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Biochar application in alkaline soil and its effect on soil and plant

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Biochar application in alkaline soil and its effect on soil and plant

Abstract: Scientists reported that biochar can improve soil properties in acidic soils, while in alkaline soils were shown negative results. A field study was done to evaluate the effect of biochar application solely in alkaline soil compared with biochar composts with farm yard manure (BC-FYM) and sulfur (BC-S). The results revealed that using solely biochar decreased yield of potatoes tubers to more than 6 % and 10 % using mineral and organic fertilization, respectively. This was attributed to the alkalinity effect of biochar and raises the soil pH, which might precipitate macro and micro elements in soil and become unavailable for plant absorption. While using mixtures of BC-FYM and BC-S were shown to enhance yield productivity of potatoes tubers 11.7 % and equal to control under mineral fertilization; and 25.13 % and 10.53 % using organic fertilization, respectively. Mixture of BC-FYM and BC-S proved to have the ability for recovering the alkalinity effect of biochar, improve nutrients availability in soil and increase crop yield of potatoes. In general, mixing biochar with FYM was efficient, economical and environmentally sound solution in alkaline soils.

Keywords: biochar; alkaline soil; potatoes; nutrient availability; crop yield

Uporaba oglja na alkalnih tleh in učinek na tla in rastlino

Izvleček: Znanstveniki poročajo, da uporaba oglja izboljša lastnosti kislih tal, medtem ko so učinki na alkalnih tleh negativni. V poljskem poskusu so bili ovrednoteni učinki uporabe samo oglja v primerjavi z njegovo kombinacijo s hlevskim gnojem (BC-FYM) in žveplovimi spojinami (BC-S). Rezulati so pokazali, da je uporaba samo oglja zmanjšala pridelek krompirja za več kot 6 %, oziroma 10 %, ko je bilo gnojeno z mineralnimi in organskimi gnojili. To je bila posledica alkalnega učinka oglja preko dviga pH tal, kar je lahko oborilo mikro in makro elemente in jih naredilo nedostopne za prevzem v rastline. Uporaba mešanic BC-FYM in BC-S je povečala pridelek gomoljev krompirja za 11,7 %, kar je bilo enako kontrolnemu obravnavanju pri gnojenju z mineralnimi (25,13 %) in organskimi (10,53 %) gnojili. Mešanica BC-FYM in BC-S je imela dokazano sposobnost blaženja alkalnega učinka oglja, kar je izboljšalo dostopnost hranil v tleh in povečalo pridelek gomoljev krompirja. Nasplošno je bilo mešanje oglja s FYM učinkovita, ekonomsko in okoljsko dobra rešitev na alkalnih tleh.

Ključne besede: oglje; alkalna tla; krompir; dostopnost hranil; pridelek

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1 INTRODUCTION

Biochar is a carbon(C) -rich product obtained by thermal decomposition of biomass at relatively high temperatures (<700 °C) and absence of oxygen, in a process known as pyrolysis (Verheijen et al. 2010). Biochar claimed to have potential benefits for soil including water holding capacity (Busch et al., 2012; Busscher et al., 2010; Kammann et al., 2012; Karhu et al., 2011), water infiltration (Asai et al., 2009; Ippolito et al., 2012), soil water availability (Baronti et al., 2014), nutrient retention (Clough et al., 2013; Ventura et al., 2013), hydraulic conductivity (Buss et al., 2012), and soil aeration (Case et al., 2012; Cayuela et al., 2013), increased microbial activity (Lehmann et al., 2011; Warnock et al., 2007), shifts in microbial diversity (Jin, 2010), increase in electrical conductivity (Husson, 2012) and immobilization of contaminants such as trace elements (especially Cu) (Borchard et al., 2012; Buss et al., 2012; Ippolito et al., 2012) or pesticides (Gomez-Eyles et al., 2013; Graber et al., 2012). However, significant increase in soil fertility, plant growth and yield was reported due to biochar application in tropical and subtropical soils (Asai et al., 2009; Atkinson et al., 2010; Glaser et al., 2002; Lehmann and Rondon, 2006; Lehmann and Steiner, 2009a; Major et al. 2010). This was attributed to the liming effect of biochar which decrease significantly soil acidity, resulting in better conditions for growing crops (Steiner et al. 2007; Yuan and Xu2011). The application of biochar in alkaline soils showed different effects: the application of biochar solely lead to reduction in crop yield in alkaline soil. This was reported by many scientists (Ding et al., 2010; Graber and Elad, 2013; Jin, 2010; Taghizadeh-Toosi et al., 2011) who referred this effect to nutrients adsorption onto biochar surface (e.g. the adsorption of ammonium, phosphate and other cations). Consequently, to avoid the alkalinity effects of biochar, different suggestions were proposed, such as enhancement of biochar with organic or mineral nutrients (Alburquerque et al., 2012; Bruun et al., 2011; Gathorne-Hardy et al., 2009; Joseph et al., 2013a, b), composting BC with compost (Fischer and Glaser, 2012; Steiner et al., 2010), charge the porous biochar matrix with nutrients, stimulate microbial colonization (Pietikäinen et al., 2003), reduce noxious pyrogenic materials during production of BC (Tuomela et l., 2000), or increase the biochar surface reactivity using enhanced oxidative ageing (Cheng and Lehmann, 2009b; Zimmerman, 2010) as well as DOC adsorption (Prost et al., 2012). Thus, in the present study, we aimed to reduce alkalinity effect of BC through composting BC with farmyard manure (BC-FYM) and sulfur (BC-S) for enhancing the elements availability, crop yield and crop quality in alkaline soil as compared with freshly produced biochar (BC) under recommended mineral and organic fertilizer conditions.

2 MATERIALS AND METHODS

2.1 PRODUCTION OF BIOCHAR

Eggplant shoots were used to synthesize BC under low oxygen conditions using small-scale unit. The unit was designed as described by Abd el-hafez et al (2014). Briefly, barrel with a diameter of 55 × 85 cm was served as a burning barrel. For the lid, a well tight lid of the burning barrel with another half barrel inverted and supported with 20 cm diameter chimney tube was used to

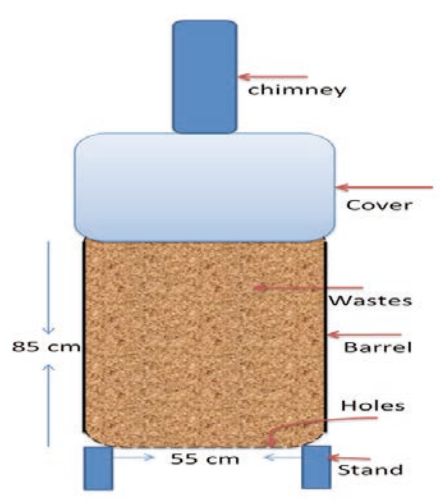

Figure 1: Scheme of designed unit for biochar production.

Table 1: Physical and chemical characteristics of the experimental soil

	Particle size distribution %						
Soil depth	Coarse sand	Fine sand	Silt	Clay	Texture class	OM %	$CaCO_3$ %
0 - 20	6.18	19.4	37.3	36.6	Clay loam	2.80	1.85
20 - 50	13.2	26.0	33.3	29.5	Clay loam	2.70	2.20
50 - 70	10.5	20.5	35.2	33.8	Clay loam	2.38	2.25

		EC	Soluble anions (mmol l^{-1})				Soluble cations (mmol l^{-1})			
Soil depth	pH	(dS m^{-1})	CO_2^{--}	HCO_3^-	Cl^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	K^+
0 - 20	7.93	3.41	0.00	1.80	26.70	4.50	9.20	6.40	19.90	0.50
20 - 50	8.01	3.52	0.00	2.20	25.30	6.50	10.00	5.50	18.00	0.50
50 - 70	8.02	2.32	0.00	1.70	14.60	3.70	9.00	3.20	10.50	0.30

cover the burning barrel (Fig. 1). The unit was stroked from the bottom in addition to three metal sheets were placed at the bottom of the unit to guarantee that the air derives up regularly. The produced biochar was denoted as BC. Then, BC was mixed and composted with farmyard manure (BC-FYM) and/or sulfur (BC-S) with a ratio of 1:1 (mass/mass) for 3 months. The stack was covered, stirred and moisturized every week. The final products were added to soil during soil preparation two week before sowing day. Different physical and chemical analyses were done on initial unfertilized soil as described below (Table 1).

2.2 EXPERIMENT SETUP

The investigation was carried out in Dokki site El-Giza governorate, Egypt which is situated at 30° 03` N latitude, 31° 20` E longitude during winter time of 2015 and 2016 to explain the effect of modified BC on growth and yield of potatoes (*Solanum tuberosum* L.) grown in alkaline soil. A field experiment was done at a clay loam soil, around 250 m^2 were roared and cleaned from weeds. This land was divided into plots (3 x 3.5 m), These treatments were evaluated at two kinds of fertigation (mineral and organic). Split plot design was used in this experiment as follows: main plots were divided into 1) mineral fertigation and 2) organic fertigation, while sub-main plots were used the different BC treatments including (□) control, (□) BC, (□) BC-FYM, and (□) BC-S. BC dose was fixed at 12 Mg ha^{-1} for each kind of BC. Each treatment was replicated three times. Required quantities of BC were added to the selected treatment plots and were mixed thoroughly with the soil using spade at January two weeks before sowing date. The recommended dose of NPK nutrients were added to all mineral fertilization treatments (including control) through ammonium sulphate, mono superphosphate and potassium sulphate, respectively. While full doses of P were applied as basal with BC, 50 % of the N and K doses were applied as basal and the remaining 50 % were top-dressed after 1 month from planting. Organic fertilization (30 t h^{-1-}) was applied according to N % before sowing with two weeks. Each plot was divided into three rows (width 90 cm and highest 30 cm). A tunnel was made in each row and tubers (‘Spunta’) were planted by hand at 10 cm depth and 25 cm spacing between tubers, then tunnels were covered with soil and the field was irrigated using drip irrigation. The soil was irrigated when required, and was kept weed-free by hand weeding.

2.3 EXPERIMENTAL ANALYSIS

Total N of biochar was determined in the supernatant of digested biochar by mixture of sulfuric and salicylic acid using Kjeldahl method according to Jones J. Benton. (1991), while total C of biochar was measured following ASTM1762-84 (American Standard of Testing Material, 2001). EC and pH of biochar was determined as described by Masulili et al (2010). Briefly, 1 g of material was dissolved in 100 ml de-ionized water under heating to 90 °C and stirred for 20 minutes. Then the suspensions were cooled to room temperature which after EC and pH was measured using EC and pH-meter (Masulili et al., 2010). To determine P and K soil samples were digested using hydrochloric and nitric acid (Cottenie et al., 1982), while for N determination another mixture of acids were used for digestion as described by Jones J. Benton. (1991). Nutrients accumulated in tubers were determined af-

Table 2: Chemical characteristics of materials used in the experiment

Parameter	FYM	Compost	BC	BC-FYM	BC-S
EC µS cm^{-1}	456	2080	1085	846	818
pH	7.00	7.6	7.6	7.4	6.9
OC %	34.80	12.5	38.20	37.78	36.63
C:N ratio	24.26	12.5	509.3	47.52	466.6
N %	1.40	1.00	0.075	0.795	0.0785
P %	0.071	0.41	0.074	0.136	0.044
K %	0.085	0.32	0.003	0.042	0.002
Fe %	1.90	0.35	1.21	0.906	0.61
Mn mg kg^{-1}	423.60	61.9	257.75	269.70	121.65
Zn mg kg^{-1}	77.25	79.2	81.25	107.15	0.60
Cu mg kg^{-1}	39.40	24.1	45.35	43.30	30.55
B mg kg^{-1}	19.15	32.6	14.40	14.00	8.30

ter digestion using mixture of sulfuric and perchloric acid (5:1). P was determined in the solution digested using inductively coupled plasma (ICP- JY ULTIMA). Chemical analysis results for materials used are in Table 2.

2.3.1 Quantitative determination of surface acidic groups

Biochar surface acid functional groups were determined according to the description of Boehm titration method (Boehm et al., 1964 and Mukherjee et al., 2011). Briefly, about 0.5 g of coarse biochar sample was added to 50 ml of each of three 0.05 M bases of $NaHCO_3$, Na_2CO_3 and NaOH. Then, the mixtures beside control solution without any material were shaken for 24 h. Thereafter, the mixtures were filtered through a 42 Whatman filter paper to remove solids. Then, a 1 ml of suspension from each filtrate was added to 10 ml of HCl (0.05 M) to guarantee complete neutralization of bases and then back-titrated with NaOH (0.05 M). Phenolphthalein color indicator was used to identify the endpoint. The total surface acidity was calculated as the moles neutralized by NaOH, and the carboxylic acid groups as the moles neutralized by $NaHCO_3$, and the lactonic groups as those neutralized by Na_2CO_3. The difference between moles neutralized by NaOH and Na_2CO_3 was considered as phenolic groups content (Rutherford et al., 2007).

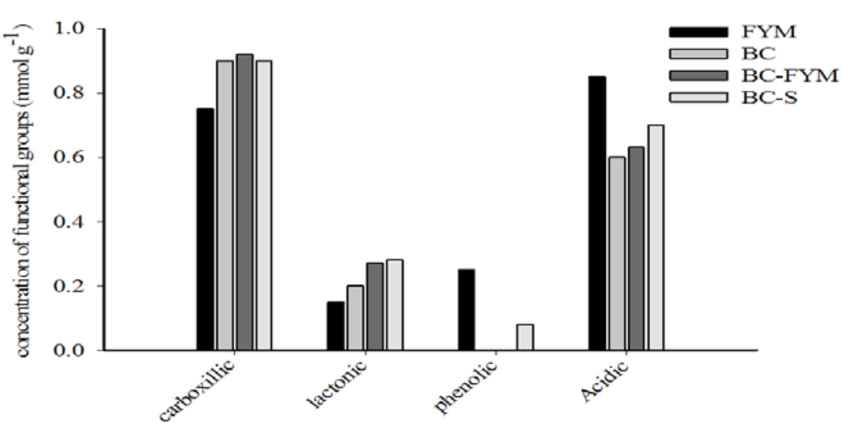

Figure 2: Functional groups concentration on the surface of used materials

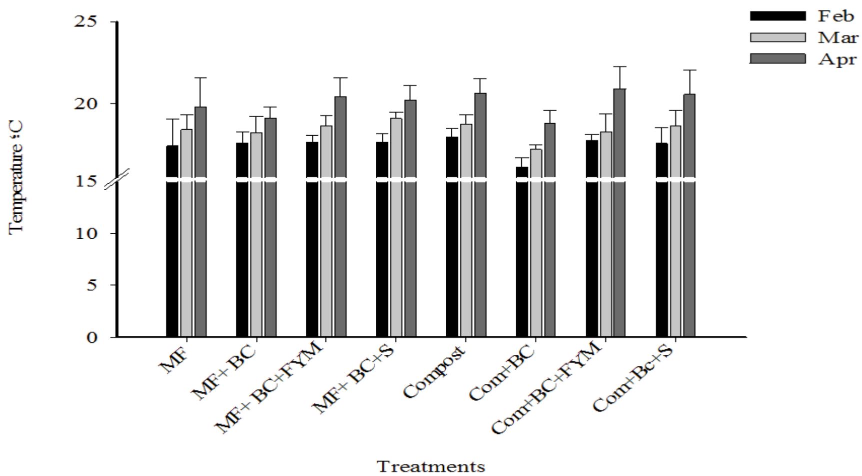

Figure 3: Influence of biochar on soil temperature during three months of potato cultivation in alkaline soil

2.3.2 Determination of total carbohydrates

Acid hydrolysis of tubers (0.2 g) was done in sealed tube using 10.0 ml H_2SO_4 solution (1.0 M). The sealed tubes were boiled in water bath for 10 h. After complete hydrolysis, suspension was neutralized by a known amount of barium carbonate and the precipitate was filtered through whatman No.1 filter paper. The filtrate was made up to a known volume. Total carbohydrates were determined in acid using phenol-sulfuric acid method as described by Dobois et al. (1965) as follows: A known volume of filtrate (1.0 ml) was transferred into a clean dry test tube. 1.0 ml of phenol solution (5 %) and 5.0 ml of H_2SO_4 were added. The yellow orange color was measured at 490 nm using spectrophotometer against blank.

3 RESULTS AND DISCUSSION

3.1 BIOCHAR CHARACTERIZATION

Yield of BC (as the mass ratio of biochar recovered after pyrolysis and the initial feedstock) was approximately 35 %, while BC carbon content was recorded 38.2 %. Biochar pH (extracted according to Masulili et al., 2010) was slightly decreased using FYM and S from 7.6 for BC to 7.4 and 6.9 for BC-FYM and BC-S, respectively. These finding were already proven by Boehm titration method which is commonly used technique to determine the acidic oxygen surface functional groups on carbon samples. The total acidic groups were slightly higher in BC-S and BC-FYM than BC (Fig. 2). This was attributed to the acidic products resulted from decomposition of FYM or formation of $SO_4^{=}$ anions during hydration of sulfur in BC-FYM and BC-S, respectively. This might explain how pH values of BC-FYM and BC-S were decreased compared to BC alone.

3.2. INFLUENCE OF BIOCHAR APPLICATION ON SOIL PROPERTIES.

3.2.1. Soil temperature

McCormack et al. (2013) reported that biochar enhances soil microbial activity by enhancing soil aggregation and porosity, pH, moisture retention and soil temperature, as well as nutrient retention. This work studies the effect of BC and modified-BC application on soil properties such as nutrient availability, soil temperature and chemical characteristics. The influence of different treatments of biochar on soil temperature during field study is shown in Fig. 3. Soil temperature was measured monthly during potato growing season (Quartz digi-thermo thermometer). The results revealed that soil temperature was higher using BC-FYM and BC-S by 0.9 to 2.1 °C as compared with control or biochar only. This might be attributed to the high energy release during decomposition of FYM or sulfuric acid that resulted from hydration of sulfur. It was also mentioned that biochar has positive effect on soil biota (Lehmann et al., 2011; Warnock et al., 2007) which might increase soil temperature. In general, soil temperature has an important role creating a healthier and more active soil environment. Soil biota plays an important role in soil nutrient cycling (McLaughlin et al., 1988; Frossard et al., 2000). Phosphate-solubilizing bacteria enhance P transfer from soil to plants: soil biota may contain a significant amount of P, typically 10–50 kg

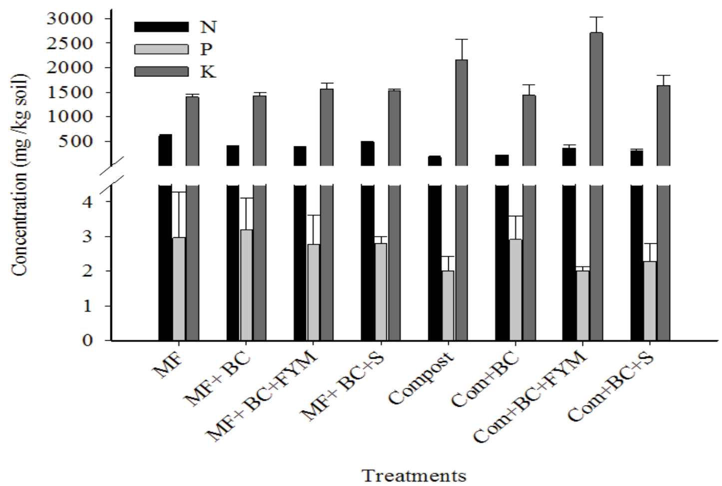

Figure 4: The influence of biochar and modified biochar on nutrient availability of macronutrients in alkaline soil cultivated with potatoes

P ha^{-1}, or 1–10 % of the total P, and around 10–15 % of soil organic P (Brookes et al., 1984; Richardson, 2001), so soil biota considered a major factor controlling organic and inorganic P concentrations in temperate soils (Seeling and Zasoski, 1993). All these findings showed that BC plays an important role in nutrient availability and yield due to its effect on soil temperature and soil biota. Soil temperature increased from February to April due to climatic conditions (Fig. 3).

3.2.2. Soil nutrient availability

Glaser et al. (2002) and Lehmann et al. (2011) reported that biochar used as a soil amendment to enhance soil fertility and plant growth, since it has shown potential as a sustainable amendment to improve chemical properties of soil. BC also was found to have a positive effect on soil nutrient availability (Mengel and Kirkby, 2001). In this study we investigate effect of biochar treatments on soil nutrients availability during field study on potatoes. Available NPK were measured in soil 70 days after planting (Fig. 4). The results revealed in general, that using solely biochar lowered the nutrient availability in soil, since biochar application generally raises soil pH (Hass et al., 2012) which reduces the availability of nutrients in alkaline soil. Modified biochar (BC-FYM or BC-S) showed higher nutrient availability than control despite the sig-

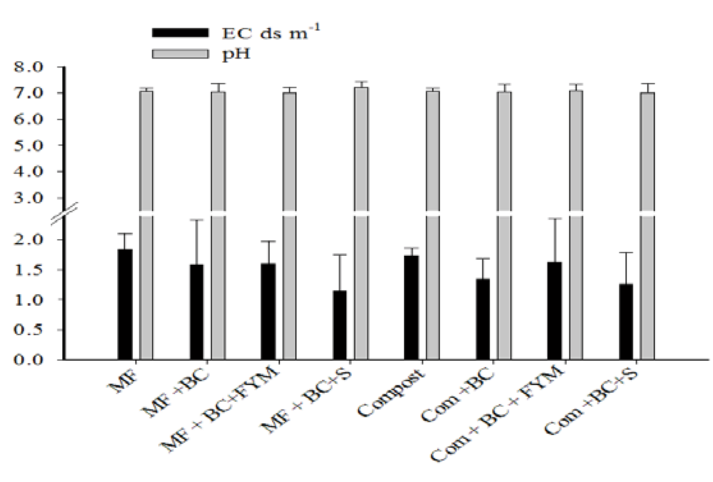

Figure 5: Influence of BC addition onto soil characteristics (EC and pH)

nificance was low in some cases. This might be attributed to excess of the amount of nutrients that exist in FYM composted with biochar or/and decomposition of organic matter or sulfur had led to decrease of soil pH which release more nutrients adsorbed or precipitated into soil solution. Biochar was also found to have an important role in fertilizer use efficiency due to adsorption of nutrients on its surface and keep it from leaching (Blackwell et al., 2010; Laird et al., 2010). In addition, BC was found to improve soil biota, such as arbuscular mycorrhizal fungi (AMF), which enhance nutrient availability in soil (Warnock et al., 2007).

3.2.3. Chemical characteristics

Figure 5 shows the influence of materials studied application onto soil chemical characteristics (EC and pH). The pH level of alkaline soils would be affected by biochar application and the possible increase of soil pH in alkaline soil is harmful for plant growth (Liu and Zhang, 2012). While the results revealed that EC and pH of soil weren't affected significantly by the addition of BC or modified BC (BC-FYM or BC-S). This was attributed to the amount of added BC amendment (12 Mg ha^{-1}), which was not enough to change the pH number. These results were agreed with those obtained by Somchai-Butnan et al. (2015) who found that soil pH was not affected by biochar amendment except in the soil amended with the highest rate of flash carbonization (FC) biochar excess than 12 Mg ha^{-1}. Biochar relatively reduced soil EC, this might be attributed to the high adsorption capacity of biochar which enhance the mutual form and reduce the soluble form of salts.

3.3. INFLUENCE OF BIOCHAR APPLICATION ON PLANT CHARACTERISTICS.

3.3.1. Crop yield

Influence of studied materials on the productivity of potatoes tubers is shown in Fig. 6. The results revealed that solely addition of biochar decreased the yield of potatoes more than 6 % and 10 % as compared with control using mineral and organic fertilization, respectively. This was attributed to the alkalinity effect of biochar which reduce the availability of some nutrients; consequently the total yield was reduced. These results are similar as those obtained by Van Zwieten et al. (2010), who reported that the application of biochar 1 with pH value of 9.4 and biochar 2 with pH value of 8.2 both increased the pH of ferrosol (initial pH at 4.2), but only biochar 2 increased the pH value of calcareous soil (initial pH at 7.67). Also Fellet et al. (2011) reported that application of BC in mine tailing soil had led to excess in soil pH from 8.13 to 10.2 at 10 % biochar application rate. Treatment BC-FYM resulted in yield increase for 11 and 25 % in both mineral and organic fertilization. This was similar to the results reported by Glaser et al. (2002) who concluded the fact that crop yield is increased using biochar combined with mineral or organic fertilizers. BC-FYM application with organic fertilization produced higher yield than mineral fertilization due to the acidity effect of compost which decreases alkalinity of BC. It benefits in releasing nutrients slowly in available form for plant absorption during growth period. This led to minimizing nutrient leaching from soil rather than mineral fertilization. Also, we found that the yield was much higher using BC-FYM than BC-S with both types of fertigation. This

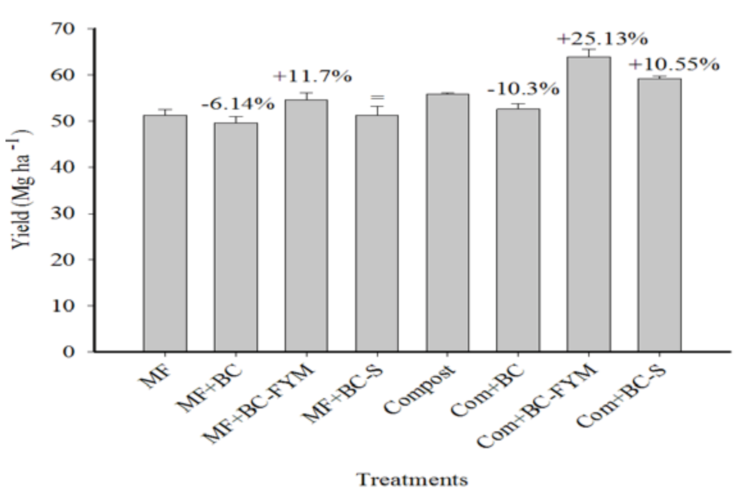

Figure 6: Biochar addition efficacy on yield of potato tubers cultivated in alkaline soil

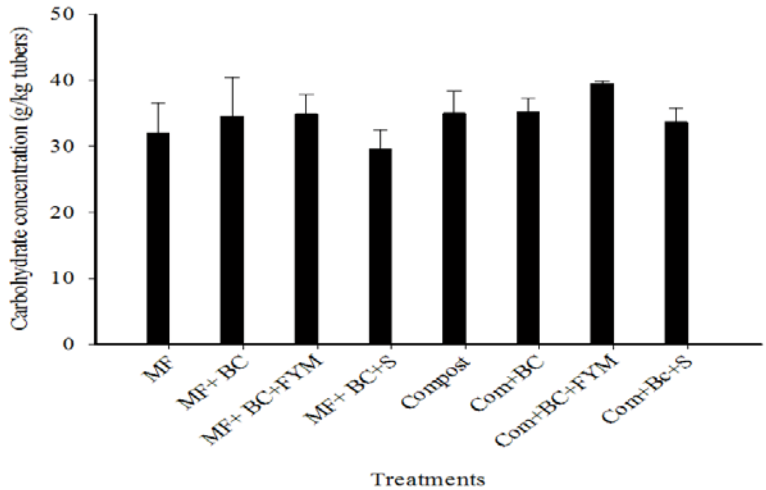

Figure 7: Biochar addition efficacy on carbohydrate concentration of potatoes tubers cultivated in alkaline soil

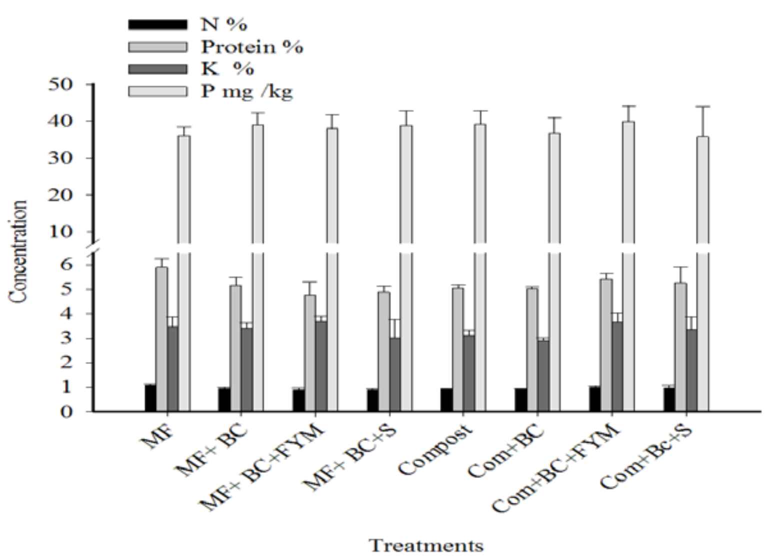

Figure 8: Biochar addition efficacy on content of macronutrients in tubers

might be attributed to the additional amounts of N exist in BC-FYM and/or higher nutrient availability due to higher microbial activity, such as arbuscular mycorrhizal fungi (AMF) (Warnock et al., 2007). So we recommend using BC in alkaline soils after composting with FYM to enhance crop productivity and soil chemical characteristics. More work is needed to state the adequate amount of BC added.

3.3.2. Yield component

Total carbohydrates in potatoes tubers were measured to study the efficiency of biochar addition on yield component grown in alkaline soil compared with modified biochar (BC-FYM or BC-S) (Figure 7). Total carbohydrate was significantly increased using BC-FYM or BC-S as compared with using BC solely, while there wasn't any significance with control. This was attributed to the excess amount of potassium in FYM found in BC-FYM, which are responsible for carbohydrate transferring from leaves to tubers. Since BC has a high adsorption capacity for K ions (Lehmann et al., 2003) because of its high porosity and surface/volume ratio and can improve plant nutrients uptake and P, Ca, K availability (Chan et al., 2007; Yamato et al., 2006). Elemental concentration of N P K in potatoes tubers weren't significantly affected by biochar treatments (Fig. 8). Consequently, protein content wasn't also affected by biochar addition, with the exception of BC-FYM and BC-S using organic fertilization where a significant increase in tubers protein content was measured than in control and BC solely.

4 CONCLUSION

Biochar proved to enhance soil chemical and physical properties, while this effect was negative in alkaline soils since literature reported that BC raise soil pH. Composting biochar with other materials (FYM and Sulfur) was suggested to modify biochar action in alkaline soil. A field experiment was conducted using modified BC (BC-FYM or BC-S) compared with BC solely addition to alkaline soils under mineral and organic fertilization. BC-FYM proved to be the best treatment, since BC-FYM increased crop yield of potatoes 11 and 25 % compared to control under mineral and organic fertilizers, respectively. BC-FYM was recorded higher amount of carbohydrate and protein as compared with BC solely especially under organic fertilization. Yield content of elements (N P K) in potatoes tubers weren't affected significantly with biochar application as found in carbohydrate concentration. So we recommend composting biochar with FYM before using it in the alkaline soil to enhance crop productivity and soil chemical characteristics. More work is needed to state the adequate amount of BC added.

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