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Effect Of Using Biochar And Compost On Soil Properties And On Mitigation Of Climate Change Impacts: A Case Study From Jordan

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Abstract
Biochar and compost can greatly impact soil chemical and physical properties. Therefore, the aim of this study was to determine the effect of using biochar and compost on soil properties and mitigation of climate change impact. Compost, biochar, and biochar-compost mixture were added to the soil, soil organic matter (SOM) content, concentrations of the oxidizable organic carbon (OOC) and the total organic carbon (TOC)) were measured. The experiment was conducted in the National Agricultural Research Center, Al-Khaledeyyah Agricultural Research Station, Mafraq. Biochar and compost were added to soil individually at the percentages of 10%, 25%, and 50%, each. The biochar-compost mixture was added to the soil too at the percentages of 10%, 25%, and 50%. The results revealed that at 50% biochar-compost mixture (consisting of 50% biochar and 50% compost) increases SOM content from 1.5% to 9.3%; the concentration of the OOC increased from 0.05 mg.kg^{-1} to 4.9 mg.kg^{-1}; and the concentration of the TOC increased from 1.0 mg.kg^{-1} to 6.1 mg.kg^{-1}. The results of this study illustrate that the 50% biochar-compost mixture affected the highest increase in the concentration of the OOC, TOC and SOM content in the soil. These findings demonstrate that soil treatment with a 50% mixture of biochar and compost does sharply increase its organic matter content.

Keywords: *Biochar, Compost, Soil, Climate change, Jordan*

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I. Introduction

The increase in World population-imposed pressure on the agricultural sector to increase animal and plant production. This resulted in intensification of non-sustainable agricultural practices and an increased use of chemical fertilizers, which had a great role in deterioration of soil and significantly decreased soil fertility. Also, it negatively impacted the biogeochemical processes and brought about an increase in greenhouse gas (GHG) emissions since use of the chemical fertilizers in the beginning of the agricultural revolution contributed to production increase, without consideration of the future effects of this increase on soil and the environment (USGCRP, 2017). Hence studies started to search for agricultural methods and practices that can contribute to the enhancement of soil properties, protection of plants from pathogenic agents that exist in the soil, and mitigation of the effects of climate change on soil and agricultural production. Through follow-up and review of those studies, appropriate alternatives have been identified to dispose of the chemical fertilizers and replace them with organic fertilizers, including biochar and compost (Barus, 2016; Global Soil Partnership, 2015). In this regard, studies have shown that use of biochar and compost can improve physical and chemical properties of soil. These soil amendments can provide the major nutrient elements for improving plant growth and productivity and increasing storage of carbon dioxide (CO_2) – or carbon sequestration – in the soil.

Biochar application to the soil to improve agricultural yields by has been extremely researched by many scientists (Kumar et al., 2018; Song et al.,2019). Soils nutrients retention and availability can be increased by biochar application (Glaser et al., 2002). The impact of compost and biochar addition on soil properties and the organic matter percentage in the aggregate size fractions under the field conditions was investigated by Jennifer et al (2020). The results showed that application of biochar to soil enhanced storage of organic carbon in the soil, and that biochar and compost were drivers for the overall formation of the sub-soil. Both compost and charcoal had positive effects on organic carbon storage in the soil.

Titova and Baltrėnaitė (2021) postulated that biomass and waste valorization and chemical and physical properties of the biochar produced from plant biomass and sewage sludge compost are important for improvement of the soil fertilized with them. These researchers found that the biochar produced from aromatic plants at 700 ºC was the most suitable amendment to mix with infertile, light-textured soil for the purpose of stopping its deterioration and improving its properties. They maintain that biochar generated from willow at 450 ºC too can be recommended for soil improvement. The effect of compost addition to the soil on the average growth rate of lettuce to reduce the use of aqueous solutions of inorganic nutrients was investigated by Metwalli (2015). The results unveiled that compost is a source of organic matter that can be used as an alternative source for plant nutrients in place of the aqueous solutions of inorganic nutrients that are prepared from mineral fertilizers.

Climate change is regarded as one of the biggest challenges nowadays as the industrial revolution raised the concentrations of the GHGs in the atmosphere by effect of the human activities, in addition to natural processes (IPCC, 2007). For instance, CO_2 concentration of grew from 280 ppm before the industrial revolution to 400 in 2014 (NASA, 2014). Therefore, researchers started searching for a means for sequestering carbon in the soil while improving its fertility and found that biochar is the most suitable choice as it can reduces the climate change impact through sequestering carbon in the soil (Cerri, et al., 2010; Smith, 2016). Biochar is considered a home for the microorganisms in the soil due to the pores and, hence, paths it provides that facilitate movement of organisms in the soil (Verheijen, et al., 2010). It helps in preserving the microbiological assemblages at high levels and, in the meantime, reduces GHG emissions from the soil (Compant, et al., 2010). It also contributes to availability of organic matter in the soil and suitable soil pH (Lehman, et al., 2011).

The benefits of compost application to the soil encircle can increase organic matter content, which improve soil chemical and physical properties, in addition to improving its ability to keep the nutrient elements. Its benefits include increasing the soil microbial populations and populations of other living organisms; improving productivity of agricultural crops; and increasing the concentrations of nutrients, especially nitrogen and phosphorous, in the soil (Bernal et al., 2017). As well, its addition to soil lowers the concentration of total dissolved solids (TDS) in the soil (Crohn, 2011). Some organic amendments can possibility improve various soil physical properties, it reduced bulk density, increased its porosity and water holding capacity at the field capacity and also increased the concentrations of soil nutrient elements Balaeyyah (2014). It also improved soil biological properties such as soil enzymes activities (Song et al., 2019). Based on the type of feed stock such as plant residue or animal waste, biochars may have different nutrient contents (Gaskin et al., 2008; Kumar et al., 2021). Biochar addition to the soil can reduces nitrogen fertilizer needs (Hagemann et al., 2017).

In Jordan, there is a scarcity of studies of the effect of using biochar and compost on soil properties. Thus, the objective of this study was to determine the effect of addition of biochar to soil on its organic matter (SOM) content and the concentrations of the oxidizable organic carbon (OOC) and the total organic carbon (TOC) in it; and mitigation of climate change impacts

II. Methodology

This study was conducted at the National Agricultural Research Center (Al-Khalidiya Center - Mafraq), lies between 32°10'50.7"N and 36°18'11.7" E for six months. Compost was prepared in Al-Khaledeyyah Agricultural Research Station (the National Agricultural Research Center) in Mafraq under supervision of experts in this field. The production process used animal wastes (cows, livestock, and chicken), household wastes (food residues), and plant residues such as hay, straw, and tree leaves. The wastes and residues were added together and mixed. Compost was prepared by making a pile of 1.5 m x 1.5 m dimensions and a pyramidal shape to facilitate handling substances, which were nitrogen and carbon at the carbon-nitrogen ratio of 30:1. In the pile, nitrogen represents the green matter, which is kitchen residues and green plant leaves and other parts, while carbon represents the brown substances, which are dry plant leaves and other parts, paper bags, straw, hay, plant pruning residues, and mulch (sawdust). The substances were all cut into small pieces to facilitate and speed up maturity. Then, sulfur was added to it in order to prevent fungal growth. These substances were mixed by adding a layer of the green substance over every brown layer and moisturizing them. Then, these layers were covered for four days without upturning to benefit from the thermophilic microorganisms in sterilizing the pile.

Thereafter, the pile was upturned once every two days until maturity, which coincided with the eighteenth day, where pile size decreased to almost one third its original size and the mixture became granular and dark brown in color. Its smell became similar to that of the moist soil. The principal conditions that were taken into account in production of compost are summarized in Table 1.

Table 1: Principal conditions used in compost production

Parameter	Specification
Temperature	50 – 60 ºC
Aeration	Well aerated
Raw Material	Animal and plant residues
Moisture	65%

C:N Ratio	25-30
Dimensions	1.5 m x 1.5 m
Odor	Objectionable smell as a result of escape of methane (NH_3) gas

The process of manual production of the biochar was performed in Al-Khaledeyyah Agricultural Research Station, Mafraq. This biochar consisted of residues of pruning of olive and citrus trees. This biochar was prepared in semi-closed tank enveloping well-sealed barrels. Biochar was produced in three thermal decomposition steps. The first step starts from ambient temperature and extends to 200 ºC. This step involves loss of moisture and light volatile matter. Moisture loss brings about breaking of bonds and formation of hydroperoxide groups according to Aguiar, et al., 2017. The second step starts at temperature of 200 ºC and extends to 500 ºC. In this step, cellulose and hemicellulose are decomposed according to Ding, et al., 2014. The third step is the step of degradation of lignin and other organic material with strong chemical bonds. It takes place at temperatures above 500 ºC according to Aguiar, et al., 2017.

For production of biochar with low pH values, combustion was performed gradually such that the temperature is low in the initial stage because fixing the salts increases as temperature increases. Biochar production proceeded according to the following steps: 1) Raw materials of plant source (e.g., citrus and olive trees) were managed; 2) Biochar was prepared in barrels, where two barrels (A and B) were used. Barrel B is well sealed while Barrel A has holes in its sides. Barrel B is placed inside Barrel A and both are filled with tree residues; 3) Fire is gradually ignited in Barrel B and temperature grows gradually. The barrel is, then, left for 3-6 hr; 4) Barrel A is then uncovered to check whether biochar reached maturity or yet did not; 5) The biochar is placed in water or in compost soak for three days to be charged with oxygen and the elements present in the water.

Soil samples were taken 3 times during the experiment (at the beginning of the study before starting soil treatment, during the second month of the experiment, and at the end of the experiment). Nutrient content analysis for both soil and compost were conducted, pH for biochar used in the experiment was measured. All analyses were done at the laboratories department in the National Agricultural Research Center. The experiment was performed in agricultural basins, each having different treatment. Compost was added to soil in three percentages: 10%, 25%, and 50%. The biochar was added to the respective basins in the same percentages. Biochar and compost were mixed in similar percentages (10%, 25%, and 50%) and, then, added to basins. The experimental design for this study was the completely-randomized design (CRD) and the data were statistically analyzed using SPSS program.

III. Results

Outcomes for soil analysis presented in Table 2, whilst the results for compost analysis are presented in Table 3. The variations in biochar pH values are ascribed to type of the raw materials and the temperature employed in its production process, the results showed that the biochar had a pH value of 7.8.

Table 2: Soil physical and chemical properties at the beginning of the Study

Parameter	Soil Depth (cm)	
	30	60
Texture	Loam	loam
pH	8	7.7
EC (dS/m)	50	58
Organic Matter (%)	1.63	1.77
CEC (meq/100g)	30.8	28.4
Clay (%)	23.4	19.1
Silt (%)	39.2	39.7
Sand (%)	37.2	41.2
$CaCO_3$ (%)	15.3	12.8
N (%)	0.154	0.14
K (Ppm)	999.7	850
P (Ppm)	41.3	42.7
Ca (meq/L)	19.5	65.7
Mg (meq/L)	26.5	26.8
Na (meq/L)	55.41	88.6
Cl (meq/L)	70	157.5
Fe (Ppm)	0.1908	0.1578
Mn (Ppm)	1.3784	1.9086
Cr (Ppm)	0.005	0.005
Cu (Ppm)	0.6136	0.6676
Co (Ppm)	0.0492	0.5
Cd (Ppm)	0.15	0.12
Pb (Ppm)	0.0056	0.0062
Ni (Ppm)	0.2916	0.2882
Zn (Ppm)	4.012	2.066

Mo (Ppm)	0.012	0.066

Table 3: Compost physical and chemical Properties

No.	Parameter	Jordan limit for animal organic fertilizer	Manure 7/10/2021	Unit	Analysis Method
1.	pH		8.6		AOAC 973.04,Dry basis
2.	EC	< 15	1.3	dS/m	AOAC 973.04,Dry basis
3.	Ash	< 50%	38.5	wt/wt %	AOAC 967.04,Dry basis
4.	Moisture	< 20%	13.6	wt/wt %	AOAC 973.03,wet basis
5.	Organic Matter	> 50%	61.5	wt/wt %	AOAC 967.05,Dry basis
6.	N	> 2	2.4	wt/wt %	AOAC 995.04,970.02,978.02,Dry basis
7.	P	> 0.4	1.2	wt/wt %	AOAC 957.02,958.01,977.01,Dry basis
8.	K	> 0.4	3.4	wt/wt %	AOAC 983.02,Dry basis
9.	C/N	< 1:15	1:14		
10.	Ca		6.1	wt/wt %	AOAC 965.09,Dry basis
11.	Mg		1.5	wt/wt %	AOAC 965.09,Dry basis
12.	Na		3.7	wt/wt %	AOAC 983.02,Dry basis
13.	Cl		2.5	wt/wt %	AOAC 928.02,Dry basis
14.	Fe		0.6	wt/wt %	AOAC 965.09,Dry basis
15.	Mn		540.3	ppm	AOAC 965.09,Dry basis
16.	Zn		431.7	ppm	AOAC 965.09,Dry basis
17.	Cu		81.6	ppm	AOAC 965.09,Dry basis
18.	Mo		15.3	ppm	AOAC 965.09,Dry basis
19.	Ni	< 50	11.3	ppm	AOAC 965.09,Dry basis
20.	Cr	< 100	11.4	ppm	AOAC 965.09,Dry basis
21.	Co		< 0.011	ppm	AOAC 965.09,Dry basis
22.	Cd	< 3	< 0.0012	ppm	AOAC 965.09,Dry basis
23.	Pb	< 120	< 0.013	ppm	AOAC 965.09,Dry basis

Effect of Use of Biochar and Compost on Soil Organic Matter Content

All treatments influenced the SOM content significantly ($p < 0.05$). (Table 4). The addition of biochar, compost, or biochar-compost mixture to the soil increased SOM content. However, the highest mean difference (7.80) is obtained when treating soil with 50% biochar-compost mixture (Table 4). The second, third, and fourth highest improvements of the SOM content were associated with the 50% compost treatment, the 25% mixture treatment, and the 10% mixture treatment, respectively, corresponding to mean differences in SOM contents of 5.90, 4.70, and 3.90 mg/kg .The relatively lowest improvement in SOMC was associated with the 10% biochar treatment (Table 4).

Table 4: Dunnett's Post-hoc Test for soil organic matter content

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Standard Error	*Sig.*
10% Compost	Control [1]	1.1500	.23995	*0.004
25% Compost		2.1500	.23995	*0.000
50% Compost		4.7000	.23995	*0.000
10% Biochar		.7500	.23995	*0.061
25% Biochar		1.3500	.23995	*0.001
50% Biochar		2.0000	.23995	*0.000
10% Mixture		3.9000	.23995	*0.000
25% Mixture		5.9000	.23995	*0.000
50% Mixture		7.8000	.23995	*0.000

[1] The soil before treatment

The numbers of basins under each examined treatment; the differences in the mean SOM contents after and before each investigated treatment, and the concomitant standard deviations are compiled in Table 5.

Table 5: Differences in the mean for soil organic matter contents before and treatment

Treatment (I)	Frequency	Mean	Standard Deviation
10% Compost	2	2.6500	.21213
25% Compost	2	3.6500	.35355
50% Compost	2	6.2000	.42426
10% Biochar	2	2.2500	.21213
25% Biochar	2	2.8500	.07071
50% Biochar	2	3.5000	.14142
10% Mixture	2	5.4000	.42426
25% Mixture	2	7.4000	.28284
50% Mixture	2	9.3000	.28284
Control	3	1.5000	.00000
Total	**21**	4.3286	2.48297

Effect of Use of Biochar and Compost on Concentration of the Oxidizable Organic Carbon in Soil

As shown in Table 6 , all treatments affected soil OOC concentration significantly ($p < 0.05$). Soil treatment with biochar, compost, or biochar-compost mixture raises the concentration of the OOC in the soil. The results also uncover that the highest difference in the mean concentration of the OOC was (4.82) is concomitant to treatment of soil with the 50% biochar-compost mixture. The second, third, and fourth highest increases in the concentration of the OOC were obtained from the 25% mixture treatment, the 50% compost treatment, and the 10% mixture treatment, respectively, corresponding to mean soil OOC differences of 4.02, 3.42, and 3.22 mg/kg. On the other hand, the comparatively lowest increase in concentration of OOC in the soil was associated with the 10% biochar treatment, which increased the mean OOC concentration in the soil by 0.82 mg/kg over that of the control sample. (Table 6)

Table 6: Dunnett's Post-hoc Test for soil oxidizable organic carbon concentrations

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Standard Error	*Sig.*
10% Compost	Control [1]	1.42500	.155700	*0.000
25% Compost		2.72500	.155700	*0.000
50% Compost		3.42500	.155700	*0.000
10% Biochar		.82500	.155700	*0.002
25% Biochar		1.22500	.155700	*0.000
50% Biochar		2.12500	.155700	*0.000
10% Mixture		3.22500	.155700	*0.000
25% Mixture		4.02500	.155700	*0.000
50% Mixture		4.82500	.155700	*0.000

[1] The soil before treatment

The numbers of agricultural basins receiving each treatment; differences in the mean for soil OOC after and before every studied treatment, and the associated standard deviation values are given by Table 7.

Table 7: Differences in the Mean for soil oxidizable organic carbon concentrations before and after treatment

Treatment (I)	Frequency	Mean (mg/kg)	Standard Deviation
10% Compost	2	1.50000	.141421
25% Compost	2	2.80000	.141421
50% Compost	2	3.50000	.282843
10% Biochar	2	.90000	.141421
25% Biochar	2	1.30000	.282843
50% Biochar	2	2.20000	.000000
10% Mixture	2	3.30000	.282843
25% Mixture	2	4.10000	.141421
50% Mixture	2	4.90000	.000000

Control	3	.07500	.000000
Total	**21**	2.34405	1.544848

Table 8 presents a summary of the results of Dunnett's post-hoc test for differences between the varied treatments and the control soil for different soil parameters under study.

Table 8: Dunnett's Post-hoc Test for Differences between treatments and the Control Sample in Values of Soil Parameters

Element	Treatment (I)	Treatment (J)	Mean Difference (I-J)	*Sig.*
N	50% Mixture		.23900	*0.000
P	50% Mixture	Control [1]	109.00000	*0.000
K	50% Compost		7185.000	*0.000
Zn	50% Mixture		50.4000	*0.000
Na	10% Mixture		14.8050	*0.000
Ca	00% Biochar		1336.0333	*0.000
Mg	50% Biochar		2535.1000	*0.000
Cl	50% Compost		1059.8400	*0.000
pH	10% Biochar		4.8900	*0.000
EC	50% Compost		-34.1300	*0.000
CEC	50% Mixture		23.1000	*0.000
OM	50% Mixture		7.8000	*0.000
Mo	50% Mixture		.12400	*0.000
OOC	50% Mixture		4.82	*0.000
TOC	50% Mixture		5.1	*0.000

[1] The soil before treatment

IV. Discussion

The results of current study showed that (MIX 50%) which consist of compost (50%) and biochar (50%), had the greatest effect in increasing many soils elements content. It increased Nitrogen content from (0.13 $mg.kg^{-1}$ to 0.369 $mg.kg^{-1}$), phosphorus content increased from (30 $mg.kg^{-1}$ to 139 $mg.kg^{-1}$), potassium content increased from (1025 $mg.kg^{-1}$ to 8210 $mg.kg^{-1}$), magnesium content increased from (2092 $mg.kg^{-1}$ to 4627.1 $mg.kg^{-1}$). Zinc content was also increased from (1.1 $mg.kg^{-1}$ to 51.5 $mg.kg^{-1}$). The results also showed that (MIX 10%) which consist of compost (10%) and biochar (10%) increased calcium content from (2777.4 $mg.kg^{-1}$ to 4113.5 $mg.kg^{-1}$) and sodium content from 32.6 $mg.kg^{-1}$ to 47.46 $mg.kg^{-1}$

It was reported by other studies that biochar produced from manure is a good source of nitrogen (Hossain et al., 2020), and can improve the availability of nitrogen to plants (Chan et al., 2007). Compost addition to the soil also can have positive impact on soil physical and chemical properties, it maintains higher nutrients contents available for plant uptake and therefore can increase crops yield (Das, et al., 2013). Biochar application can also increase available phosphorus in the soil (Chan et al., 2008), Lehmann et al., 2006 reported that soil amended with biochar can retains nutrients needed for plant growth especially phosphorus. potassium, calcium, zinc, and copper uptake by plants was also elevated by biochar application to different soils (Lehmann et al., 2003). Higher potassium content was found in soils when biochar that is made from manure was added compered to biochar made from crop residue (Hossain et al., 2020). therefore, for soil amendment with both compost and biochar can be used to improve soil fertility.

Applying (MIX 50%) which consist of compost (50%) and biochar (50%) to the soil greatly enhanced cation exchange capacity (CEC), the value increased from 31.7 meq/100g soil to 54.8 meq/100g soil. And this explains higher nutrients retention in soil after the treatment when the CEC increased. The finding from (Domingues et al., 2017) study revealed that applying chicken manure biochar produced at low temperature increased soil CEC and therefore higher nutrient contents was present in the soil. This treatment (mix 50%) increased oxidizable organic carbon (OOC) concentration in soil from (0.07 $mg.kg^{-1}$ to 4.9 $mg.kg^{-1}$) and also increased the carbon (C) content from 1 to 6.1 $mg.kg^{-1}$.

The results from this study reported that adding biochar and compost at 50% ratio reduced both EC and pH. The EC in the control samples before the treatments was 59.23 ml/cm and after treatment the EC was reduced to 25.1 ml/cm, while soil pH value decreased from 8.06 in the control to 7.05 after the treatment with biochar and compost mix 50%. Previous study showed that biochar produced from wheat straw residue mixed with bird manure had high EC values (Kumar et al., 2021). Biochars and compost can significantly impact soil pH and EC

(Gaskin et al., 2007). Biochars addition to the soil based on feedstock type can have different pH values, peanut hulls biochar had higher pH value when compared to poultry litter biochars (Gaskin et al., 2008).

The results of the current study showed that biochar and compost play an important role to improve soil porosity water holding capacity, and bulk density. Addition of organic matter-based amendments increased the rate of water infiltration (Asai et al. 2009), enhanced the formation soil aggregate leading to soil structural stability (Six, et al., 2004). Previous studies reported lower soil density, higher porosity with biochar application to the soil and that enhance soil aeration and drainage (Laird, 2008).

V. Conclusions

The results of this study illustrate that the 50% mixture (50% biochar and 50% compost) affected the highest increase in the concentration of the OOC in the soil, corresponding to a change from an initial concentration of 0.07 mg/kg to 4.9 mg/kg after its addition to soil. This supports that treatment of soil with a 50% biochar-compost mixture raises concentration of the OOC in the soil greatly. The study results demonstrate that the 50% biochar-compost mixture affected the highest improvement in the concentration of the TOC in the soil, which was raised from 1.0 mg/kg in the beginning of the experiment to 6.1 mg/kg after its addition to soil. This suggests that treating the soil with a 50% biochar-compost mixture leads to high increase in concentration of the TOC in the soil. The outputs of this study show that the 50% biochar-compost mixture affected the largest rise in the SOM content, which was improved from 1.0 mg/kg initially to 9.3 mg/kg after addition of this mixture to the soil. This finding demonstrates that soil treatment with a 50% mixture of biochar and compost does sharply increase its organic matter content.

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