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Effect of Biochar on Yield and Quality of Potato (*Solanum tuberosum*) Tuber

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Abstract

A field experiment was conducted in Sher-e-Bangla Agricultural University (SAU), Dhaka, Bangladesh during the period from November, 2017 to March, 2018 in rabi season 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 Control (no chemical fertilizer and biochar), Recommended Fertilizer Dose; Recommended Fertilizer Dose+Biochar @ 2.5 t ha^{-1}; Recommended Fertilizer Dose+Biochar @ 5.0 t ha^{-1}; Recommended Fertilizer Dose+Biochar @ 7.5 t ha^{-1}; $^1/_2$ of Recommended Fertilizer Dose+Biochar @ 2.5 t ha^{-1}; ½ of Recommended Fertilizer Dose+Biochar @ 5.0 t ha^{-1}; ½ of Recommended Fertilizer Dose + Biochar @ 7.5 t ha^{-1}; Biochar @ 10 t ha^{-1}. The experiment was laid out in a Randomized Complete Block Design 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. The results indicated that biochar application significantly (p<0.05) increased plant height, weight of tubers, yield of tubers, tuber dry matter content, tuber specific gravity, soil organic carbon. Results suggested that biochar application had significant positive effect on plant and soil.

Keywords: Biochar, growth, yield, potato tuber

1. Introduction

Increasing human pressure on agricultural fields and pastures while depleting land currently under agricultural use further increasing climate change and so on (Lal, 2009). Therefore, sustainable concepts for increased food production are now needed to lower the pressure on our soil. In this regard it is the need to preserve and replenish soil organic matter reserves to sustain nutrient cycling, aid water use efficiency and help mitigate against climate change. Under this situation, the use of biochar (BC) can be an effective means for sustainable agriculture in the long term, increasing soil C sequestration (C reduction strategy), fertility and productivity (soil quality) and reducing greenhouse gas emissions (Jeffery et al., 2014).

Soil organic carbon (SOC) is a basic factor in soil fertility and plays a significant role in the global carbon cycle (Liang et al., 2019). Biochar can increase SOC via either the release of biochar-derived dissolved organic matter or by preserving the existing natural SOC (Al-Wabel et al., 2017; Aller et al., 2017). Biochar's positive role in increasing crop yields is often credited to its porosity and sorption capacity (Gul et al., 2015); its liming effects in acidic soils (Peng et al., 2011); its enhancement of soil water holding capacity, pore-size distribution, and soil structure

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stability (Chan et al., 2007; Jhou et al., 2019); its high rate of nutrient transformations and utilization efficiency (Mizuta et al., 2004); and its stimulation of microbial and enzymatic activity (Bhattacharjya et al., 2016).

Biochar is the solid, carbon-rich material obtained by pyrolysis using different biomasses under low or no oxygen conditions (Brassard et al., 2016). It has been documented in some previous studies that biochar improves crop growth and yield (Rawat et al., 2019), increases nutrient availability in the soil and plant root colonization by mycorrhizal fungi (Koide, 2017), reduces emissions of other greenhouse gases from soil (Van Zwieten et al., 2015) and increases soil CEC, which improves plant nutrient availability and is thus beneficial for plant growth (Atkinson et al., 2010).

Treating plants with biochar increased plant growth, yield and quality (Gupta et al., 2020, Silva et al., 2017, Bonanomi et al., 2017, Dou et al., 2012, Carter et al., 2013, Vaccari et al., 2015, Akhtar et al., 2014). Also, biochar addition to mineral fertilizers significantly increased plant growth (Schulz and Glaser, 2012, Biederman and Harpole, 2013). Graber et al. (2010) mentioned that treating tomato plants by biochar positively enhanced plant height and leaf size. Nair (2015), on potato cv. Atlantic, found that there was a general trend of increasing yields with increasing biochar application rates. Adding biochar to the field of potato plants improved plant growth, tuber yield and its components with good tubers quality (Youseef et al., 2017, El-Metwaly, 2020).

Potato (*Solanum tuberosum* L.) is one of the most widely cultivated vegetable crops with a world production of about 368 million tons per year. In the world, it is the 4th crop after wheat, rice and maize (FAOSTAT, 2019). Potato has excellent food qualities such as water, carbohydrates, starch, proteins and contains negligible fat. In the present study, Potato (*Solanum tuberosum*) was grown under different treatments (biochar and mineral fertilization) in a field experiment. The objectives of this study were: (1) to observe the effect of biochar on yield and yield contributing factors of potato (2) to study the efficacy of biochar on quality of potato tuber (3) to find out the optimum dose of biochar along with inorganic fertilizer for achieving the maximum yield of potato.

2. Materials and Methods

2.1. *Description of the study area*

The study was conducted in the farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207. Bangladesh in the year 2017. It is located at $23^0 74'$N latitude and $90^0 33'$E longitude at an altitude of 8.6 meter above the sea level. The mean annual maximum and minimum temperatures are 26.8°C and 11.4°C and the relative humidity's are 91.4% and 39.92%, respectively. The mean annual rainfall of the study area is 1500 mm.

2.2. *Treatments details of experimental fields*

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 t ha^{-1}; T_5=RFD+Biochar @ 7.5 t ha^{-1}; T_6=$^1/_2$ of RFD+Biochar @ 2.5 t ha^{-1}; T_7=½ of RFD+Biochar @ 5.0 t ha^{-1}; T_8=½ of RFD+Biochar @ 7.5 t ha^{-1};T_9=Biochar @ 10 t ha^{-1}. RFD (Recommended Fertilizer Dose): for potato N_{150}, P_{30}, K_{140}, S_{15}, Zn_3 kg ha^{-1} (FRG, 2012).

2.3. *Experimental procedure*

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. 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. The well sprouted healthy and uniform sized potato tubers were planted maintaining a spacing 40×20 cm^2 and 4-5 cm depth. Normal growth conditions were ensured and the field was irrigated to maintain the soil moisture in field capacity.

2.4. *Harvesting of potatoes and collecting of data*

Plant height, number of stems hill^{-1} and tubers hill^{-1} were counted at harvest. Harvested potato tubers were separated into marketable (fresh weight>20 g), non-marketable tubers (fresh weight <20 g) as per treatment and yield was calculated tonha^{-1}. The tuber sub samples were collected from each treatment. After peel off the tubers the samples were dried in oven at 72°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 (Elfresh et al., 2011). 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)

2.5. *Soil analysis*

Soil samples were analyzed at the beginning of experiment and after the harvest of potato to determine soil pH, organic carbon, total nitrogen (N), available phosphoprus (P), exchangeable potassium (K), available sulphur (S). Soil pH was measured by using a pH meter in a 1:2.5 soil water ratio, organic carbon in soil sample was determined by wet oxidation method (Page et al., 1982). Kjeldahl method was used to determine the total N content of soil. Available P was determined by ascorbic acid blue color method. (Olsen et al., 1984). Exchangeable K was determined by 1N NH_4OAc (pH=7) extraction methods, available Sulphur was determined by $CaCl_2$ extraction method (Page et al., 1982) (Table 1).

2.6. *Statistical analysis*

The data obtained for different parameters were statistically analyzed by using statistix10 software to find out the significant (p<0.05) difference among the results of different levels of biochar application on growth, yield and yield contributing

Table 1: Physical and chemical properties of experimental field soil at the beginning of experiment at a depth 15 cm of surface soil

Physical properties	Value	Chemical properties	Value
Mechanical fractions:		pH	5.9
% Sand (2.0-0.02 mm)	27	Organic carbon (%)	0.72
% Silt (0.02-0.002 mm)	43	Total N (%)	0.06
% Clay (<0.002 mm)	30	Available P (ppm)	16.27
Textural class	Clay loam	Exchangeable K (me 100 g^{-1} soil)	0.12
		Available S (ppm)	16.5

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).

3. Results and Discussion

3.1. Effect of biochar on plant growth

Plant height was significantly (p<0.05) influenced due to application of different levels of biochar (Table 2). The maximum plant height 63.23 cm at harvesting which was recorded from T_5 treatment whereas, the minimum plant height was recorded from control treatment. Plant height was significantly (p<0.05) increased due to application of biochar. Graber et al. (2010) emphasized that treating plants by biochar positively enhanced plant height. Biochar addition to mineral fertilizers significantly increased plant growth (Schulz and Glaser, 2012). Therefore, the combination of biochar with organic fertilizer (compost) is most promising for agronomic performance.

The number of stems per hill at haulm cutting stage significantly (p<0.05) increased only over control (Table 2). The maximum stem numbers hill^{-1} (5.17) was obtained from T_6 treatment which was statistically not significant (p<0.05) with other treatments. Youseef et al. (2017) revealed that the number of main stems significantly increased with increasing biochar application rates up to 12 m^3 ha^{-1}.

3.1.1. Effect of biochar on yield attributes potato yield

We found the number of tubers hill^{-1} increased significantly due to different rate of biochar application (Table 2). The maximum number of tubers hill^{-1} was produced from $^1/_2$ of RFD+Biochar @ 2.5 t ha^{-1} treatment whereas the minimum was produced from control treatment. Youseef et al. (2017) found that fertilizing with biochar positively increased number of tubers. The tuber yield of potato increased significantly (p<0.05) due to application of biochar in combination with chemical fertilizers (Table 2). The highest tuber yield (35.76 t ha^{-1}) was obtained from T_5 (RFD+Biochar @ 7.5 t ha^{-1}) treatment lowest tuber yield (14.51 t ha^{-1}) was obtained from T_1 (control) treatment.

Numerous studies have indicated the strong potential of biochar application for improving crop yields (Van Zwieten et al., 2010; Zhang et al., 2012; Nair et al., 2014). A number of other studies have shown only small improvements or even reductions in grain yield with biochar application in nutrient-rich soils (Deenik et al., 2010; Gaskin et al., 2010; Van Zwieten et al., 2010). For instance, Gaskin et al. (2010) noted a decrease in grain yield with increasing rates of biochar application. Increased crop yield is a mostly recognized benefit of biochar application; however, crop responses are highly variable and reliant on biochar type and application rates.

3.1.1.1. Effect of biochar on quality of potato

Dry matter content (%) of tubers increased significantly (p<0.05) by different levels of biochar application. Youseef et al. (2017) found that the total dry weight of tubers significantly increased (15.60%) with increasing of biochar application rate. Specific Gravity Specific gravity of tuber increased significantly (p<0.05) with different levels of biochar application (Table 2). The highest specific gravity (1.12) of tuber was recorded from T_5 (RFD+Biochar @ 7.5 t ha^{-1}) treatment and the lowest was found from T_1 (1.03) treatment. Based on weight, tubers have been graded into marketable tuber (>20 g) and non-marketable tuber (<20 g). 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 g) was produced from control treatment and the lowest percentage (23.55%) of non-marketable tuber (<20 g) was produced from T_5 treatment. The maximum percentage (76.45%) of marketable tuber (>20 g) was produced from T_5 (RFD+Biochar @ 7.5 t ha^{-1}) treatment while the minimum percentage (68.14%) of marketable tuber was produced from T_1 treatment.

3.2. Effect of biochar on postharvest soil properties

We found no significant (p<0.05) difference in soil pH between treatments. (Table 3). 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).

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 t ha^{-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 (Table 3). Increase in organic C (up to 69%) due to biochar application was found by Laird et al., 2010.

Table 2: Effect of biochar on plant growth, yield and quality attributes of potato tuber

Treatment	Plant height (cm)	No. of stem hill^{-1}	No. of tubers hill^{-1}	Weight of tubers (kg hill^{-1})	Yield of tuber t ha^{-1}	Tuber dry matter content (%)	Tuber specific gravity	Weight of marketable yield >20 g (%)	Weight of non -marketable yield <20 g (%)
T_1	40.23^{h}	4.00^{c}	5.52^{c}	0.11^{d}	14.51^{e}	15.00^{e}	1.03^{f}	68.14^{b}	31.86^{a}
T_2	55.73^{d}	4.27^{bc}	7.27^{ab}	0.41^{abc}	25.96^{bcd}	18.00^{cd}	1.06^{cde}	73.62^{ab}	26.38^{ab}
T_3	61.26^{b}	4.70^{abc}	7.62^{ab}	0.50^{a}	31.56^{abc}	20.33^{bc}	1.07^{c}	73.25^{ab}	26.75^{ab}
T_4	58.45^{c}	5.10^{a}	7.60^{ab}	0.49^{ab}	33.56^{ab}	22.67^{ab}	1.10^{b}	74.04^{ab}	25.96^{ab}
T_5	63.23^{a}	4.37^{abc}	8.00^{a}	0.51^{a}	35.76^{a}	25.33^{a}	1.12^{a}	76.45^{a}	23.55^{b}
T_6	54.28^{e}	5.17^{a}	8.37^{a}	0.34^{abc}	25.94^{bcd}	23.33^{a}	1.07^{cd}	75.22^{a}	24.79^{b}
T_7	53.59^{e}	4.83^{ab}	6.67^{bc}	0.34^{bc}	25.10^{cd}	20.33^{bc}	1.05^{ef}	75.59^{a}	24.41^{b}
T_8	47.75^{f}	4.43^{abc}	6.63^{bc}	0.41^{abc}	24.14^{cd}	16.67^{de}	1.06^{cde}	74.30^{ab}	25.70^{ab}
T_9	45.55^{g}	4.77^{abc}	5.67^{c}	0.30^{c}	19.78^{de}	16.33^{de}	1.05^{de}	74.74^{a}	25.56^{b}
LSD (p=0.05)	1.24	0.82	3.39	0.17	1.75	2.74	0.02	6.18	6.18

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

Biochar application significantly ($p<0.05$) influenced the total nitrogen (%) content of soil. The maximum total nitrogen (0.089%) was recorded in T_5 (RFD+Biochar @ 7.5 t ha^{-1}) treatment and minimum was recorded from control treatment (Table 3). We found that biochar application increased the total nitrogen (%) content of soil. Such an effect could be interpreted as CEC was increased due to the presence of cation exchange sites on the biochar surface (Lehmann, 2007; Sohi et al., 2010). This contributed to retain higher NH_4^+ concentrations leading to improved N nutrition in the biochar-amended soil (Hollister et al., 2013). Liard et al. (2010) found that the biochar amendments significantly increased total N (up to 7%).

The different treatment showed significantly variation in the Available phosphorus. The highest available phosphorus (28.7 ppm) was recorded from T_4 while the lowest available phosphorus (17.5 ppm) was recorded from T_1 treatment (Table 3). 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.

Exchangeable potassium was significantly influenced by different treatment. The highest exchangeable potassium

Table 3: Effect of biochar on of postharvest soil properties

Treatment	Soil pH	Organic carbon (%)	Total N (%)	Available P (ppm)	Exchangeable K (cmol kg^{-1} soil)	Available S (ppm)
T_1	6.0	0.70^{f}	0.05^{i}	17.5^{d}	0.15^{f}	16.50^{c}
T_2	6.10	0.76^{e}	0.063^{h}	21.8^{c}	0.18^{d}	21.50^{c}
T_3	6.12	0.79^{de}	0.081^{c}	23.2^{bc}	0.19^{c}	22.50^{c}
T_4	6.13	0.82^{cd}	0.087^{b}	28.7^{a}	0.20^{c}	22.50^{c}
T_5	6.15	0.88^{b}	0.089^{a}	27.3^{a}	0.24^{a}	26.66^{a}
T_6	6.20	0.84^{c}	0.072^{g}	27.0^{a}	0.22^{b}	25.00^{b}
T_7	6.10	0.86^{bc}	0.075^{f}	22.5^{c}	0.20^{c}	22.00^{c}
T_8	6.11	0.88^{b}	0.078^{e}	24.3^{bc}	0.19^{c}	22.20^{c}
T_9	6.12	0.98^{a}	0.079^{d}	26.3^{ab}	0.16^{e}	19.97^{d}
LSD (p=0.05)	NS	0.05	0.04	0.66	0.02	0.88

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

(0.24 cmol kg^{-1} soil) was recorded in T_5 treatment while the lowest exchangeable potassium (0.15 cmol kg^{-1} soil) was recorded in T_1 treatment (Table 3). 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.

Application of different level of biochar significantly influenced the available Sulphur (ppm) in soil (Table 3). The maximum available Sulphur (26.66 ppm) found from T_5 (RFD+Biochar @ 7.5 t 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.

4. Conclusion

Potato growth, tuber yield and quality of potato significantly increased when biochar was applied in combination with inorganic fertilizers. Application of biochar @ 7.5 t ha^{-1} along with recommended dose of inorganic fertilizer resulted highest tuber yield (35.76 t ha^{-1}) and quality parameters like % dry matter content (25.33) and specific gravity (1.12).

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