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RESEARCH PAPER

Akha biochar enhances soil fertility and productivity of red amaranth plant

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Biochar is a carbon-rich co-product resulting from pyrolyzing biomass. Its application to soil may increase fertility and productivity of soils. Biochar utilization as an innovative technology has undertaken by the Christian Commission for Development in Bangladesh (CCDB) for the improvement of marginal and poor including tribal ethnic communities. The utilization of biochar as a source of nutrients for red amaranth production in the field was investigated in this study at Naogaon district of Bangladesh. Red amaranth (*Amaranthus tricolor* L) is a short duration vegetable crop that cultivated throughout the year in Bangladesh. This study was also undertaken to assess the perception of the prospects of biochar produced through Akha Chula also known as mixed biochar was used as a biochar source. This study aims to obtain a proper dose of biochar for the growth and yield of red amaranth plants in the farmer's field. Biochar also serve fresh foods without chemical fertilizers and its sound for human health. 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 observed that the biochar used red amaranth were better appearance than fertilizer used red amaranth. Result also showed that biochar amendment significantly ($P \geq 0.05$) increased soil pH, soil organic matter, P, Ca, S, Zn, Cu, Fe, Mn and B in the bulk soil. This study concluded that biochar has the potential to improve soil fertility and productivity of red amaranth plant. Our findings urged that reduction of chemical fertilizer application is possible with supplementation of akha biochar.

Keywords: Pyrolysis, Akha Chula, Carbon Sequestration, Soil Organic Matter.

Abstract

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 – 800°C) in a limited oxygen environment. Biochar is distinguished from charcoal by its intended use to both improve soil properties and sequester soil carbon (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).

Biochar incorporation into agricultural soils has recently stimulated much scientific research due to its agronomic, financial and ecological benefits (Khan et al., 2013). Biochar amendment to soil has the potential to improve soil fertility and increase crop yield (Liu et al., 2017). Biochar application to soils has been shown to improve soil physical and chemical properties (Liu et al., 2012). Recent reviews have highlighted that biochar application can also stimulate plant growth and yield (Biederman & Harpole, 2013). Combined application of biochar and chemical fertilizer had a better performance than either alone, in terms of soil properties and crop yield (Glaser et al., 2015).

Red amaranth known as the scientific name of *Amaranthus tricolor* L. is a plant of shrubs are much loved by all levels of society. This red amaranth besides tastes good and soft also can facilitate digestion. Red amaranth as one source of antioxidants needs to be developed because of the potential as a vegetable is very useful because of the high content of phenols and flavonoids that 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. 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; Major, et al., 2010). Similarly, a single biochar application had been observed to provide benefits for crop nutrition for several years after an initial “neutral” year. 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 improve 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 akha or mix biochar field application with red amaranth plant productivity. Therefore, this study was undertaken with the aims: (i) To recommend 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 inorganic fertilizer will be improved red amaranth plant productivity.

Materials and methods

This section presents a brief description of different steps of the experiment are given below:

Chemical properties of 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). Physiochemical properties of the Akha biochar used in this study is shown as below in Table 1.

Table 1: Properties of Akah biochar used in this experiment

Element evaluated	Biochar
Physical condition	Dust
Colour	Black
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

Figure 1: Akah biochar used in this study

Plant

The red amaranth (*Amaranthus tricolor* L) variety Rangila was used as a testing plant. The yield performance of red amaranth is best among 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 plant was 2 kg/ha.

Akha biochar application to the field

Akah biochar was applied in the field according to Dias *et al.* 2010. Mix or Akha biochar was incorporated into the soil in the field during final land preparation. Mix or Akha biochar was evenly spread the desired amount onto the soil according to treatments, then tilled it in with by hand. Akha or Mix biochar was ground properly before mixing with soil. Mix or Akha biochar was added and mixed to the soil before 14 days of seed sowing.

Soils

The experiment was conducted at the brined tract region of Bangladesh. The experimental soil was located in the Naogaon region which was located at 5^{th} AEZs (Agroecological 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 was in between 4.8-6.0 (Bhuiya *et al*. 2005). The initial soil basic physiochemical properties of the experimental field soil are shown in Table 2.

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

Experimental design and treatments

The experiment was laid out in randomized complete block design (RCBD). The treatments were replicated three times in all 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 (T_5) BARC recommended fertilizer with biochar (10 kg /decimal).

Fertilizer additions

Several tiny fertilizer doses were added in separate plot according to BARC recommended fertilizer doses for red amaranth production in Bangladesh. Fertilizer was added according to initial soil basic physical and chemical properties. Magnesium was not added to the soil due its availability to the initial soil as well as availability within mixed biochar. The amount of fertilizer mixed within soil is shown in Table 3.

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 (Cowdung)	20 (kg/decimal)

Experimental procedure

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 1m × 1m. Seeds were well germinated before sowing. Red amaranth plant was harvested after 47 days after sowing (DAS) that was edible as a fresh vegetable.

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

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, plant weight were recorded.

Measurement of soil properties

The pH of the bulk soil was determined in deionized water using a soil-to-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).

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 mix biochar application on red amaranth leaf number

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

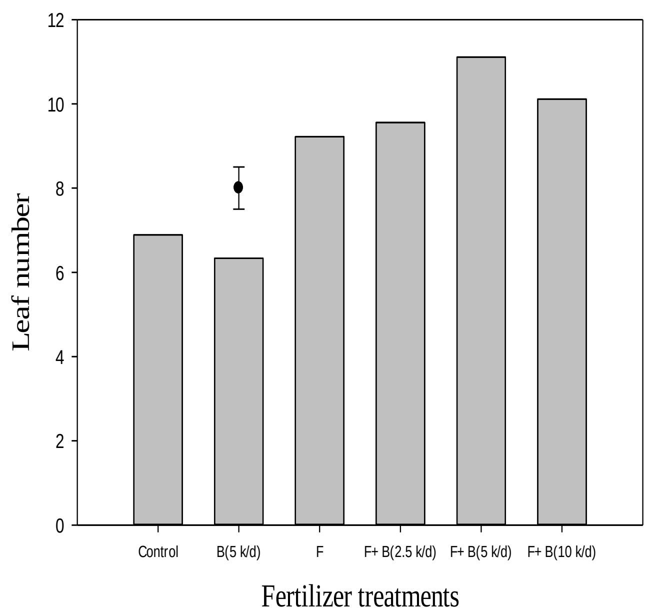

Figure 3: Effect of mix biochar application on leaf number of red amaranth plant. Vertical bar represents LSD ($P \geq 0.05$) for fertilizer treatments and leaf wide interaction. B means mixed biochar, F means BARC (Bangladesh Agricultural Research Council) recommended chemical fertilizer for red amaranth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

Effect of mix biochar application on red amaranth plant weight

Combined mixed 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.

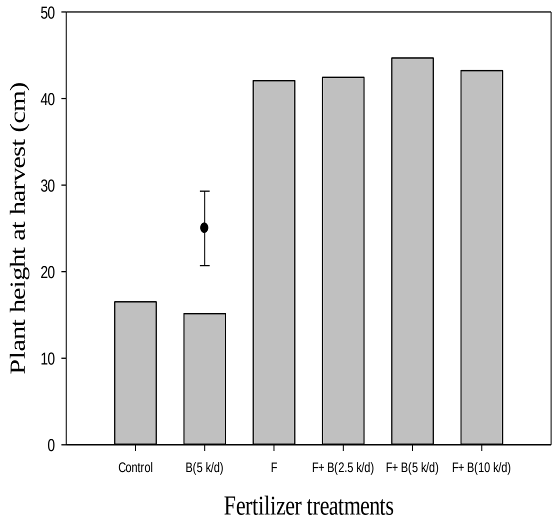

Figure 4: Effect of mix biochar application on red amaranth plant height for various fertilizer management. Vertical bar represents LSD (*P*≥0.05) for fertilizer treatments and leaf wide interaction. B means mixed biochar, F means BARC (Bangladesh Agricultural Research Council) recommended chemical fertilizer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

Effect of mix 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.

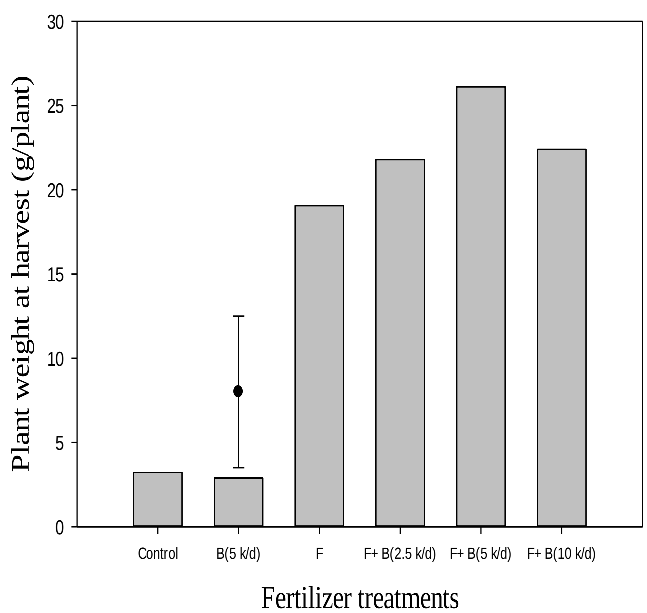

Figure 5: Effect of mix biochar application on red amaranth plant weight at harvest for various fertilizer management. Vertical bar represents LSD (*P*≥0.05) for fertilizer treatments and leaf wide interaction. B means mixed biochar, F means BARC (Bangladesh Agricultural Research Council) recommended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

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).

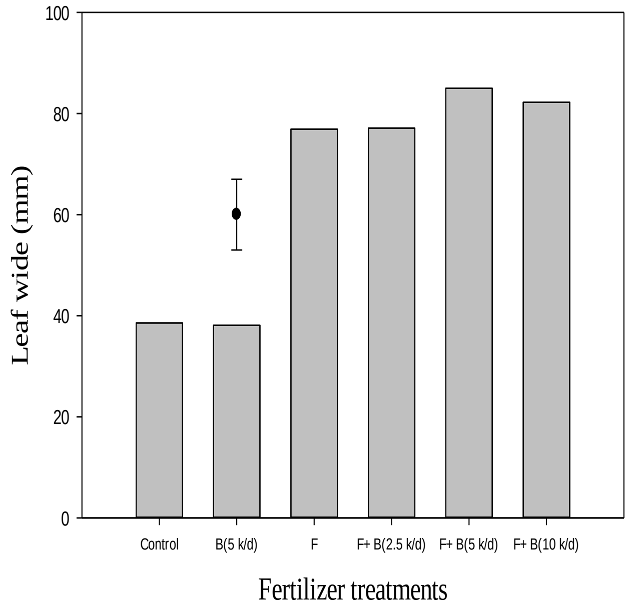

Figure 6: Variation of leaf wide of red amaranth plant due to different fertilizer treatment. Vertical bar represents LSD (*P*≥0.05) for fertilizer treatments and leaf wide interaction. B means mixed biochar; F means BARC (Bangladesh Agricultural Research Council) recommended chemical fertilizer for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

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.

Effect of mix biochar application on red amaranth leaf length

Combined application of mix biochar and inorganic fertilizer proliferate leaf of red amaranth plant. 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).

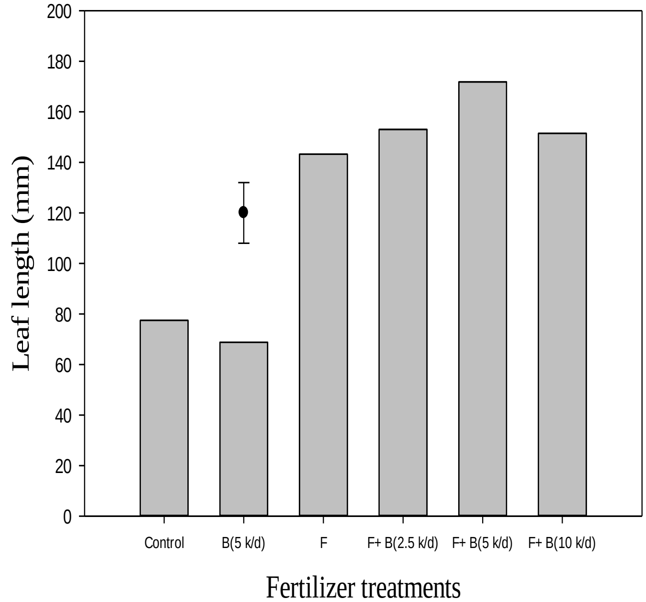

Figure 7: Variation of leaf wide of red amaranth plant due to different fertilizer treatment. Vertical bar represents LSD ($P \geq 0.05$) for fertilizer treatments and leaf wide interaction. B means mixed biochar; F means BARC (Bangladesh Agricultural Research Council) recommended chemical fertilizer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

Changes in soil physiochemical properties due to biochar amendment

Soil pH and soil organic matter increase due to biochar amendment within soil (Table 4). However, N, K, 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.

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

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

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 production. Application of mix biochar showed increased red amaranth growth parameters (Figure 3 to Figure 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). Findings demonstrated that application of akha biochar alone is not able to supply enough nutrients for the healthy growth of red amaranth plant.

The application of chemical fertilizer along with akha biochar resulted in an improvement of red amaranth production as shown by an increase in red amaranth biomass yield. This could be due to the reason that the effect of akha biochar on red amaranth production were mainly ascribed to the properties of akha biochar, soil physiochemical properties and red amaranth variety used in this study.

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. Akha biochar addition to soil improved soil physical and chemical properties as compared to soil without biochar amendment (Table 4). 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 (Figure 3 to Figure 7). The main reason behind akha 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, Ming *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.*, 2009). 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.

Soil organic matter increased from 0.83% to 0.98% in the highest akha biochar amended bulk soil (Table 4). Similarly, other study also found that bulk soil organic matter increased 0.54%–4.09% from control to biochar amended treatment (Masulili, Utomo, & Syechfani 2010). As akha biochar were partially decomposed during biochar preparation that results increase soil organic matter in bulk soil.

Bulk soil S content increased 6.60 to 17.76 ppm due to akha biochar amendment. Similarly, bulk soil B and Zn content increased 0,19 to 1.16 ppm and 0.40 to 0.70 ppm, respectively (Table 4). Other study also speculated that biochar also directly adds some macronutrients (P, K, Na, Ca, and Mg) and micronutrients (Cu, Zn, Fe, and Mn) which are needed for sustainable agriculture to the soil (Glaser, Lehmann, & Zech 2002).

Our findings showed that addition of akha biochar increase soil pH (Table 4). 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 4). 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). 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 applied to the field. In contrast, red amaranth productivity declined due to elevated biochar application. 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 in Bangladesh. 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. This study concluded that akha biochar has the potential to increase red amaranth plant productivity and can be act as a soil amendment. Further research will be undertaken with same biochar and with same level of biochar for wheat production in the Nagaon district of Bangladesh.

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