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Effect of Biochar Source, Particle Size and Application Rates on Soil Properties and Maize Yield (*Zea mays L.*) under Sandy Soil Conditions

Abdel-Hamied, A. S.[1*] and A.M. El-Shiekha[2]

[1]Department of Soil Sciences, Faculty of Agriculture, Damietta University, Damietta 34517, Egypt.
[2]Department of Agricultural Engineering, Faculty of Agriculture, Damietta University, Damietta 34517, Egypt.

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ABSTRACT

In Egypt, huge additions of mineral fertilizers are considered a thoughtful issue, so the scientific hypothesis of this study based on application of biochar could improve organic matter contents and reducing nutrients leaching as well as maize performance under sandy soil conditions.Two field experiments were conducted to study soil properties and maize yield (*Zea mays L.*) in sandy soils amended with different two lignocellulosic-based biochars i.e., *Casuarina equisetifolia* tree chips (WC) and guava chips (*Psidium guajava L.*) (GC) which were generated into two particle sizes i.e., large ground (L-ground; 2 – 4 mm) and small ground (S-ground; 0.06 – 0.5 m) and their application rates of 0, 4 and 8 t fed^{-1}. The obtained results revealed that small ground biochar exhibited elevated soil quality and enhanced plant performance than large ground particle biochars. Better soil quality and enhanced maize growth to GC biochar than WC biochar treatment were recorded. Further, the amount of biochar application had marked influences on maize grain yields thereafter maximum application rate of 8 t fed^{-1} showed the greater performance to 4 t fed^{-1}. While, the highest mean values of available N, K, oxidizable organic carbon (OOC) in soil were noticed at 8 t fed^{-1} treatment with S-ground biochar processed from WC compared with the other treatments. Biochar amendment at 8 t fed^{-1} caused maximum values in soil available P, organic matter, dissolved organic matter (DOC), stover and grain yields, harvest index, protein (%), P uptake by maize grains with S-ground GC biochar compared to the other treatments.

Keyword; Sandy soils, Lignocellulosic-based biochars, Particle sizes, Biochar rates, Maize plant

INTRODUCTION

Globally, population is growing every day by 2050 it is anticipated to reach 9 billion (Haider *et al*. 2017). So, the food challenges, energy and freshwater upsurge progressively (Haider *et al*. 2017; Zabel *et al*. 2014).

Soils play an essential role in the carbon cycle and account for more than two-thirds of the carbon stocks on terrestrial lands (Lal, 2004). Moreover, sandy soils are characterized by low water-holding retention, high infiltration rates, high evaporation, low fertility levels, and very low organic-matter content that may induce low water and fertilizer use efficiency (Selim and Mosa, 2012). Therefore, precise management settings are principle for development of these sandy soils in Egypt.

With respect to a soil-amendment carbonaceous substantial, biochar, or black carbon, generated by pyrolysis of biomass under low oxygen fluxes, represent 1– 10 % of total soil organic matter (Gustafson & Gschwend, 1997; Verheijen *et al*. 2010and Zhang *et al*. 2015). Due to biochar particles have a great specific surface area, it acts as a soil modifier which results in markedly enhanced crops and improved soil quality (Feng and Zhu 2017).

Concerning particle size, it is a considered effective factor in biochar properties which has potential interactive effects between soil and biochar, because of smaller biochar particles will basically have greater physical features with soil aggregates (Sigua *et al*., 2014 and Chen *et al*., 2017). Further, there is evidence that biochar with minor particle sizes can increase nutrient and organic compound sorption (Xie *et al*., 2015). In this regard, Sun *et al*. (2012) reported that the smaller the feedstock particle size-based biochar, the greater the soil porosity. Also, smaller biochar feedstock particles enhance the release rate of volatile organic materials and syngas and the biochars having smaller particle sizes might greater plant nutrient availability (Sigua, *et al*., 2014). Further, it could be forecasted that the large biochar particles may improve porosity, elevate oxygen in the pore space between the soil particles and enhance the root elongation. On the other hand, coarser biochar particles can have larger macropores and generate larger spaces between biochar particles and soils (Trifunovic *et al*., 2018).

The effects of biochar in soil amendment totally depend on the application rate and methods of biochar that are applied to the soil (Edenborn *et al*. 2015; Chan *et al*. 2007 and Hagner *et al*. 2016). It improves soil physical properties such as bulk density, water holding capacity, permeability, chemical properties such as nutrients retention of soil for nitrogen, phosphorus, and potassium thereby increases the stability of soil organic carbon (Wardle *et al*., 2008 and Kameyama *et al*., 2014 and Shimotsuma *et al*. 2017), cation exchange capacity, and microbial biomass and thus eventually augmented the yield of cropping system (Glaser *et al*., 2002; Lehmann *et al*., 2006 and Sarfraz *et al*., 2017).

Normally, biochar has a strong adsorption capacity for nitrate (NO_3^-) and ammonium (NH_4^+) due to its porous properties (Shenbagavalli and Mahimairaja 2012). It can

[*] **Corresponding author.**
E-mail address: ahmedsalah@du.edu.eg
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increase the retention of ammonium- N in soil (Taghizadeh-Toosi *et al*. 2012), enhance N immobilization, minimize the volatile ammonium (Rondon *et al*. 2007), and improve the availability of nitrogen for agricultural crops (Rondon *et al*. 2007 and Sarfraz *et al*., 2017). However, the application of biochar to the coastal saline soils with appropriate rates reduces N leaching and not increasing NH^{+}_{3} volatilization (Clough and Condron 2010 and Sun *et al*., 2017).

Maize (*Zea mays L.*) is a versatile as well as complete cereal crop proving food for human being and feed for animals, particularly in poor and arid lands which are cultivated in summer as well as spring season for fodder and grain purpose in many developing countries (Ali *et al*., 2016). It provides the majority of raw materials for the livestock and numerous agricultural products worldwide (Bello and Olaoye 2009) and it contains vitamins and some essential nutrients for metabolic pathways (Orhun, 2013).

Although the optimistic influence of biochar on soil properties and crop yields has been reported, the obtained information respect with biochar impact is still sparse. With respect to maize crop, effective responses of maize yield indices to biochar as soil amendment have been reported and the positive responses were principally due to enhancing water retention of the soil, the same as a result throughout the growing season nutrients availability, moisture content were increased (Sarfraz *et al*., 2017 and Liao and Thomas, 2019).

However, there is steady progress in the recent decays on biochar research, however, the influence of biochar characteristics on carbon sequestration, C and N cycling, and yield response of crops in various soils still little is known and the application of biochar and its influence on physical and chemical characteristics of soil and crop growth in sandy soil also remain unclear. Thus, the main hypothesis of the current study is based on the following objectives: (1) to determine the biochar sources, particle sizes, amounts of applied biochar and their interactive effects on maize growth and yield parameters, and (2) to assess the residual effect of biochar amendments on some soil properties after maize harvesting.

MATERIALS AND METHODS

Description of experimental site: -

A trial was set up as a field experiment in a private farm at Kafr El-Batiekh city (31°24′ 14.33″ N, 31° 44′ 16.01″ E.), Damietta governorate. This site characterized a hot dry in summer and slight in rainy winter. Also, it is famous for many sources of charring biomass such as guava, mango farms, wood and palm trees which cover the north coast at the Mediterranean Sea that represents as fuel or direct addition to soil as an amendment. Thus, there will often be an opportunity cost if biomass is renewed to biochar manufacturing. In arid regions, biomass availability is less and the opportunity cost of charring biomass is likely to be higher. In other situations, the opportunity costs of using available biomass for biochar production will be much lower and in cases where the old guava and wood trees are an unwanted waste product, its use for biochar production might reduce disposal costs. Considering the low use of inorganic fertilizers in Egypt, smallholder farming systems and the potential availability of biomass waste, there is huge potential for pyrolysis of biomass for soil fertility improvement.

Design of Experiment and planting

The experimental design was Split-split plot under randomized complete block design with three replications. The whole plots were assigned biochar source i.e., old wood and old guava chips; the Sub- plot to the biochar particle size i.e., large ground; L-ground and small ground; S-ground while the sub-sub plot was for the three biochar rates 0, 4 and 8 t fed^{-1}. The distance between the plants was 25 cm and row to row distance was 75cm. The net harvested plot area was 4 m^2. Recommended rates of fertilizers are used as follows: N = 200 kg fed^{-1}, P = 60 kg fed^{-1} and K = 40 kg fed^{-1}. Urea (46% N), single superphosphate (SSP) (16% P_2O_5), and potassium sulphate (SOP) (52% K_2O) were used as sources of N, P, and K in the field experiment, respectively. The first half dose of nitrogen was used at the first irrigation, the remaining half dose of nitrogen further divided into two equal amounts; one half was side dressed at knee high stage and remaining dose was side dressed at tasseling stage. All agricultural practices were kept in the same normally practiced according to the recommendation of ARC. Before planting two-week age, the generated biochar was added to the sandy soil by broadcasting and manually incorporated with a dig to 0-15cm soil depth approximately.

Maize (*Zea mays*) seeds were sown on 15^{th} May in the first and second seasons, respectively. corn seeds were hand sown (dry sowing method) on one side of the ridge in hills 25 cm apart at the rate of 3-5 seed/hill and the plots were irrigated immediately after sowing. After one month, plants were thinned to two plants /hill and singled to one plant/hill after 30 days from sowing. The other agricultural practices were kept in the same normally practiced according to the recommendation of ARC. A top soil sample was taken from the examined soil in both seasons. The soil sample was air-dried and passed through 2-mm sieve. The sample was then subsequently analyzed for various soil properties (Table 1). Basic soil properties were analyzed by commonly used laboratory methods (Haluschak, 2006).

Table 1. Some physico-chemical properties of experimental top soil.

Particle size distribution (%)				Texture class	Chemical properties					
Coarse sand	Fine sand	Silt	Clay		O.M (%)	EC (dSm^{-1})	pH (1:2.5)	Available nutrients (mg kg^{-1}soil) N	P	K
1^{st} s season										
10.65	70.69	5.30	13.36	Sandy Loam	0.75	3.82	7.85	36.1	5.2	67.5
2^{nd} season										
10.25	70.99	5.61	13.25	Sandy Loam	0.78	3.61	7.78	37.8	6.1	75.1

Biochar production, particle sizes, and preparation: -

Biochar was generated from *Casuarina equisetifolia* tree chips (wood tree chips (WC)) and guava (*Psidium guajava L.*) tree chips. After fully air drying, wood chips samples were pyrolyzed using slow pyrolysis with top temperature of 400°C for 3 h with a special biochar's pyrolysis Kiln El-Sheikha and Hegazy (2020).

The ground biochars were produced from pyrolyzed wood chips and divided into two sizes; The large ground (L-ground) biochar was ground with a mortar and pestle and then sieved through a 4 mm sieve, with collection by a 2 mm sieve. While, the small ground biochar (S-ground) was ground with a laboratory mill and then sieved by a 0.5 mm mesh and collected by a 0.0635 mm mesh. The chemical characteristics of biochar used in this study are shown in Table 2.

Table 2. Some chemical analysis of ground biochar guava and wood tree chips.

Biochar sources	Particle sizes	Physicochemical parameters					Available nutrients (mg kg^{-1}biochar)		
		BD g cm^{-3}	pH (1:2.5)	EC (dSm^{-1})	TOC g kg^{-1}	TN (%)	N	P	K
Wood tree chips	L-ground	1.09	8.22	0.40	894	0.98	105	15	240
	S-ground	1.01	8.45	0.50	880	1.2	200	20	270
Guava tree chips	L-ground	1.00	8.12	0.44	914	1.32	105	17	234
	S-ground	0.89	8.25	0.54	980	1.42	200	23	280

Plant growth parameters: -

Plant height was measured in centimeter (cm) with the help of a meter rod from soil surface to the top of the plant at the harvest stage. Mean plant height was calculated by taking average of three replications. Fresh and dry biomass was calculated by taking mean values of replicate plants using an electric balance. Stem width (cm plant^{-1}) was determined at harvest stage a 10 cm from soil surface.

Estimation of total carbohydrates and protein contents in grain maize: -

Total carbohydrate percentage was determined in maize grains after dried at 70 and ground as described by (Shumaila and Safdar, 2009). While, protein percentage was calculated by the following equation: - Protein percentage = N% in grain x 5.57.

Plant sampling analysis: -

Air-dried shoots and grains of harvested maize plants were oven dried at 70°C to obtain a constant weight. After recording shoot dry matter, oven-dried samples were then ground with stainless steel blade and stored for analysis. Wet digestion was done with sulfuric acid and perchloric acid in a digestion block until a colorless extract Cottenie *et al.,* (1982). In the digesting solution, nutrients i. e., phosphorus, nitrogen and potassium were estimated according to the methods of AOAC International (2012). Nitrogen was tested in grain tissues by using Kjeldhal method subsequently N was calculated by the following formula: % N = (T x N x1.4)/sample weight (T = volume of acid used for titration (mL), N = normality of acid = 0.0l N, and sample weight = 0.1 g. Also, potassium was determined using the Flame photometer model PFP7 while phosphorous was determined by calorimetric method by using spectrophotometer. Finally, N, P, and K uptake were calculated as the following formula: Nutrient uptake (kg fed^{-1}) = N % in grains x dry matter of grain in kg fed^{-1}/100 (Sharma, *et al*. 2012).

Soil sampling analysis: -

After maize harvesting, composite samples at 0–15 cm depth of topsoil were collected by soil core sampler from each plot. The samples were sealed in plastic bags and shipped to the laboratory within 2 days after sampling and stored to set the further analysis. Soil was extracted by using 2.0 N KCl according to van Reeuwijk (2002) to determine the available nitrogen. using half automatic kjeldhal apparatus. While, the soil was extracted by using 0.5 N $NaHCO_3$ - at pH, 8.5 according to van Reeuwijk (2002) to estimate available phosphorus in this extraction. Extractable K in soil was set 1.0 N (CH_3 $COONH_4$) according to Carter and Gregorich (2007) and measured by using Flame photometer model PFP7. Soil organic matter content was determined by Walkley black rapid titration method as described by Hesse (1971). Dissolved and oxidizable organic carbon was estimated as describe by Tatzber, *et al*. (2015).

Statistical analysis: -

Data were statistically analyzed using descriptive statistics and analysis of variance (ANOVA). Based on a split split-plot with randomized complete block design (RCBD), the effect of biochar source and its rates as well as their interactions were computerized using statistical software SPSS 17.0 and graphs were prepared by using Origin 8.0 (Origin Lab Corporation, USA). Means of treatments were considered significantly different using the least-significant-differences test (LSD) at the confidence level of 5% according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect of biochar source, particle size and application rates on soil properties after maize harvesting: -

Under the current study, the effect of source, particle size, application rates and their interactions of biochar are presented in Figs 1 (a, b, c & d) and 2 (a, b & c). Generally, application rates of generated biochar either in large ground (L-ground) or small ground (S-ground) with *Casuarina* tree chips (WC) or guava tree chips (GC) caused significantly improvement in some chemical properties of soil after maize harvesting such as N-NO_3, available-P and extractable K nutrients (mg kg^{-1} soil) and organic matter decomposition in the soil.

It is noticeable that N-NO_3, available-N, P and extractable K nutrients in the soil were significantly affected by main and interactive effect of biochar source, particle sizes and application rates. N-NO_3, available-N, P and extractable K nutrients in the soil were greater for treatment under *Casuarina* tree chips biochar than under guava tree chips biochar, and higher for treatment under S-ground than L-ground biochar. Also, biochar amendment at 4 and 8 t fed^{-1} caused a significant increase in N-NO_3 available-N, P and K nutrients in soil. The interaction effect of biochar source, particle size and application rates were also significant as illustrated in Fig. 1 (a, b, c & d). Biochar amendment at 4 t fed^{-1} caused a highest mean in soil N-NO_3 by 111.96 mg kg^{-1} soil with S-ground old wood chips biochar as compared with the other treatments (Fig 1 a). While, the highest means of available N and K in soil were 75.25 and 454.38 mg kg^{-1} soil noticed for the treatment having biochar at 8 t fed^{-1} with S-ground Casuarina tree chips biochar as compared with the other treatments, respectively as illustrated in Fig 1 (b & d). However, Fig. 1 (c) showed that the maximum soil available P was 18.29 mg kg^{-1} soil recorded for the treatment having biochar at 8 t fed^{-1} with S-ground old guava chips biochar as compared with the others.

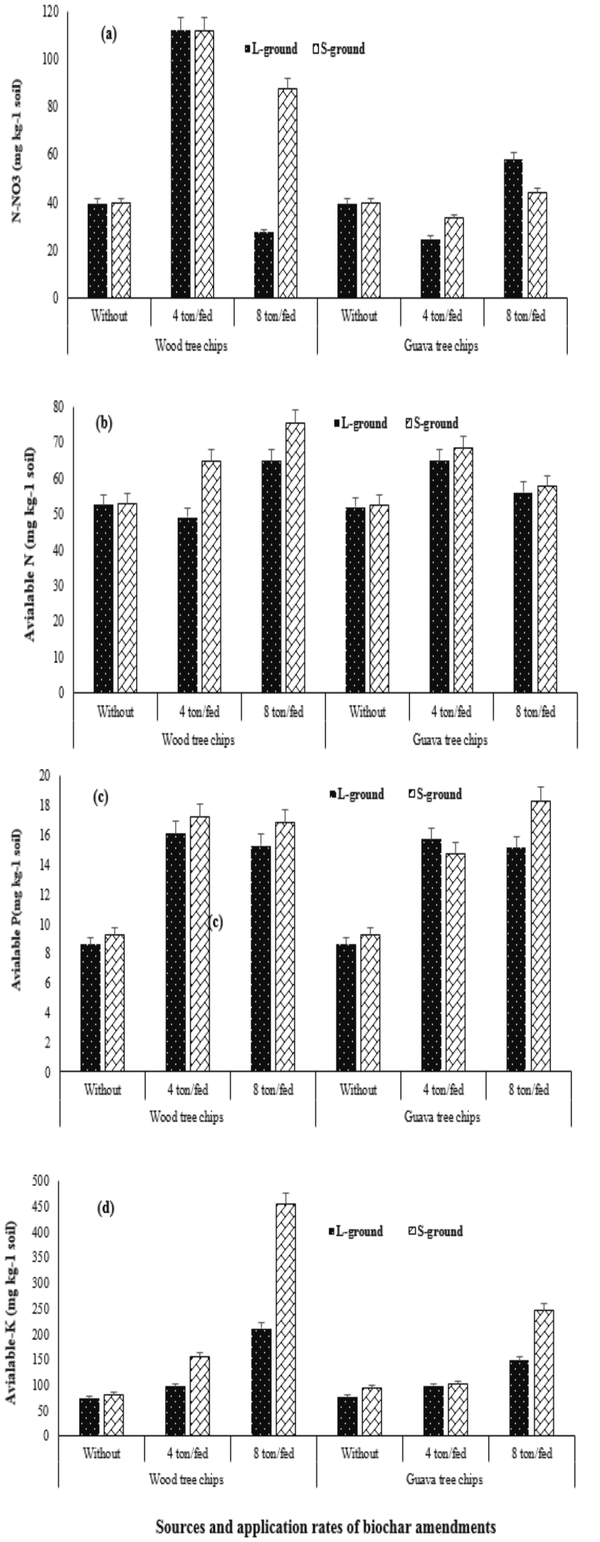

Fig. 1. Integrated impacts of biochar source, particle size and application rates on (a) soil-N-NO_3 (b) Available -N (c) Available -P and (d) Available -K in the soil after maize harvest.

It is obvious that, mineral nutrients will be greater concentrated in generated biochar after pyrolysis process (Gaskin *et al*. 2010), suggesting that biochar will diminish leaching of N and K nutrients in soil (Zwieten *et al.* 2010). However, Zwieten *et al*. (2010) found that the functional groups of pyrolyzed biochar were progressively lost reducing its capability to hold nutrients at higher temperatures especially more than 400°C. Also, Chan *et al*., (2007) found that N losses could be restricted through biochar application because it holds soil-N with increases cation exchange capacity (CEC) of soil. Greater available nutrients in the studied soil observed which are confirmed with the previous literatures (Novak *et al*. 2009; Gaskin *et al*. 2010 and Zwieten *et al.* 2010).

Soil organic matter (OM) was greater under guava tree chips biochar than under Casuarina wood chips biochar, and better for treatment under S-ground biochar than L-ground biochar. Further, soil OM was found to increase by 17.33% under biochar amendment at 4 t fed^{-1} and by 65.33% under biochar amendment at 8 t fed^{-1} as compared to no biochar treatment, respectively.

Dissolved organic carbon (DOC) represents a small molecules of soil organic matter and acts great functions in the soil biomass, largely due to its mobility and reactivity, affecting microbial activities in soil, transporting metal contaminants and mineral weathering (Chantigny, 2003). DOC was better for treatment under *Casuarina* tree chips biochar than the treatment under guava tree chips biochar, and greater for treatment under S-ground biochar than L-ground biochar. Further, DOC was found to increase by 42.27% under biochar amendment at 4 t fed^{-1} and by 90.70% under biochar amendment at 8 t fed^{-1} as compared to no biochar treatment, respectively. On the other hand, soil amended with guava tree chips biochar had greater oxidizable organic carbon (OOC) compared with the soil amended with C*asuarina* tree chips biochar. Interestingly, it worth observing that S-ground biochar induced greater OOC value *vs*. L-ground biochar which recorded decrease in the same character. Application of 8 t fed^{-1} from biochar was the most efficient treatment for increasing OOC content in soil with significant differences between treatments. There had been 61.57% and 102.52% increases soil-OOC in biochar application at the rate of 4 t fed^{-1} and 8 t fed^{-1} over the control, respectively.

As illustrated in Fig. 2(a), there were obvious records of soil organic matter as affected by supplementary biochar applications under different biochar source and particle size. Over the whole maize growing season, the highest mean concentration of soil organic matter was 1.28% occurred with 8 t fed^{-1} of S-ground biochar derived from guava tree chips while the lowest mean was 0.69% occurred under without addition of biochar treatments.

It is clearly shown in Fig.2 (b) that DOC contents were significantly increased by increasing the rate of biochar application in the soil as maximum mean value of DOC (754.33mg kg^{-1}) was observed in treatment at 8 t fed^{-1} in soil with S-ground biochar derived from guava chips. Generally, Fig 2(c) showed that application of 8 t fed^{-1} with S-ground biochar derived from Casuarina wood chips recorded the highest value (363.17 mg kg^{-1} soil) of OOC. While, the lowest mean value of aforementioned attribute was 147.50 mg kg^{-1} soil occurred with the untreated soil. The obtained results under this study confirmed that organic carbon enhanced in soil markedly with the application of biochar. The main effect of biochar addition may be either positive or passive, on basis of the biochar type (Zimmerman *et al*. 2011). A biochar is not completely inert in soil and can be oxidized, especially at the surface, through chemical and microbial activity (Cheng *et al*. 2008) and slow oxidization of biochar in soils can produce carboxylic functional groups (Cheng *et al*. 2008), decomposition of soil organic carbon may be enhanced (Wardle *et al*. 2008). Also, Major *et al*. (2010a) reported that biochar from old mango (*Mangifera indica L*.) trees applied at the rate of 2.23 - 23.2 t ha^{-1} to a savanna *Oxisol* soils in Colombia induced greater CO_2 elevation, which was attributed to the enhanced below-ground net primary productivity under biochar addition.

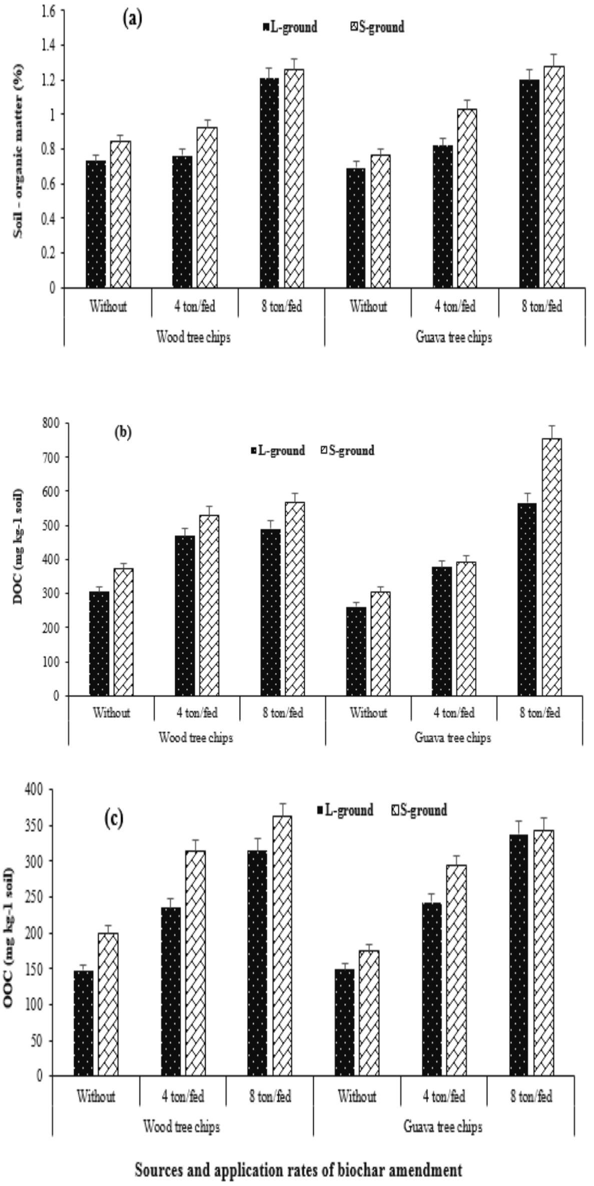

Fig. 2. Integrated impacts of biochar particle size, source and application rates on (a) organic matter (OM) (b) dissolved organic carbon (DOC) (c) oxidizable organic carbon (OOC) of the soil after maize harvest.

Effect of biochar source, particle size and application rates on the growth of maize plant: -

Due to leakage in this study concern to experimentally assay for plant performance as affected by biochar particle size, it noticeable that the best growth in soil amended with S-ground biochar greater than L-ground biochar particles.

Plant growth indices were significantly affected by main and interactive effect of source, particle size and application rates of biochar as presented in Table 3. Data revealed that maize height (m) and aboveground biomass (fresh and dry weights) were greater for old wood chips biochar than guava tree chips biochar. Also, the same parameters were greater for treatment receiving L-ground biochar than S-ground biochar over the whole maize growing seasons. While, maize stem width (cm) was better for treatment under old guava chips biochar than Casuarina tree chips biochar. Interestingly, maize plants having the maximum values of maize growth indices receiving biochar at the rate of 8 ton fed^{-1} as compared with the other treatments.

Regarding an interactive effect of source, particle size and application rates of biochar as presented in Table 3, plants having 3.05 and 3.20 m of plant height receiving S-ground biochar at the rate of 8 t fed^{-1} with old guava chips over whole growing seasons. While, the highest mean value of maize stem width was 2.30 and 2.76 cm obtained from plants receiving S-ground biochar at the rate of 4 t fed^{-1} with old guava chips as compared the others over the whole maize growing seasons.

Significantly greatest fresh and dry weights of aboveground biomass were 27.21and 29.92 Mg fed^{-1} for fresh weights and 11.44 and 12.01 Mg fed^{-1} for dry weights obtained for treatment receiving biochar at 8 t fed^{-1} as compared with the other treatments over growing seasons, respectively. The data illustrated in Table 3 revealed that fresh and dry biomass of maize plant were also significantly affected by interactive effect of source, particle size and application rates of biochar. Maximum mean maize shoot biomass was 32.36 and 35.59 Mg fed^{-1} for fresh weights and 12.92 and 13.57 Mg fed^{-1} for dry weights recorded with 8 t fed^{-1} of L-ground biochar derived from old guava chips while minimum mean fresh weight of maize shoot was 18.65 and 20.68 Mg fed^{-1} recorded with untreated plants with L-ground biochar derived from old guava chips and the minimum mean dry weight of maize shoot was 7.58 and 7.56 Mg fed^{-1} occurred with untreated plants with S-ground biochar derived from old wood chips over the whole maize growing seasons. This increase in maize biomass may be attributed to greater physiological pathways such as metabolism in plant, more nutrient acceleration and improved soil quality by biochar application (Jeffery *et al*. 2011).

Effect of biochar source, particle size and application rates on maize yield (Mg fed^{-1}): -

The effect of biochar source, particle size, application rates and their interaction on maize yield indices i.e., weight of 100 grains, stover, grain yields and harvest index (HI) are presented in Table 4. The results revealed that the weight of 100 grains was better for plants amended old guava chips derived biochar than that amended old wood chips biochar over the whole maize growing seasons. While, maize stover, grain yields and HI were better for old wood chips biochar than old guava chips biochar.

Regarding the main effect of biochar particle size, maize stover and grains were greater for treatment under S-ground biochar than L-ground biochar. Meanwhile, HI and weight of 100 grains were greater for plants amended L-ground biochar than that amended S-ground biochar. Stimulatingly, maximum maize yield, HI and weight of 100 grains were recorded in rate of 8 ton fed^{-1} as compared with the other treatments.

Table 3. Effect of biochar particle size, source and application rates on the growth of maize plant.

Treatments			Plant Height (m plant^{-1})		Stem width (cm plant^{-1})		Aboveground biomass (Mg fed^{-1})			
							Fresh		Dry	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Casuarina tree chips (WC)	Without	L-ground	2.65	2.78	1.40	1.68	19.02	20.92	7.62	8.00
		S-ground	2.65	2.78	1.40	1.68	19.02	20.92	7.58	7.56
	4 t fed^{-1}	L-ground	2.85	2.99	2.10	2.52	20.10	22.11	7.74	8.13
		S-ground	2.61	2.74	1.90	2.28	24.60	27.06	7.94	8.34
	8 t fed^{-1}	L-ground	2.81	2.95	2.10	2.52	27.74	30.51	11.04	11.59
		S-ground	2.85	2.99	2.23	2.68	26.08	28.69	12.84	13.48
Guava tree chips (GC)	Without	L-ground	2.48	2.61	1.73	2.08	18.65	20.68	7.80	7.96
		S-ground	2.47	2.61	1.75	2.10	19.02	20.92	7.58	7.96
	4 t fed^{-1}	L-ground	2.56	2.69	1.80	2.16	20.10	22.11	8.34	8.76
		S-ground	2.55	2.68	2.30	2.76	20.32	22.35	9.60	10.08
	8 t fed^{-1}	L-ground	2.75	2.89	2.10	2.52	32.36	35.59	12.92	13.57
		S-ground	3.05	3.20	2.17	2.6	22.64	24.90	8.94	9.39
LSD at 0.05			0.30	0.28	0.26	0.03	1.18	2.10	1.30	3.18

Table 4. Interactive effect of biochar source, particle size and application rates on maize yield (Mg* fed^{-1}) over the whole maize growing seasons.

Treatments			W eight of 100 grains (g)		Maize yield (Mg fed^{-1})				Harvest Index (%)	
					Stover		Grain			
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Casuarina tree chips (WC)	Without	L-ground	18.37	20.20	11.52	12.67	5.6	6.14	32.67	32.63
		S-ground	26.2٠	28.82	11.52	12.67	5.80	6.55	33.49	34.06
	4 t fed^{-1}	L-ground	25.1	27.61	12.36	13.60	6.99	7.25	36.08	34.78
		S-ground	26.2٠	28.82	16.94	14.63	8.53	7.51	33.49	33.92
	8 t fed^{-1}	L-ground	34.20	37.62	17.40	19.14	9.74	10.65	35.89	35.73
		S-ground	28.69	31.56	17.52	19.27	9.51	11.18	35.19	36.37
Guava tree chips (GC)	Without	L-ground	25.87	28.48	11.46	12.38	5.34	6.00	31.51	32.38
		S-ground	26.2٠	28.82	11.52	12.67	5.74	6.80	33.22	34.93
	4 t fed^{-1}	L-ground	22.27	24.50	12.3	13.53	6.53	7.58	34.68	35.91
		S-ground	28.9٣	31.82	11.92	13.45	6.38	7.12	34.86	34.58
	8 t fed^{-1}	L-ground	30.7١	33.78	14.96	16.45	8.57	9.24	36.36	35.97
		S-ground	29.57	32.52	21.92	19.99	11.99	11.43	36.40	36.70
LSD at 0.05			0.87	1.00	1.03	0.98	0.98	0.77	--	--

***Mg = 1000kg**.

However, maximum weight of 100 grains (34.20 and 37.62 g) was recorded with application rate 8 t fed^{-1} of L-ground biochar derived from old wood chips during both seasons, respectively. While minimum mean weight of 100 grains (18.37 and 20.20 g) was obtained from untreated plants, respectively. Stover and grain yields of maize plants were significantly affected by interactive effect of source, particle size and application rate of biochar (Table 4). Maximum stover and grain yields (21.92 & 19.99 and 11.99 & 11.43 Mg fed^{-1}) were recorded with application rate of 8 t fed^{-1} of S-ground biochar derived from old guava chips during both seasons, respectively. While, minimum stover and grain yields (11.46 & 12.38 and 5.34 & 6.00 Mg fed^{-1}) were recorded for the control treatment during both seasons, respectively. The higher maize yield in biochar amended soil may be attributed to the ability of biochar to absorb nutrients and increases available nutrients (Verheijen *et al*., 2010) which reflects on increasing soil fertility and maize yield and to enhanced physico-chemical properties associated with minimized bulk density of soil.

Even though statistical non-significant, the highest mean values of harvest index were 36.40 and 36.70% recorded for treatment receiving 8 t fed^{-1} of S-ground old guava chips biochar while the lowest harvest index were 31.51 and 32.38% recorded for the control treatment during both seasons, respectively. Our results are confirmed with Blackwell, (2010) who concluded that addition of biochar enhanced the yield of crops. Major *et al*. (2010b) observed in the first year no alteration on maize yield while marked increase in the following 3 years at 20 tha^{-1} of wood tree biochar in savanna *Oxisol* and *Ultisols*, Colombian. Further, Major *et al*., (2010) decided that additional rate of biochar significantly ($p < 0.05$) increased HI values in each year by 44% in 2003, 47% in 2004 and 50% in 2005, respectively.

Effect of biochar source, particle size and application rates on maize indices: -

Maize indices such as carbohydrates and protein contents in grains are significantly affected by the biochar source, particle size, application rates and their interaction over the whole maize growing seasons are illustrated in Figs 3 (a, b, c & d). Obviously, carbohydrates and protein concentrations (%) in grains were greater for treatment under old guava (*Psidium guajava L.*) chips than old wood chips *(Casuarina equisetifolia L.)* derived biochar. While, carbohydrates concentration (%) in grains having higher values recorded under L-ground than S-ground biochar but protein concentration (%) in grains was greater for treatment under L-ground than S-ground of amended biochar. Generally, biochar amendment at 4 and 8 t fed^{-1} caused a significant increase in maize indices over the whole maize growing seasons.

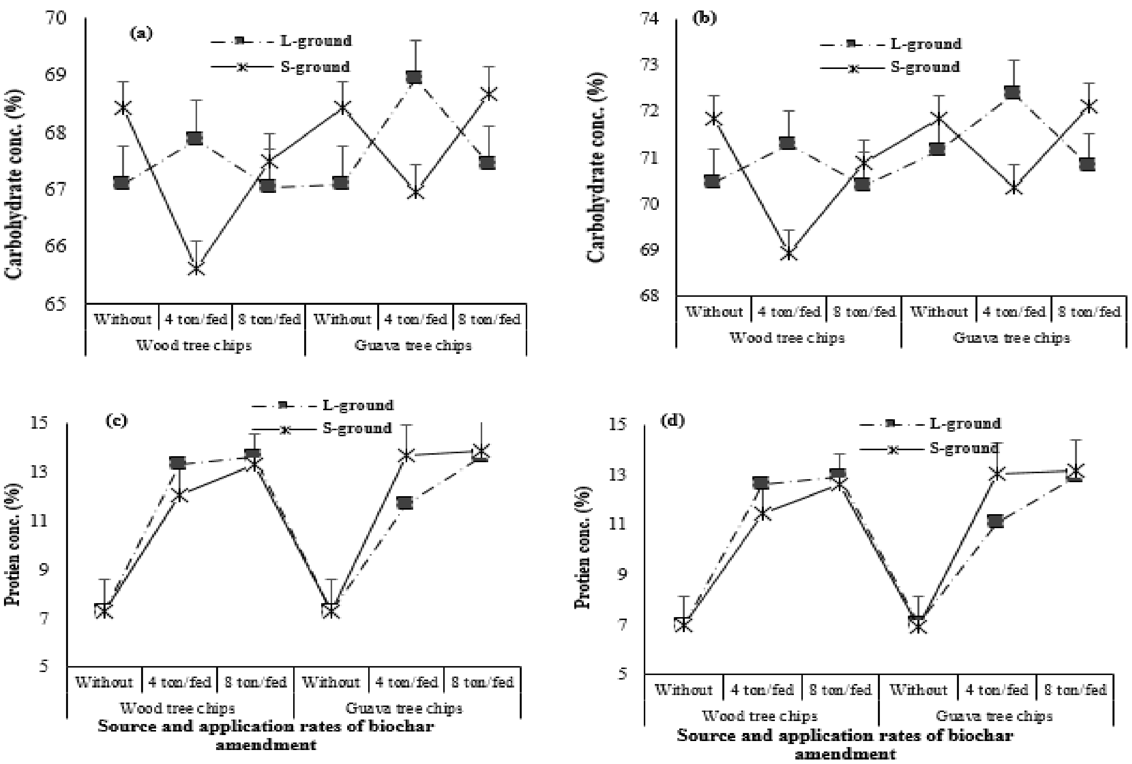

Fig. 3. Integrated impacts of biochar source, particle size and application rates on(a) carbohydrate concentration in 1st season (b) carbohydrate concentration in 2nd season (c) protein concentration in 1st season (d) protein concentration in 2nd season.

Regarding with the interactive effect of source, particle size and application rates on maize indices, there was significant differences between treatments as illustrated in Fig. 1 (a, b, c & d). Biochar amendment at 4 t fed^{-1} caused a highest mean in carbohydrate concertation (%) in grain maize by 68.93 and 72.38 % with L- ground guava tree chips biochar as compared with the other treatments over the whole maize growing seasons (Fig 1a & b). While, the highest means of protein concentration (%) were 13.85 and 13.16 % recorded for the treatment having biochar at 8 t fed^{-1} with S-ground guava tree chips biochar as compared with the other treatments, over the whole maize growing seasons respectively as illustrated in Fig 3 (c & d).

Effect of biochar source, particle size and application rates on on N, P and K uptake by maize grains: -

It is clear that biochar source, particle size, application rates and their interaction in the soil significantly increased N, P, and K uptake by maize grains (Table 5).

Regarding main effect of biochar treatments, N absorbed by grain tissues of maize plants were greater for treatment under *Casuarina* tree chips biochar than under guava tree chips biochar, and higher for treatment under S-ground biochar than L-ground biochar. Further, N uptake in maize grains is significantly increased by increasing the rate of biochar application in 8 t fed^{-1} treatment as compared with the other treatments. While, P and K absorbed by grain tissues of maize plants were greater for treatment under guava tree chips biochar than under *Casuarina* tree chips biochar, and higher for treatment under S-ground biochar than L-ground biochar. The maximum mean values of P and K nutrients uptake were recorded in 8 t fed^{-1} treatment while the mean minimum value of P and K nutrients uptake were observed in control treatment over the whole maize growing seasons.

There was a significant interactive effect of source, particle size and biochar rates on maize plant N, P and K nutrients uptake (Table 5).

The mean maximum value of N uptake by grain maize were 268.63 and 269.68 kg fed^{-1} recorded in 8 t fed^{-1} treatment of L-ground biochar derived from guava tree chips during both seasons, respectively. Meanwhile, the mean minimum values of the same attribute were 62.47 and 74.94 kg fed^{-1} occurred with the control under the old guava tree chips over the whole maize growing seasons, respectively. The increase in N uptake might be due to greater cation exchange capacity of biochar and its potential to retain NH_4^+ in the soil particles (Sohi *et al.* 2010). Nigussie *et al.* (2012) also reported an improved N uptake by plants, grown in biochar amended soils and availability of total N was also increased as a result of biochar application (Lehmann *et al*., 2006). On the other view, applications of wood-based biochars impede soil-N availability, with the descending in N plant tissue, which was associated with small ground (S-ground) biochar treatment. There is evidence that plant species more sensitive to N limitation tend to exhibit neutral or negative responses to biochars (Gale *et al*., 2017), so, the limited growth of annual ryegrass to smaller-sized biochar particles may be attributed to N immobilization and sensitivity to N restriction in soil.

Biochar amendment at 8 t fed^{-1} with S-ground biochar resulted a highest mean in P uptake by 37.60 and 35.80 kg fed^{-1} under guava tree chips during both seasons, respectively. While, untreated plants produced the mean minimum values by 8.59 and 9.41 kg fed^{-1} of absorbed P by grain tissues during both seasons, respectively. In this study, P biomass concentration increases under biochar application which may be due to biochar promotes root performance and P availability, stronger retention of P to the charged functional groups found on biochar surfaces, enhanced biological process, and improved soil parameters leads to greater P absorption and higher crop yield. In this concern, several authors i.e., Nelson and Sommers (1982) and Cao and Harris (2010) favored the results that additional rates of biochar can enhance the availability of P in soil and performed the root growth in plants amended with processed biochar due to increased P uptake (Spokas *et al*. 2010 and Sarfraz *et al*., 2017).

Table 5. Effect of biochar source, particle size and application rates on N, P and K uptake by maize grains.

Treatments			Nutrients uptake by maize grains (kg fed^{-1})					
			N		P		K	
			1st season	2nd season	1st season	2nd season	1st season	2nd season
Casuarina tree chips (WC)	Without	L-ground	65.46	86.11	8.59	9.41	26.88	31.74
		S-ground	67.88	91.87	10.26	11.58	32.17	35.12
	4	L-ground	148.69	122.53	14.27	20.54	63.05	46.41
		S-ground	164.68	140.99	22.19	21.29	64.88	64.86
	8	L-ground	212.36	246.13	27.61	24.61	96.47	95.40
		S-ground	202.33	251.12	26.95	29.06	109.93	109.18
Guava tree chips (GC)	Without	L-ground	62.47	74.94	10.86	9.82	47.01	34.00
		S-ground	67.00	90.43	10.53	14.51	52.06	37.69
	4	L-ground	122.18	140.49	18.30	17.43	61.58	65.95
		S-ground	139.91	139.49	18.11	19.93	69.95	59.56
	8	L-ground	186.82	209.44	28.22	30.49	81.35	95.48
		S-ground	268.63	269.68	37.60	35.80	103.05	108.91
LSD at 0.05			10.09	9.89	4.00	3.00	6.09	4.00

But the mean highest values of K uptake were 109.93 and 109.18 kg fed^{-1} calculated at 8 t fed^{-1} with S-ground biochar derived from *Casuarina* tree chips while the mean lowest value of K uptake by grain maize were 26.88 and 31.74 kg fed^{-1} obtained from untreated plants under *Casuarina* tree chips over the whole maize growing seasons. In this trend, Chan *et al*. (2007) introduced greater absorption of P and K nutrients by plant tissues in some studies, which suggests more accretion of these nutrients in generated biochar and their accessibility for absorption by plant tissues.

CONCLUSION

Our findings show that post pyrolysis (mechanical generating) of biochars is one of the promise potential technique for enhancing biochar properties combined with soil and plant nutrients, thereby resulting higher plant performance. Soil quality and maize growth parameters were significantly enhanced by increasing the rate of biochar application. With respect to biochar particle sizes, it appears that small ground biochars can achieve greater soil quality and plant performance than large ground biochars. The amount of biochar application had marked influences on maize grain yields at rate 8 t fed^{-1} showed greater performance compared with the other treatments. The highest means of available N, K, oxidizable organic carbon (OOC) in soil were noticed at 8 t fed^{-1} treatment with S-ground biochar processed from WC compared with the other treatments. Biochar amendment at 8 t fed^{-1} caused maximum in mean soil available P, organic matter, dissolved organic matter (DOC), stover and grain yields, harvest index, protein (%), P uptake by maize grains with S-ground GC biochar but the mean highest values of K-uptake were calculated at 8 t fed^{-1} with S-ground WC biochar compared to the other treatments. The mean maximum value of N uptake by grain maize were recorded in 8 t fed^{-1} treatment of L-ground GC biochar. Finally, it should be cost-effectively be expanded the potential processing of particle size biochars in agricultural applications.

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تأثير مصادر وحجم حبيبات ومعدلات إضافة الفحم الحيوي علي خصائص التربة ومحصول الذرة تحت ظروف الأراضي الرملية

أحمد صلاح عبد الحميد[١] و أحمد محمد الشيخه[٢]

[١]قسم الأراضي ـ كلية الزراعة ـ جامعة دمياط

[٢]قسم الهندسة الزراعية ـ كلية الزراعة ـ جامعة دمياط.

يعتبر استهلاك الأسمدة المعدنية بكميات عالية في مصر مشكلة كبيرة، لذلك فإن الأساس العلمي لهذه الدراسة مبني على أن إضافة الفحم الحيوي الناتج من مخلفات النباتات يمكن أن يحسن من مكونات المادة العضوية ويقلل من غسيل العناصر الغذائية وكذلك زيادة محصول الذرة تحت ظروف التربة الرملية.تم إجراء تجربتين حقليتين من خلال تصميم القطع المنشقة مرتين ذو ثلاث مكررات لدراسة خصائص التربة ومحصول الذرة المنزرع في التربة الرملية المضاف إليها مصدرين ذات مركبات لجنينية lignocellulosic من الفحم الحيوي ، وهي قطع من أشجار الكازورينا (*Casuarina equisetifolia L.*)، وقطع من أشجار الجوافة (*Psidium guajava L.*)، والتي تم طحنها ونخلها إلي حجمين من الحبيبات ، حبيبات كبيرة الحجم (L-ground ; ٢-٤ مم) وحبيبات صغيرة الحجم (S-ground ; ٠,٠٦ - ٠,٥ مم)، والتي تم إضافتها بمعدلات ٠ ، ٤ و ٨ طن/ فدان. تم خلط الفحم الحيوي الناتج ودفنه يدويًا علي عمق ١٥ سم من سطح التربة، وبعد الحصاد تم قياس بعض مؤشرات جودة التربة والمحصول وامتصاص العناصر الغذائية في حبوب الذرة. أوضحت النتائج أن حبيبات الفحم ذات الحجم الصغيرS-ground جودة عالية في خصائص التربة ، وأداء نباتي عالي بالمقارنة لحبيبات الفحم الحيوي ذو الحجم الكبير L-ground. كما لوحظ أفضلية في جودة التربة ومحصول الذرة عند المعاملة بالفحم الناتج من قطع أشجار الجوافة مقارنةً بالفحم الناتج من قطع أشجار الكازورينا. كما وأن لمعدلات إضافة الفحم الحيوي تأثيرات إيجابية على محصول حبوب الذرة. حيث أوضح معدل إضافة ٨ طن/فدان تحسن أكبر مقارنة بمعدل ٤ طن/فدان.فيما يتعلق بالتأثيرات التفاعلية، تسبب إضافة الفحم الحيوي S-ground الناتج من قطع أشجار الكازورينا عند معدل ٤ طن/فدان زيادة متوسط محتوي التربة من النترات مقارنة بالمعاملات الأخرى. بينما، لوحظت أعلى قيم للكربون العضوي القابل للأكسدة، والنتروجين والبوتاسيوم الصالحين في التربة عند معدل ٨ طن/فدان مع الفحم الحيوي S-ground الناتج من قطع أشجار الكازورينا مقارنة بالمعاملات الأخرى. وقد أدى إضافة الفحم الحيوي S-ground والناتج من قطع أشجار الجوافة بمعدل ٨ طن/فدان لزيادة قيم الفوسفور الميسر بالتربة، والمادة العضوية، والكربون العضوي الذائب (DOC)، ومحصول حبوب وحطب الذرة، ومؤشر الحصاد، والبروتين (٪) ، وامتصاص الفوسفور بواسطة حبوب الذرة ، بينما وجد أعلى معدل امتصاص للبوتاسيوم عند إضافة ٨ طن/ فدان باستخدام الفحم الحيوي S-ground الناتج من قطع أشجار الكازورينا مقارنة بالمعاملات الأخرى. كما أدت إضافة ٨ طن/ فدان من الفحم الحيوي L-ground والناتج من قطع أشجار الجوافة الحصول علي أعلي امتصاص للنتروجين بواسطة حبوب الذرة. أخيراً، أدت إضافة الفحم الحيوي L-ground والناتج من قطع أشجار الجوافة بمعدل ٤ طن/ فدان أعلى متوسط للكربوهيدرات (٪) في حبوب الذرة biochar مقارنةً بالآخرين.