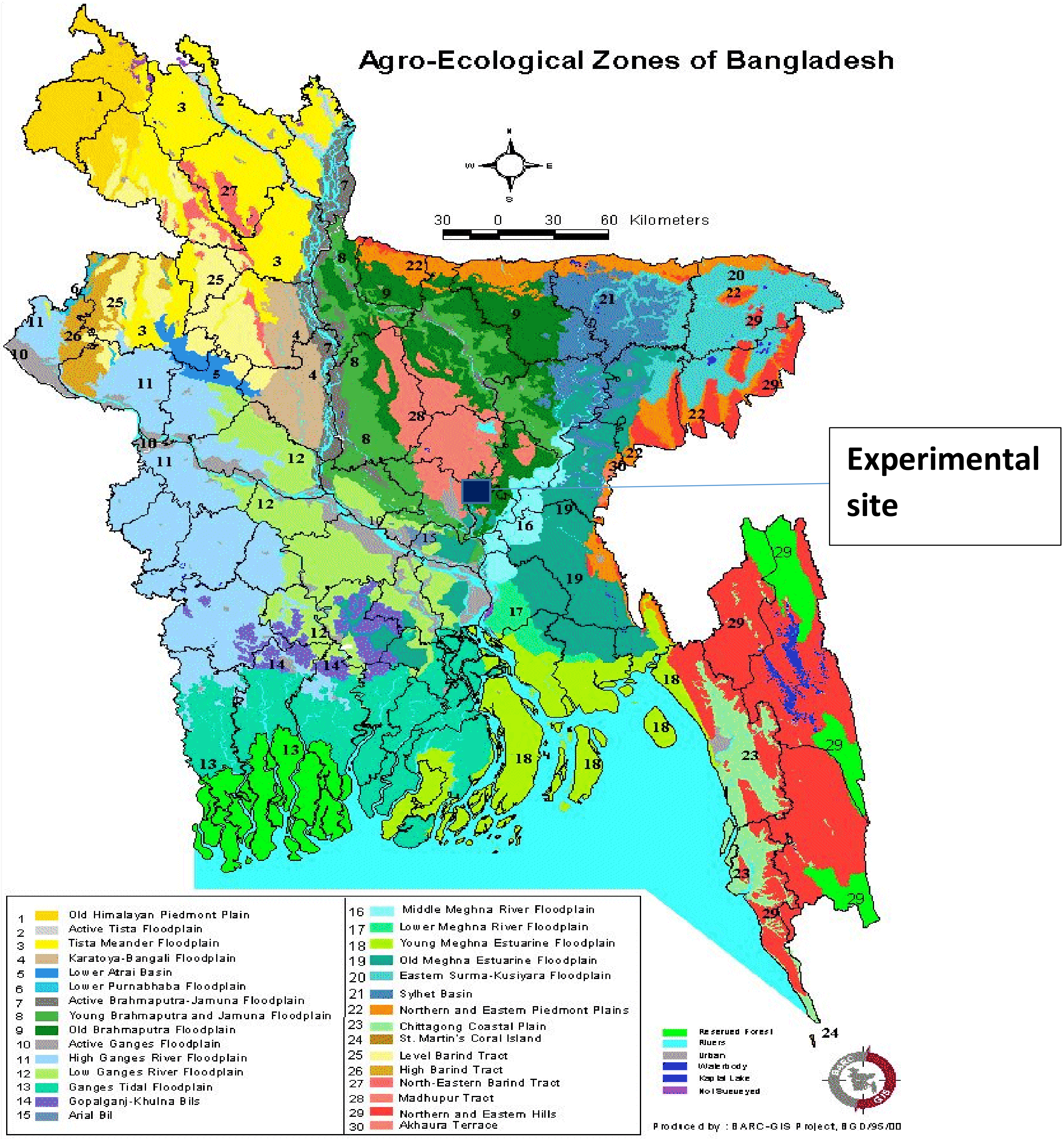
Zee, T.E., Nelson, N.O. and Newdigger, G. (2017). Biochar and Nitrogen Effects on Winter Wheat Growth. *Kansas Agric. Expt. Station Res.* **3**: 539-557.

Zheng, X., Yang, Z., Xu, X., Shi, X., Dai, M. and Guo, R. (2018). Distillers' grains anaerobic digestion residue biochar used for ammonium sorption and its effect on ammonium leaching from an Ultisol. *Environ. Sci. Pollut. R.* **25**(15): 14563-14574.

Zimmerman, A.R. (2010). Abiotic and Microbial Oxidation of Laboratory Produced Black Carbon (Biochar). *Environ. Sci. Tech.* **44**: 1295-1301.

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, 2017 to March, 2018

Months	Air temperature (^0C)		Relative humidity (%)	Total rainfall (mm)
	Maximum	Minimum		
November	30	21	58	5.25
December	27	19	59	17.61
January	25	15	47	0
February	30	19	44	1.21
March	34	22	46	17.62

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

APPENDIX III: Morphological characteristics, physical and chemical characteristics of the initial soil and properties of Biochar

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) % Silt (0.02-0.002 mm) % Clay (<0.002 mm)	 27 43 30
Textural class	Clay loam
pH	5.9
Organic carbon	0.72
Organic matter (%)	1.24
Total N (%)	0.06
Available P (ppm)	16.27
Exchangeable K (me/100g soil)	0.12
Available S (ppm)	16.5

Table C: Properties of Biochar

Organic carbon (%)	1.053

Appendix-IV: Layout of the experimental plot

Plot size: 2.5 m × 1.65 m (4.125 m^2)

Plot to plot distance: 0.50 m

Block to block distance: 0.75 m