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Effect of Biochar, Vermicompost and Polymer on Wheat and Maize Productivity in Sandy Soils under Drought Stress

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THE DROUGHT is one of the most important abiotic stresses limiting the crop productivity especially in sandy soils in arid and semi-arid areas. So, using soil amendments such as vermicompost (VC), biochar (BC), and polymer (PL) are more important in these areas. Lysimeter experiments with sandy soil were carried out at Sakha Agric. Res. Station, Kafr El-Sheikh, Egypt to study the effect of 0.4% PL, 4.0% VC and 1.0% BC (W:W soil) on productivity of wheat (2018/019) and maize (2019) under two irrigation levels (irrigation after depletion of 50% and 75% from soil moisture. The obtained results indicated that irrigation at 75% moisture depletion (irrigation deficit) decreased plant height, 100-grain weight, grain and straw yields, water applied to wheat (-16.8%) and maize (-20%) compared to that with higher irrigation level (50% depletion). Also, water productivity was slightly decreased for wheat, but it slightly increased for maize and ECe values were slightly increased due to irrigation deficit. Also, applications of soil amendments and their combinations significantly increased plant height, 100-grain weight, yield and water productivity of both crops and improved soil porosity and field capacity. The VC was more effective treatment followed by BC and PL treatments, while their interactions were the most effective on these parameters. Moreover, soil amendments alleviated the deleterious effects of irrigation deficit on plant growth and salt accumulation. Finally, applying BC combined with VC and PL could be recommended as a good approach to maintain long-term productivity of sandy soils and mitigate the hazardous effects of drought stresses.

Keywords: Wheat, Maize, Polymer, Vermicompost, Biochar, Drought stress.

Introduction

Drought and salinity are the major abiotic stresses that affect crop production especially in sandy soils. Drought is a major constraint to agricultural production which clearly decreases with increasing soil moisture stress (Samson et al. 2002; Saad and Abo-Koura (2018) and El-Kallawy and Hefeina, 2019). Deficit irrigation greatly reduced 1000-grain weight (Emam et al. 2007), growth and grain yield of wheat (Moghaddam et al. 2012), plant height and grain yield of wheat (Akbar et al. 2010 and Aiad, 2019), while the maximum wheat yield was achieved by 84% of full evapotranspiration (Zhang et al. 2008). Also, fully irrigation greatly increased wheat grain yield (Ibrahim et al., 2005) due to a decrease in intercepted light which ultimately reduced its efficiency into economic part (Wajid et al. 2007). The grain yield and water use efficiency were affected by water stress (Ghodsi et al., 2008) whereas; wheat yield was reduced by 6% under deducing 30% of full irrigation (Wang et al., 2008). However, the soil amendments reduce the stresses of water deficiency (Ahmad et al., 2013), through improving soil chemical, physical and biological properties (Hueso-González et al., 2014 and Mann, 2011).

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The biochar (BC), vermicompost (VC), and polymer (PL) are being used as soil amendments. BC is a solid carbon-rich organic material generated by heating biomass at 300-600 ºC under condition of limited or no oxygen (Lehmann and Joseph, 2009; Mosa et al., 2017 and Amer and El-Emary, 2018) and can be used as a soil amendment for improving soil quality and productivity (Hossain et al., 2010 and Zheng et al., 2010) because it has high porosity and large specific surface area (Obia et al., 2016). Organic amendments have to be applied every year because of its rapid decomposition (Gupta and Monika, 2016), so, more stable compounds such as BC could be alternatively used (Glaser et al., 2002). BC at 2% improved wheat growth and increased its height by 11% (Kanwal et al., 2018), while 5 % BC under salinity improved soil fertility and increased sorghum biomass yield by 25 % (Edmunds, 2012). In addition, 1.5, 3.0 and 4.5 % BC in saline-sodic paddy soil reduced stress and promoted rice yield (Jin et al., 2018), while BC improved the legume yield in the calcareous soil in arid area (Azeem et al., 2016). Diatta (2016) reported that 20 tons BC/ha could improve soil fertility and crop productivity in temperate soils but had limited effects on sandy, salt-stressed soils may be due to differences in soil properties.Bayoumy et al. (2019) reported that BC with compost tea and gypsum improved plant height, 1000-grain weight, straw yield and grain yield of wheat in salt-affected soils.

The interests are shifted towards the organic amendments like VC, which produced from compost through the earth worms and contains essential nutrients and plant growth regulating hormones (Allardice, 2015) and it improves soil quality (Kheir et al., 2017 and Mahmud et al., 2018). Joshi et al. (2014) suggested 20 tons VC/ha as an ideal for better growth, higher plant height and total yield of wheat. Chemical fertilizers with VC would help to maintain the long-term soil productivity, whereas 10-ton VC/ha with 50% chemical fertilizers (Muktaet al., 2015) or 15-ton VC/ha+50% NPK (Suthar, 2009) was the best performance for the height and yield of plant due to presence of plant nutrients and some essential growth-promoting substances in VC. Also, VC promotes growth and productivity of wheat (Suthar, 2006 and Ibrahim et al., 2015), while VC with BC provides pathogen suppression to plants and increase crop productivity (Shoaf, 2014). Moreover, 5 tons BC with 20 tons FYM/ha (Gautam et al., 2017) or 2.5-5.0% BC+ compost with or without the mineral fertilizer (Schulzand Glaser (2012) provide beneficial effects on plant growth, plant height, crop yield and soil chemical properties.

Soil amendments may be used to overcome the negative effects of drought stress. So, Riad et al. (2018) observed that amending sandy soil in lysimeter by 0.7% PL and 1.0% BC alleviated the deleterious effects of water deficit (75% depletion) on plants compared with the full irrigation due to improving soil water holding capacity. Also, using PL improves land and water productivity, evaporation and infiltration rates (Ekebafe et al., 2011), while it with BC enhances its positive effects on plant growth (Ruqin et al., 2015) whereas, the germination rate was 76.9-83.7% with BC alone, increased to 83.6-85.8% with BC+PL, through inhibiting the rise of pH and EC due to BC application. Alkhasha et al. (2018) reported that 0.2-0.8% PL and 2-8% BC improved hydro-physical properties of sandy soil, whereas mixture of 0.8% PL with 8.0% BC resulted in the highest increase in soil moisture content at field capacity.

Concerning alleviating the drought stresses, Oo et al. (2015) observed that compost and VC were more effective in alleviating salinity and improving growth, plant height and maize dry matter through reducing soil pH and ECe and increasing its organic carbon. Also, Torkashvand et al. (2017) showed that the substrate containing 20% VC+15% rice wastes+15% manure+50% soil had the best yield and can modify the effect of 10-day irrigation interval compared to the 5-day.Therefore, evaluating the impacts of BC, PL and VC as well as their mixtures on wheat and maize productivity in sandy soil was the objective of this study.

Materials and Methods

Lysimeter experiments were conducted at Sakha Agric. Res. Station, Kafr El-Sheikh Gov. (30^0 3' N latitude, 31^0 3' E longitude) during two successive growing seasons (2018/019 and 2019). The objective of this study was to evaluate the productivity of sandy soil supplied by vermicompost (VC), biochar (BC) and polymer (PL) under two irrigation levels (irrigation after depletion of 50% and 75% from available water) as well as their interactions. The irrigation water quantities were calculated for each plot with both soil moisture depletions to compensate soil moisture to field capacity according to Israelsen and Hansen (1962) as follow:

$$Q=(FC- SMC) /100* Bd *D*A$$

Where, Q: quantity of water/plot/irrigation (m^3), FC: field capacity (%), SMC: soil moisture content before irrigation, Bd: bulk density (Mgm^{-3}), D: soil depth required to be irrigated (m) and A: plot area (m^2).

The lysimeter plots (0.455 m^2 area and 0.6 m depth with 0.1 m gravel filter) were planted by wheat (Gemmeza 11) on Nov., 20th, 2018 and harvested on May, 4th, 2019, while maize (Hybrid cross 10) was planted on June, 6th, 2019 and harvested on Oct., 20th, 2019. Chemical NPK fertilizers were applied to the soil based on the rate recommended by Ministry of Agriculture recommendation. The experiment was conducted in complete randomize design with three replicates. 0.4% PL, 4.0%VC and 1.0% BC as W:W of soil (about 0.395, 3.95 and 0.95 kg/plot, respectively) as well as their interactions were mixed with the soil in top 15-cm layer before wheat sowing.

The VC was made from rice straw and animal wastes with earthworm species *Eisenia fetida* and *Dendrobaena veneta* (Joshi et al. 2014). BC is a fine-grained and porous substance produced through the slow pyrolysis of orange trees at medium temperatures (*i.e.* 650°C) in absence or limited oxygen source (Odesola and Owoseni, 2010). Both materials in addition to the PL were obtained from the Central Lab. of the Agric. Climate, Agric. Res. Centre, Giza, Egypt and some chemical characteristics of these materials are listed in Table 1. The climate of this region is semi-arid and the temperature, relative humidity, wind speed and the annual precipitation in winter were shown in Table 2.

TABLE 1. Some basic characteristics of the applied soil conditioners

Materials	pH (1: 2.5)	EC_e (dS/m)	Total nutrients (%) N	P	K	C (%)	Water holding capacity (%)
Vermicompost	7.6	4.65	1.6	1.2	1.05	18.3	150
Biochar	7.9	2.05	1.9	2.2	2.9	66.7	139
Super absorbent polymers (SAPS)						Major components	
	Aqua keep					Polyacrylic acid	
A	Arasoubu S-107					Polyacrylic acid	
	Aron T-121					Polyacrylic acid	
B	Bargas 700					Polyacrylic acid	
1	Sanwet H-5000D					Polyacrylic acid	
	Composites						
B1	SAP-20%					Bentonite+SAP-20%	
K1	A SAP-20%					Kaolinite+SAP-20%	
Some characteristics	pH					7.12	
	Bulk density, g cm^{-3}					0.67	
	Real density, g cm^{-3}					1.72	
	Total porosity, %					61	
	Water Holding Capacity (WHC), cm^3 g^{-1}					60	

TABLE 2. Meteorological data of the two growing seasons, 2018/019 and 2019

Year	Month	T (°C) Max	T (°C) Min	RH (%) Max	RH (%) Min	Wind velocity (m/se)	Precipitation (mm)
2018	Nov.	25	17.4	86.8	54.6	24.4	
	Dec.	19.5	13.9	88.7	62.4	24.5	
2019	Jan.	18.9	12.3	82.3	53.3	33.1	
	Feb.	19.7	14.3	86.9	58.2	28.6	70.1
	Mar.	21.1	17.6	87.8	56.6	45.7	
	Apr.	25.1	21.3	80.8	48.9	44.8	
	May.	31.9	25.4	76.4	37.9	68.4	
	Jun.	33	28	81.5	50	103	
	Jul.	33.3	28.4	85.2	54.4	83.8	
	Aug.	34.2	28.9	89.7	55.6	68.7	
	Sep.	32.4	27.9	83.4	52.9	76.9	
	Oct.	30.3	26.7	87.3	54.3	56.6	

Representative soil samples were taken from surface layer in each plot before planting and after harvesting of each crop and subjected to chemical and physical analysis. Electrical conductivity, EC (dSm^{-1}), soluble ions were determined in soil paste extract according to Page et al. (1982). Particle size distribution of soil was measured using pipette method according to Gee and Bauder (1986). Soil bulk density (BD) was determined before experiment and at the end of the experiment for each treatment using core method according to Klute (1986). Total soil porosity (TP) was estimated from the bulk density and particle density of the soil (Black, 1965) using the equation :

$$\text{Total Porosity}=1- (\rho b / \rho s) \times 100$$

Where: ρb: soil bulk density and ρs: soil particle density (2.65 g cm^{-3}).

Field capacity and permanent wilting point were calculated from soil moisture tension curve (Black, 1965). Some physical and chemical properties of the soil are shown in Table 3.

Plant height, 100-grain weight, grain yield and straw yield of both crops were measured and subjected to the statistical analyses according to Gomez and Gomez (1984). Treatment means were compared using the least significant difference test (LSD) at 0.05 level.

Results and Discussion

Effects of soil amendments and soil moisture depletion on soil characters

Soil salinity (ECe)

Because the initial soil salinity was relatively low, its ECe values were slightly increased due to irrigation at 75% depletion (I_2) after harvesting of wheat and maize (6.5 and 8.8%, respectively) compared to higher irrigation level (I_1) as shown in Table 4 and Fig. 1. This may be due to the decrease in water applied, leading to slight accumulation of salts. On the other hand, soil amendments differ in their effects on soil salinity. The application of PL combined with BC leads to the highest decreases in ECe with both crops (-23.4 and -5.0%, respectively), while PL with VC resulted in the highest accumulations of salts with both crops (6.0 and 17.0%, respectively). Also, the application of soil amendments alleviated the negative effects of irrigation deficit on salt accumulation, whereas ECe values in untreated plots (CK) with wheat or maize under I_2 were increased by 9.9 or 13.8%, respectively, while with soil amendments the corresponding increases with both crops were 6.3 or 8.0%, respectively. These results are in somewhat similar to Oo et al. (2015) who observed that ECe was decreased by application of compost and VC. However, Liang et al. (2006); Rondon et al. (2007) and Zhu et al. (2014) observed increases in ECe with BC due to its large surface area and charge density.

Soil organic matter (OM)

Soil OM contents after harvesting of both crops slightly affected by irrigation level and clearly affected by soil amendments as shown in Table 4 and Fig. 1. Irrigation at 75% depletion (I_2) decreased soil OM contents after harvesting of wheat and maize by 4.0 and 4.2%, respectively comparing to higher irrigation level (I_1). This decrease may be related to that with I_2 treatment inhibits the growth of plant roots and microorganism in soil, leading to decrease in its OM content. However, the application of soil amendments led to appreciable increase in soil OM. The highest increases in OM with wheat and maize (56.8 and 53.5%, respectively) were achieved with application of VC+BC+PL followed by VC+BC (39.2 and 39.4%, respectively), while the lowest increases with both crops (23.0 and 21.1%, respectively) were recorded with PL compared to untreated soil. Moreover, positive effect on soil OM was observed with the interaction between irrigation levels and soil amendments. Therefore, the highest OM contents with both crops were achieved with PL+VC+BC under I_1. This trend is in somewhat similar to that observed by Oo et al. (2015).

Bulk density (BD) and total porosity (TP)

Soil BD and TP at the end of the experiment were slightly affected by irrigation level and clearly affected by soil amendments as shown in Table 5 and Fig. 2. The bulk density and total porosity values in soil received lower irrigation water (I_2) were slightly changed at the end of the experiment compared to that with I_1 (1.9 and -2.5%, respectively). However, the data show that amending soil with VC, BC and PL have the potential to affect its bulk density and total porosity, may be in the same rate but in an opposite trend. The highest decrease in bulk density (-7.1%) and the highest increase in total porosity (8.4%) were achieved in the soil supplied by VC+BC+PL followed by VC+BC. These results are agreed with those obtained by Kheir et al. (2017) and Mahmud et al. (2018). In addition, the interaction between irrigation level and soil amendments slightly affected soil OM content. Therefore, the highest OM contents with wheat and maize (0.56 and 0.60%, respectively) were achieved in soil amended by VC+BC+PL with I_1, while the lowest contents were recorded in un-amended plots with both irrigation levels (0.36-0.38%).

TABLE 3. Some physical and chemical properties of soil before experiment

Particle size distribution (%)	Value	Soluble cations (mmol L^{-1})	Value
Sand	91.4	Na^+	15.8
Silt	4.2	K^+	0.5
Clay	4.4	Ca^{2+}	6.0
O.M (g 100 g^{-1})	4.1	Mg^{2+}	3.5
Bulk density (g cm^{-3})	1.55	Soluble anions (mmol L^{-1})	-
Total porosity (%)	43.4	CO_3^{-2}	0.0
FC (%)	19.9	HCO_3^-	3.5
WP (%)	9.1	Cl^-	11.1
Available water (%)	10.8	SO_4^{-2}	11.2
ECe (dS m^{-1})	2.55	SAR	7.25

TABLE 4. Mean effects of soil amendments and irrigation levels on soil salinity, and OM

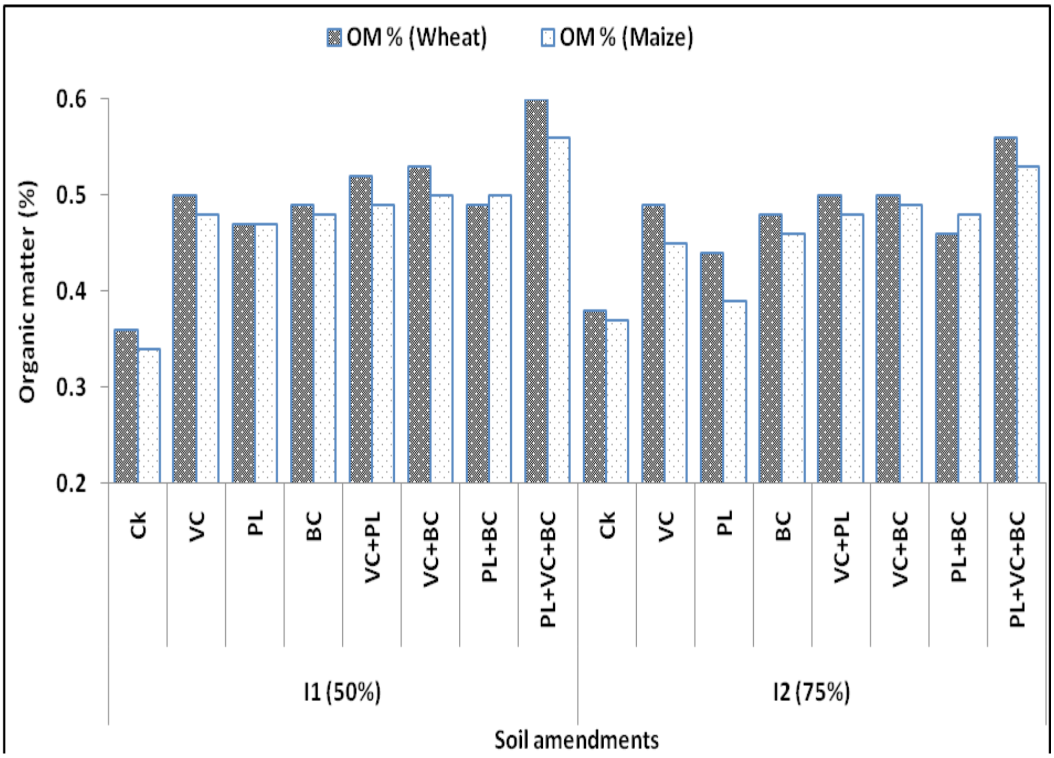
Amendment*	Wheat				Maize			
	ECe (dS m^{-1})	± %	OM (%)	± %	ECe (dS/m)	± %	OM (%)	± %
CK	2.66	0.0	0.37	0.0	2.71	0.0	0.36	0.0
VC	2.57	-3.2	0.50	33.8	2.74	1.1	0.47	31.0
PL	2.57	-3.4	0.46	23.0	2.65	-2.0	0.43	21.1
BC	2.43	-8.7	0.49	31.1	2.58	-4.8	0.47	32.4
VC+PL	2.82	6.0	0.51	37.8	3.17	17.0	0.49	36.6
VC+BC	2.09	-21.5	0.52	39.2	2.66	-1.7	0.50	39.4
BC+PL	2.04	-23.4	0.48	28.4	2.57	-5.0	0.49	38.0
VC+BC+PL	2.63	-0.9	0.58	56.8	2.58	-4.8	0.55	53.5
Mean I_1	2.39	0.0	0.50	0.0	2.59	0.0	0.48	0.0
Mean I_2	2.55	6.5	0.48	-4.0	2.82	8.8	0.46	-4.2
I_1 with A	2.37	0.0	0.51	0.0	2.6	0.0	0.50	0.0
I_2 with A	2.52	6.3	0.49	-5.8	2.81	8.0	0.47	-6.0
I_1 without A	2.53	0.0	0.36	0.0	2.53	0.0	0.34	0.0
I_2 without A	2.78	9.9	0.38	5.6	2.88	13.8	0.37	8.8

*CK: Control, VC: vermicompost, BC: biochar, PL: polymer, I_1:50% depletion, I_2:75% depletion

TABLE 5. Mean effects of soil amendments and irrigation levels on soil bulk density (BD) and total porosity (TP)

Amendment*	BD (g/cm^3)	±%	TP %	±%	FC%	±%	AW %	± %
CK	1.54	0.0	42.4	0.0	20.1	0.0	10.0	0.0
VC	1.52	-1.4	42.7	0.6	21.5	7.0	10.7	6.9
PL	1.58	2.2	40.5	-4.4	20.3	1.1	10.1	1.0
BC	1.49	-3.0	43.6	2.8	20.4	1.7	10.2	1.6
VC+PL	1.51	-2.1	43.1	1.6	22.5	12.0	11.2	11.9
VC+BC	1.49	-3.5	43.9	3.4	22.5	12.1	11.2	12.1
BC+PL	1.54	0.2	41.7	-1.5	20.9	4.1	10.4	4.0
VC+BC+PL	1.43	-7.1	46.0	8.4	22.8	13.6	11.4	13.5
Mean I_1	1.50	0.0	43.5	0.0	21.4	0.0	10.7	0.0
Mean I_2	1.53	1.9	42.4	-2.5	21.3	-0.8	10.6	-0.8

*CK: Control, VC: vermicompost, BC: biochar, PL: polymer, I_1:50% depletion, I_2:75% depletion



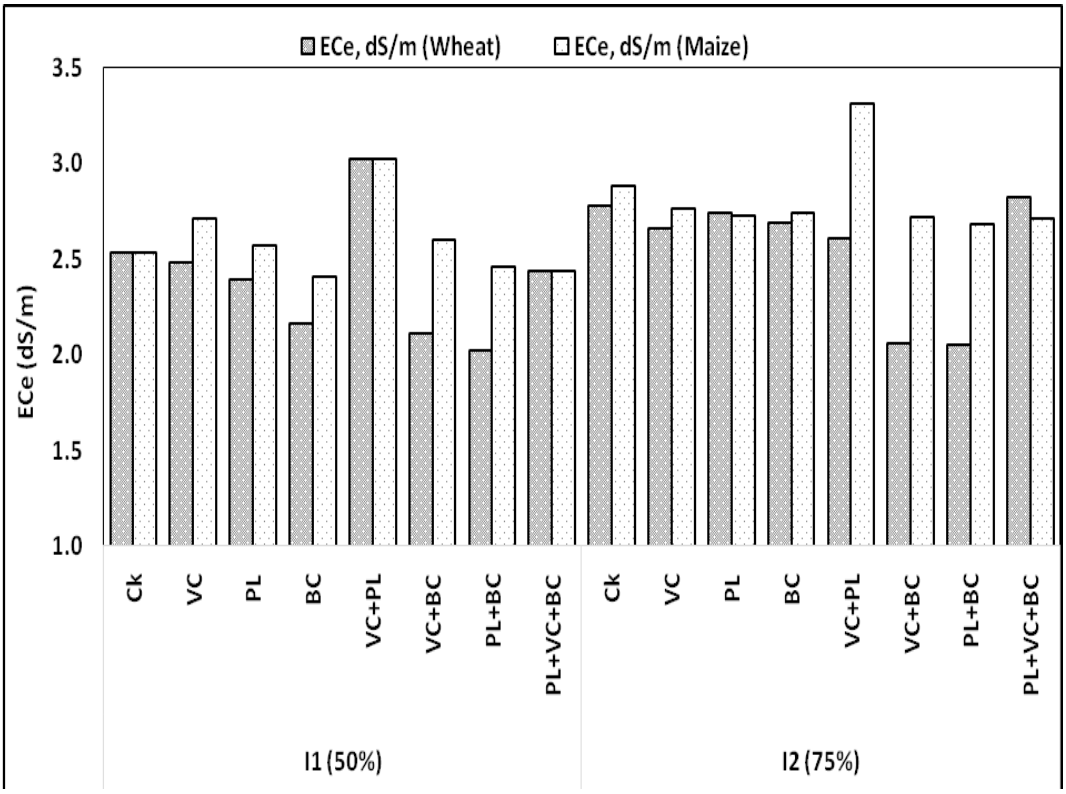
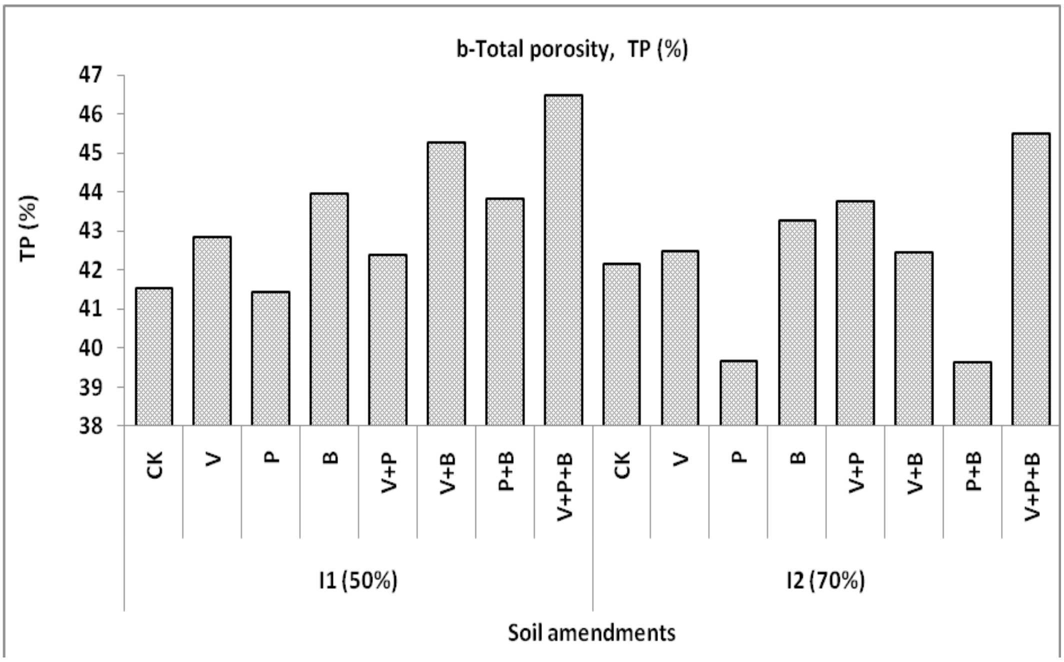


Fig. 1. Effects of soil amendments and irrigation levels on ECe and OM,
*CK: Control, VC: vermicompost, BC: biochar, PL: polymer, I_1:50% depletion, I_2:75% depletion.



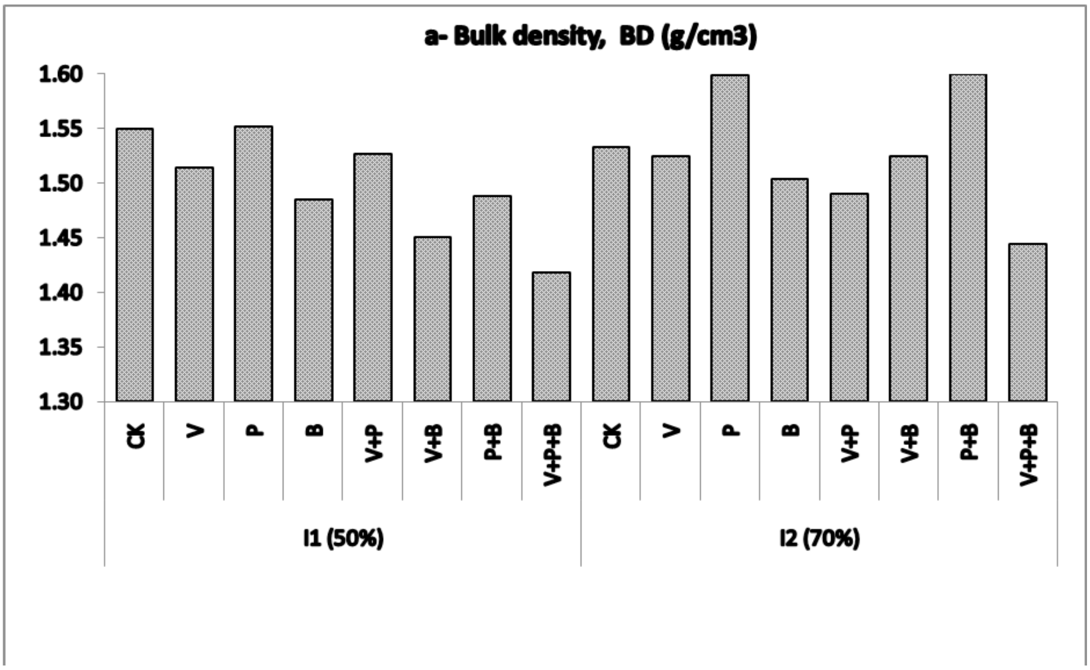
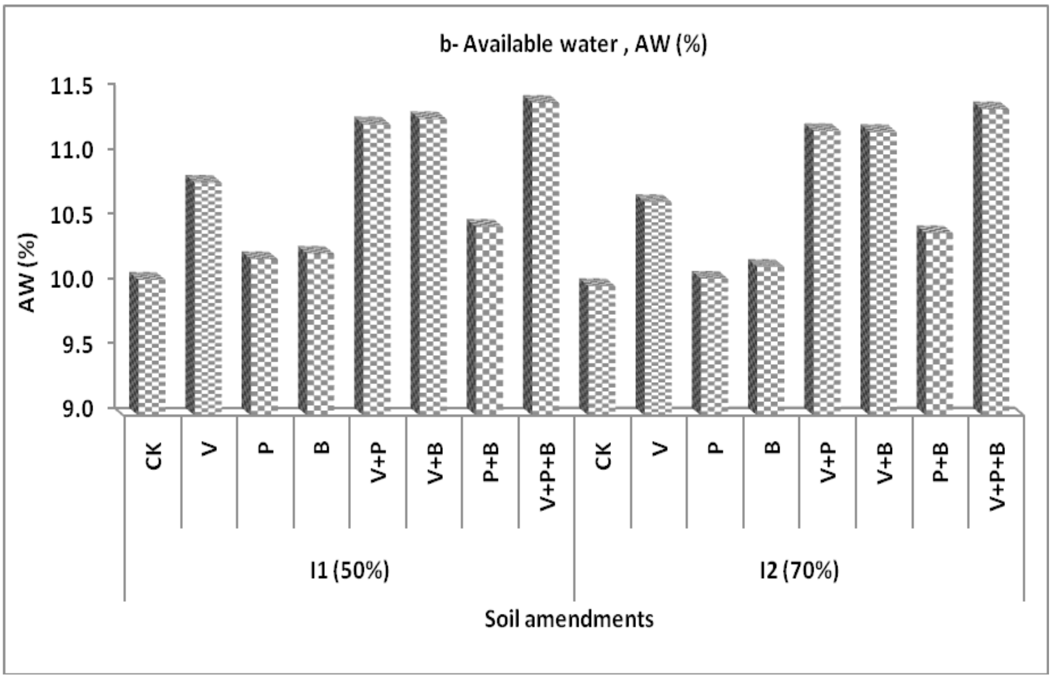


Fig. 2. Effects of soil amendments and irrigation levels on a-BD and b- TP,
*CK: Control, VC: vermicompost, BC:biochar, PL: polymer, I_1:50% depletion, I_2:75% depletion

Field capacity (FC) and available water (AV)

As shown in Table 5 and Fig. 3, the irrigation levels not affect both of soil field capacity and available water. However, soil amendments appreciably affected its hydro-physical properties. The plots supplied by PL+VC+BC achieved the highest increases in soil field capacity and available water (13.6 and 13.5%, respectively) followed by VC with BC or with PL (about 12% for both parameters). The lowest effects on both parameters were recorded with application of PL (1.1 and 1.1%, respectively) or BC (1.7 and 1.6%, respectively) when compared to the control. These results are agreed with that obtained by Ibrahim et al. (2015), Kheir et al. (2017), Alkhasha et al. (2018) and Riad et al. (2018) who observed that soil amendments improved hydro-physical properties of sandy soils in lysimeter experiment such as water holding capacity.



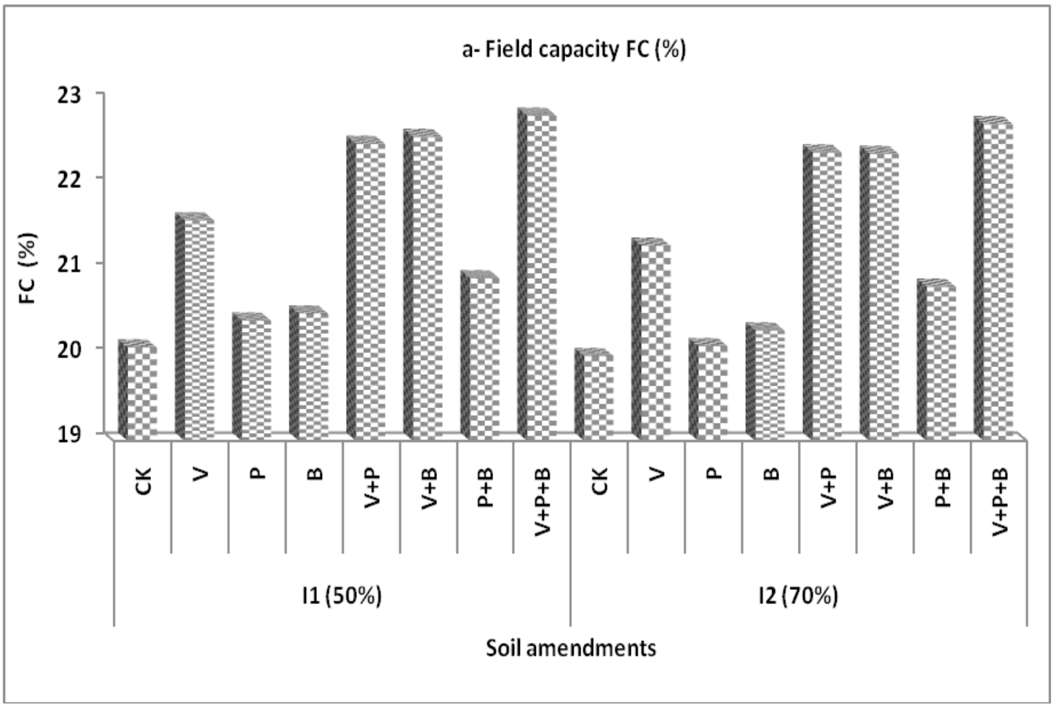


Fig. 3. Effect of soil amendments and irrigation levels on a. field capacity and b. available water,
*CK: Control, PL:polymer, VC: vermicompost, BC: biochar, I_1:50% depletion, I_2:75% depletion

Effect of soil amendments and soil moisture depletion on plant parameters

Plant height and 100-grain weight

The data illustrated in Table 6 and Fig. 4, showed significant effects of irrigation levels and soil amendments on growth parameters of wheat and maize. Pronounced decreases in plant height and 100-grain weight of both crops were found with increasing the irrigation depletion from 50% (I_1) to 75% (I_2). The 100-grain weight in wheat and maize was decreased with I_2 by 12.9 and 2.9%, respectively, while plant height of both crops was decreased by 19.7 and 17.2 %, respectively compared to that with I_1. The reductions in both parameters with water deficit (I_2) may be due to the hindering impact of drought stress on cell division and enlargement (Taiz et al. 2015), lower rates of water and nutrients absorption (Farooq et al. 2009) and the partial or full closure of stomata to prevent water loss through the transpiration process (Osakabe et al. 2014). These results are in agreement with those obtained by Osman (2015), Riad et al. (2018), Emam et al. (2007) and Akbar et al. (2010) who reported that plant growth parameters and 1000-grain weight were greatly reduced with drought stress.

The applications of soil amendments as well as their combinations significantly increased 100-grain weight and plant height of both crops compared to that recorded from the untreated plots (CK). The application of soil amendments individually affected the plant height and 100-grain weight according the following descending order: VC> PL>BC. The addition of VC with PL and BC was the most effective treatment on both parameters under the both irrigation levels, followed by VC combined with Pl or BC, while the untreated plots in most cases recorded the lowest values. Eventually, the highest increases in 100-grain weight in wheat and maize (16.3 and 62.25, respectively) and the highest increases in their heights (22.4 and 27.2%, respectively) were achieved with VC combined with PL and BC compared to that recorded in the untreated plots. The positive effects of soil amendments such as VC may due to the presence of available nutrients, large amounts of microbial life and diversity and plant growth regulating hormones (Allardice, 2015), so it a potential source of nutrients for sustainable crop production (Suthar, 2009). Also, VC with BC provides some benefits such as pathogen suppression and increasing of crop productivity (Shoaf, 2014).

Additionally, the significant impacts due to the interaction of irrigation levels with soil amendments were observed as shown in Fig.4. The highest values of 100-grian weight in wheat and maize (6.0 and 45.5 g, respectively) and plant height in both crops (91.8 cm and 183.3 cm, respectively) were achieved with PL+VC+BC treatment under I_1, while the lowest values of both parameters were recorded in untreated plots under I_2. These results may attribute to that the soil amendments such as BC has a pronounced enhancement in vegetative growth parameters of crops under reduced irrigation (Akhtar et al., 2014, Batool et al., 2015, Liu et al., 2017 and Nadeem et al., 2017). Also, BC improves soil physicochemical properties under normal and abiotic-stress conditions (Abel et al., 2013 and Hammer et al., 2015), or it enhances soil fertility, water use efficiency and carbon sequestration (Akhtar et al., 2014 and Batool et al., 2015). Similarly, PL under reduced irrigation level stimulates the growth of different crops (Kamal and El-Shazly, 2013; Shahrokhian et al. 2013; Fernando et al. 2014; El Sagan, 2015; Beig et al. 2014; El-Tohamy et al. 2014 and Ahmed et al., 2015b).

TABLE 6. Mean effects of soil amendments and irrigation levels on plant height (cm) and 100-grain weight (g) of wheat and maize.

Amendment (A)	Wheat				Maize			
	100-grain	± % vs CK	plant height	± % vs CK	100-grain	± % vs CK	Plant height	± % vs CK
CK	4.6	0.0	71.0	0.0	27.5	0.0	137.0	0.0
VC	5.0	8.7	76.8	8.1	35.4	28.7	150.2	9.6
PL	4.7	2.2	78.8	10.9	35.9	30.4	151.4	10.5
BC	4.8	4.3	74.9	5.5	37.5	36.4	150.9	10.1
VC+PL	5.3	15.2	79.3	11.6	43.5	58.2	160.0	16.8
VC+BC	5.1	10.9	80.4	13.2	44.4	61.5	153.5	12.0
BC+PL	5.1	10.9	83.2	17.1	43.9	59.5	156.2	14.0
VC+BC+PL	5.4	16.3	86.9	22.4	44.6	62.2	174.3	27.2
Mean I_1	5.3	0.0	87.5	0.0	39.7	0.0	168.7	0.0
Mean I_2	4.7	-12.9	70.3	-19.7	38.5	-2.9	139.7	-17.2
I_1 with A	5.4	0.0	88.7	0.0	41.0	0.0	172.1	0.0
I_2 with A	4.7	-12.9	71.3	-19.7	40.4	-2.1	141.2	-18.0
I_1 without A	4.9	0.0	79.0	0.0	30.0	0.0	145.0	0.0
I_2 without A	4.3	-12.2	63.0	-20.3	25.0	-16.7	129.0	-11.0
LSD (0.05) I	0.1	-	1.5	-	0.5	-	2.7	-
LSD (0.05) A	0.2	-	3.1	-	1.5	-	5.9	-
I*A	**	-	**	-	**	-	**	-

*CK: Control, VC: vermicompost, BC: biochar, PL: polymer, I_1:50% depletion, I_2:75% depletion

Moreover, soil amendments under this study slightly mitigated the adverse effect of drought stress on wheat heights and grain filling in maize. Therefore, irrigation deficit (I_2) without soil amendments decreased wheat heights by 20.3%, while with soil amendments the decrease was 19.7%. Also, the decrease in 100-grain weight in maize due to I_2 without amendments was 16.7%, while with soil amendments the decrease was only 2.1%, compared to I_1. These results may be attributed to that the soil amendments reduced the stresses of water deficiency on crops (Ahmad et al., 2013) through improving soil chemical, physical and biological properties (Hueso-González et al. 2014 and Mann et al. 2011). Also, the positive effects may due to increasing soil water-holding capacity with soil amendments (Akhter et al. 2004, and Ahmed et al. 2015a) and slow release of water through soil (Orzeszyna et al., 2006 and Khadem et al., 2010), causing better water use efficiency and plant growth under normal or drought stress conditions (Kim et al., 2010, Kamal and El-Shazly, 2013, Shahrokhian et al., 2013 and El Sagan, 2015).

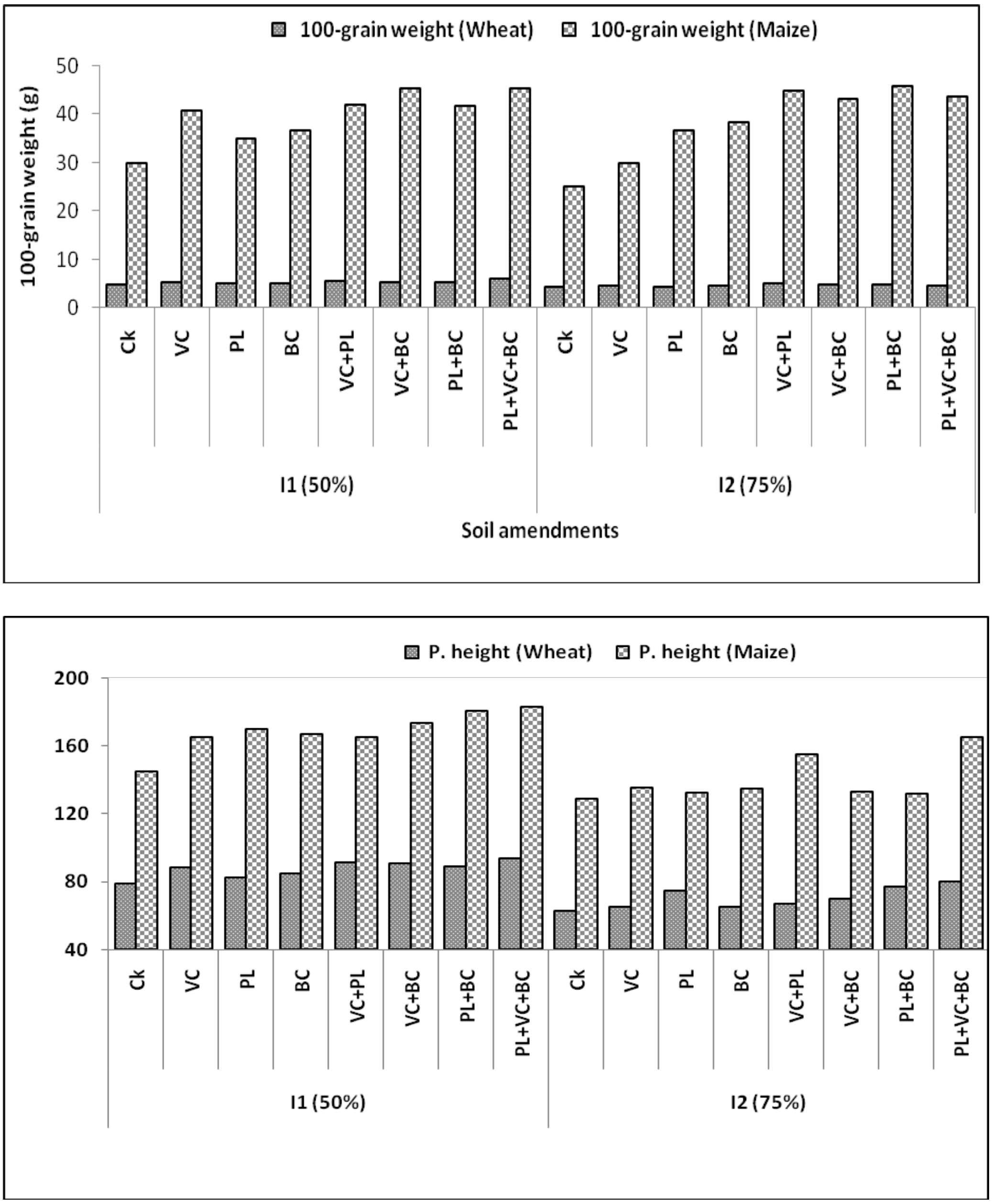


Fig. 4. Effects of soil amendments and irrigation levels on 100-grain weight and plant height,
*CK: Control, VC: vermicompost, BC: biochar, PL: polymer, I_1:50% depletion, I_2:75% depletion

Grain and straw yields

It could be concluded through the statistical analysis that wheat and maize yields were significantly affected by soil amendments and irrigation levels as illustrated in Table 7 and Fig. 5. Concerning the effect of irrigation level, the increase of irrigation depletion from 50 to 75% decreased the grain and straw yield by 21.9 and 18.7%, respectively in wheat and 17.2 and 17.1%, respectively in maize. The inhibition of crop yield with the drought stress (I_2) may be attributed to stomatal closure resulting in reductions of transpiration rate and CO_2 uptake during photosynthesis (Neumann, 2008) or due to a decrease in intercepted light which ultimately reduced its efficiency into the economic parts (Wajid et al., 2007). Similar reductions in crop yield under drought condition were observed by Moghaddam et al. (2012) and Ibrahim et al. (2005).

In case of soil amendments, data show that the application of VC, PL and BC as well as their interactions led to pronounce increases in grain and straw yields of wheat and maize compared to the untreated plots (Ck). The decreases in yield of both crops approximately showed a trend as PL+VC+BC >VC+BC >PL+BC >VC+PL >VC >BC >PL >CK. Therefore, the highest increases in grain yield of wheat and maize (34.4 and 60.1%, respectively) were achieved with combination of VC+PL+BC, while the highest straw yields in both crops (17.8 and 49.1%, respectively) were achieved with VC combined with BC. The lowest increases in grain in both crops (3.4 and 16.1%, respectively) and straw (8.9 and 12.1%, respectively) were recorded in plots treated by PL when compared with the untreated plots. The increase in crop yield with soil amendments such as VC may be related to their effectiveness in improving its growth through alleviating the drought and salinity stress (Ooet al. 2015). Also, VC and BC increase crop productivity may due to suppress pathogens (Shoaf, 2014), or enhance the nutrient uptake by plants (Ruqin et al., 2015).

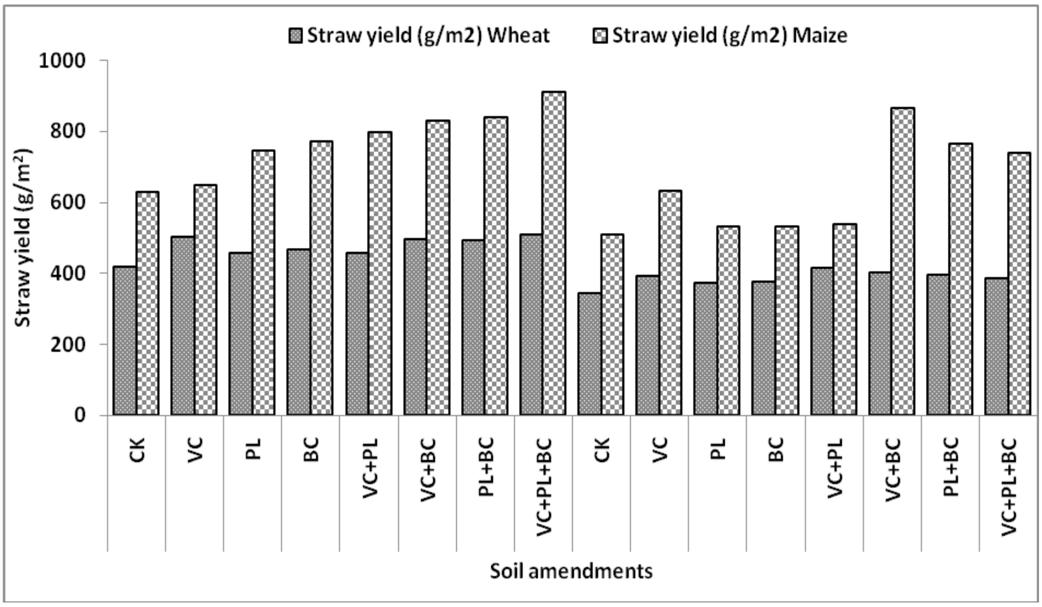
TABLE 7. Mean effect of soil amendments and irrigation levels on yield (g/m²)

Amendment*		Wheat				Maize			
		Grain	± % vs.CK	Straw	± % vs.CK	Grain	±% vs CK	Straw	± % vs.CK
CK		458	0.0	382	0.0	770	0.0	570	0.0
VC		504	10.0	450	17.7	942	22.3	642	12.6
PL		474	3.4	416	8.9	894	16.1	639	12.1
BC		487	6.2	424	10.9	1020	32.5	653	14.6
VC+PL		518	13.1	439	14.8	1080	40.3	670	17.5
VC+BC		510	11.2	450	17.8	1107	43.8	850	49.1
BC+PL		507	10.7	446	16.8	1103	43.2	803	40.9
VC+BC+PL		616	34.4	450	17.8	1233	60.1	827	45.1
Mean I_1		572	0.0	477	0.0	1115	0.0	773	0.0
Mean I_2		447	-21.9	387	-18.7	923	-17.2	641	-17.1
I_1 with A		579	0.0	485	0.0	1152	0.0	793	0.0
I_2 with A		454	-21.6	393	-18.8	956	-17.0	582	-26.7
I_1 without A		520	0.0	420	0.0	850	0.0	630	0.0
I_2 without A		443	-23.8	394	-18.1	750	-18.8	634	-19.0
LSD (0.05)	**I**	10.7	-	6.5	-	16.4	-	11.7	-
	A	19.6	-	16.3	-	39.7	-	27.6	-
	I*A	**	-	**	-	**	-	**	-

*CK: Control, VC: vermicompost, BC: biochar, PL: polymer, I_1:50% depletion, I_2:75% depletion.

Ultimately, the interaction between soil moisture depletion and soil amendments significantly impacts the yield of both crops as shown in Fig. 5. Therefore, the highest grain and straw yields in wheat (708 and 512 g/m^2, respectively) and maize (1300 and 914 g/m^2, respectively) were obtained from the plots amended by VC+PL+BC with 50% depletion (I_1). The lowest values of both parameters in wheat (396 and 344 g/m^2, respectively) and maize (690 and 510 g/m^2, respectively) were recorded in untreated plots under 75% depletion (I_2).

Moreover, application of soil amendments may in somewhat alleviate the negative effects of drought stress on grain yield of both crops. So, the grain yield of wheat with 75% depletion was decreased by 21.6% with soil amendments, but without amendments the decrease was 23.8%. Also, the grain yield of maize subjected to 75% depletion was decreased by 17.0% with soil amendments, while without amendments it was depressed by 18.8%, compared to 50% depletion (Table 7). This behavior may be attributed to that applying soil amendments such as PL and BC under drought condition alleviate its deleterious effects in sandy soils due to enhancing water holding capacity, improves soil characteristics and crop yield (Ekebafe et al., 2011 and Riad et al., 2018).



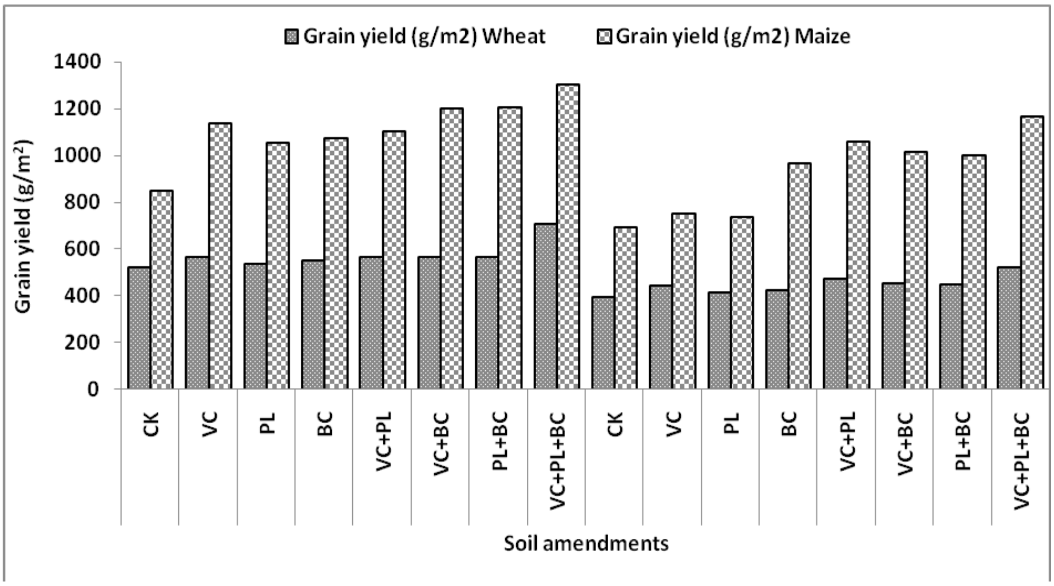


Fig. 5. Effect of soil amendments and irrigation levels on grain and straw yields,
*CK: Control, VC: vermicompost, BC: biochar, PL: polymer, I_1:50% depletion, I_2:75% depletion

Water applied (Wa) and water productivity (WP)

The data illustrated in Table 8 and Fig. 6, show the effects of irrigation levels and soil amendments on Wa and WP values. The data show an obvious reduction in water applied to wheat and maize (16.8 and 20.0%, respectively) with75% depletion (I_2) compared to 50 % depletion (I_1). Also, under I_2, the value of WP was slightly decreased with wheat (5.9%), but slightly increased with maize (3.4%) when compared with I_1. The variations in WP values depend on the amounts of water applied and the grain yield of both crops under both irrigation levels. Similar reduction in WP was observed by Zhang et al. (2008) and Ghodsi et al. (2008) who observed that higher water use efficiency for wheat was achieved with water stress.

TABLE 8. Mean effects of soil amendments and irrigation levels on water applied, Wa (L/m²) and water productivity, WP (kg/m³).

Amendment		Wheat				Maize			
(A)		Wa	± (%)	WP	± (%)	Wa	± (%)	WP	± (%)
CK		435	0.0	1.05	0.0	540	0.0	1.43	0.0
VC		435	0.0	1.16	10.5	540	0.0	1.73	20.6
PL		435	0.0	1.09	3.8	540	0.0	1.65	15.0
BC		435	0.0	1.12	6.7	540	0.0	1.90	32.9
VC+PL		435	0.0	1.19	13.9	540	0.0	2.02	41.3
VC+BC		435	0.0	1.17	12.0	540	0.0	2.06	44.1
BC+PL		435	0.0	1.16	11.0	540	0.0	2.05	43.0
VC+BC+PL		435	0.0	1.41	34.4	540	0.0	2.30	60.8
Mean I_1		475	0.0	1.20	0.0	600	0.0	1.86	0.0
Mean I_2		395	-16.8	1.13	-5.9	480	-20.0	1.92	3.4
I_1 with A		475	0.0	1.22	0.0	600	0.0	1.92	0.0
I_2 with A		395	-16.8	1.15	-5.6	480	-20.0	2.28	3.6
I_1 without A		475	0.0	1.09	0.0	600	0.0	1.42	0.0
I_2 without A		395	-16.8	1.00	-8.3	480	-20.0	1.44	1.4
LSD (0.05)	I	-	-	0.01	-	-	-	0.01	-
	A	-	-	0.05	-	-	-	0.01	-
	I*A	-	-	*	-	-	-	**	-

*CK: Control, VC: vermicompost, BC: biochar, PL: polymer, I_1:50% depletion, I_2:75% depletion.

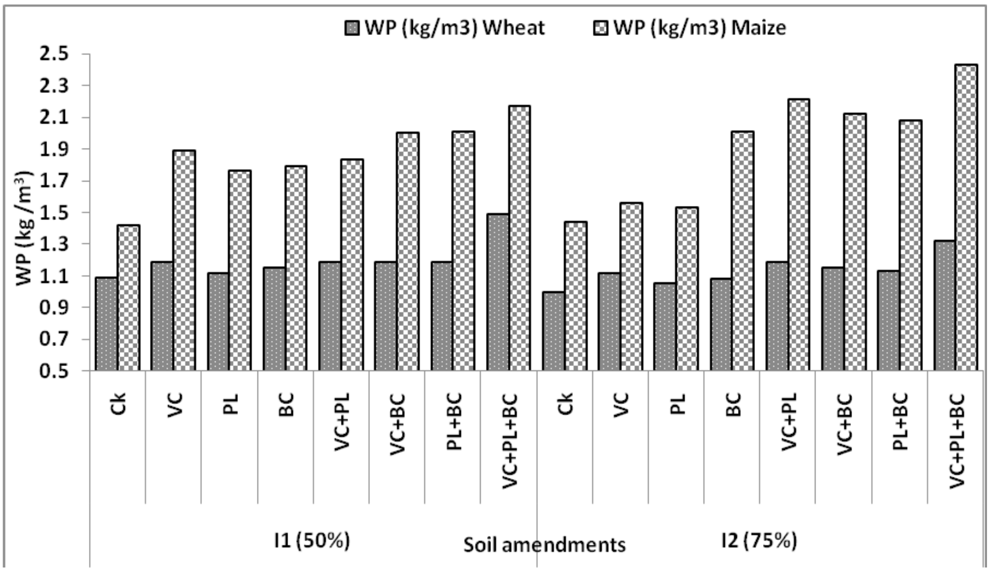


Fig. 6. Effects of soil amendments and irrigation levels on water productivity of wheat and maize,
*CK: Control, VC: vermicompost, BC: biochar, PL: polymer, I_1:50% depletion, I_2:75% depletion

The role of soil amendments in improving WP may due to their positive effects on crop yield. The VC was the most effective amendment on WP followed by BC and PL. The highest increases in WP values for wheat and maize (34.4 and 60.8%, respectively) were achieved with the combination of VC+PL+BC, while the lowest increases (3.8 and 15.0%, respectively) were recorded from PL treated plots comparing to untreated plots. Moreover, the interaction between irrigation levels and soil amendments was effective on WP values in both crops (Fig. 6). The highest WP values were obtained in plots amended by VC+PL+BC with I_1 for wheat (1.49 kg/m^3) or with I_2 for maize (2.43 kg/m^3), while the lowest values (1.00 and 1.44 kg/m^3, respectively) were recorded in untreated plots with I_2. Similar trend was observed by Ekebafe et al. (2011).

Conclusion

This study evaluated the productivity of sandy soil supplied by vermicompost, biochar and polymer under two irrigation levels (50 and 75% depletions). It could be concluded that application of 4.0 % vermicompost with 1% biochar and 0.4% polymer significantly enhanced growth, yield and water productivity and improved soil porosity and field capacity under both irrigation levels. In conclusion, applying vermicompost combined with biochar and polymer is a proper approach to help crop cultivation in sandy soil, whereas they maintain long-term productivity of these soils and mitigate the deleterious effects of drought stresses.

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