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EFFECTIVENESS OF COMPOST AND BIOCHAR IN IMPROVING WATER RETENTION CHARACTERISTICS AND AGGREGATION OF A SANDY CLAY LOAM SOIL UNDER WIND EROSION

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Abstract: The profitability of a sandy clay loam (*SCL*) soil is well known to be constrained due to poor aggregation and aggregate stability, rapid infiltration and drainage of water, as well as low capability of retaining water and nutrients, and thereby culminating in decreased water and fertilizer use efficiency, which in turn decrease agricultural production. Thus, organic materials have long been reported as a promising avenue for addressing the aforementioned difficulties in different soil types. In this regard, the aims of this study were to determine the effect of applying Oleaster tree pruning residues (*OPR*) in two the different forms (compost and biochar) as an organic material on improving aggregation and water retention characteristic of a *SCL* soil. Biochar was obtained from *OPR* through pyrolysis process at 450^0C, while compost was obtained from composting of the *OPR* through windrow composting process. Compost and biochar were individually applied to a *SCL* soil at a rate of 0, 1, 2 and 4% (wt/wt) with four replications and thoroughly mixed with the soil, then moistened to field capacity (*FC*) equated to 0.29 g g^{-1} and subsequently incubated for the period of two months. At the end of incubation period, obtained experimental results indicated that applied compost and biochar significantly improved aggregation and water retention characteristics of a *SCL* soil and improvements were proportional to application rates. We concluded that both applied forms of the *OPR* (compost and biochar) could be considered leading soil amendments for improving aggregation and water retention capacity of a *SCL*, and thereby enhancing agricultural production.

Keywords: Soil water retention, Soil aggregation, SCL soil, Biochar, Compost

1. INTRODUCTION

Due to poor soil productivity of a sandy clay loam (*SCL)* soil, induced by poor aggregation and soil aggregate stability (*SAS*), poor soil organic matter (*SOM*), weak structure, low water and nutrients holding capacity, as well as other correlated poor soil physical, chemical and biological properties, rational agricultural practices are required for improving the aforementioned difficulties found in a *SCL* soil on grounds of enhancing agricultural production. Compost and biochar applications as soil amendments derived from organic materials are considered amongst rational agricultural practices, which increase *SOM* playing role in improving soil aggregation and water holding capacity via decreasing water losses due to deep percolation and evaporation, and herein lies the root of improving soil water use efficiency and decreasing irrigation frequency. It has been noted that soil amendments effectively play an important role in increasing water retention, decreasing infiltration rate and evaporation as well as enhancing conservation of water under a sandy soil (Al-Omran et al., 1987) and the agronomical potential of soil amendments has been reviewed by Manirakiza & Şeker (2018) and also validated by Manirakiza & Şeker (2019).

Compost as one of the organic amendments, is used to avail suitable soil physical condition, such as improved aggregation and water retention capacity for plant root development resulting in increased agricultural production. Previous study revealed that the infusion of compost into the soil improved soil water storage via decreasing evaporation (Opara-Nadi & Lal, 1986), as well as deep percolation, especially in the *SCL* soil. The impact of compost on soil physical properties improvement has been investigated by several researchers, and Eusufzai & Fujii (2012) reported that compost addition has a potent impact on improving quality, hydraulic properties and pore size distribution of the soil. Newly, evidenced studies have reflected that compost addition to soil decreased soil bulk density (*Bd*) and particle density (*Pk*), as well increased soil total porosity, soil water retention capacity and plant available water content (*PAWC*) (Barus, 2016).

In contrast, biochar as a material endowed with a sizeable amount of carbon, which is generated from pyrolysis process at a hefty temperature ranging from 300 to 1000ºC under either constrained or free-oxygen environment (Verheijen et al., 2010), is also considered soil amendment, which has been proven to be recalcitrant to microbial activity than organic materials (Zimmerman, 2010), and thereby resulting in long-term organic matter maintenance in the soil. It was revealed that biochar possesses a tremendous perk in enhancing soil physical and chemical properties (Luo et al., 2017), due to being endowed with good physical condition, such as high porosity and surface area (Van Zwieten et al., 2010). Rillig & Thies (2012) found that biochar application enhanced physicochemical soil properties due to being endowed with a high porosity, surface area and able to adsorb organic matter and plant nutrients. This adsorption effect could elucidate that it has the high capability of being adsorbed by water, and thereby increasing water retention capacity of a soil. The potentiality of biochar for improving soil physical properties increasingly raised from being identified as a material endowed with a high porosity (Hina et al., 2010; Liang et al., 2006) and an extensive inward surface area (Kishimoto, 1985; Van Zwieten et al., 2010). It was reported that biochar's porosity increases with pyrolysis' temperature (Schimmelpfennig and Glaser 2012) and also depends on biomass types (Hina et al., 2010). Similarly, biochar produced at a high temperature is endowed with a lower nutrient contents and higher micro-porosity, whereas the one produced at low temperature is endowed with a higher nutrient content and lower micro-porosity (Lehmann & Joseph, 2009). Many studies touching on how biochar as a soil amendment affect soil physical properties were conducted. Previous results revealed that the infusion of biochar into a soil decreased *Bd* (Brewer et al., 2014; Laird et al., 2010) and increased soil water holding capacity (Ouyang et al., 2013), increased total porosity (Omondi et al., 2016) and mean weight diameter (*MWD*) (Hseu et al., 2014).

The objective of this research was to determine the impact of Oleaster (*Oleaster angustifolia L.*) applied in two different forms namely compost and biochar as soil amendments on improving poor aggregation and water retention capacity of a *SCL* soil subjected to wind erosion in a short period of two months.

2. MATERIALS AND METHODS

2.1. Site characteristics, preparation of used amendments and laboratory experimental design

The study was a pot experiment conducted from the 1st of August to the 1st October, 2018 in the laboratory condition. The employed materials at this experiment were: a) *SCL* textured soil (60.48% sand, 13.33% silt and 26.19 % clay) with a pH of 8.62, electrical conductivity of 0.236 mS cm^{-1} and lime content of 660 g kg^{-1} collected from Karapinar region subjected to wind erosion (37.72°N latitude and 33.55°E longitude, 0-20 cm depth) located in Konya, Turkey and the soil of this region was classified as Xeric Haplogypsid (Akça, 2001; Soil Survey Staff, 1999); b) compost as soil amendment was produced from Oleaster tree pruning residues (*OPR*) whereby C/N ratio and moisture were adjusted exactly at 25:1 and 70% for facilitating microbial activities and detailed composting processes are described by Mücehver et al. (2018) and after composting, obtained compost was passed through 2 mm sieve prior to application; c) Biochar as soil amendments was produced from *OPR* through pyrolysis process, in which charring of *OPR* occurred at 450°C in the muffle furnace as elucidated in detail by Brewer (2012) and Mücehver et al., (2018). After pyrolysis process, carbonized product was removed from the muffle furnace and cooled at room temperature, then ground to pass through a 2-mm sieve prior to use. The basic chemical properties of compost are a pH of 8.86, electrical conductivity of 3.60 $mScm^{-1}$ and lime content of 58.9 g kg^{-1} while the one of biochar are pH of 8.95, electrical conductivity of 0.192 $mScm^{-1}$ and lime content of 60.2 g kg^{-1}. The physical properties of experimental soil, which used in this research, are presented in Table 1.

During the experiment, 28 pots were employed according to the following experimental design: Two forms of *OPR* (compost and biochar) x 3 rates of application x 4 replications plus 4 controls in a randomized plot design. The applied rates were: 1, 2 and 4 % (wt/wt) for every applied amendment, which were thoroughly mixed with 3 kg of air-dried soil sieved through 2-mm sieve, subsequently potted in a 5 litre plastic pot, all pots including the control (i.e. 0% application rate) were moistened to exactly field capacity (*FC)* equated to 0.29 g g^{-1}, then incubated for two months for homogenizing the mixture and weekly water was brought back to *FC*. Soil samples were collected from every pot for evaluating the responses of aggregation and water retention capacity of a SCL soil to the individually applied two forms of the *OPR* at the end of incubation period. In this study, compost and biochar of *OPR* were preferred due to the fact that Oleaster tree is widely grown in the area of the study to prevent wind erosion. We hypothesized that the application of two different forms of the *OPR* as compost and biochar would improve physical properties of a *SCL* soil endowed poor aggregation and water retention capacity via improvement of *SOM*, *Bb*, soil *Pk*, soil total porosity, *FC*, Permanent wilting point (*PWP)*, *PAWC*, air filled porosity (*AFP*), *SAS* and *MWD*. In turn, the knowledge of the impact of two forms (compost and biochar) of the *OPR* on the improvement of aggregation and water retention capacity of a *SCL* soil would be a promising agricultural management practices for boosting agricultural production via enhancement of physical quality of a *SCL* soil.

For testing our hypothesis, two forms of the *OPR* as compost and biochar individually applied at a rates of 0 (control), 1, 2 and 4% were mixed with a *SCL* soil possessing poor aggregation and water retention capacity, then potted in a pot and subsequently incubated for two months in order to keep homogenous interaction within the mixture. At the end of incubation, we scrutinized the improvement of aggregation and water retention capacity of a *SCL* soil after the addition of *OPR* in two different forms.

Table 1. The physical characteristics of the experimental soil used in the study

Parameters	Units	Experimental soil
Soil texture	% of S, C and Si	SCL
Bd	g cm^{-3}	1.19
Pk	g cm^{-3}	2.59
Total porosity	cm^3 cm^{-3}	0.54
SAS	%	24.87
MWD	mm	0.11
FC	g g^{-1}	0.29
PWP	g g^{-1}	0.12
PAWC	g g^{-1}	0.17

S: Sand (60.48%); C: Clay (26.19 %); Si: Silt (13.33%).

2.2. Measurements of soil physical properties

At the end of incubation period of two months, soil was evenly mixed and subsequently samples were taken from every pot. Prior to analyses of soil physical properties, soil samples were air dried and passed through a 2- mm sieve, except 4-mm sieve for *MWD* analysis.

Total organic carbon which was subsequently converted into *SOM* was determined through Smith and Weldon wet combustion method (Nelson & Sommers, 1982). *Bd* was measured through the protocol developed by Jacobs et al. (1964). Briefly, oven dry (105°C) disturbed soil sample sieved through 10-mesh and 100 cm^3 cylinder were used. Firstly, dry soil sample was filled into 100 cm^3 cylinder up to one-fourth, then simulate natural packing was done by carefully tapping the cylinder five times, and thereafter cylinder was filled with the soil again up to three-fourth and packed similarly. Finally, cylinder was fully filled with the soil and *Bd* was calculated using the following formula:

$Bd = Grams\ of\ soil\ / Volume\ of\ soil$ (1).

Pk was measured through the pycnometer method (Blake & Hartge, 1986). Both *Bd* and *Pk* were used to calculate total porosity of the soil, and by inference the water holding capacity of the soil (Danielson et al., 1986). The determination of *SAS* was achieved through artificial rainfall simulator device and employed procedures are described in the protocol formulated by Gugino et al. (2009).

MWD is an important indicator of soil aggregate size distribution, which is also tied to *SAS* and was determined as described by Elliott (1986). A set of four sieves were employed to get four sizes of aggregates, such as large soil macro-aggregates (2-4mm), macro-aggregates (0.25-2mm) and micro-aggregates (0.053-0.25mm). The separation of the aforementioned aggregates was achieved through wet-sieve method whereby sieves were shaken electronically up and down movement in nearly 3 cm pure water, 50 times within 10 minutes. The remained aggregates on each sieve were collected, then dried at 105°C for 24 hours and weighted for obtaining the mass of oven dry aggregates (mass of real aggregates + sand) for every sieve. The real mass of aggregates in every aggregates size fraction, such as large soil macro-aggregates (2-4 mm), macro-aggregates (0.25-2mm) and micro-aggregates (0.053-0.25mm) were obtained through subtracting sand content from the measured total aggregates in every aggregates size fraction. The determination of sand content was done through sieving dispersed subsample of aggregates for every sieve with sodium hexametaphosphate by employing 0.053 mm-sieves. The remained sand on the 0.053mm-sieve was oven dried at105°C for 24 hours and weighted, in order to be subtracted from the total weighted aggregates size fraction for every sieve size fraction. The *MWD* (mm) was calculated through the following formula:

$MWD = \sum_{i=1}^{n} xiwi$ (2), where n is sieves' number; *xi* is the mean diameter of every aggregates size fraction and *wi* is the proportion of sample's total weight found in related size fraction.

Water content at different suction pressures was determined using sandbox and pressure plate method (Klute, 1986) and water potential meter device (*WP4C*) (ASTMD6836-02, 2008). Briefly, specimen per pot was collected in all pots (2 forms of *OPR* x 3 doses x 4 replicates plus 4 control =28 pots) and compacted (at *Bb* of 1.4 g cm^{-3}) into a stainless steel cylinder with diameter and height of 5 and 5 cm respectively. After compaction, specimens were saturated for four days using sandbox and subsequently water retention measurements at saturation (i.e. 0 kPa or Pf=0), *FC* (i.e. 33 kPa or Pf=2.5) and *PWP* (i.e. 1500 kPa or Pf =4.18) were determined. Prior to applying any pressure to saturated samples, water content at saturation was considered saturated water content. Thereafter, saturated samples were subjected to 33 kPa through pressure plate to get water content at *FC*. Water content at *PWP* was calculated from the water retention curve obtained from matric potentials measured by *WP4C*. Seven samples of 10 g oven dry sample at 105°C for each were respectively moistened to 2, 4, 6, 8,10, 12 and 14 %, then mixed evenly and samples were kept for 24 hrs prior to being read using *WP4C* and we have tried different amount of soil and we came to conclusion that 10g is fine for *WP4C*. Thereafter, the read values from the entire samples were used to plot water retention curve and water content at *PWP* was calculated from the predicted equation from the curve. *PAWC* was calculated as (*FC-PWP*). *AFP* (i.e. sum of drainage and aeration pores) was quantified by subtracting water content at *FC* from water content at saturation. Water content was gravimetrically measured, and subsequently converted into volumetric water content (θv).

2.3. Statistical analysis of soil physical parameters

The responses of soil physical parameters to the individually applied two forms of *OPR* (i.e. compost and biochar) were quantified: a) *SOM*; b) *Bd*; c) *Pk*; d) total porosity; e) *FC*; f) *PWP*; g) *PAWC*; h) *AFP*; i) *SAS* and (j) *MWD*. The aforementioned parameters were statistically subjected to one-way ANOVA using Minitab 16 software and differences between means for every applied form of *OPR* considered statistically to be significant at $P < 0.05$ through Tukey's test.

3. RESULTS

3.1. Soil organic matter

Both compost and biochar applications had a potent effect on *SOM* and increase in *SOM* was proportional to applied rates as shown in Figure 1 and Tukey's test was applied for all the *OPR* treatments and the letters a, b, c, d, e and f were compared within all treatments.

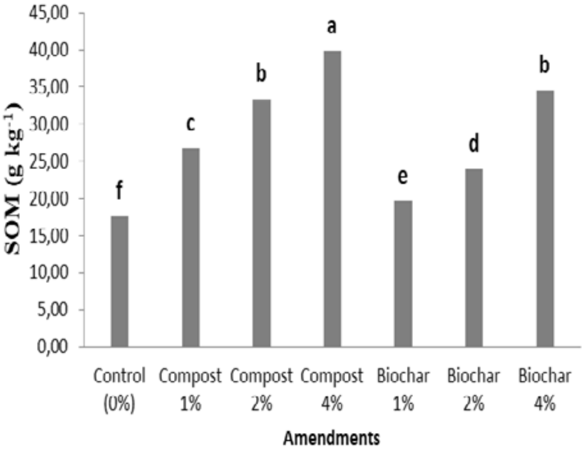

Figure 1. Impacts of amendments on *SOM*.
For every amendment, columns with the identical letter are insignificantly different, while those with different letter are significantly different at ($P<0.001$, one-way ANOVA followed by Tukey's test).

3.2. Soil bulk density

The two-month incubation significantly ($P<0.001$) resulted in a lower *Bd* in both compost- and biochar-amended *SCL* soil as presented in Fig. 2 and Tukey's test was applied for all the *OPR* treatments and the letters a, b, c, d, e and f were compared within all treatments. As envisioned, applying compost and biochar, substantially decreased *Bd* and accordingly the decrease in *Bd* was concomitant of increasing application doses. Although both amendments reflected an enormous decrease in *Bd*, the greatest decrease in *Bd* was recorded from biochar-amended *SCL* soil and these results were expected. The application rates of 1, 2 and 4 % for both amendments were statistically significant for improving *Bd* at small scale within short-term trial (Fig. 2). The recorded *Bd* values for the both amendments varied from 0.95-1.17 g cm^{-3}, which fitted into the range (<1.4 g cm^{-3}) for honing plant growth suggested by USDA-NRCS (2014) in the *SCL* soil.

3.3. Particle density

Compost and biochar applications were found to be incumbent upon significantly improving *Pk* at ($P<0.001$) as illustrated in Figure 2 and Tukey's test was applied for all the *OPR* treatments and the letters a, b, c, d and e were compared within all treatments. As such, the decrease in *Pk* was concomitant of increasing application rates. Significant differences were detected in both compost and biochar- amended

SCL soil at all applied rates relative to the control, except when applying compost at the rate of 1 %. As expected, reduction in *Pk* was highest in biochar-amended *SCL* soil; however the difference between compost and biochar amendments at 4% application rate was almost insignificant.

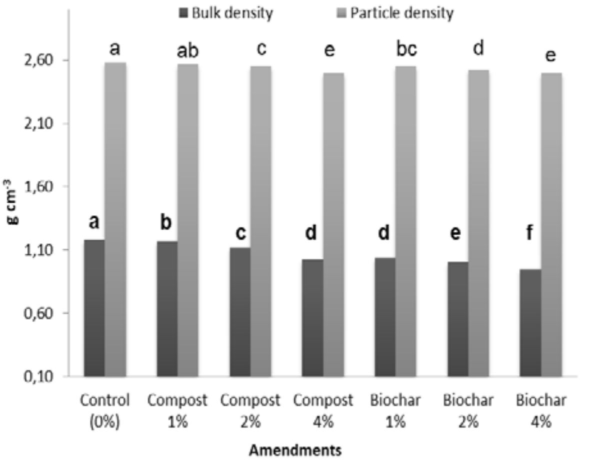

Figure 2. Impacts of amendments on *Bd* and *Pk*
For every amendment, columns with the identical letter are insignificantly different, while those with different letter are significantly different at ($P<0.001$, one-way ANOVA followed by Tukey's test).

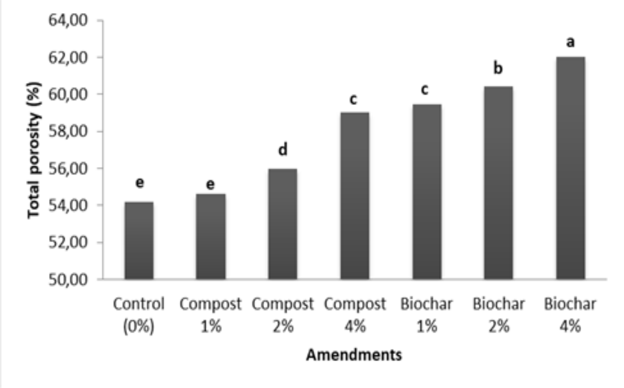

Figure 3. Impacts of amendments on soil total porosity. For every amendment, columns with the different letter are significantly different at ($P<0.001$, one-way ANOVA followed by Tukey's test).

3.4. Soil total porosity

Without any exception, value of soil total porosity was positively ($P< 0.001$) impacted by virtue of applied compost and biochar to the *SCL* soil as presented in Figure 3 and Tukey's test was applied for all the *OPR* treatments and the letters a, b, c, d and e were compared within all treatments. Soil total porosity experienced an upward trend by virtue of applied both amendments and these increments were linear to the application rates. Although compost and biochar additions had a greater values of soil total porosity than control amendment, biochar's impact on soil total porosity improvement outraced that of the biochar.

3.5. Water retention at different suction pressures and *PAWC*

As a *SCL* soil is commonly renowned for low water holding capacity, retained water expressed in θv under the *SCL* soil at different suction pressures namely 6.3 kPa, 33 kPa and 1500 kPa as impacted by applied amendment is illustrated in Figure 4 and Tukey's test was applied inside all the *OPR* treatments and the letters a, b, c, d, e, f and g were compared within all treatments. Experimental results revealed that retained θv at the aforementioned suction pressures significantly ($P<0.001$) increased as compared with the control.

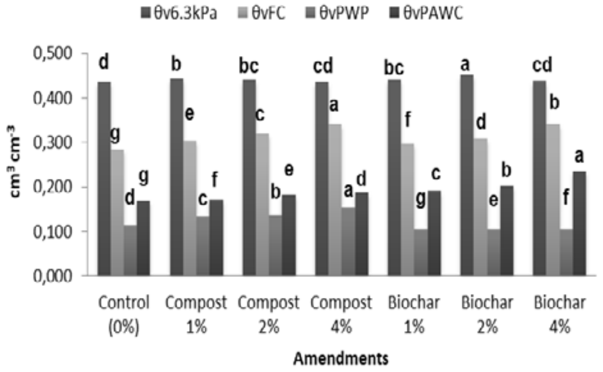

Figure 4. Impacts of amendments on Θv at 6.3 kPa, 33 kPa (i.e. *FC*), 1500 kPa (i.e. *PWP*) and *PAWC*.
For every amendment, columns with the identical letter are insignificantly different, while those with different letter are significantly different at ($P<0.001$, one-way ANOVA followed by Tukey's test).

At 6.3 kPa (i.e. at pF=1.8) recorded values of retained θv in compost-amended *SCL* soil at 1, 2 and 4% application rates were respectively 1.02, 1.01 and 1.00-fold those of the control, while those recorded in biochar-amended *SCL* soil at similar application rates were respectively 1.01, 1.00 and 1.04-fold those of the control as presented in Figure 4. The responses of water retention capacity to the applied both amendments at low suction pressure of 6.3 kPa (i.e. at pF=1.8) were trivial in the context of increasing water holding capacity.

All applied amendments were statistically significant ($P<0.001$) in the magnitude of positively affecting water holding capacity at *FC* (i.e. 33 kPa), yet mathematically increments were trivial relative to the control ranging from 0.02 to 0.06 cm^3 cm^{-3} for compost addition and from 0.01 to 0.06 cm^3 cm^{-3} for biochar addition and these increments were proportional to the applied doses (Figure 4).

At 1500 kPa (i.e. pF=4.18) retained θv in compost-amended *SCL* soil at 1, 2 and 4% application rates were respectively was 1.158, 1.192 and 1.338 times that of the control (Figure 4). Conversely, biochar addition showed a downward trend by decreasing *θv* by 0.010, 0.009 and 0.009 $cm^3\ cm^{-3}$ when the similar rates were applied. Significant differences were observed in all applied amendments (*P*<0.001). In contrast, compost-amended *SCL* soil increased water retention capacity, yet biochar-amended one decreased water retention capacity at *PWP* (i.e. 1500 kPa).

Due to the fact that retained *θv* at *FC* (i.e. 33 kPa) was far beyond the one retained at *PWP* (i.e. 1500 kPa), it is of great importance to note that *PAWC* calculated as (retained *θv* at pF =2.5 – retained *θv* at pF =4.18) scaled up as reflected in Figure 4. Applied both amendments (i.e. compost and biochar) significantly (*P*< 0.001) increased *PAWC*, and *PAWC* was higher in biochar- amended *SCL* soil than that of compost- amended one. Significant differences were found in all applied amendments alongside their respective application rates and the betterment of *PAWC* was proportional to the applied doses, as envisioned. The infusion of either compost or biochar to the experimental soil at the aforementioned application rates were found to be fine for increasing *PAWC* ranged from 0.002 to 0.018 $cm^3\ cm^{-3}$ for compost addition and 0.022 to 0.065 $cm^3\ cm^{-3}$ for biochar addition in short-term trial at small scale.

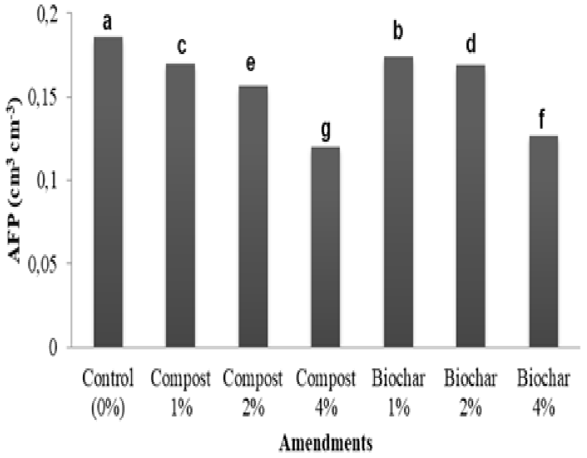

Figure 5. Impacts of amendments on *AFP*.
For every amendment, columns with different letter are significantly different at (*P*<0.01for compost and *P*<0.001 for biochar, one-way ANOVA followed by Tukey's test).

3.6. Air filled porosity

As *AFP* in the soil is the prominent indicator for facilitating not only microbial respiration and water retention capacity but also crop growth and development culminating in soared both soil profitability and agricultural yields. In this regard, applied compost and biochar as soil amendments significantly (*P*<0.001) decreased soil *AFP* in the studied *SCL* soil as presented in Figure 5 and Tukey's test was applied inside all the *OPR* treatments and the letters a, b, c, d, e, f and g were compared within all treatments. Significant differences were observed in all amendments and soil *AFP* decreased with increasing application rates, as expected.

3.7. Soil aggregate stability

With some exceptions, compost and biochar additions statistically (*P*<0.001) showed a significant increase in *SAS* as represented in Fig. 6 and Tukey's test was applied inside all the *OPR* treatments and the letters a, b, c and d were compared within all treatments. *SAS* increased linearly with application rates for both amendments. The observation of *SAS* in both compost-and biochar-amended *SCL* soil at the similar application rate reflected that the impact was statistically insignificant, yet significant relative to the control. Statistically, significant differences were noted at 2 and 4% application rates for both compost- and biochar-amended *SCL* soil as compared to the control. It is interesting to note that 2 and 4% application rates of both compost and biochar statistically were fine for increasing *SAS* as observed in the compost-amended *SCL* soil, the increase in *SAS* ranged from 2.86 to 24.62 %, while in biochar-amended *SCL* soil ranged from 2.78 to 24.57 %.

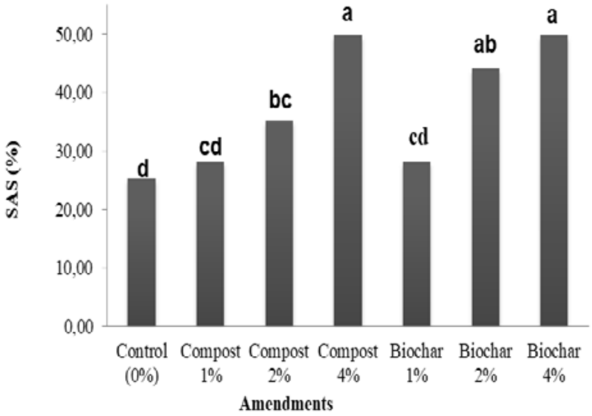

Figure 6. Impacts of amendments on *SAS*.
For every amendment, columns with the identical letter are insignificantly different, while those with different letter are significantly different at (*P*<0.001, one-way ANOVA followed by Tukey's test).

3.8. Mean weight diameter

Regarding the impact of applied amendment (i.e. compost and biochar) on *MWD*, it was shown that both amendments significantly ($P< 0.001$) increased *MWD* as illustrated in Figure 7 and Tukey's test was applied inside all the *OPR* treatments and the letters a, b, c, d, e and f were compared within all treatments. *MWD* increments were proportional to the applied rates and the highest values of *MWD* were in compost- and biochar- amended *SCL* soil as compared to the control. This shows that there was a linear relationship between obtained values of *MWD* and applied rates. Significant differences were noted among amendments in the magnitude of improving *MWD*. Moreover, 4% of biochar followed by 4 % of compost application were more effective for enhancing *MWD* than other amendment's application rates.

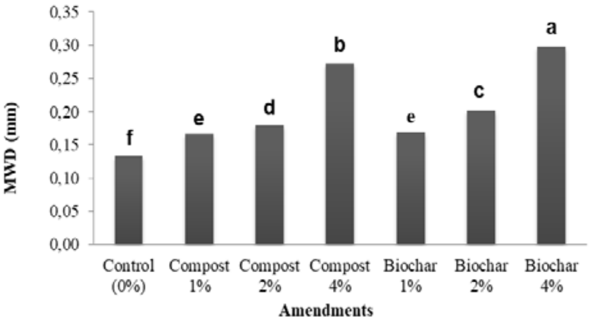

Figure 7. Impacts of amendments on *MWD*.
For every amendment, columns with the different letter are significantly different at ($P<0.001$, one-way ANOVA followed by Tukey's test).

4. DISCUSSIONS

This breakthrough was a short-term study to scrutinize the impact of the *OPR* applied in two different forms namely compost and biochar as soil amendments on aggregation and water retention capacity of a *SCL* soil as far as *SOM*, *Bd*, *Pk*, total porosity, and *FC*, *PWP*, *PAWC*, *AFP*, *SAS* and *MWD* were concerned. In this section, we are going to elucidate the obtained findings throughout this research.

4.1. Soil organic matter

In accordance with our expectations, the experimental results revealed that compost and biochar additions significantly increased soil organic carbon, which is a leading indication of accumulation and sequestration of carbon in the soil. The increase in *SOM* was due to these amendments are endowed with a sizeable amount of total carbon within their structure with respectively 236 and 521 g kg^{-1} for compost and biochar, which underwent microbial decomposition, as well as could have sequestered atmospheric CO_2. An upward trend in *SOM* due to compost addition was in agreement with (Cox et al., 2001; Mensah & Frimpong, 2018), while the one due to biochar addition was also in accordance with (Demisie et al., 2014; Mensah & Frimpong, 2018). Additionally, the contribution of organic materials in escalating *SOM* has been previously evidenced by Theobald et al. (2018).

4.2. Soil bulk density

All the amendments tested; compost and biochar additions, were able to decrease *Bd* and these results are consistent with (Agegnehu et al., 2015); the impact might be a result of light material additions (i.e. compost and biochar), which are commonly endowed with a lower bulk density (Ouyang et al., 2013) and an increasing of porosity (Barus, 2016) due to highly porous material additions, which might have made the experimental soil become increasingly light and herein lies the root of decreasing *Bd*. Additionally, increased of *SOM* as indicated in Fig. 1 is also another of decreasing *Bd.* Barnes et al. (2014) found that bulk density of biochar was less than that of experimental soil and also (Hina et al., 2010; Liang et al., 2006) found that biochar is endowed with a high porosity, which might have lightened experimental soil as a results of decreasing *Bd* in our study and these results were also evidenced by Mukherjee & Lal (2013). In contrast, biochar amendment stood out from compost in the context of lowering *Bb* and these findings are in agreement with (Agegnehu et al., 2015), this may signify that biochar might be substantially lighter than compost. In contrast to our results, Barus (2016) observed that compost addition stood out from biochar in the context of decreasing *Bd*; nevertheless, trial was set for 1 month, indicating that biochar addition become more effective in the soil with time prolongation.

Decreases in *Bd* throughout our study are in accordance with other researches. For instance, Barus (2016) reflected that at 10 t ha^{-1} application rate, compost and biochar additions lowered *Bd* by 0.11 and 0.06 g cm^{-3}, respectively. The positive perks of compost and biochar additions in the context of improving *Bd*, have been reported by previous researchers. With compost addition, *Bd* decreased by 0.05 (Agegnehu et al., 2015) and 0.42 g cm^{-3} (Emami & Astaraei, 2012) and in the same way, due to biochar addition, *Bd* decreased by 0.15 (Agegnehu et al. 2015) and 0.27 g cm^{-3} (Jien & Wang, 2013). Overall, the application rates of 1, 2 and 4% for either compost or biochar were markedly fine for decreasing *Bd* and these evidences were reviewed by Aslam et al. (2014).

4.3. Particle density

Our findings showed that compost and biochar additions seemed able to decrease *Pk* in the 2-months trial; this might be due to the applied amendments increased *SOM* (Fig. 1) which might have contributed to declined *Pk* and these results are consistent with (Busscher et al., 2011) who noted that organic matter originated from organic amendments can significantly decrease *Pk*. Jien & Wang (2013) found that micro-aggregates were flocculated by virtue of biochar addition, and this can be a result of increasing macro-pore at the expenses of micro-pores which also might have been an important reason for decreasing *Pk*. Another reason might be that *Pk* of both applied amendments was lower than that of experimental soil, which might have also induced gradual decreases in *Pk*. Barus (2016) reported that *Pk* reduction was due to compost addition endowed with low bulk density as compared with experimental soil, and this also might have been a reason of decreasing *Pk* due to compost addition. These results were expected, since biochar directly affect soil water storage due to its high inner porosity resulting in increased soil pore size distribution and likewise for compost addition. It was found that the application rate of 2 and 4% for compost and 1, 2 and 4% for biochar were noticeably fine for lowering *Pk*.

4.4. Soil total porosity

Experimental results showed that the applied amendments (i.e. compost and biochar) markedly increased soil total porosity; these increases might be due to the applied amendment increased *SOM* (Fig. 1) which might have interacted with mineral fraction as a result of contributing in the betterment of soil aggregation, *SAS*, *Bb* and *Pk*, all of which might have contributed to increased soil total porosity and these reasons are consistent with (Amlinger et al., 2007). Also, increases in soil total porosity might be due to the applied amendments were endowed with a high porosity, for example of biochar as stated by Hina et al. (2010) and Liang et al. (2006) and lower bulk density as stated by Hati et al. (2007). Additionally, rearranging and forming of macro-and micro-pores due to the applied amendments might be also the utmost other reason for increasing soil total porosity and this reason also is in agreement with (Hseu et al., 2014). Furthermore, the applied amendments might have supported microbial activities by providing microorganisms with habitat and substrate, which in turn might have involved in soil aggregation resulted in forming macro-pores at the expense of micro-pores, and thereby probably being an important reason of increasing soil total porosity over the course of our study, and these results were also evidenced by Barus (2016). Cantón et al. (2009) reported that increasing of *SAS* and aggregates size distribution might be responsible for maintaining genuine size of soil pores and these results corresponded with our results by the fact that the applied amendments increased *SAS* (Fig. 6) and macro-porosity (data not given), which in turn might have led to increased soil total porosity.

There are other researchers who elucidated the rallies of soil total porosity due to compost and biochar additions. Our findings due to compost addition are in agreement with (Barus, 2016), and that of biochar are also in agreement with Herath et al. (2013). The positive responses of soil total porosity to compost and biochar additions have been revealed by Barus (2016) and Burrell et al. (2016), respectively. Soil total porosity increased by 8.5% due to biochar addition (Omondi et al., 2016), and also both biochar and compost additions increased soil total porosity by 2.97 and 4.64 %, respectively (Barus, 2016). Several studies revealed that biochar application increased soil total porosity (Głąb et al., 2016; Jien & Wang, 2013; Ouyang et al., 2013; Peng et al., 2016 and Wang et al., 2017). The two-months experiment showed a sparse increase in soil total porosity due to compost and biochar additions, yet the increases should likely be high in long-terms experiment. Biochar-incubated soil for 5 months and 18 days increased soil total porosity by16-20% as indicated by Hseu et al. (2014) and one with 1 month incubation period increased soil total porosity by 2.97 %; due to biochar being recalcitrant to microbial activities (Hunt et al., 2010), it is clear that its effect in the context of improving soil properties increases with time and also depends on soil types, biomass and used temperature during pyrolysis. As such, it is of great importance to note that 2 and 4 % application rates of either compost or biochar were fine to enhance soil total porosity and these results were reviewed by Aslam et al. (2014).

4.5. Water retention at different suction pressures and *PAWC*

At a selected matric potentials, additions of compost and biochar significantly increased θv at 6.3 kPa, 33 kPa (i.e. *FC*) and 1500 kPa (i.e. *PWP*) as well as *PAWC* as compared with the control (Fig. 4); this was due to increased *SOM* (Fig. 1) which might have adsorbed a sizeable amount of water and increased specific surface area which also might have increased water storage capacity, decreased *Bd* and *Pk* (Fig. 2) and also might be due to increasing of pore size distribution (i.e. meso, micro-and macro-pores) as evidenced by Herath et al. (2013) and the aforementioned reasons were also consistent with Hillel (1982). This increasing of water retention could be also a prominent indicator of changing soil water retention curve. Our results are in support of other studies, such as Ouyang et al. (2013) who found that water content at *FC* and *PWP* increased due to biochar addition in the light of being endowed with a high porosity as stated by Hina et al. (2010) and Liang et al. (2006), and similarly compost addition increased θv at *FC* and *PWP* (Gümüş and Şeker, 2017; Laila, 2011). It is surprisingly to note that there was a decrease in θv at *PWP* due to biochar addition and retained θv decreased with increasing application; this might be a positive result of increasing *PAWC* range as presented in Fig. 4 at the expense of water content at *PWP*. In contrast to our study, Herath et al. (2013) found a controversial effect where biochar addition increased θv at *PWP*, still in long-term experiment. The creation of hydrophilic feature for biochar due to the oxidation of carboxylic acid group featured on its external surface might be also another reason for increasing soil water retention capacity in our study as elucidated by Zimmerman (2010). An upward trend in *FC* due to biochar addition was also reported by Glaser et al. (2002), yet Busscher et al. (2011) reported that applied biochar produced at 700°C in a sandy loam soil did not affect water content at *FC*, signifying that biochar potential decreases with increasing temperature during pyrolysis process.

The subtraction of water retained at *PWP* from that retained at *FC* dubbed '*PAWC*' was significantly increased due to compost and biochar applications; these increases were attributable to the unparalleled increase in *FC* and decrease in *PWP* as elucidated above (Fig. 4), increase in soil total porosity (Fig. 3) as far as macro-and micro-porosity are concerned and increase in surface area (data not given), all of which might have been responsible for expanding *PAWC* range in the *SCL* soil, and the results are consistent with (Hseu et al., 2014) who said that biochar increased *PAWC* due to increasing soil micro-pores. For instance, Van Zwieten et al. (2010) stated that biochar is endowed with a sizeable amount of porosity and surface area, which might have been a reason of increasing *PAWC* and this is presumably for compost addition. The sizeable increases were found in compost-amended *SCL* soil and the lowest in biochar-amended *SCL* soil; this might be due to a higher recalcitrance of biochar to microbial activities than compost and herein lies the root of compost being a phenomenon adsorbent than biochar in short-term trial, yet biochar can stand out from compost under long-term trial. For instance, although rate of application differed, biochar addition yielded the high value of *PAWC* (e.g. *PAWC* increased by 18 to 89%) compared to our study due to extended incubation period of 168 days (Hseu et al., 2014). This increase in *PAWC* can be also elucidated in the context of increasing micro-porosity possessing diameter lies between 28.8-0.19 mm at the expenses of macro-porosity having diameter greater than 28.8 mm (Laila, 2011), and macro-porosity as an indicator of *AFP* measured at 10 kPa suction pressure, when soil water attains its equilibrium (El-Hady et al., 1990). As expected, Fig. 5 shows that *AFP* decreased with increasing application rates, signifying that micro-porosity increased at the expenses of macro-porosity which might have increased water holding capacity resulted in increased *PAWC.* This could be an obvious indicator for the proliferation of water storing pores in the SCL soil which is very important for increasing water reservoir in the *SCL* soil of arid region. Our results were expected and in accordance with (Laila, 2011). The reported similar findings by Barus (2016) indicated that compost and biochar additions increased water retention at *FC*, *PWP* and *PAWC.*

4.6. Air filled porosity

In regard to the responses of *AFP* to the applied amendments (i.e. compost and biochar), *AFP* experienced a downward trend, which differed between application rates and decreases in *AFP* were concomitant of increasing application rates in all tested amendments. Decrease in *AFP* might be by virtue of increasing *SOM* (Figure 1) and micro-porosity at the expenses of macro-porosity, all of which led to expanded range of *PAWC* (Fig. 4). Broadening range of *PAWC* as a result increasing micro-porosity at the expenses of macro-porosity was also reported by Laila (2011). Clogging of soil pores due to biochar dust might have been another reason of decreasing macro-pores as a result of decreasing *AFP* as reviewed by Aslam et al. (2014). As expected, *AFP* which has to be at least 10% for optimum plant growth and development (Grable & Siemer 1968) ranged from 12 to 17 % due to compost addition and 13 to 17 % due to biochar addition. With few exception, the recorded *AFP* values for the both amendments (Fig. 4), fitted into the range (> 14%) for honing plant growth as suggested by Carter (1988); Drewry (2006) and Mueller et al. (2009) from sandy loam to clay loam soil. Eventually, there is a gap on how compost and biochar additions affect *AFP* and further research is need for providing enough evidences.

4.7. Soil aggregate stability

Our findings illustrated a significant increase in *SAS* compared with the control due to compost and biochar infusions; this might be attributable to increasing of *SOM* content induced by addition of a high organic matter-rich amendments as also stated by Lehmann & Joseph (2009), adding of nutrients (e.g. Mg^{2+}, K^{+}, Ca^{2+}, Fe^{2+}, Mn^{+} and others) and improving of microbial pool and activities, all of which might have contributed in soil aggregation and *SAS* through drawing soil individual particle together into aggregates of all shapes and sizes, and these reasons were under the auspices of Six et al. (2004). This upward trend in *SAS* might be also due to the applied amendments were endowed with higher pore spaces as stated by Hina et al. (2010) and Liang et al. (2006) for supplying a hefty habitat to soil micro-organisms (e.g. play a role of secreting polysaccharide compounds), which might have involved in soil aggregation resulted in the formation and stabilization of aggregates. Our results are in accordance with Downie et al. (2009) who found that biochar addition increased *SOM* which substantially enhanced soil microbial activities, and thereby leading to forming and stabilizing soil aggregates. Furthermore, microorganism bind themselves on the external surface of the carbon particle, in order to perform their duties, such as decomposing adsorbed pollutants and other organic acid (De Laat et al., 1985; Kim et al., 1997; Rice et al., 1978), which in turn might have contributed in soil aggregation and *SAS* betterments. Findings of previously conducted study reported that biochar was endowed with a high internal surface area and macro-porosity, which provided biochar ability of increasingly adsorbing soluble cations and providing habitat for the reproduction and growth of soil microorganisms (Pietikäinen et al., 2000), and herein lies the evidences of that biochar might have contributed to soil aggregation and *SAS* and likewise for the compost addition in our study. Also, interacting of minerals with oxidized carboxylic acid group found at the surface of biochar should be accountable for forming and strengthening bond between soil particles, and thereby enhancing *SAS* (Glaser et al., 2002). Additionally, this could be also an indication for substantially sequestering carbon within the soil which also ties to increased *SAS*. Herath et al. (2013) stated that soil aggregates formation considered a function of microbial activities and time, still take a long time in case of biochar addition and this might have been a reason why effect of compost measured up that of biochar. The obtained results were envisioned, and also are in accordance with (Annabi et al., 2011; Emami & Astaraei, 2012) who showed that compost addition increased *SAS* and (Abdulwhhab & Şeker, 2019; Herath et al., 2013; Jien & Wang, 2013; Omondi et al., 2016; Ouyang et al., 2013) indicated that biochar application substantially increased *SAS* of the studied soil.

Other researches have reflected that addition of compost increased *SAS* (Albiach et al., 2001; Annabi et al., 2004; Şeker, 2003) and similarly, biochar addition increased *SAS* (Burrell et al., 2016; Głąb et al., 2016; Peng et al., 2016; Wang et al., 2017).

4.8. Mean weight diameter

Compost and biochar applications significantly increased *MWD* and *MWD* in compost- and biochar-amended *SCL* soil was higher than in the control, suggesting that all amendments might have supported soil microbial activities through habitat and substrate (i.e. adsorbed organic compounds) provision and added organic matter into the soil, all of which might have contributed to soil aggregation culminated in forming and stabilizing micro- and macro-aggregates. For instance, Brodowski et al. (2006) noted that micro-aggregates increased due to biochar addition, nevertheless, Herath et al. (2013) found that biochar addition did not contribute to micro-aggregates formation and this was due to employed biochar (> 0.5mm), which might have constrained interaction between soil, biochar and microorganism, yet increased macro-aggregates and this might have been an utmost reason of macroaggregates formation culminated in increasing *MWD* during our study. In regard to the contribution of microorganisms, biochar as a porous material, might have served as microsites for providing microorganism with a better condition for their excellent development as noted by Zackrisson et al. (1996), and herein lies the root of positively affecting *MWD* through microbial involvements in soil aggregation and *SAS*, and similar effect of increasing *MWD* due to the formation of aggregates of all shapes and sizes as a result of microbial activities, might have been occurred in our study. This also could be an indicator for increasing soil structural stability.

By considering other previous studies, an increase in *MWD* due to biochar applications have been, in all cases, ascribed to increasing *SOM* (Fig. 1) which might have contributed to the formation and stabilization of micro-and macro-aggregates (Ouyang et al., 2013), raising soil microbial population and activities (Pietikäinen et al., 2000). Likewise, compost addition increased *MWD* as result of *SOM* addition (Barus, 2016). Furthermore, high clay content of approximately 27% in our experimental soil might have contributed to the formation of hefty aggregates of different shapes and sizes as similarly reported by

Kristiansen et al. (2006) and Wick et al. (2009). The paucity of *MWD* value due to biochar addition, was attributed to its recalcitrance to microbial activity, *MWD* values should likely be high in long-term trial (Ouyang et al., 2013). For instance, in biochar-amended soil for 168 days of incubation period, *MWD* increased from 0.59 to 0.94 mm as indicated by Hseu et al. (2014), yet their application rate differed to the rate used in our study, and this cannot rule out time effect on the effectiveness of biochar within the soil system. In other words, the effect of biochar addition depends upon time set for experiment, biomass types for its production as well as pyrolysis condition (i.e. temperature). In the same way as indicated earlier, the application of 1, 2 and 4 % for either compost or biochar is recommended for increasing *MWD* in short-term trial.

5. CONCLUSION

This study being carried out on disturbed soil samples, the paper has theoretical importance. The effectiveness of biochar and compost application in improving soil aggregation, as well as soil water holding capacity and *PAWC* was evidenced in this study. Overall, Increases in *PAWC* due to compost and biochar addition could be a solution for drought experienced region by increasing elongation of irrigation frequencies which results in decreased irrigation water need and costs. Additionally, the findings of this study will be promising agricultural practices for improving aggregation and water retention capacity of a *SCL* soil, which in turn will help boost agricultural production. It is in this regard, future investigations to implement the results found in this work in undisturbed soils to be useful for farmers is required.

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REFERENCES

Abdulwhhab, Q. R. & Şeker, C. 2019. *Effect of biochar applications on soil aggregation status.* In: Proceedings e-book of the 10th International Soil Congress. Successful Transformation toward Land Degradation Neutrality: Future Perspective. Ankara, Turkey**:** 308-312.

Agegnehu, G., Bass, A.M., Nelson, P.N., Muirhead, B., Wright, G. & Bird, M.I. 2015. *Biochar and biochar-compost as soil amendments: effects on peanut yield, soil properties and greenhouse gas emissions in tropical North Queensland, Australia*. Agriculture Ecosystem Environment 213, 72-85.

Al-Omran, A.M., Mustafa, M.A. & Shalaby, A.A. 1987. *Intermittent evaporation from soil columns as affected by a gel farming conditioners.* Soil Sci Soc Amer J. 51, 1593-1599.

Albiach, R., Canet, R., Pomares, F. & Ingelmo, F. 2001. *Organic matter components and aggregate stability after the application of different amendments to a horticultural soil.* Bioresour Technol.76, 125-129.

Akça, E. 2001. *Determination of the soil development in Karapinar Erosion Control Station Following Rehabilitation.* Ph.D. Thesis, University of Çukurova, Institute of Natural and Applied Sciences, Adana, Turkey, 195 P.

Amlinger, F., Peyr, S., Geszti, J., Dreher, P., Karlheinz, W. & Nortcliff, S. 2007. *Beneficial effects of compost application on fertility and productivity of soils.* Literature Study, Federal Ministry for Agriculture and Forestry. Environment and Water Management, Austria: 225 p.

Annabi, M., Houot, S., Poitrenaud, M., Rampon, J., Gaillard, H. & Le Bissonnais, Y. 2004. *Effect of organic amendments on soil aggregate stability.* Sustainable organic waste management for environmental protection and food safety1, 51-54.

Annabi, M., Le Bissonnais, Y., Le Villio-Poitrenaud, M. & Houot, S. 2011. *Improvement of soil aggregate stability by repeated applications of organic amendments to a cultivated silty loam soil.* Agriculture, ecosystems and environment 144, 382-389.

Aslam, Z., Khalid, M. & Aon, M. 2014. *Impact of biochar on soil physical properties.* SJAS 4, 280-284.

ASTMD6836-02. 2008. *Standard Test Methods for Determination of the Soil Water Characteristic Curve for Desorption Using a Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, and/or Centrifuge*. ASTM International,West Conshohocken, PA. http://dxdoiorg/101520/D6836-02R08E02**.**

Barnes, R.T., Gallagher, M.E., Masiello, C.A., Liu, Z. & Dugan, B. 2014. *Biochar-induced changes in soil hydraulic conductivity and dissolved nutrient fluxes constrained by laboratory experiments*. PLoS One 9, e108340.

Barus, J. 2016. *Utilization of crops residues as compost and biochar for improving soil physical properties and upland rice productivity*. Journal of Degraded and Mining Lands Management 3, 63.

Blake, G.R. & Hartge, K. 1986. *Bulk density 1 Methods of Soil Analysis: Part 1-Physical and Mineralogical*

Methods 363-375.

Brewer, C.E., Chuang, V.J., Masiello, C.A., Gonnermann, H., Gao, X., Dugan, B., Driver, L.E., Panzacchi, P., Zygourakis, K. & Davies, C.A. 2014. *New approaches to measuring biochar density and porosity*. Biomass and Bioenergy 66, 176-185.

Brewer, C.E. 2012. *Biochar characterization and engineering"*. Doctor of Philosophy, Iowa State University, Ames, Iowa.

Brodowski, S., John, B., Flessa, H. & Amelung, W. 2006. *Aggregate-occluded black carbon in soil.* European Journal of Soil Science 57, 539-546.

Burrell, L.D., Zehetner, F., Rampazzo, N., Wimmer, B. & Soja, G. 2016. *Long-term effects of biochar on soil physical properties*. Geoderma 282, 96-102.

Busscher, W.J., Novak, J.M. & Ahmedna, M. 2011. *Physical effects of organic matter amendment of a southeastern US coastal loamy sand*. Soil Science 176, 661-667.

Cantón, Y., Solé-Benet, A., Asensio, C., Chamizo, S. & Puigdefábregas, J. 2009. *Aggregate stability in range sandy loam soils relationships with runoff and erosion*. Catena77, 192-199.

Carter, M. 1988. *Temporal variability of soil macroporosity in a fine sandy loam under mouldboard ploughing and direct drilling*. Soil and Tillage Research 12, 37-51.

Cox, D., Bezdicek, D. & Fauci, M., 2001. *Effects of compost, coal ash, and straw amendments on restoring the quality of eroded Palouse soil.* Biology and fertility of soils 33 (5), 365-372.

Danielson, R., Sutherland, P. & Klute, A. 1986. *Porosity, in: Methods of soil analysis. Part 1. Physical and mineralogical methods, Soil Science Society of America*. American Society of Agronomy, Madison, Wisconsin 443–461.

De Laat, J., Bouanga, F. & Dore, M. 1985. *Influence of microbiological activity in granular activated carbon filters on the removal of organic compounds.* Science of the Total Environment 47, 115-120.

Demisie, W., Liu, Z. & Zhang, M. 2014. *Effect of biochar on carbon fractions and enzyme activity of red soil.* Catena 121, 214–221.

Downie, A., Crosky, A. & Munroe, P. 2009. *Physical properties of biochar*. In: Lehmann, J., Joseph, S. (eds), Biochar for Environmental Management Science and Technology, Earthscan, London 13-29.

Drewry, J. 2006. *Natural recovery of soil physical properties from treading damage of pastoral soils in New Zealand and Australia: a review.* Agriculture, Ecosystems & Environment 114, 159-169.

El-Hady, O.A., Lotfy, A.A. & Abd El-Hady, B.M. 1990. *The interaction between polyacrylamide as conditioner for sandy soils and some plant nutrients.* II. Effect on the extractability of nutrients. Egypt JSoil Sci. 30, 545-557.

Elliott, E. 1986. *Aggregate Structure and Carbon, Nitrogen, and Phosphorus in Native and Cultivated Soils.* Soil science society of America journal 50, 627-633.

Emami, H. & Astaraei, A.R. 2012. *Effect of organic and inorganic amendments on parameters of water retention curve, bulk density and aggregate diameter of a saline-sodic soil.* Journal of Agricultural Science and Technology 14, 1625-1636.

Eusufzai, M.K. & Fujii, K. 2012. *Effect of organic matter amendment on hydraulic and pore characteristics of a clay loam soil.* Open Journal of Soil Science 2, 372.

Głąb, T., Palmowska, J., Zaleski, T. & Gondek, K. 2016. *Effect of biochar application on soil hydrological properties and physical quality of sandy soil.* Geoderma 281, 11-20.

Glaser, B., Lehmann, J. & Zech, W. 2002. *Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal–a review*. Biology and fertility of soils 35, 219-230.

Grable, A.R. & Siemer, E. 1968. *Effects of Bulk Density, Aggregate Size, and Soil Water Suction on Oxygen Diffusion, Redox Potentials, and Elongation of Corn Roots1*. Soil Science Society of America Journal 32, 180-186.

Gugino, B.K., Abawi, G. S., Idowu, O.J., Schindelbeck, R.R., Smith, L.L., Thies, J.E., Wolfe, D.W. & Van Es, H.M. 2009. *Cornell soil health assessment training manual.* Cornell University College of Agriculture and Life Sciences.

Gümüş, İ. & Şeker, C. 2017. *Effects of spent mushroom compost application on the physicochemical properties of a degraded soil.* Solid Earth 8, 1153-1160 doi:10.5194/se-8-1153-2017.

Hati, K.M., Swarup, A., Dwivedi, A., Misra, A. & Bandyopadhyay, K. 2007. *Changes in soil physical properties and organic carbon status at the topsoil horizon of a vertisol of central India after 28 years of continuous cropping, fertilization and manuring*, Agriculture, ecosystems & environment 119,127-134.

Herath, H., Camps-Arbestain, M. & Hedley, M. 2013. *Effect of biochar on soil physical properties in two contrasting soils: an Alfisol and an Andisol.* Geoderma, 209,188-197.

Hillel, D. 1982. *Introduction to soil physics*. Academic press.

Hina, K., Bishop, P., Arbestain, M. C., Calvelo-Pereira, R., Maciá-Agulló, J. A., Hindmarsh, J., Hanly, J.A., Macìas, F. & Hedley, M.J. 2010. *Producing biochars with enhanced surface activity through alkaline pretreatment of feedstocks.* Soil Research 48, 606-617.

Hseu, Z.Y., Jien, S.H., Chien, W.H. & Liou, R.C. 2014. *Impacts of biochar on physical properties and erosion potential of a mudstone slopeland soil.* The Scientific World Journal, 2014.

Hunt, J., DuPonte, M., Sato, D. & Kawabata, A. 2010. *The basics of biochar: A natural soil amendment.*

Soil and Crop Management 30, 1-6.

Jacobs, H.S., Reed, R.M., Thien, S.J. & Withee, L.V. 1964. *Soils laboratory exercise source book*. Amer. Soc. of Agron., Madison, WI.

Jien, S.H. & Wang, C.S. 2013. *Effects of biochar on soil properties and erosion potential in a highly weathered soil.* Catena 110, 225-233.

Kim, D.J., Miyahara, T. & Noike, T. 1997. *Effect of C/N ratio on the bioregeneration of biological activated carbon*. Water science and technology 36, 239-249.

Kishimoto, S. 1985. *Charcoal as a soil conditioner* 12-23.

Klute, A. 1986. *Water retention: laboratory methods Methods of soil analysis: part 1-physical and mineralogical methods* 635-662.

Kristiansen, S.M., Schjønning, P., Thomsen, I.K., Olesen, J.E., Kristensen, K. & Christensen, B.T. 2006. *Similarity of differently sized macro-aggregates in arable soils of different texture.* Geoderma 137, 147-154.

Laila, K.M.A. 2011. *Significance of Applied Cellulose Polymer and Organic Manure for Ameliorating Hydro-physico-chemical Properties of Sandy Soil and Maize Yield.* Australian Journal of Basic and Applied Sciences 5, 23-35.

Laird, D.A., Fleming, P., Davis, D.D., Horton, R., Wang, B. & Karlen, D.L. 2010. *Impact of biochar amendments on the quality of a typical Midwestern agricultural soil.* Geoderma 158, 443-449.

Lehmann, J. & Joseph, S. 2009. *Biochar for environmental management: an introduction.* Biochar for environmental management: science and technology 1-12.

Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O'neill, B., Skjemstad, J.O., Thies, J., Luizao, F.J. & Petersen, J. 2006. *Black carbon increases cation exchange capacity in soils.* Soil Science Society of America Journal 70, 1719-1730.

Luo, X., Liu, G., Xia, Y., Chen, L., Jiang, Z., Zheng, H. & Wang, Z. 2017. *Use of biochar-compost to improve properties and productivity of the degraded coastal soil in the Yellow River Delta, China.* Journal of Soils and Sediments 17, 780-789.

Manirakiza, N. & Şeker, C. 2018. *Effects of natural and artificial aggregating agents on soil structural formation and properties-a review paper.* Fresenius Environmental Bulletin 27A, 8637-8657.

Manirakiza, N. & Şeker, C. 2019. *Impact of Compost and Biochar on the Management of Soil Sustainability*. In: Proceedings e-book of the International Symposium for Environmental Science and Engineering Research (ISESER 2019) from 25-27 May, Konya/Turkey. Page 237-241. Available online at https://iseser.com/doc/2019/ISESER2019-Proceeding-Book.pdf?e3.

Mensah, A. K. & Frimpong, K. A. 2018. *Biochar and/or Compost Applications Improve Soil Properties, Growth, and Yield of Maize Grown in Acidic Rainforest and Coastal Savannah Soils in Ghana.* International Journal of Agronomy, 2018.

Mueller, L., Kay, B.D., Deen, B., Hu, C., Zhang, Y., Wolff, M., Eulenstein, F. & Schindler, U. 2009. *Visual assessment of soil structure: Part II. Implications of tillage, rotation and traffic on sites in Canada, China and Germany*. Soil and Tillage Research 103, 188-196.

Mukherjee, A. & Lal, R. 2013. *Biochar impacts on soil physical properties and greenhouse gas emissions.* Agronomy 3, 313-339.

Mücehver, O., Akbaş, F., Bağcı, M. & Şeker, C. 2018. *Compost and biochar production from prunnings of Elaeagnus tree to remediate erosion subjected area-Karapinar case study.* VI. International KOP Regional Development Symposium "KOPBKS-2018" 26-28 October, Konya-Turkey.

Nelson, D., & Sommers, L. E. 1982. *Total carbon, organic carbon, and organic matter 1*, Methods of soil analysis. Part 2. Chemical and microbiological properties (methodsofsoilan2*)* 539-579.

Omondi, M.O., Xia, X., Nahayo, A., Liu, X., Korai, P.K. & Pan, G. 2016. *Quantification of biochar effects on soil hydrological properties using meta-analysis of literature data*. Geoderma 274, 28-34.

Opara-Nadi, O.A. & Lal, R. 1986. *Influence of method of mulch application on growth and yield of tropical root crops in southeastern Nigeria.* Soil And Tillage Research 9, 217-230.

Ouyang, L., Wang, F., Tang, J., Yu, L. & Zhang, R. 2013. *Effects of biochar amendment on soil aggregates and hydraulic properties*. Journal of soil science and plant nutrition 13, 991-1002.

Peng, X., Zhu, Q., Xie, Z., Darboux, F. & Holden, N.M. 2016. *The impact of manure, straw and biochar amendments on aggregation and erosion in a hillslope Ultisol*. Catena 138, 30-37.

Pietikäinen, J., Kiikkilä, O. & Fritze, H. 2000. *Charcoal as a habitat for microbes and its effect on the microbial community of the underlying humus.* Oikos 89, 231-242.

Rice, R.G., Miller, G.W., Robson, C.M. & Kuhn, W. 1978. *A review of the status of preozonation of granular activated carbon for removal of dissolved organics and ammonia from water and wastewater Carbon adsorption handbook*, 485.

Rillig, M.C. & Thies, J.E. 2012. *Characteristics of biochar: biological properties.* In: Biochar for environmental management. Routledge, 117-138.

Schimmelpfennig, S. & Glaser, B. 2012. *One step forward toward characterization: some important material properties to distinguish biochars*. Journal of Environmental Quality 41, 1001-1013.

Six, J., Bossuyt, H., Degryze, S. & Denef, K. 2004. *A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics.* Soil and Tillage Research 79, 7-31.

So**il Survey Staff,** 1999. *Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. 2nd edition.* Natural Resources

Conservation Service. U.S. Department of Agriculture Handbook 436.

Şeker, C. 2003. *Effects of selected amendments on soil properties and emergence of wheat seedlings*. Can J Soil Sci. 83, 615-62.

Theobald, B., Alexis, K., Noel, M. & Khaldoon, A. M. 2018. *The Effect of Land Use Systems on Soil Properties; A case study from Rwanda. Sustainable Agriculture Research* 7(2), 30-40.

USDA-NRCS. 2014. *Soil Bulk Density / Moisture / Aeration-Soil Quality Kit.* [On-line].Available at:https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053260.pdf.

Van Zwieten, L., Kimber, S., Morris, S., Chan, K.Y., Downie, A., Rust, J., Joseph, S. & Cowie, A. 2010. *Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility*. Plant and soil 327, 235-246.

Van, Z.L., Singh, B., Joseph, S., Kimber, S., Cowie, A. & Chan, K.Y. 2009. *Biochar and emissions of non-CO2 greenhouse gases from soil.* Biochar for environmental management: science and technology 1, 227-250.

Verheijen, F., Jeffery, S., Bastos, A., Van der Velde, M. & Diafas, I. 2010. *Biochar application to soils A critical scientific review of effects on soil properties, processes, and functions*. EUR 24099, 162.

Wang, D., Fonte, S.J., Parikh, S.J., Six, J. & Scow, K.M. 2017. *Biochar additions can enhance soil structure and the physical stabilization of C in aggregates.* Geoderma 303,110-117.

Wick, A.F., Huzurbazar, S.V. & Stahl, P.D. 2009. *Use of Bayesian methods to model soil aggregation in undisturbed semiarid grasslands.* Soil Science Society of America Journal 73, 1707-1714.

Zackrisson, O., Nilsson, MC. & Wardle, D.A. 1996. *Key ecological function of charcoal from wildfire in the Boreal forest*. Oikos, 10-19.

Zimmerman, A.R. 2010. *Abiotic and microbial oxidation of laboratory-produced black carbon (biochar).* Environ Sci Technol 44, 1295–1301

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