Net Journal of Agricultural Science
Vol. 8(1), pp. 1-7, February 2020
ISSN: 2315-9766
Full Length Research Paper

Akha biochar enhances soil fertility and productivity of red amaranth plant

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Accepted 7 January, 2020

ABSTRACT

Biochar is a carbon-rich co-product resulting from pyrolyzing biomass. Its application to soil may increase fertility and productivity of soils. The utilization of biochar as a source of nutrients for red amaranth production was investigated in this study at Naogaon district of Bangladesh. Red amaranth (*Amaranthus tricolor* L) is a short duration vegetable crop that is cultivated throughout the year in Bangladesh. This study aims to obtain a proper dose of biochar for the growth and yield of red amaranth plants. Six treatments like control (nothing was added), 5 kg/decimal biochar only, BARC (Bangladesh Agricultural Research Council) recommended fertilizer for red amaranth production, BARC recommended fertilizer plus 2.5 kg/decimal biochar, BARC recommended fertilizer plus 5 kg/decimal biochar and BARC recommended fertilizer plus 10 kg/decimal biochar were considered for red amaranth cultivation. Result showed that the BARC recommended dose with 5 kg biochar/decimal produced highest red amaranth yield among the other treatments. It was also observed that the biochar used red amaranth were better appearance than fertilizer used red amaranth. This study concluded that biochar has the potential to improve soil fertility and productivity of red amaranth plant in Bangladesh.

Keywords: Pyrolysis, Akha Chula, carbon sequestration, soil organic matter.

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Introduction

Biochar is charred organic matter intended for use as a soil amendment. Biochar is produced by a thermochemical decomposition process called pyrolysis, which consists of heating biomass at a high temperature (≈400 to 800°C) in a limited oxygen environment (Lehmann and Joseph, 2009). The pyrolysis of biomass results in biochar as well as gas and liquid products in varying proportions depending on the type of organic material and heating temperature (Verheijen et al., 2010).

Red amaranth (*Amaranthus tricolor* L.) is a plant of shrubs loved by all levels of society mostly in Asia. The red amaranth besides it's good tastes and softness, can also facilitate digestion. Red amaranth as one source of antioxidants needs to be developed because it's potential as a vegetable is very useful for the high content of phenols and flavonoids which function as antioxidant compounds (Ahmed et al., 2010).

Beneficial effects of biochar in terms of increased crop yield and improved soil quality had been reported (Iqbal et al., 2019). The ability of many biochars to retain nutrients develops over time; so it is possible to not see any differences in the first cropping season after application (Cheng et al., 2008). Similarly, a single biochar application had been observed to provide benefits for crop nutrition for several years after an initial "neutral" year (Major et al., 2010). Research information on Akha or mixed biochar in agricultural use for red amaranth plant productivity around the glove is scanty.

A study showed that rice straw biochar amendment in calcareous soil increase about ten percent yield of wheat in Bangladesh (Iqbal, 2017). Likewise, another study showed that rice straw biochar helps to translocate phosphorus within wheat plant tissue and accumulate phosphorus within wheat grain (Iqbal et al., 2019). Similarly, another research showed that both compound and rice straw biochar improves soil fertility and productivity of mulberry plant (Ahmed et al., 2017). However, there was no study undertaken about mix biochar field application with red amaranth vegetable plant productivity. Therefore, this study was undertaken with the aims: (i) To determine suitable dose of mix biochar for red amaranth vegetable production in the field; (ii) To investigate growth and yield of red amaranth for mixed biochar utilization in the field; (iii) To quantify changes in soil physical and chemical properties due to incorporation of biochar within soil. It was hypothesized that combined mixed biochar and BARC recommended fertilizer will improve red amaranth productivity.

Figure 1. Akah biochar used in this study.

MATERIALS AND METHODS

Chemical properties of Akha biochar used in this study

Biochar is the carbon-rich solid product resulting from the heating of biomass in an oxygen-limited environment. Due to its highly aromatic structure, biochar is chemically and biologically more stable compared with the organic matter from which it was made. Generally, the properties of biochar vary widely, depending on the source of biomass used and the conditions of production of biochar (Lehman and Joseph, 2009). The physiochemical properties of the Akha biochar (Figure 1) used in this study is shown in Table 1.

Table 1. Properties of Akah biochar used in this experiment.

Element evaluated	Biochar
pH	7.8
Moisture (%)	8.72
OC (%)	41.60
N (%)	3.22
P (%)	0.54
K (%)	1.03
S (%)	0.80
Cu (%)	0.014
Zn (%)	0.011
Pb (ppm)	0.90
Mn (ppm)	5.13
Mg (ppm)	4.37
Cr (ppm)	2.40

Plant

The red amaranth (*Amaranthus tricolor* L) variety Rangila was used as a testing plant. The yield performance of red amaranth is best compared to all released red amaranth varieties of Bangladesh. For that reason, the red amaranth variety Rangila has been selected in this study. The seed rate for red amaranth was 2 kg/ha.

Akah biochar application to the field

Akah biochar was applied in the field according to Dias et al. (2010). Akha biochar was incorporated into the soil in the field. The desired amount of Akha biochar was evenly spread onto the soil according to treatments, then tilled by hand. Akha biochar was ground properly before mixing with soil. Akha biochar was added and mixed into the soil before 7 days of seed sowing.

Study site

The experiment was conducted at the brined tract region of Bangladesh on 24°22′36″N latitude and 88°38′27″ E longitude at an elevation of 20 m above the sea. The experimental soil was located in the Naogaon region which was located at 5th AEZs (Agro-ecological Zone) of Bangladesh named lower Atrai Basin. The texture of the soil was clayey. The organic matter status and soil fertility was high and the pH of the soil is between 4.8 and 6.0 (Bhuiya et al., 2005). The initial soil basic physiochemical properties are shown in Table 2.

Experimental design and treatments

The experiment was laid out in randomized completely block design (RCBD) in the year 2019. The treatments were replicated three times in six treatments. These are (T_0) Control (nothing was added), (T_1) Biochar without fertilizer (5 kg/decimal), (T_2) BARC recommended fertilizer without biochar (T_3) BARC recommended fertilizer with biochar (2.5 kg/decimal), (T_4) BARC recommended fertilizer with biochar (5 kg/decimal) and (T5) BARC recommended fertilizer with biochar (10 kg/decimal).

Fertilizer additions

Several split fertilizer doses were added in each plot according to BARC recommended fertilizer doses for red amaranth production in Bangladesh (BARC, 2019). Fertilizer was added according to initial soil basic physical and chemical properties. Magnesium was not added to the soil due to its availability to the initial soil as well as

Table 2. Initial soil basic physiochemical properties and nutrient contents from the experimental site.

Soil pH	OM (%)	TN (%)	P (ppm)	K (me/100g)	S (ppm)	Zn (ppm)	Ca (me/100g)	Mg (me/100g)	Cu (ppm)	Fe (ppm)	B (ppm)	Mn (ppm)	AMF spores (nos/10 g soil)
5.36	0.82	0.05	9.97	0.12	6.57	0.36	3.75	1.14	0.51	31.43	0.19	3.37	51

Data were means of three replicates.

availability within mixed biochar. Amount of fertilizer reduced to half for the half BARC recommended fertilizer treatment. The amount of fertilizer mixed within soil is shown in Table 3.

Experimental procedure

Akha Biochar was mixed at different doses with the field soil and left to incubate for seven days. Plot size for each replication was 1 m × 1 m (Figure 2). Seeds were well germinated before sowing. Red amaranth plant was harvested after 47 days of sowing that was edible as a fresh vegetable.

Biochar was mixed at different doses with the field soil and keep 7 days for incubation into the soil. Plot size for each replication was 1 m × 1 m. Seeds were well germinated before sowing. Red amaranth plant was harvested after 47 days of sowing that was edible as a fresh vegetable.

Plant harvest and data collection

The red amaranth plant growth and mature leaf data were collected during the experiment period. Plant growth and mature leaf parameter like plant height, leaf number, leaf wide, leaf length and plant weight were recorded.

Measurement of soil properties

Initial and final soil was collected before and after experiment. The pH of the bulk soil was determined in deionized water using a soil-to-water solution ratio of 1:5. Organic carbon of the bulk soil samples was determined by wet oxidation method (Walkley and Black, 1934). Bulk soil organic matter content was determined by multiplying the percent value of organic carbon with the conventional Van-Bemmelen's factor of 1.724 (Piper, 1950). The nitrogen content of the bulk soil sample was determined by distilling soil with alkaline potassium permanganate solution (Subbiah and Asija, 1956). The distillate was collected in 20 ml of 2% boric acid solution with methylred and bromocresol green indicator and titrated with 0.02 N sulphuric acid (H_2SO_4) (Podder et al., 2012). Bulk soil available S (ppm) was determined by calcium phosphate extraction method with a spectrophotometer at 535 nm (Petersen et al., 1996).The soil available K was extracted with 1N NH_4OAC and determined by an atomic absorption spectrometer (Biswas et al., 2012). The available P of the bulk soil was determined by spectrophotometer at a wavelength of 890 nm. The bulk soil sample was extracted by Olsen method with 0.5 M $NaHCO_3$ as outlined by Huq and Alam (2005). The Zn in the bulk soil sample was measured by an atomic absorption spectrophotometer (AAS) after extracting with DTPA (Soltanpour and Schwab, 1977).

Table 3. Amount of BARC recommended fertilizer added in several treatments.

Fertilizer name	Amount added
Urea	845 (g/decimal)
Triple super phosphate (TSP)	150 (g/decimal)
Murate of potash (MP)	225 (g/decimal)
Gypsum ($CaSO_4$)	130 (g/decimal)
Dolomite ($CaCO_3.MgCO_3$)	5 (kg/decimal)
Organic matter (Cow dung)	20 (kg/decimal)

Figure 2. Field experiment showing treatments difference of red amaranth plant.

Statistical analysis

Results were analyzed by a one-way analysis of variance (ANOVA) using Genstat 12th edn for Windows (Lawes Agricultural Trust, UK). One way ANOVA were conducted for treatment effects on growth performance of red amaranth. Bulk soil physiochemical properties data were analyzed using the Statistical Analysis System (SAS9.1.3). All the statistical testing was performed based on $P \leq 0.05$ for least significance difference (LSD).

RESULTS

Effect of Akha biochar application on red amaranth leaf number

Optimum level of Akha biochar with recommended chemical fertilizer helps to proliferate more roots than other treatments (Figure 3). The leaf number

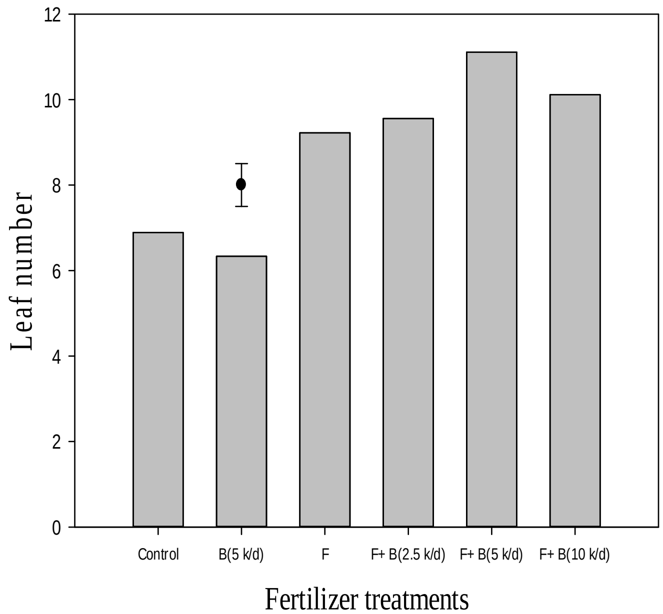

Figure 3. Effect of akha biochar application on leaf number of red amaranth plant. Vertical bar represents LSD ($P \geq 0.05$) for fertilizer treatments and leaf wide interaction. B means mixed biochar, F means BARC (Bangladesh Agricultural Research Council) recommended chemical fertilizer for red amaranth production. Data were means of three replicates.

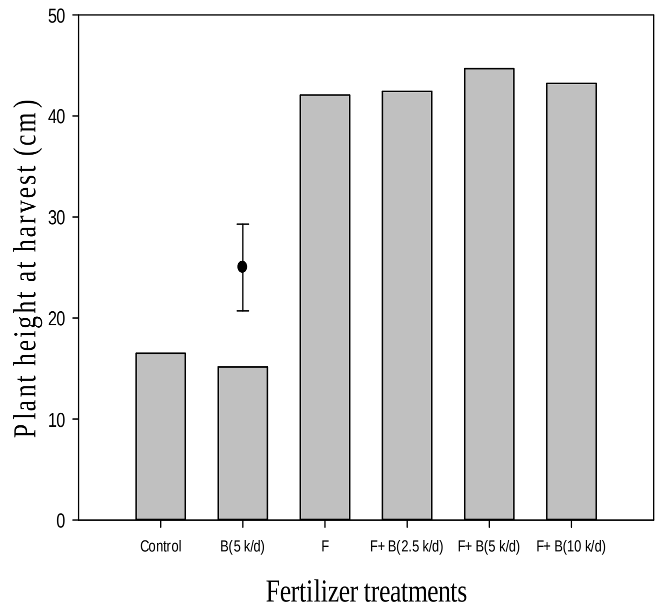

Figure 4. Effect of Akha biochar application on red amaranth plant height for various fertilizer management. Vertical bar represents LSD ($P \geq 0.05$) for fertilizer treatments and leaf wide interaction. B means mixed biochar, F means BARC (Bangladesh Agricultural Research Council) recommended chemical fertilizer for red amaranth production. Data were means of three replicates.

of red amaranth plant for the control, 5 kg/decimal biochar only, BARC recommended fertilizer, BARC recommended fertilizer plus 2.5 kg/decimal biochar, BARC recommended fertilizer plus 5 kg/decimal biochar, BARC recommended fertilizer plus 10 kg/decimal biochar were 6.89, 6.33, 9.22, 9.56, 11.11 and 10.11, respectively.

Effect of Akha biochar application on red amaranth plant weight

Combined Akha biochar with chemical fertiizer application enhances growth of red amaranth plant (Figure 4). The plant weight at harvest for the control, 5 kg/decimal biochar only, BARC recommended fertilizer, BARC recommended fertilizer plus 2.5 kg/decimal biochar, BARC recommended fertilizer plus 5 kg/decimal biochar, BARC recommended fertilizer plus 10 kg/decimal biochar were 16.51, 15.14, 42.07, 42.43, 44.68 and 43.22 cm, respectively.

Effect of Akha biochar application on red amaranth plant height

Utilization of biochar with inorganic fertilizer has great effect on weight of red amaranth plant height (Figure 5). The BARC recommended fertilizer along with 5 kg/decimal mix biochar has highest plant weight among all the treatments. The plant weight at harvest for the control, 5 kg/decimal biochar only, BARC recommended fertilizer, BARC recommended fertilizer plus 2.5 kg/decimal biochar, BARC recommended fertilizer plus 5 kg/decimal biochar, BARC recommended fertilizer plus 10 kg/decimal biochar were 3.22, 2.89, 19.06, 21.79, 26.11 and 22.39 g, respectively.

Effect of mix biochar application on red amaranth width of leaf

Mixed biochar with BARC recommended fertilizer has great effect on width of leaf of red amaranth plant (Figure 6). The width of leaf of red amaranth plant for the control, 5 kg/decimal biochar only, BARC recommended fertilizer, BARC recommended fertilizer plus 2.5 kg/decimal biochar, BARC recommended fertilizer plus 5 kg/decimal biochar, BARC recommended fertilizer plus 10 kg/decimal biochar were 38.56, 38.11, 76.89, 77.11, 85.00 and 82.22, cm respectively. Leaf wide was highly significant among treatments (Table 4).

Effect of mix biochar application on red amaranth leaf length

Combined application of mix biochar and inorganic

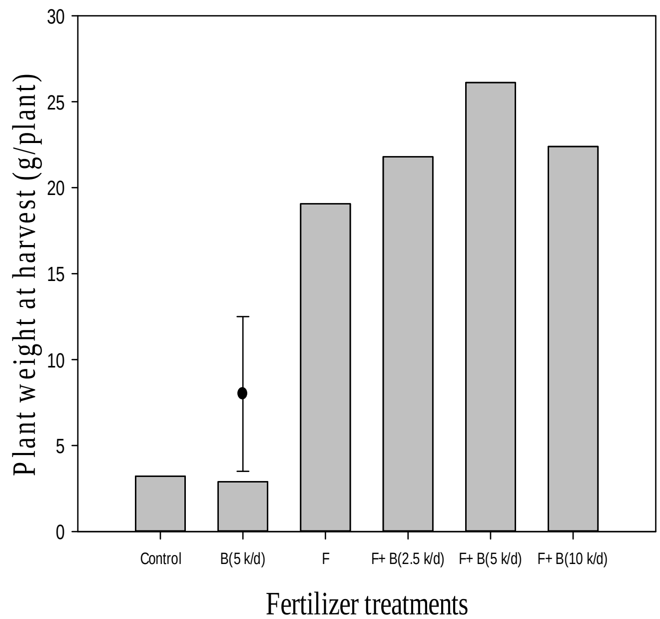

Figure 5. Effect of mix biochar application on red amaranth plant weight at harvest for various fertilizer management. Vertical bar represents LSD ($P \geq 0.05$) for fertilizer treatments and leaf wide interaction. B means mixed biochar, F means BARC (Bangladesh Agricultural Research Council) recommended chemical fertilizer for red amaranth production. Data were means of three replicates.

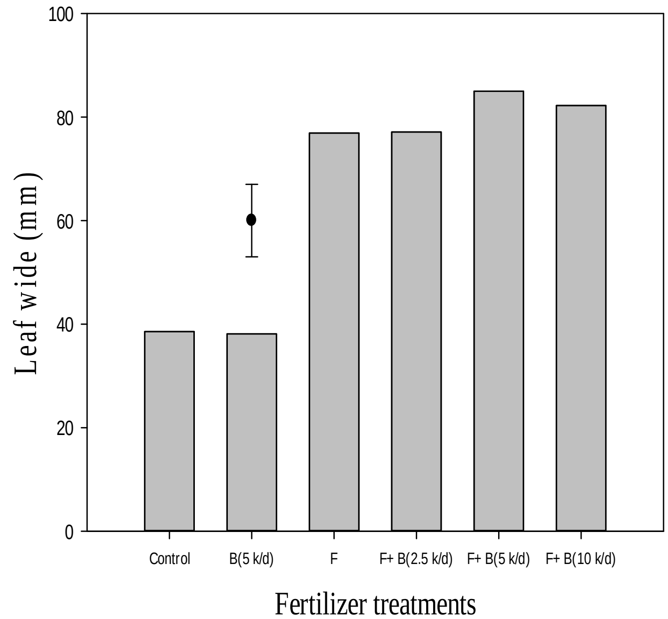

Figure 6. Variation of leaf wide of red amaranth plant due to different fertilizer treatment. Vertical bar represents LSD ($P \geq 0.05$) for fertilizer treatments and leaf wide interaction. B means mixed biochar, F means BARC (Bangladesh Agricultural Research Council) recommended chemical fertilizer for red amaranth production. Data were means of three replicates.

Table 4. Level of significance for main effects among fertilizer treatments for the red amaranth plant productivity.

Source of variation	Leaf wide	Plant height	Leaf number	Plant weight at harvest	Leaf length
Treatments	***	***	*	***	***

Where * and *** represents probability of ≤ 0.05 and ≤ 0.001 respectively. Values were means of three replicates.

fertilizer proliferate leaf of red amaranth plant was carried out. However, elevated mix biochar application with BARC recommended dose of chemical fertilizer reduces growth of red amaranth plant. The leaf length of red amaranth plant for control (nothing was added), 5 kg/decimal biochar only, BARC (Bangladesh Agricultural Research Council) recommended fertilizer for red amaranth production, BARC recommended fertilizer plus 2.5 kg/decimal biochar, BARC recommended fertilizer plus 5 kg/decimal biochar and BARC recommended fertilizer plus 10 kg/decimal biochar were 77.44, 68.78, 143.22, 153, 171.78 and 151.44 mm, respectively (Figure 7).

Changes in soil physiochemical properties due to biochar amendment

Soil pH and soil organic matter increase due to biochar amendment within soil (Table 5). However, N, K and Mg did not changed remarkably in the bulk soil due to biochar amendment. Interestingly, P content increased significantly ($P \geq 0.05$) in the post harvest soil due to biochar amendment. Similarly, both Fe and Mn increased 3 to 4 ppm due to biochar amendment. Likewise, bulk soil B content increased 3 to 5 times for biochar addition to initial soil.

DISCUSSION

Effect of biochar on red amaranth productivity

Biochar only application has no effect on red amaranth productivity. Findings showed that no significant difference between control and 5 kg/dec biochar treatments for the red amaranth production (Table 4). When fertilizer was applied with 5 kg/dec biochar, the red amaranth produced maximum yield. However, red amaranth productivity decline due to 10 kg/dec biochar with recommended fertilizer application. It indicates that optimum level of biochar is efficient for red amaranth

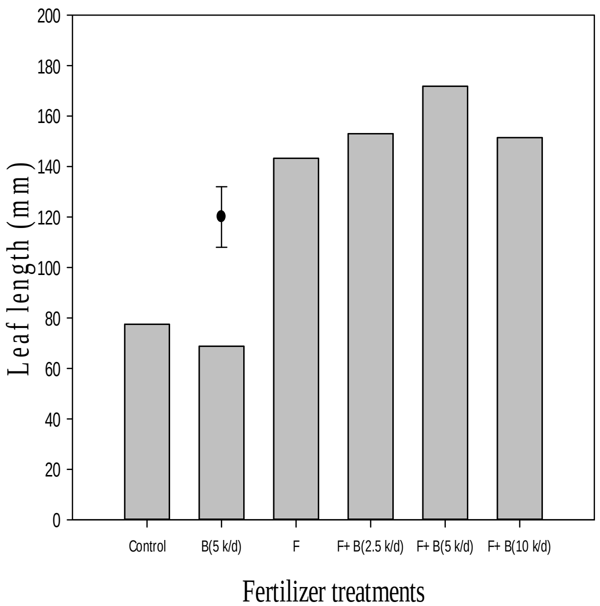

Figure 7. Variation of leaf wide of red amaranth plant due to different fertilizer treatment. Vertical bar represents LSD (*P* ≥ 0.05) for fertilizer treatments and leaf wide interaction. B means mixed biochar, F means BARC (Bangladesh Agricultural Research Council) recommended chemical fertilizer for red amaranth production. Data were means of three replicates.

production. Application of mix biochar showed increased red amaranth growth parameters (Figures 3 to 7); as mix biochar did reduce exchangeable acidity, increased soil pH of acidic soils, and inherently contains significant amounts of plant nutrients such as Potassium, Sulphur and Nitrogen (Table 2).

Potential benefits of biochar utilization on soil properties

Biochar as a soil enhancer has been able to improve soil physical properties, increase microbial activity, and improve soil fertility. Our findings supported that biochar application to soil improve soil physiochemical properties and nutrient availability in soils (Table 5). With soil fertility improvements, it will enhance the ability of plants to absorb nutrients and water in the soil and encourage the vegetative growth of red amaranth plants and sunlight interception by leaves to produce photosynthesis (Figures 3 to 7). The main reason behind Biochar utilization on large scale is level of organic matter content in Bangladeshi soil is alarmingly low for sustainable crop production. Increases in soil organic matter by biochar amendment were also observed by a number of researchers (McHenry, 2011). Likewise, Li et al. (2015) found that the biochar-amended soils had 37.7, 7.3 and 227.6% more soil organic carbon (SOC) than the control soil. It may be due to the reason that concerning possible priming effect whereby accelerated decomposition of soil organic matter occurs upon biochar addition to soil (Verheijen et al., 2010). Thus, biochar contains essential plant nutrients such as potassium, carbon, and magnesium as well as properties (alkaline pH and high CEC) that could be optimized for used as a soil amendment to improve the fertility of poor and acidic soils and increase crop yields.

Our findings showed that addition of biochar increase soil pH (Table 5). Other study also showed that when added to acidic soils, biochar soil characteristics such as increase in soil pH (Djousse et al. 2016; Siamak et al. 2017). Result also showed that Akha biochar amendment to soil improves soil organic matter status (Table 5). Similar, studies have shown that adding biochar to soils increases soil organic matter (SOM) and organic carbon which then enhances nutrient supply to plants and promote plant growth (Weyers and Spokas, 2014; Dotaniya et al. 2016).

Table 4. Changes in soil physiochemical properties due to several treatments.

Treatment	Soil pH (in H_2O)	SOM (%)	N (%)	P (ppm)	Ca (ppm)	K (me/100 g)	Mg (me/100 g)	S (ppm)	Zn (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	B (ppm)
Control	5.37^{b}	0.83^{b}	0.050^{a}	9.90^{d}	3.75^{b}	0.12^{a}	1.14^{a}	6.60^{b}	0.40^{c}	0.52^{b}	31.43^{b}	9.47^{b}	0.19^{d}
Biochar (5 kg/dec)	5.47^{b}	0.86^{b}	0.047^{a}	26.67^{b}	4.22^{ab}	0.13^{a}	1.23^{a}	7.31^{b}	0.41^{c}	0.59^{ab}	34.03^{ab}	10.70^{ab}	0.61^{bc}
BARC	5.50^{b}	0.83^{b}	0.050^{a}	18.47^{c}	4.15^{ab}	0.13^{a}	1.15^{a}	8.10^{b}	0.51^{abc}	0.54^{b}	33.90^{ab}	10.37^{ab}	0.33^{cd}
BARC + Biochar (2.5 kg/dec)	6.30^{a}	0.85^{b}	0.047^{a}	29.30^{b}	4.06^{ab}	0.14^{a}	1.28^{a}	8.98^{b}	0.48^{bc}	0.60^{ab}	40.43^{ab}	11.33^{ab}	0.81^{ab}
BARC + Biochar (5 kg/dec)	6.33^{a}	0.90^{ab}	0.053^{a}	30.03^{b}	4.55^{a}	0.13^{a}	1.38^{a}	17.04^{a}	0.60^{ab}	0.62^{ab}	40.93^{ab}	11.77^{a}	0.93^{ab}
BARC + Biochar (10 kg/dec)	6.67^{ab}	0.98^{a}	0.047^{a}	39.00^{a}	4.45^{a}	0.15^{a}	1.45^{a}	17.37^{a}	0.70^{a}	0.68^{a}	41.77^{a}	12.03^{a}	1.16^{a}

Data were means of three replicates. Means with the same letter are not significantly different. SOM = Soil Organic Matter.

Therefore, biochar addition to soil can provide a potential sink for C that results soil carbon sequestration.

CONCLUSION

This study demonstrated that red amaranth produced highest yield when 5 kg/dec plus BARC recommended fertilizer were applied to the field. Elevated biochar application did not have any significant effect on red amaranth productivity. This study concluded that optimum level of biochar should be applied with recommended dose of BARC fertilizer for getting high red amaranth production. However, high Biochar application (10 kg per decimal) was too high and would be expensive. Therefore, recycling crop wastes to biochar is strongly recommended to smallholder farmers for use in agriculture to improve fertility and crop productivity due to their high nutrient content and soil fertility attributes. Further research will be undertaken with same biochar and with same level of biochar for wheat production in the Nagaon district of Bangladesh.

ACKNOWLEDGEMENT

We thank the Christian Commission for Development in Bangladesh (CCDB) for technical and financial support. We also acknowledge Soil Resources Development Institute (SRDI) for measuring the soil basic physiochemical properties in the post-harvest soil.

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Citation: Islam M, Jalal S, Islam S, Hossain M, Işik M, Iqbal T, 2020. Akha biochar enhances soil fertility and productivity of red amaranth plant. Net J Agric Sci, 8(1): 1-7.