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Ameliorating a Sandy Soil Using Biochar and Compost Amendments and Their Implications as Slow Release Fertilizers on Plant Growth

Mahmoud A. M. El-Shony[1,2], Ihab M. Farid[1], Faten A. El-Kamar[2], Mohamed H.H. Abbas[1] and Hassan H. Abbas[1]
[1]*Benha University, Faculty of Agriculture, Soils and Water Department, Egypt*
[2]*Soil, Water and Environment Res. Inst, Agric, Res. Center (ARC), Giza, Egypt*

POOR fertility and low water retention at the different soil moisture constants are both limiting factors of crop productivity in sandy soils. Recycling organic wastes might provide such soils with nutritive elements, at the same time, improves their chemical and physical characteristics. Thus, two organic amendments (biochar and compost) were selected in the current study to investigate their effectiveness as amendments of a sandy soil while considering the following two assumptions: (H1) efficiency of a half dose of biochar or less is comparable to the effect of the full dose of compost for improving soil physical and chemical characteristics. Furthermore, the residual effects of biochar (vs. compost) on soil properties seemed to be more noticeable in the successive growing season. (H2) Biochar can negatively affect the bio-availability and concentrations of P and soil micro- nutrients within the areal parts of plants due to its alkaline nature on one hand, and its relatively high persistence in soil, on the other one. Accordingly sandy soil (of low buffering capacity) was amended with either biochar (BS at elevated rates) and/or compost (CT), solely or in combination and then planted with peanut. The residual effect of these amendments was investigated in the successive season on wheat. Results revealed that the effect of applying 12.5 Mg Bs ha^{-1} was almost similar to that of applying 25 Mg CT ha^{-1} during the two seasons of study. On the other hand, the application of only 5 Mg Bs ha^{-1}could improve slightly; but insignificantly some soil characteristics. The combination between “Bs+CT” recorded further significant improvements in the abovementioned characteristics especially at the higher doses of application. Thus, we partially accept the first assumption. To investigate the second one, the availability of N, P, K, Fe, Zn and Mn nutrients was considered in the investigated soil by the end of each growing season in addition to the concentrations of these nutrients within the areal parts of the grown plants. Results obtained herein indicate that biochar underwent considerable decomposition in sandy soils shifting the pH slightly towards alkalinity. On the other hand, both the biochar and compost could improve significantly the availability of soil macro-and micro- nutrients and hence increased their uptake by the grown plants. These finding does not support the second hypothesis. In conclusion, biochar is recommended as a slow release fertilizer for macro- and micro- nutrients when applied at only a half dose of compost and its effect on soil physical and chemical characteristics may extend for more than one year after application.

Keywords: Biochar, Compost, Sandy soil, Chemical properties, Physical properties, Peanut, wheat

Introduction

Limitations of plant available nutrients and soil moisture are the borders affecting crop productivity in sandy soils (Liu et al., 2012). Moreover, the extensive human activities have resulted in remarkable degradations in soil quality and fertility (El-Naggar et al., 2019). To restore and/or improve soil fertility, recycling of organic wastes might be the optimum choice (Abbas et al., 2011; Farid et al., 2014 and Ding et al., 2016); after

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*Corresponding e-mail: mohamed.abbas@fagr.bu.edu.eg
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considering appropriate preparations of composts or biochar from these organic wastes (Abdelhafez et al., 2017). Generally, compost and biochar amendments improve soil, physical and chemical characteristics (Farid et al., 2018; Bassouny and Abbas, 2019; de Jesus Duarte et al., 2019) while reduce the ecological impacts of the residual wastes produced in large amounts annually (Coomes and Miltner, 2016). Unlike compost, the organic carbon in biochar is considered relatively stable (Song et al., 2019)and can persist in soils for several years e.g. seven (Giagnoniet al., 2019) to ten years (Kätterer et al., 2019). This might take place through reducing readily C-available to microbes with regard to compost, thus biochar induces slightly or insignificantly microbial activities (Fiorentino et al., 2019; Li et al., 2019)and hence minimizes the emissions of the greenhouse gases (Agegnehu et al., 2016; Clark et al., 2019; de Jesus Duarte et al., 2019).

Biochar is a carbon rich product which is derived from the pyrolysis of organic carbon under limited oxygen conditions (Nguyen et al., 2019). This amendment can stabilize and reduce the availability of the potentially toxic metals while remediating contaminated soils because of its high adsorption capacity (Abdelhafez et al, 2014 and 2016; Mohamed et al., 2018; Wang et al., 2019). Probably, this mechanism affects, on the other hand, the availability of soil nutrients in arid soils. Although, several researches highlighted the capability of biochar to retain soil nutrients, *e.g.* NPK in readily available forms for plant uptake (Rens et al., 2018); however, some others pointed out to negative implications of biochar on inducing N deficiency in plants e.g. lettuce (Kim et al., 2015).Also, increasing soil pH which is considered the main factor for stabilizing PTEs in contaminated soils (Wang et al., 2019) might negatively reduce the availability of P (Cerozi and Fitzsimmons, 2016) and micronutrients in soils (Rutkowska et al., 2014). To what extent can biochar decrease the availability of soil nutrients for the grown plants e.g. N and P is the question of the current investigation especially when applied at relatively high application rates. It is worthy to mention that the amendmentmade of mixing composted materials and biochar can serve as a sustainable source of nutrients (Liu et al., 2012). This mixture can further improve the efficiency of both amendments (Wu et al., 2017), *e.g.* improve significantly soil organic-matter content, nutrients levels, and water-storage capacity of a sandy soil (Liu et al., 2012). Accordingly, the current research aims at investigating the hypotheses indicating that the efficiency of amending soils with a half dose of biochar or less can improve soil physical and chemical characteristics comparable with the effect of the full dose of compost.

The first assumption: “the amount of biochar needed as a soil amendment might be relatively lower than the corresponding amount of compost. Moreover, the residual effect of biochar could be of more pronounced effect versus compost on the plant growth in the successive growing seasons”. On the other hand, this biochar can negatively affect the concentrations of macro- and micro-nutrients within the areal parts of plants grown on a sandy soil mainly because of its alkaline nature. Thus the second assumption: “increasing the dose of the applied biochar to an arid sandy soil may negatively affect the availability of NPK and micronutrients for the plants grown during the first season; however, the residual effect of this amendment serves as slow release fertilizers in the second growing season”.

This investigation was conducted on a sandy soil (poor in nutritive contents and of low buffering capacity) for two successive seasons i.e. a winter and a summer seasons and the outcome yields and economic returns were considered. Moreover, the interactions between these two organic amendments were a matter of concern in this study.

Materials and Methods

This investigation was carried out in the experimental farm of Ismailia Agric. Research Station (Ismailia Governorate, Egypt) to study the impacts of amending a sandy soil with two types of soil amendments (compost vs. biochar) on its productivity under sprinkler irrigation system. This study also considered the residual effect of the applied organic amendments on the growth of plants attained at the successive seasons (planted at the same plots).

Materials of study

A representative surface soil sample (0-30 cm depth) was collected from the experimental field of Ismailia Agric. Research Station prior to the summer season. This sample was air dried, crushed using a wooden roller and then sieved to pass through a 2 mm sieve. Chemical and physical characteristics of the collected sample were determined as outlined by Sparks et al. (1996) and Klute (1986) and the results are presented in Table 1.

TABLE 1. Physical and chemical characteristics of the studied soil.

Parameter	Soil chemical characteristic			Particle size distribution%				Textural class	Soil bulk density, Mg m^{-3}	Available nutrients, mg kg^{-1}					
	pH (1:2.5)	EC, dS m^{-1}	$CaCO_3$, g kg^{-1}	Coarse sand	Fine sand	Silt	Clay			N	P	K	Fe	Mn	Zn
Value	7.85	1.4	5.1	77.1	13.6	3.1	6.2	Sand	1.6	10.9	6.1	58.2	1.91	2.3	0.38

Table 2. Physical and chemical properties of the applied compost and biochar amendments

Property	Bulk density, Mg m^{-3}	Moisture content, %	pH*	EC*, dS m^{-1}	Total-C, g kg^{-1}	Total-N, g kg^{-1}	C/N ratio	Total-P, g kg^{-1}	Total-K, g kg^{-1}	Total content, mg kg^{-1}		
										Fe	Zn	Mn
Compost	0.52	8.0	6.7	1.91	274.7	17.8	15.4:1	2.9	6.1	5200	78.0	80.0
Biochar	0.33	5.0	7.7	1.84	173.6	10.3	17:1	2.6	3.5	5831.0	75.0	131.0

pHand EC were determined in 1:10 organic-amendment: water suspensio

Compost was obtained from El Sharkia Company, Egypt and biochar was supplied by the Egyptian Garden Company. Physical and chemical characteristics of these amendments are presented in Table 2. Seeds of peanut (*Arachis hypogaea* L., C.V. Giza 6) and wheat (Triticum vulgare, c.v. Misr1) were obtained from Agric, Res. Center (ARC), Egypt. All seeds were treated with N-fixing bacteria, half an hour before planting, *i.e.* Rhizobium sp.under the commercial name "Microbin" for peanuts and *Azospirillum brasilens* under the commercial name "Cerialin" for wheat in presence of black honey as an adhesive material and then left to dry.

The experimental design and the field study

A field experiment was conducted at the experimental farm of Ismailia Agric, Res Station during summer 2016 and winter season 2016/2017. The experimental design was a complete randomized block one comprising the following treatments: control (no added amendment, T1), compost applied at a rate of 25 Mg ha^{-1} (CT, T2), biochar applied at rates of 5Mg ha^{-1}(Bs, T3), 8.75Mg ha^{-1} (Bs, T4) and 12.5 Mg ha^{-1}(Bs, T5) and the combined treatments consisted of .25 Mg CT ha^{-1}+5 Mg Bs ha^{-1} (T6), 25 Mg CT ha^{-1}+8.75 Mg Bs ha^{-1} (T7) and 25 Mg CT ha^{-1}+12.5 Mg Bs ha^{-1} (T8). The experimental plot was 10.5 m^2 (3m×3.5m) and all the treatments were carried out in triplicate. The investigated soil amendments were mixed thoroughly with the topsoil (0-30 cm) before crop planting.

The peanut experimental work (summer season)

The experimental plots were planted with peanut during the summer season at a rate of 143 kg ha^{-1}. All plots received NPK at the recommended doses of the Ministry of Agriculture (Egypt) for sandy soils *i.e.* 240 kg ha^{-1} ammonium sulphate (205 g N kg^{-1}), 480 kg ha^{-1}calcium superphosphate (65.5g P kg^{-1}) and 120 kg ha^{-1} potassium sulphate (400 g K kg^{-1}). The agricultural practices were followed as usual in the area of study. At the physiological maturity growth stage, the different growth parameters and yield components of peanut (shilling, 100-seed weight, pod and seed yields) were estimated. Also, plant samples were collected from each plot. Moreover, soil samples were collected from the rhizosphere of each plot during plant harvest.

The wheat experimental work (winter season)

Wheat seeds were planted (broadcasting) at a rate of 167 kg ha^{-1} during the winter season (11/2016-4/2017) at the same experimental plots after harvesting peanut to study the residual effect of the previously applied amendments on soil physical and chemical characteristics beside of their consequent effect on plant productivity. All plots received the recommended doses of NPK. After physiological maturity, the different growth parameters were assessed for wheat plants in each plot and plants were sampled for analysis of their nutrient contents: Soil samples were further collected from the rhizosphere of each plot during plant harvest.

Soil and Plant analyses

Soil analysis

Soil bulk density (BD) was estimated in the undisturbed soil samples using a steel ring of 100 cm^3. Soil pH was determined in 1:2.5 soil: water suspension by the pH meter and soil EC was estimated in the soil paste extract using EC meter according to Page et al. (1982). Organic carbon content was determined by the modified Walkley and Black method as outlined by Sparks et al. (1996). Available nutrients were determined in the soil samples according to the procedures described by Page et al. (1982) as follows: (1) available N was extracted by K_2SO_4 (1%), and then determined using micro Kjekdahel apparatus in presence of MgO and Devarda alloy. (2) Available P was determined using Spectrophotometer (JENWAY 6405 UV/Vis) after being extracted by $NaHCO_3$ (0.5N, pH 8.5). (3) Available K was extracted by ammonium acetate (1N, pH 7) and then determined by flame photometer (JENWAY PFP7 flame). Available Fe, Zn,Mn and Cu were extracted by ammonium acetate DTPA according to Soltanpour and Schwab (1977) and then determined with Atomic Absorption photometer (Perkin-Elmar 372).

Plant analysis

Plant samples were oven dried at 70 C for 72 hr, ground and then stored for chemical analysis Plant portions (equivalent to 0.2 g of the dried plant materials) were digested using a mixture of concentrated sulphuric and perchloricacidat a ratio of 2:1 as outlined by Mohamed et al. (2019). Afterwards, the digest was diluted to a volume of 100 mL by deionized water. Total contents of nutrients in the plant digests were estimated as follows: total-N by micro-Kjeldahel apparatus, total-P spectrophotometrically and total K by flame photometer.

Data analysis

The obtained data were statistically analyzed using PASW Statistics software through the analysis of variance (ANOVA) and Dunken Test at 0.05 probability level. Figures were drawn using Sigma Plot 10.0.To calculate the financial revenues, the cost prices of using the investigated organic amendments (per hectare), were estimated in the US dollar (one Egyptian Pound (L.E. = 0.06 $) as follows: Fixed costs include land renting (6000 L.E. per season equivalent to 353 $). The variable costs include (1) land preparation and irrigation management costs (700 L.E. or ≈ 41 $), (2) the agricultural input prices (seeds, fertilizers, pesticides and fungicides valued by 2860 L.E. (≈ 168.24 $) for peanut production and 1990 L.E. for wheat production (≈ 117 $), labor costs (wages) valued by 1900 L.E. (≈ 112 $) during peanut production season and 2850 L.E. (≈ 168 $) wheat production season. (3) The prices of the organic amendments were as follows: 500 L.E. (≈29.4 $) for the price of one mega-gram of biochar and 200 L.E. (≈1.2 $) for the price of one mega-gram of compost. On the other hand, the selling price of one mega-gram of wheat grains was 4400 L.E. (≈258.8 $), and the selling price of one mega-gram of wheat straw was 1000 L.E. (≈58.8 $) per one mega-gram. The selling price of one mega-gram of peanut pods was 15,000 L.E. (≈882.4 $) and peanut residues were sold for 2400 L.E. (≈141.2 $ irrespective of the quantity of these residues). The net profit was calculated as the difference between the total revenue (selling prices of seeds and straw/ residues) minus the fixed and variable costs of crop production.

Results and Discussion

Effect of the organic amendments on the outcome yield

Peanut yield

Amending the soil under study with the investigated organic amendments increased significantly the pod (F=58.831, P=<0.001) and seed (F=211.391, P<0.001) yields of peanut. Likewise, such amendments increased 100 g weight (F=15.60, P<0.001) of the peanut seeds as well as shelling percentage (F=7.080, P=0.001). The highest increases in both straw and grain yields of peanut were recorded for the combined application of compost and biochar, especially with increasing their rate of application (Fig. 1). Such increases were higher than the corresponding ones recorded for the application of biochar solely (T3-T5) or CT alone (T2). In this concern, "25 Mg CT ha^{-1}+12.5 Mg Bs ha^{-1} (T8)" seemed to be the most efficient treatment recording significant increases in pod and seed yields by 1.26 and 1.32 fold, respectively higher than the non-amended control treatment. Although, application of biochar improved the growth parameters and yield components of peanut as compared to the control treatment; however, such increases were relatively lower than those occurred due to the application of the compost solely.

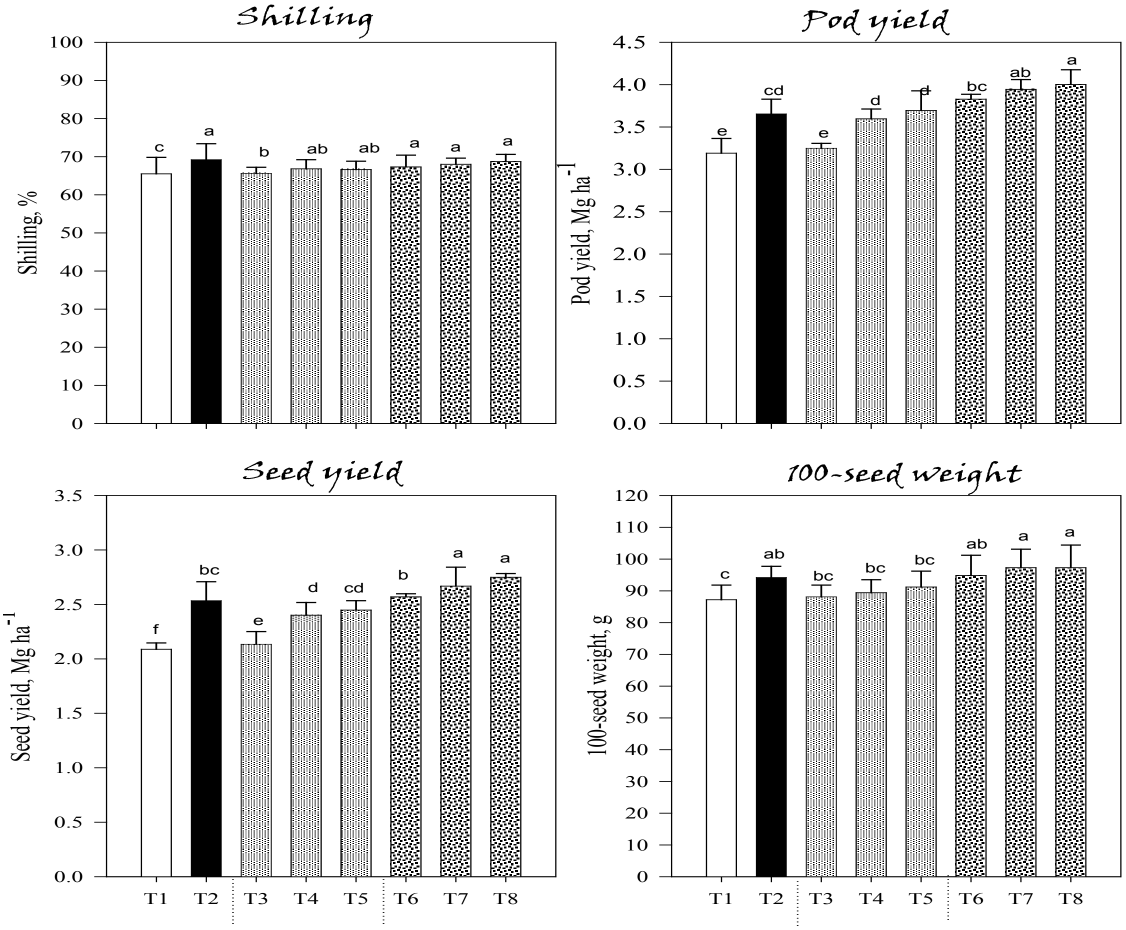

Fig. 1. Peanut growth parameters and yield components (means ±SD) as affected by amending soil with compost and biochar solely or in combinations:no added amendment (T1), compost applied at a rate of 25 Mg ha-1(T2), biochar (Bs) applied at rates of 5 Mg ha-1(T3), 8.75Mg ha-1(T4)and 12.5 Mg ha-1(T5) as well as the combined treatments, *i.e.* 25 Mg CT ha-1+5 Mg Bs ha-1 (T6), 25 Mg CT ha-1+8.75 Mg Bs ha-1 (T7) and 25 Mg CT ha-1+12.5 Mg Bs ha-1 (T8).Different letters indicate significant differences between treatments (P<0.05).

Wheat yield

Analysis of variance revealed that the investigated organic amendments increased significantly the straw (F=51.901, P<0.001) and grain (F=73.843, P<0.001) yields of wheat plants. On the other hand, no significant effect was detected for the application of these amendments on 100 g seed-weight (F=0.691, P=0.679). The application of biochar improved significantly the wheat yields of both straw and grains as compared to the non-amended control treatment; however such increases seemed to be comparable with those occurred due to the application of compost (T2)only at its highest application rate (T5) (Fig 2). Moreover, mixed applications of both biochar and compost resulted in further significant increases in straw and grain yields as compared to the single ones especially with increasing the rate of application up to "25 Mg CT ha-1+8.75 Mg Bs ha^{-1} (T7)"; afterwards, no significant increases occurred.The assessed increases that occurred in both straw and grain yields owing to the application of "25 Mg CT ha^{-1}+8.75 Mg Bs ha^{-1} (T7)"were estimated by ≈1.4 fold higher than the control treatment.

Effect of organic amendments on soil physical characteristics

Effect of organic amendments on soil water retention and available soil-moisture contents

Application of the organic amendments improved significantly soil moisture contents at both the welting point and field capacity; consequently, increased the available water content as compared to the control treatment (Fig 3). The highest increases were recorded for the combined treatments especially with increasing their applied rate. Concerning, sole effect of each of the used organo-treatments, it seemed that the biochar effect was less obvious than that of the compost on the studied moisture constants and available water content as well; however, its efficiency seemed to be comparable with that of compost only at its highest application rate (12.5 Mg Bs ha^{-1}).

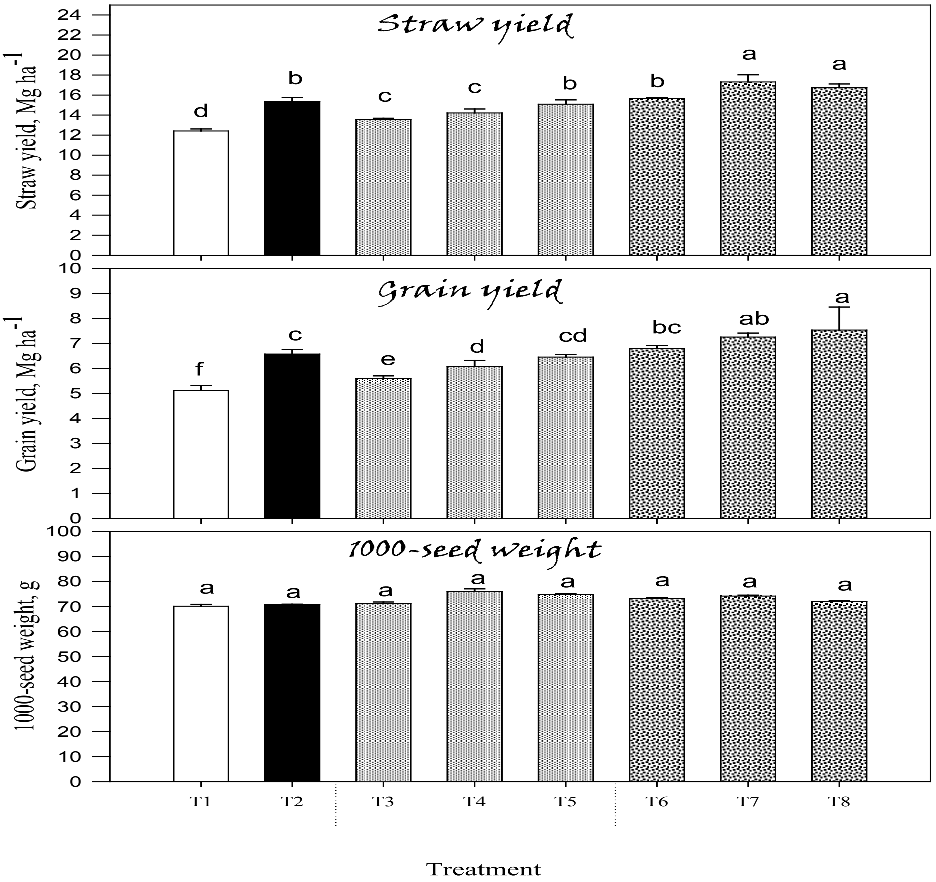

Fig 2. Wheat growth parameters and yield components (means ±SD) as affected by amending soil with compost and biochar solely or in combinations (see footnote Fig. 1). Different letters indicate significant differences between treatments (P<0.05)

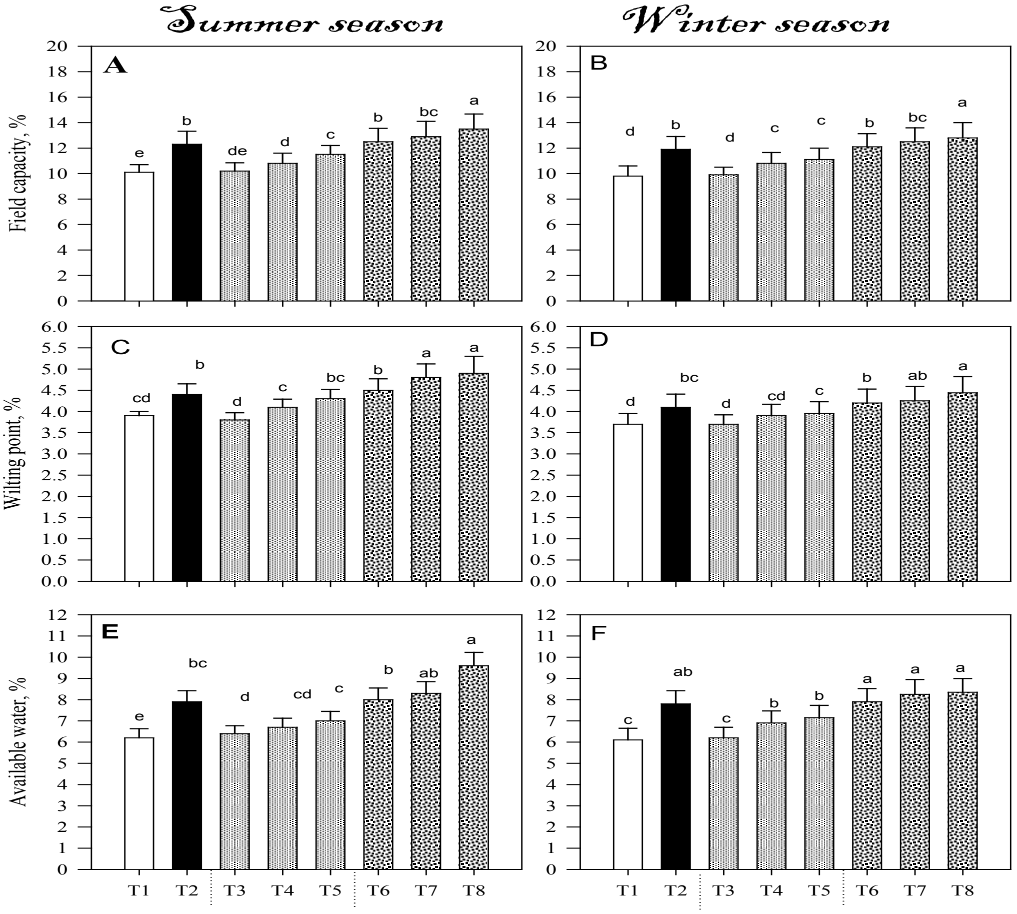

Fig 3. Soil moisture contents (means ±SD) as affected by amending soil with compost and biochar solely or in combinations(see footnote Fig. 1). Different letters indicate significant differences between treatments (P<0.05)

Effect of the organic amendments on soil bulk density

Amending the investigated soil with either compost or biochar significantly decreased its soil bulk density (Fig 4). In this concern, the compost application reduced soil bulk density more effectively than the biochar did. The combined treatments especially “25 Mg CT ha^{-1}+8.75 Mg Bs ha^{-1} (T8)” recorded further significant reductions in the bulk density of the soil as compared with application of the compost solely.

Effect of the organic amendments on soil chemical characteristic

Effect of the organic amendments on soil chemical characteristic

Soil pH: Figure 5 reveals that the application of compost decreased significantly soil pH during both seasons of study. On the other hand, soil pH increased significantly owing to the application of biochar. Such increases seemed to be more pronounced with increasing the rate of the applied biochar. The combined treatments seemed to have no significant effect on soil pH as compared to the control treatment.

Residual organic C (ROC) and soil CEC

Amending the soil with either compost or biochar increased significantly the residual organic carbon content of the soil (Fig. 6). Increasing dose of the applied biochar resulted in further significant increases in ROC in soil; however, such increases stood below the ones recorded for the compost treatment during both seasons of study. The combined organic-treatments resulted in further significant increases in ROC in soil. Likewise, soil CEC increased in soils amended with either of the investigated organic treatments. Only 12.5 Mg Bs ha^{-1} recorded comparable increases in soil CEC with the application of 25 Mg CT ha^{-1}. Moreover, the combined treatments resulted in further significant increases in soil CEC as compared with the single ones and such increases were more pronounced only up to “25 Mg CT ha^{-1}+8.75 Mg Bs ha^{-1} (T7)”; afterwards, no significant variations were detected

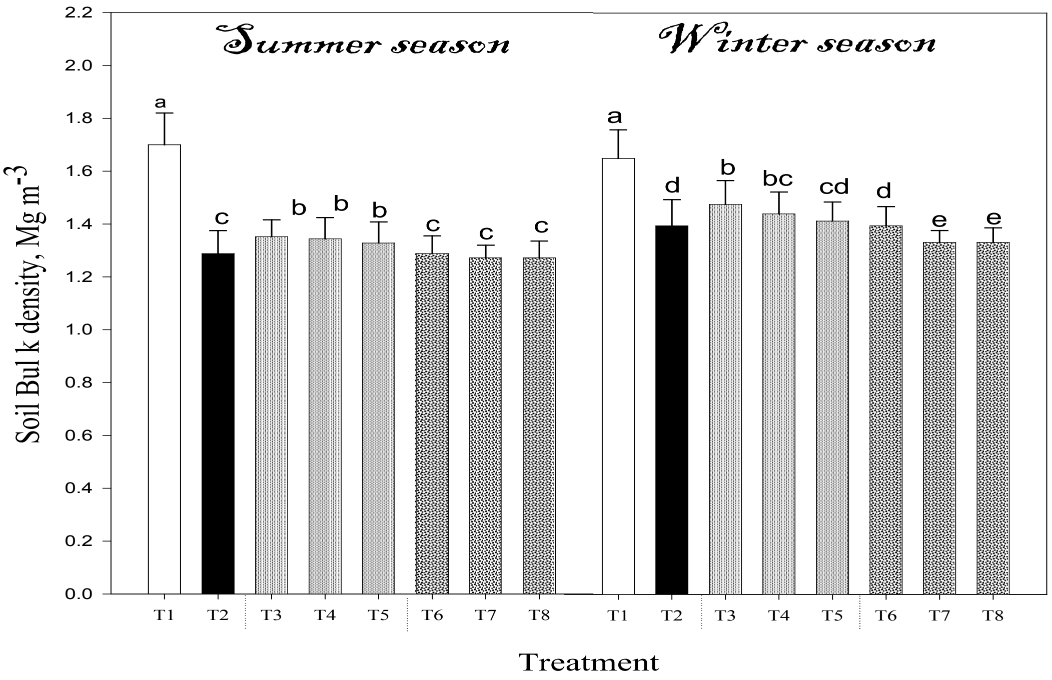

Fig 4. Soil bulk density (means ±SD)as affected by amending soil with compost and biochar solely or in combinations(see footnote Fig 1). Different letters indicate significant differences between treatments (P<0.05)

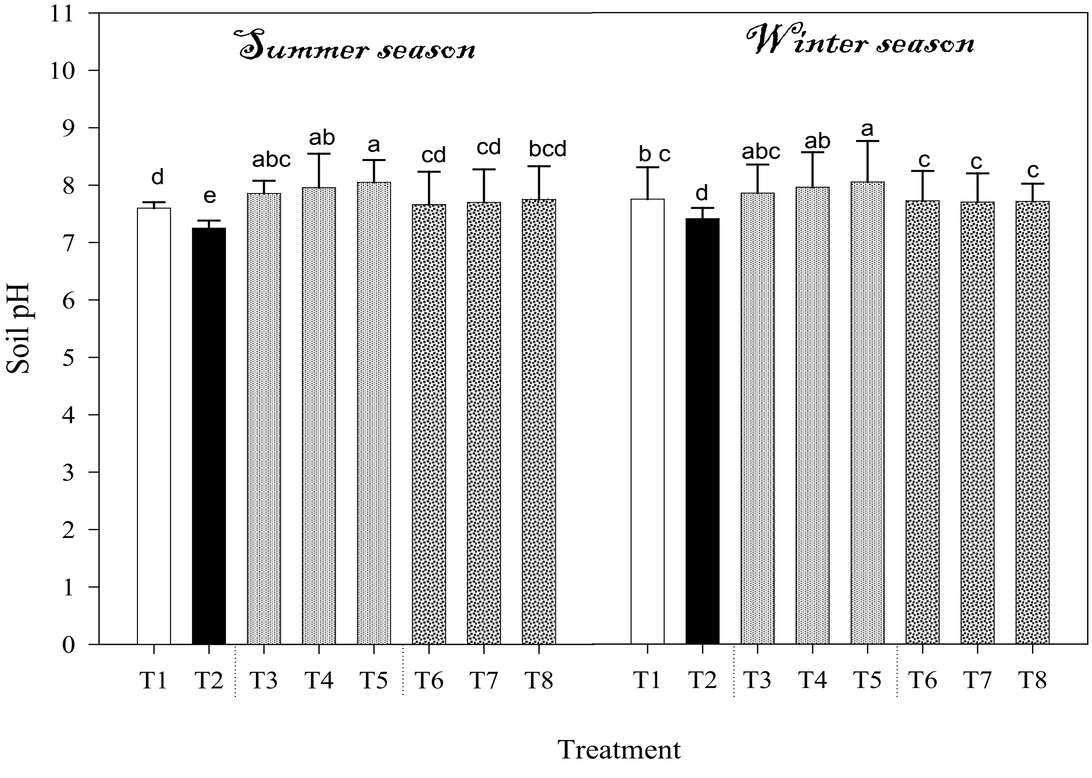

Fig. 5. Soil pH and EC (means ±SD)as affected by amending soil with compost and biochar solely or in combinations(see footnote Fig 1). Different letters indicate significant differences between treatments (P<0.05)

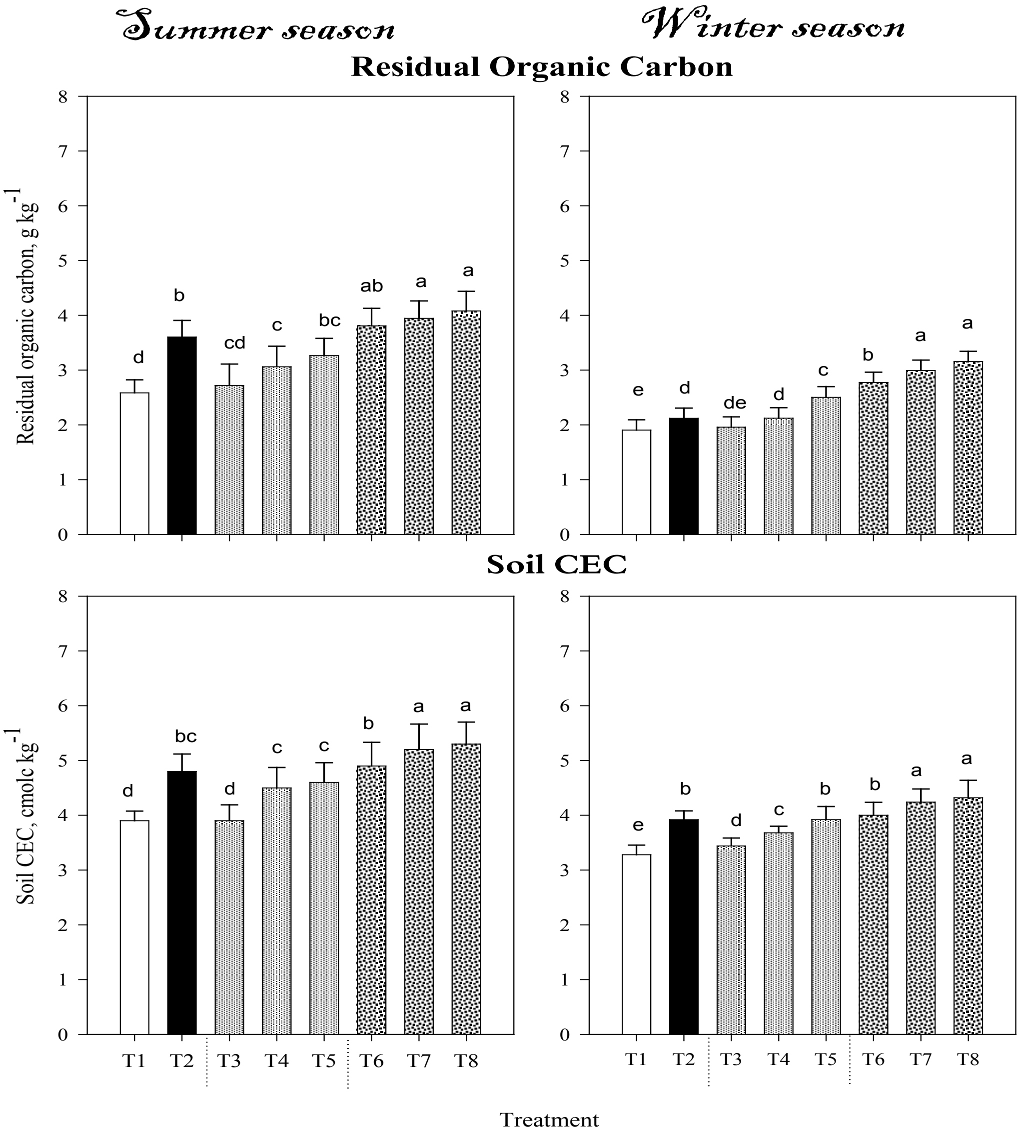

Fig. 6. Soil CEC and the residual organic C (ROC)(means ±SD)as affected by amending soil with compost and biochar solely or in combinations(see footnote Fig 1). Different letters indicate significant differences between treatments (P<0.05)

Effect of organic amendments on the availability of soil nutrients and their concentrations within the different plant parts

Available-NPK in soil and their concentrations within the different plant parts

The results revealed that application of either the compost or biochar increased significantly NPK availability in soil (Table 3). The increases occurred due to the application of 5 Mg Bs ha^{-1} seemed to be comparable with those attained due to the control treatment; however, increasing the rate of the applied biochar resulted in further significant increases in NPK availability in soil. Combinations between compost and biochar resulted in extra significant increases in NPK availability in soil and consequently raised their uptake by the grown plants especially with increasing the rate of application.

Available-Fe, Mn and Zn in soil and their concentrations within the different plant parts

Amending the studied soil with either of the organic amendments increased significantly the extractability of Fe, Zn and Mn by AB-DTPA,consequently raised their concentrations within the areal plant parts (Tables 10-12). Such increases were more pronounced with the mixed amendments than the solely applied ones, especially upon increasing the dose of application. Although, the sole application of the used amendments increased significantly the extractability of these nutrients and hence their concentrations within the different plant parts as compared to the control treatment; however, such increases were relatively lower than the ones obtained due to the combined treatments. The compost treatment applied at a rate of 25 Mg ha^{-1} recorded the highest increases in the extractability of Fe, Mn and Zn during the first season of study; however, the biochar treatment applied at a rate of 12.5 Mg ha^{-1} recorded the highest increases during the second growing season.

The economic returns of using the investigated organic amendments in crop production

Figure 7 reveals that both amendments (compost and/or biochar) recorded significantly higher net profits per hectare than the control treatment. In this concern, the estimated net profit for using compost (CT) solely (applied at a rate of 25 Mg ha^{-1} as a soil amendment) was significantly higher than the net profit calculated for using biochar (BT) solely at any of its amended rates. Additionally, the combination between these two amendments (compost and biochar) recorded further significant increases in the economic outcome returns when compared to the application of each amendment solely. Generally, the net average profit increased progressively with increasing the rate of the applied amendment.

Discussion

One of the main challenges for crop production in the sandy soils is the limitations of available nutrients and soil moisture content (Liu et al., 2012). These soils suffer from continuous and significant losses in both nutrients and soil moisture levels within the surface soil layer (0-30 cm) and this might negatively affect the plant growth. To improve physical and chemical characteristics of these soils, organic amendments are recommended (Farid et al., 2014); however, the following two challenges should be considered while selecting the appropriate amendments for such soils. The first one is related to the stability of the chosen amendment in soil. According to Abdelhafez et al. (2018), the mineralization of the organic carbon in the sandy soil is relatively high because of its high thermal conductivity. Probably biochar persists in soils for longer time periods than compost (Abdelhafez et al., 2017). Thus, its residual effect might be more pronounced in the successive growing seasons. The second challenge is the amount of amendment needed to overcome the negative conditions of the sandy soils. Although these amendments can improve physical and chemical characteristics of the sandy; yet, their extensive use might have negative potential ecological risks(Zhang et al., 2019), *e.g.* high emissions of the greenhouse gases which might possess a global warming hazards (Bassouny and Abbas, 2019). Two amendments were selected in this study, *i.e.* biochar and compost to improve soil physical and chemical characteristics. The following assumptions were a matter of concern herein.

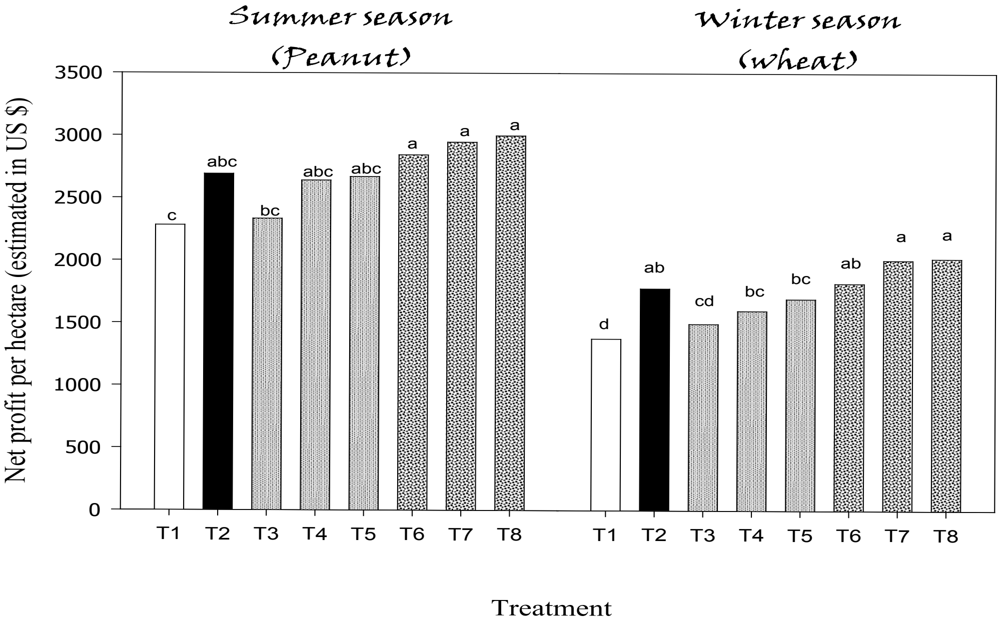

Fig 7. The average net profit of the used organic amendments in US dollar (1 US dollar= 17 L.E) (see footnote Fig 1). Different letters indicate significant differences between treatments (P<0.05)

TABLE 3. Extractable NPK in soil and their concentrations within the different plant parts (means ±SD) as affected by application of compost and biochar either solely or in combinations.

	Available content, mg kg^{-1}			Concentration in straw, g kg^{-1}			Concentration in grains, g kg^{-1}		
	N (K_2SO_4 extract)	P (Olsen extract)	K (NH_4-oAc extract)	N	P	K	N	P	K
				Summer season (peanut)					
T1	11.31.5±^{g}	6.40.1±^{g}	59.73.4±^{g}	12.80.4±^{f}	1.70.1±^{d}	10.80.7±^{e}	28.21.2±^{c}	2.80.2±^{e}	10.50.5±^{e}
T2	23.22.1±^{d}	9.20.2±^{d}	78.82.8±^{c}	17.30.5±^{cd}	2.10.1±^{b}	13.50.9±^{bc}	33.72.1±^{abc}	4.80.3±^{c}	13.30.7±^{bc}
T3	11.81.3±^{g}	6.90.2±^{f}	65.73.2±^{f}	13.20.3±^{f}	1.80.1±^{d}	11.21.3±^{de}	31.81.0±^{bc}	3.30.2±^{de}	12.01.1±^{d}
T4	14.41.0±^{f}	7.70.5±^{e}	71.42.3±^{e}	15.71.1±^{e}	2.10.2±^{c}	12.00.9±^{cd}	34.53.0±^{ab}	4.00.2±^{d}	12.70.7±^{cd}
T5	19.30.8±^{e}	8.70.2±^{d}	77.62.4±^{d}	16.40.5±^{de}	2.30.2±^{b}	13.31.1±^{bc}	36.11.2±^{ab}	4.10.3±^{c}	13.21.0±^{bc}
T6	24.31.1±^{c}	9.70.2±^{c}	79.93.1±^{c}	17.90.6±^{bc}	2.30.1±^{b}	14.01.0±^{ab}	37.31.4±^{ab}	5.00.3±^{c}	13.90.9±^{abc}
T7	26.41.1±^{b}	10.20.7±^{b}	85.44.2±^{b}	18.90.6±^{ab}	2.40.2±^{a}	14.50.8±^{ab}	37.72.0±^{ab}	5.50.3±^{b}	13.80.7±^{ab}
T8	29.81.3±^{a}	10.30.5±^{a}	87.82.2±^{a}	19.71.0±^{a}	2.70.2±^{a}	15.21.1±^{a}	37.93.0±^{a}	5.70.5±^{a}	14.80.9±^{a}
				Winter season (Wheat)					
T1	10.60.9±^{f}	5.80.4±^{g}	55.05.0±^{h}	7.30.3±^{e}	1.20.1±^{d}	9.20.7±^{d}	17.11.0±^{d}	2.10.1±^{e}	3.30.2±^{e}
T2	18.30.7±^{d}	8.30.7±^{c}	72.66.9±^{f}	8.60.3±^{bcd}	2.00.2±^{c}	12.51.1±^{c}	22.81.2±^{bc}	3.00.3±^{b}	4.40.4±^{cd}
T3	10.80.6±^{f}	6.20.6±f	59.54.1±^{g}	8.20.4±^{de}	1.30.1±^{d}	9.50.8±^{cd}	17.10.3±^{d}	2.30.2±^{d}	3.60.3±^{e}
T4	12.50.8±^{e}	7.30.7±^{e}	68.44.6±^{d}	8.60.5±^{cd}	1.70.2±^{c}	10.80.8±^{c}	20.01.6±^{c}	2.50.2±^{c}	4.20.2±^{d}
T5	14.50.6±^{d}	7.80.9±^{d}	70.53.8±^{e}	8.90.8±^{abcd}	2.00.2±^{bc}	12.30.9±^{b}	21.21.4±^{bc}	3.00.3±^{c}	4.30.3±^{d}
T6	18.81.0±^{c}	8.60.6±^{bc}	75.46.1±^{c}	9.41.0±^{abc}	2.20.2±^{bc}	12.81.0±^{ab}	22.31.5±^{ab}	3.30.3±^{b}	4.70.3±^{c}
T7	20.41.6±^{b}	9.20.5±^{ab}	80.68.5±^{b}	9.80.4±^{ab}	2.70.1±^{b}	13.51.0±^{ab}	23.52.0±^{a}	3.90.3±^{a}	5.40.3±^{b}
T8	21.41.7±^{a}	9.70.8±^{a}	83.18.6±^{a}	9.90.4±^{a}	2.70.2±^{a}	14.01.2± ^{a}	24.01.0±^{a}	4.40.3±^{a}	6.00.5±^{a}

Different letters indicate significant differences between treatments ($P<0.05$)

See footnote Fig 1

TABLE 4. AB-DTPA extractable Fe, Mn and Zn in soil and their concentrations within the different plant parts (means ±SD)as affected by application of compost and biochar either solely or in combinations.

	AB-DTPA-extractable nutrients, mg kg$_{-1}$			Concentration in straw, mg kg^{-1}			Concentration in grains, mg kg^{-1}		
	Fe	Mn	Zn	Fe	Mn	Zn	Fe	Mn	Zn
				Summer season (peanut)					
T1	11.31.5±^{f}	6.40.1±^{f}	59.63.4±^{h}	12.80.4±^{f}	1.70.1±^{f}	10.80.7±^{f}	28.21.2±^{a}	2.80.2±^{d}	10.50.5±^{f}
T2	23.22.1±^{cd}	9.20.2±^{cd}	78.82.8±^{d}	17.30.5±^{b}	2.10.2±^{c}	13.50.9±^{c}	33.72.1±^{a}	4.80.3±^{abc}	13.30.7±^{bc}
T3	11.81.3±^{e}	6.90.2±^{f}	65.73.2±^{g}	13.20.3±^{e}	1.80.1±^{ef}	11.21.3±^{ef}	31.81.1±^{a}	3.30.2±^{d}	12.00.8±^{ef}
T4	14.41.2±^{d}	7.70.5±^{e}	71.42.3±^{f}	15.71.0±^{d}	2.10.1±^{de}	12.00.9±^{de}	34.53.0±^{a}	4.00.2±^{cd}	12.70.7±^{de}
T5	19.30.8±^{d}	8.70.2±^{de}	77.62.4±^{e}	16.40.5±^{c}	2.30.2±^{d}	13.31.0±^{d}	36.11.2±^{a}	4.10.3±^{bcd}	13.20.9±^{cd}
T6	24.31.1±^{bc}	9.70.3±^{bc}	79.93.1±^{c}	17.90.6±^{b}	2.30.2±^{bc}	14.01.0±^{bc}	37.31.4±^{a}	5.00.3±^{bc}	13.90.7±^{b}
T7	26.41.1±^{ab}	10.20.7±^{ab}	85.44.2±^{b}	18.90.6±^{a}	2.40.2±^{ab}	14.50.8±^{ab}	37.72.0±^{a}	5.50.4±^{a}	13.80.9±^{a}
T8	29.81.3±^{a}	10.30.5±^{a}	87.82.2±^{a}	19.71.1±^{a}	2.70.2±^{a}	15.21.1±^{a}	37.93.1±^{a}	5.70.6±^{a}	14.80.9±^{a}
				Winter season (Wheat)					
T1	10.60.9±^{d}	5.80.4±^{e}	55.05.0±^{g}	7.30.3±^{c}	1.201±^{f}	9.20.7±^{f}	17.11.0±^{e}	2.10.1±^{f}	3.30.3±^{d}
T2	18.30.7±^{c}	8.30.7±^{d}	72.66.9±^{d}	8.60.3±^{c}	2.00.2±^{de}	12.51.1±^{cd}	22.81.2±^{de}	3.00.3±^{d}	4.40.3±^{c}
T3	10.80.6±^{d}	6.20.6±^{e}	59.54.1±^{f}	8.20.4±^{c}	1.30.1±^{f}	9.50.8±^{ef}	17.10.3±^{de}	2.30.2±^{f}	3.60.2±^{d}
T4	12.50.8±^{c}	7.30.7±^{d}	68.44.6±^{e}	8.60.5±^{bc}	1.70.1±^{e}	10.80.8±^{de}	20.01.6±^{c}	2.50.2±^{e}	4.20.3±^{cd}
T5	14.50.6±^{c}	7.80.9±^{c}	70.53.8±^{cd}	8.90.8±^{bc}	2.00.2±^{cd}	12.30.9±^{bc}	21.21.4±^{d}	3.00.3±^{c}	4.30.2±^{b}
T6	18.81.0±^{b}	8.60.6±^{b}	75.46.1±^{c}	9.41.0±^{abc}	2.20.2±^{bc}	12.81.0±^{b}	22.31.5±^{bc}	3.30.3±^{bc}	4.70.1±^{b}
T7	20.41.6±^{a}	9.20.5±^{ab}	80.68.5±^{b}	9.80.4±^{ab}	2.70.2±^{ab}	13.51.0±^{a}	23.52.0±^{ab}	3.90.3±^{ab}	5.40.3±^{ab}
T8	21.41.7±^{a}	9.70.8±^{a}	83.18.5±^{a}	9.90.4±^{a}	2.70.2±^{a}	14.01.1±^{a}	24.01.0±^{a}	4.40.2±^{a}	6.00.2±^{a}

Different letters indicate significant differences between treatments ($P<0.05$)

See footnote Fig 1.

The first assumption: "the amount of biochar needed to improve soil physical and chemical characteristics is relatively lower than the amount of compost needed as a soil amendment (biochar is relatively higher stable than compost). Moreover, the residual effect of biochar (added at lower rates) may be more pronounced versus compost on improving soil physical and characteristics as well as plant growth thereon".

To scrutinize this assumption, a sandy soil of the semi-arid region was amended with either biochar (at elevated rates) or compost, solely or in combination. It seems that the application of 12.5 Mg Bs ha^{-1} was the most efficient solely applied Bs treatment when compared to the compost treatment as they both improved soil physical properties, *i.e.* soil water contents at both the welting point and field capacity and consequently the available water content and the soil bulk density as well as the chemical characteristics, *i.e.* ROC and CEC. On the other hand, no significant variations were detected between these two amendments. Generally, biochar, which is a porous material, has the potentiality to retain soil moisture (Bassouny & Abbas, 2019 and de Jusus Duarte et al., 2019) and also restore soil fertility (Novak et al., 2019) because of its high organic carbon content (Song et al., 2019) and plant nutrients in ash (Novak et al., 2019).The results obtained herein agree with those reported by Hailegnaw et al. (2019) who found significant changes in soil pH, CEC, and exchangeable Ca^{2+}, K^{+}, and Mg^{2+} owing to the application of biochar. Likewise, Jien (2019) recorded significant reductions in soil bulk density, penetration resistance, soil losses while increased water retention capacity, aggregation stability and crop production in soils amended with biochar. Moreover, Farid et al. (2014) recorded significant improvements in chemical and physical characteristics of a sandy soil amended with compost.On the other hand, the application of only 5 Mg Bs ha^{-1} improved slightly; but insignificantly, the above mentioned physical and chemical characteristics. These results support partially the first hypothesis.

Our results highlighted the residual effect of the previously applied compost and biochar on soil physical and chemical characteristics in the successive season; however, such effects seemed to be relatively lower compared with the first season. This amendment probably induced the root growth of peanut and wheat plants and their residues e.g. plant roots (denoted by ROC) seemed to be relatively noticeable by the end of the growing seasons. It was also noticed that the applications of "biochar+compost" resulted in further improvements in the abovementioned characteristics than the single ones did especially upon increasing the dose of application.

The second assumption

"Increasing the dose of the applied biochar may negatively reduce the availability of NPK and micronutrients for the plants grown in the first season; however, the residual effect of this amendment serves as slow release fertilizers in the second growing season".

To investigate this assumption, the availability of NPK and micronutrients (Fe, Zn and Mn) were determined in soil during both seasons of study. Moreover, the concentrations of these nutrients were considered within the areal parts of the grown plants by the end of each growing season. Results obtained herein indicate that both the investigated amendments improved significantly the availability of soil macro- and micro-nutrients and hence increased their uptake by the grown plants. Combined amendments seemed to be more efficient than the single ones in this concern especially when increasing the dose of application. Concerning the applications of either of these amendments solely, results revealed that compost applied at a rate of 25 Mg ha^{-1} recorded the highest increases in the availability of the investigated macro- and micro-nutrients and therefore raised significantly their concentrations within the different plant parts. Application of only 12.5 Mg Bs ha^{-1}recorded comparable effects to those of the compost at the first growing season; however, this effect was significantly superior at the second growing season. In case of compost, its degradation in soil probably liberated organic acids (Abujabhah et al., 2016) which might, in turn, reduced soil pH (Fig. 5). Thus, the solubility of soil nutrients increased (Kumar et al., 2016), consequently, their uptake by the grown plants increased. On the other hand, the application of biochar is associated with significant increases in soil pH. Such increases are probably due to the relatively high pH value of the biochar itself,on one hand, and the hydrolysis of this organic amendment,on the other hand (Jordan and Mullen, 2007). The hydroxyl ions account for the significant increases in soil pH while the released organic acids and electrons are incorporated in increasing the solubility of many nutrients in soil as presented by Sposito (2011)

½ Mn_3O_4 (2) + $4H^+$ + e^- = Mn^{2+} + $2H_20$ (l)
log K=30.68

½ MnO٢ (s) + ٢H^+ + e^- = ½ Mn^{2+} +H_2O (l)
log K= 21.82

Fe $(OH)_3$ (s) + $3H^+$ + e^- = Fe^{3+} + $3H_2O$(l)
log K=17.14

In case of Zn, its solubility also increases with increasing soil acidity as presented by Lindsay (1979).

½ Zn(OH)2 (amorphous) + $2H^+$ = ½ Zn^{2+} +H_2O (l)
log K= 12.48

These metal ions were then sorbed on biochar which is characterized by its high porosity and its large surface area. Also, due to the presence of many functional groups on biochar surface, this amendment may serve as slow-release fertilizer (Ding et al., 2016) or being immobilized by soil biota. On the long run, these metal ions are recycled back and enrich soils with nutrients that are taken up by plants consequently increase their corresponding concentrations within the areal plant parts.

The availability of soil nutrients seemed to be higher during the first growing season which is characterized by relatively higher pH values; however, the presence of ROC at comparatively higher rates during the first season hypothesize the return back of these metal ions mainly as organic complexes to the soil solution to avoid further fixation under the alkaline conditions achieved due to biochar applications. In this concern, Smebye (2016) reported that the biochar amendment increased the released dissolved organic carbon from the soil

In case of N and P, the functional groups retain NH_4-N and NO_3-N (Yadav et al., 2019); thus reduce their leaching out the agricultural soils (Sanford et al., 2019). Furthermore, biochar adsorbs alkaline phosphatase (ALP) which is involved in phosphorus (P) cycling and; therefore, increases its thermal stability while decreases its sensitivity to elevated temperatures (Khadem and Raiesi, 2019).The released dissolved organic carbon upon biochar decomposition can further minimize P sorption (Schneider and Haderlein, 2016). Moreover, biochar increased soil organic carbon and available nutrients in soil, *e.g.* P and K contents (Li et al., 2019). Thus, biochar can be utilized for improving the soil health and nutrient status (Irfan et al., 2019). Our findings do not support the hypothesis indicating that biochar reduces the availability of soil nutrients because of its alkaline nature and stability in soils for years. However, these results recommend the usage of biochar as a slow release fertilizer and its effect can extend to the second growing season. Probably, the degree of biochar stability depends mainly on the dose of applied biochar as well as the incubation period (Wang et al., 2019). Thus, future studies are needed to investigate the effects of aging (from fresh to old) of the biochar on the physiochemical properties of the amended soils (Jien, 2019).

The consequences of the organic amendments on peanut and wheat productivity

Peanut and wheat yield increased significantly owing to the application of either or both the organic amendments. Such increases might be attributed to the improvements that occurred in soil physical and chemical characteristics. Increasing the rate of the applied biochar resulted in concurrent significant increases in the growth parameters and yield components of the grown plants. Similar results indicate that biochar increases the crop yield production e.g. maize (Glaser et al., 2015) especially when increasing the rate of the applied biochar (Liu et al., 2012). Also, compost applications improved the growth of wheat and maize plants grown on a sandy soil (Farid et al, 2014). The combination between these two amendments further promoted the investigated growth parameters and yield components than the organic matter did.

Conclusion

Our results indicated that amending a sandy soil with a half dose of Bs could improve soil physical and chemical characteristics recording comparable results to those achieved due to application of compost at its full dose during the first growing season. Moreover, Bs effect seemed to be superior to that of the compost on improving many soil properties during the second growing season. Thus, biochar is more preferable than compost from the ecological point of view; however, the economical interpretation for amending soils with biochar remained below the compost because of its relatively high price. On the other hand, the residual organic carbon decreased considerably in soil after only one season of application of both types of the studied organic amendments. This indicates that even biochar can undergo microbial degradation in the arid regions. Its degradation is associated with significant increases in soil pH while, on the other hand, the availability of soil macro and micro-nutrients increased. Further biological and biochemical studies are needed to provide more knowledge and consequently more deeply understand for the behavior of these amendments in such sandy soils on the long run especially under the alkalinity conditions prevailing in arid and semi-arid climate.

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علاج الاراضي الرملية باستخدام محسنات البيوشار والكمبوست، وتداعياتهما كاسمدة بطيئة لتحلل علي نمو النبات

محمود عبد المنعم الشوني[1،2]، إيهاب محمد فريد[1]، فاتن الكمار[2]، محمد حسن حمزة عباس[1]، حسن حمزة عباس[1]

[1] جامعة بنها، كلية الزراعة، قسم الأراضي والمياه [2]معهد بحوث الأراضي والمياه والبيئة، المركز القومي للبحوث، الجيزة (مصر)

يعتبر ضعف خصوبة الاراضي الرملية وانخفاض قدرتها علي الاحتفاظ بالرطوبة من اهم السمات المحددة لانخفاض انتاجية مثل هذه النوعية من الاراضي، ولكي يتم التغلب علي هذه المشكلات فإنه يتم معاملة الأراضي الرملية بالمحسنات العضوية،ولكن إلي أي مدى يمكن لتلك المحسنات العضوية التأثير على خصائص الارض الطبيعية والكيميائية؟، لذا يهدف البحث التالي إلى دراسة تأثيرالاضافات العضوية (البيوشار، والكمبوست) في تحسين خواص الارض الرملية خلال موسمين متتاليين، ويضع البحث الفرضيتين التالين موضع الدراسة: (1) يكفي إضافة نصف الكمية من المحسن العضوي"البيوشار" لتعطي نتائج مماثلة في تحسين الخواص الطبيعية والكيميائية للارض الرملية لاضافة الكمية الكلية من الكمبوست . علاوة علي ذلك، فإن الأثر المتبقي للبيوشار علي خواص الارض الطبيعية والكيميائية يكون اكثر وضوح في الموسم التالي من الاضافه عند مقارنتة بتأثير إضافة الكمبوست كمحسن للأرض، أما بالنسبة للفرض الثاني، فمبني علي انه بإضافة البيوشار إلي الارض الرملية (ذات القدرة التنظيمية المحدودة)، فإنه يقلل من تيسر الفوسفور، والعناصرالصغري في التربة بسبب سلوكه القلوي، وطول مدة بقاءه في الأرض، مما يؤثر سلبا علي الكمية الممتصة من هذه المغذيات بواسطة النبات، وللتحقق من صحة هذا الفرض، فإنه تم اختيار ارض رملية وتم معاملتها بالبيوشار (بمعدلات مختلفة) إما بمفرده، أو مع الكمبوست، ثمالزراعة بالفول السوداني (موسم صيفي)، كما تم التحقق من الاثر المتبقي لهذه المحسنات علي خواص الارض ونمو نبات القمح في الموسم الشتوي الذي يليه، وقد اوضحت النتائج أن إضافة 12.5 ميجاجرام من البيوشار لكل هكتار من التربة اعطي نتائجايجابية في تحسين خواص الارض، وتحفيز النمو النباتي مقاربة لتأثير اضافة 25 ميجاجرام من الكمبوست لكل هكتار، بينما لم تكنلإضافات البيوشار بمعدل 5 ميجاجرام لكل هكتار تأثير معنويعلي خواص التربة موضع الدراسة، وأيضا اظهت النتائج ان الاضافات المختلطة بين "البيوشار والكمبوست" اظهرت كفاءة اكبر في تحسين خواص التربة مقارنة بالإضافات الفردية لكل نوع محسن علي حدة، ومما سبق يتحقق صحة الفرض الاول جزئيا، أما بخصوص الفرض الثاني، فإنه تمت دراسة حالة تيسر العناصر الغذائية مثل فوسفور، والحديد، المنجنيز، والزنك في التربة، وتركيز هذه المغذيات في الاجزاء الهوائية من النباتات النامية خلال موسمين متتاليين (صيفي-شتوي)، فعلي الرغم من قيام البيوشار برفع رقم حموضة التربة ، إلا أن العناصر موضع الدراسة قد زاد تيسرها مع إضافة البيوشار، وانعكس ذلك علي زيادة مستوي هذه العناصر في النبات النامي، مما يعني رفض الفرض الثاني، فربما حدثت هذه الزيادات علي صورة معقدات عضوية ذائبة، وبالتالي توصي الدراسة باهمية استخدام البيوشار مصدر بطئ التحلل للعناصر الصغري والكبري، حيث يكتفي فقط بنصف الكمية المستخدمة من البيوشار لتحسين الخواص الطبيعية والكيميائية للارض، والتي يمتد أثرها لاكثر من عام عقب الاضافة.