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Article

Using Soil Organic Conditioners to Improve the Heavy Clay Soils Characteristics Under Deficit Irrigation Conditions

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Abstract: Clay soil has very low water permeability and aeration. Soil organic conditioner (SOC) application improves the soil properties. The objective of this study is estimate the effect of SOC application on some properties of the heavy clay soils under deficit irrigation. Three main plots to receive the irrigation treatments, i.e., I_1 (100%), I_2 (80%) and I_3 (60%) of ETc. Four sub-main plots to receive SOC application rates, i.e., zero (control), 5 t ha^{-1} of vermi-compost (VC), 10 t ha^{-1} of biochar (Bio), and (2.5 t ha^{-1} of VC + 5 t ha^{-1} of Bi). The results illustrated that the mean values of soil dry bulk density and soil salinity significantly increased by 1.59 and 3.17%, and by 20.52 and 42.35% when the deficit irrigation increased from I_1 to I_2 and I_3, respectively. While the mean values of total porosity, void ratio, hydraulic conductivity and organic matter significantly decreased by 1.08 and 2.36%, 2.30 and 4.87%, 8.0 and 16.0% and 7.69 and 12.82% when the deficit irrigation increased from I_1 to I_2 and I_3, respectively. The effect of SOC on the soil total porosity, void ratio, hydraulic conductivity, ECe and organic matter values could be descending the following order: VC > (½ VC + ½ Bi) > Bi > control. Quickly drainable pores and useful pores values were improved with I_1 and vermi-compost treatments. It could be recommended that, using irrigation treatment (I_1) with VC application to improve the heavy clayey soil characteristics, and to achieve the optimum clay soil productivity.

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1. Introduction

The water is becoming scarce and increasingly the competition for water in industry and urban areas in the arid and semi arid regions, so, the irrigation water becomes not enough. Improving surface irrigation efficiency in the old soils in Egypt (Nile valley, and Delta) is a critical portion of developing sustainable agricultural practices. The productivity of calcareous soil is relatively high when adequate nutrients and irrigation water can be supplied. The soil dry bulk density value was 1.26 g cm^{-3}, and it recorded when textural class of the soil is clay

(Twum and Nii-Annang, 2015). The development of irrigation is measure to alleviate the challenge of the food safety under irrigation water shortage **(Cao *et al.*, 2019).** Deficit irrigation is one of the practices which used in arid and semi-arid regions and aims to enhance the water productivity of crops. The agriculture is the higher consumer of irrigation water, about 70% of the all freshwater withdrawal. Up to 40 % of yearly food production comes of irrigated lands **(Wani *et al*., 2021).** The increases in the soil bulk density values promotes higher roots development in the layer up the compacted being the roots concentrate most in this the layer **(da Silva *et al*., 2022).** Deficit irrigation decreased the positive impact of the soil conditioners application **(Şahin *et al*., 2024).** The soil moisture content at the deficit irrigation was decrease than when adequate irrigation. The deficit irrigation can enhance the irrigation water use efficiency and water content in the soil. Soil moisture content in the soil was distributed in the water absorbing layer (20 - 60 cm) of the crop roots **(Yuan *et al*., 2024).**

Application of soil organic conditioners (vermi-compost and biochar) have a considerable effect on soil organic carbon percentage and some physical, chemical, and biological characteristics in the different textured soils. Vermi-compost is one of the important bio-fertilizers which is the product composting process of the different organic wastes, i.e., crop residues and/or manures using different earthworms. Vermi-compost can play a vital role in the plant growth, also in decreasing the harmful impacts of the various environmental stress on plants **(Kiran, 2019).** Level increase of the irrigation water applied quantity, and biochar led to enhance the soil physical properties, i.e., decreasing in soil dry bulk density, and increasing in the soil total porosity values **(Zhang *et al*., 2020).** The treatments with vermi-compost were able to mitigate water deficit stress **(Baghbani-Arani *et al*., 2021).** Organic conditioners application have been effect on each of the soil dry bulk density, hydraulic conductivity, infiltration rate, water holding capacity, and the soil moisture retention through different sections **(Kumar and Kahlon, 2022).** Soil treated with vermi-compost had significantly ($p < 0.01$) decreases in the soil bulk density values **(Ararso, 2023).** Soil conditioners application are one of the promising solution for improving the hydraulic properties of soil, and improve the undesirable effect of drought conditions **(Farag *et al*., 2024).**

Biochar application resulted increase in the saturated hydraulic conductivity values of 2.7 to 13.4 cm h^{-1} **(Major *et al*., 2010).** Meanwhile, biochar application causes an alteration in hydraulic conductivity and water infiltration that depending on the soil texture **(Blanco-Canqui, 2017).** The highest value of the soil dry bulk density was 1.25 g cm^{-3} in the biochar amended plots, while it was 1.35 g cm^{-3} in the unamended plots. The biochar application increased soil total porosity by 3.81% as compared to the unamended plots. There was a small soil water sorptivity in sandy clay loam soil which amended by biochar, due to slowly absorbed water and low wettability of the soil particles, which are coated with hydrophobic biochar **(Faloye *et al*., 2019).** The biochar is a highly porous carbon rich material, which conducted after the pyrolysis of the organic biomass. Biochar application increased nutrients availability and soil and crop productivity **(Christian *et al*., 2021).** Biochar increase the microbial activity, water holding capacity of the soil, cation exchange capacity, and decrease nutrient losses by providing nutrient binding sites due to its have a large surface area. Biochar decrease the mineral fertilizers requirements for the soil and reduces environmental pollution caused. The decrease in the soil bulk dry density after biochar application might be due to the increase in the total porosity values **(Alfadil *et al*., 2021).** The application of biochar could be improving the soil physicochemical characteristics and enhance the total porosity, water holding capacity and surface area of the soil **(Haider *et al*., 2022).** *The* application of biochar increased the soil organic carbon content, especially when non-acidified biochar adds at a level of 10 g kg^{-1} soil. Also, this application rate increased significantly soil salinity, but acid modified biochar decreased soil salinity **(Farid *et al*., 2025).**

Soil acidity (pH) and salinity (EC) values were significantly decreased with increasing the irrigation water level **(El-Garawany and Albaloushi, 2015).** Surface soil salinity was higher under deficit irrigation 60% and 40% of field capacity (FC) as compared to full and deficit irrigation 80% of FC **(Nagaz *et al*., 2017).** *The* application *of b*iochar led to a slightly decrease in the soil dry bulk density values, while it was increased the soil acidity (pH) values from 6.33 under control to 7.07 under double dose of biochar **(Idbella *et al*., 2024).** The soil organic-C was increased by 80.52% due to the combination effect between biochar and compost **(Zahra *et al*., 2021).** The addetion of biochar significantly increased each of pH, ECe and soil organic carbon of the soil as compared to control **(Ngalani *et al*., 2023).** Biochar addition decreased the soil dry bulk density, and increased the soil total porosity, cation exchange capacity (CEC) and the total organic carbon **(Park *et al*., 2023).** After ten years of biochar applications, there are increases in the soil organic-C from 1.27% in control to 1.73 and 2.31% in single and double doses of biochar **(Idbella *et al*., 2024).** The current research aims to estimate the effect of organic soil conditioners application on some soil physiochemical characteristics of the heavy clayey soil under deficit irrigation levels.

2. Materials and Methods

2.1. Installation of the experiments

The field experiments were illustrated at Menshat Rabie Village (about 11 km south of the Fayoum city), Itsa District, Fayoum Governorate, Egypt. The coordinates of the experimental soil location are 29° 14` 04.3‟ N and 30° 51` 19.9 E. To achieve the aim of this study, three main plots were used to receive deficit irrigation treatments. The three deficit irrigation treatments are named I_1, I_2 and I_3 (irrigation at 100%, 80%, and 60% of crop evapotranspiration (ETc), respectively. Each main plot was divided into four sub-main plots to receive the soil organic conditioners (SOCs) applications, i.e., control (without addition), 5 t ha^{-1} of the vermi-compost (VC), 10 t ha^{-1} of biochar (BC), and the mixture of VC and BC applications, (2.5 t ha^{-1} of VC + 5 t ha^{-1} of BC). The total number of the experimental units for each season was; 3 deficit irrigation × 4 soil organic conditioners application × 3 replicates = 36 experimental units.

The experimental outline was a split plot system in the randomized complete blocks design, with three replicates. Main plots which conducted the deficit irrigation treatments were isolated by a dike of 2 m of width, to avoid the horizontal water movement of irrigation treatment to another. Some chemical analysis of the organic soil conditioners (vermi-compost, and biochar) are presented in Table 1.

2.2. The irrigation water application

Amounts of the irrigation water application values (IWA, m^3) for each experimental unit during the irrigation scheme were calculated by the following Eq. **(Keller and Karmeli, 1975):**

$$IWA = \frac{A \times ETc \times Ii}{Ea \times 1000}$$

Where: A is the Area of the soil (m^2), ETc is the evapotranspiration of crop (mm day^{-1}), Ii is the irrigation intervals by day, and Ea is the irrigation efficiency which equal 60% under controlled surface irrigation.

The amounts of IWA were controlled by plastic pipes (spiles) of 2 inch (5.08 cm) in diameter, and 90 cm in length. Each plot has one spile to convey the irrigation water from irrigation channel into plot. The irrigation water discharge (Q, L $Sec.^{-1}$) values were determined by the following Eq. **(Israelsen and Hansen, 1962):**

$$Q = C\,A\sqrt{2gh} \times 10^{-3}$$

Where: C is the discharge coefficient (0.8), A is the cross-section area of the spile(irrigation pipe, cm^2), g is the gravity acceleration (cm Sec^{-2}), and h is the mean of effective head of the irrigation water above the pipe surface (cm).

The crop evapotranspiration (ET_c) values were calculated as the following Eq. **(Doorenbos and Pruitt, 1992)**:

$$ET_c = ET_o \times K_c$$

Where: Kc is the crop coefficient, a factor which used to convert the reference evapotranspiration (ET_o) to ET_c.

Some chemical analyses of the organic soil conditioners (vermi-compost, and biochar) are presented in Table 1.

2.3. Corn planting and plant evolution conditions

In the present research, corn (*Zea mays* L.) hybrid and single cross, Hytech 2031 was cultivated in two successive summer seasons during two years (2020 and 2021), used to field investigate the effect of soil organic conditioners application, deficit irrigation, and their interaction on some soil characteristics. Soil organic conditioners were applied before planting operation. Corn plants received NPK fertilizers requirements as 115 kg N, 31 kg P_2O_5 and 24 kg K_2O units which equal to 250 kg ha^{-1} of urea fertilizer (46% N), 200 kg ha^{-1} of the calcium super phosphate fertilizer (15.5%, P_2O_5), and 50 kg ha^{-1} of potassium sulphate fertilizer (48% K_2O), respectively. Nitrogen fertilizer was applied in two times equal doses. The application of first dose was after thinning operation which conducted at four leaves stage of the plant, and keeping two plants per hill. The second dose was added after four weeks of the first one. Also, supper phosphate was added before planting. Potassium sulfate fertilizer was applied after thinning. Agronomic practices were obtained as used assure optimum production, and according to the recommendations of the Agricultural Ministry.

2.4. Soil analyses

Soil samples were carried out of the experimental soil, at two depths: 0-20 and 20-40 cm, before application the SOCs and deficit irrigation treatments (initial soil samples), and after conducting such treatments (at the maximum of plant growth stage). Some soil physical determinations were carried out according to the methods described and outlined by **Klute (1986).** Also, some chemical properties of the studied soil were obtained by using the methods described by **Page *et al.* (1982).**

Table 1. The chemical analysis of the organic soil conditioners (vermi-compost, and biochar) used in the field experiment

Organic conditioners	**OC (%)**	**TN (%)**	**C/N ratio**	**pH, in (1:2.5) of suspension**	**ECe, (dS m^{-1}) in the extract (1 : 2.5)**	**$CaCO_3$ (%)**	**P (%)**	**K (%)**
Vermi-compost	41.36	1.28	32.31	7.15	2.78	1.64	0.922	0.695
Biochar	44.17	0.98	45.07	7.83	3.88	1.32	0.316	0.484

Where: OC = organic carbon, TN = the total nitrogen.

The values of calcium carbonate content ($CaCO_3$) were ranged between 10.25% in surface layer of the soil (0-20 cm) to 15.43% in layer subsurface of the soil (20-40 cm). The percentages of $CaCO_3$ within each of the soil mechanical fraction were determined by back titration (Table, 3). It is clear that $CaCO_3$ content is high at the medium size of soil fractions (fine sand and silt). $CaCO_3$ content in different soil fractions were decreased as to the descending following order: Fine sand > silt > coarse sand > clay fractions. Fine fractions of $CaCO_3$ result some problems i.e., soil crust, fixation of phosphorus and some micronutrients, deteriorate of some soil physical properties, and increasing soil compaction. These results are compatible with those conducted by **Chen *et al.* (2020),** who found that when $CaCO_3$ content increasing above 5 %, the soil shear strength values were gradually increased.

2.4.1. Some soil physical characteristics

Particle size distribution was determined by the International Pipette method, using sodium hexametaphosphate a dispersing agent (Klute, 1986).

1. Soil particle density (γ_S) values were determined on duplicate 50 g soil sample by pycnometer and toluene liquid.
2. Soil bulk density (γ_d) values were determined by the core method on three replicates of the soil samples.
3. Total porosity (n) values were calculated of the (γ_S) and the γ_d according to the Eq.:

$$n = [(\gamma_S - \gamma_d) / \gamma_S] \times 100$$

4. Void ratio (e) values in the soil were calculated from the soil total porosity (n) according to the Eq.: $e = n / (1 - n)$
5. Air porosity (n_a) values were calculated of the soil n and volumetric water content (θ) in the soil as to the following Eq.: $n_a = n - \theta$
6. Pore size distribution values of the soil were calculated by to following Eq. **(De leehneer and De Boodt, 1965)**: $P = 2\, S \cos\theta / r$

   Where: P = applied pressure (Pa), S = surface tension of the soil water (dyne cm^{-1}), r = the soil pore diameter (cm), and θ = the contact angle of water.

Soil field capacity, permanent wilting point and available water content: field capacity values of the soil were determined by the pressure cooker device at ⅓ bar, the wilting point values were determined by the pressure membrane device at 15 bar.

Table 2. Some soil physical and chemical characteristics of the experimental field (as mean values of two seasons)

Soil properties	Soil depth (cm)	
	0-20	**20-40**
Soil physical characteristics		
Particle size distribution		
Sand (%)	7.0	7.2
Silt (%)	32.9	27.3
Clay (%)	60.1	65.5
Texture class	Clayey	Clayey
Soil particle density (g cm^{-3})	2.64	2.65
Soil dry bulk density (g cm^{-3})	1.41	1.43
Total porosity (%)	46.59	46.04
Air porosity (%)	29.82	26.87
Void ratio	0.87	0.85
Hydraulic conductivity, (cm h^{-1})	0.10	0.09
Field capacity (%)	37.80	36.90
Wilting point (%)	25.50	25.80
Available water content, (%	12.30	11.10
Soil chemical characteristics		
pH (in soil paste extract)	7.35	7.52
ECe (dS m^{-1} in soil paste extract)	3.66	5.51
Soluble cations (meq L^{-1})		
Ca^{2+}	10.28	15.42
Mg^{2+}	5.84	9.66
Na^{+}	20.07	34.9
K^{+}	0.51	0.62
Soluble anions (meq L^{-1})		
CO_3^{2-}	--	--
HCO_3^{-}	1.5	2.2
Cl^{-}	9.01	17.78
SO_4^{2-}	26.19	40.62
$CaCO_3$ (%	10.25	15.43
Organic matter (%	1.89	1.06

Table 3. Fractionation of calcium carbonate in the studied soil

Depth (cm)	$CaCO_3$ equivalent in the fractions in the soil (%) Coarse sand	Fine sand	Silt	Clay	Total $CaCO_3$ (%)
0 – 20	1.66	4.64	2.50	1.45	10.25
20 – 40	2.86	7.19	3.08	2.30	15.43
$CaCO_3$ fractions (%) of total $CaCO_3$ content in the soil fractions					
0 – 20	16.20	45.26	24.39	14.15	100
20 – 40	18.54	46.59	19.96	14.91	100

The available water content (AWC) values were calculated by to following Eq.:

AWC = Field capacity (FC) - permanent wilting point (PWP).

Saturated hydraulic conductivity coefficient (K, cm Sec^{-1}) of the soil were determined according to Darcy's law as the following Eq.:

$$q = K \frac{\Delta H}{L}$$

Where: q = water flux density (cm sec^{-1}), and $\frac{\Delta H}{L}$ = hydraulic potential gradient (in cm of water cm^{-1}).

2.4.2. Some chemical characteristics of the studied soil

1. Soil pH values were estimated in the soil paste using Beckman pH-meter, and determined in the 1:2.5 water suspension for soil organic conditioners.
2. Total soluble salts values as an electrical conductivity (ECe) of the soil were estimated in soil paste extract by EC meter device.
3. Soluble cation and soluble anions were determined in the first and second seasons, the ECe and soluble cation and soluble anions values were high in first season as compared with second season due to salt leaching process during at the second season.
4. Calcium carbonate content values were determined by Collin's calcimeter device. Fractionation of $CaCO_3$, were determined by the back titration of each of the soil fractions when obtained of them from particle size distribution without digestion by HCl acid of the mineral substances in the soil ($CaCO_3$).
5. Organic matter content values were determined by wet combustion method which following described by Walkley and Black's method.
6. Total nitrogen was determined using Kjeldahl method.

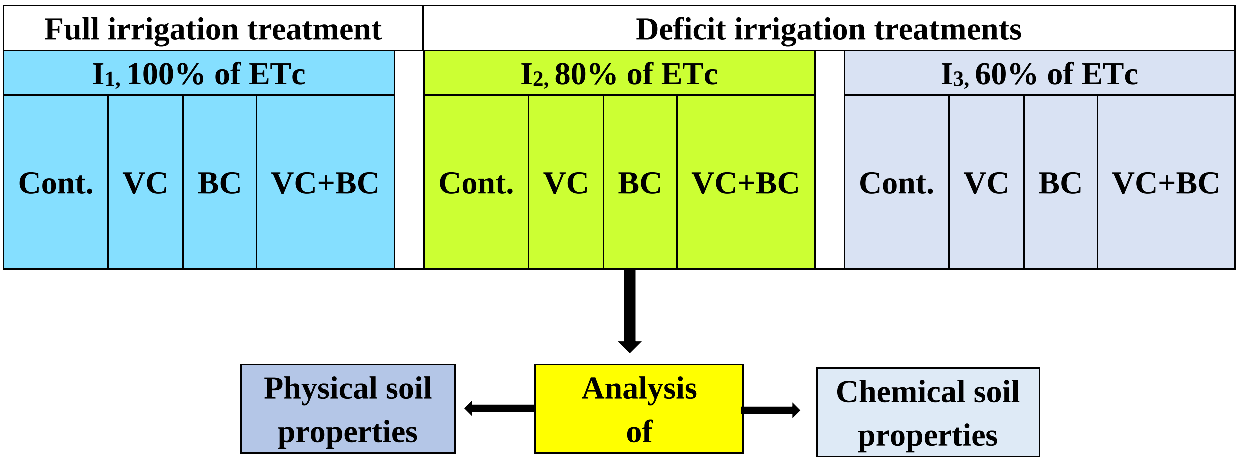

Fig. 1. Flowchart of the current study, where, cont. is control, VC is vermicompost, BC is Biochar, and ETc is the evapotranspiration.

2.5. Statistical analyses

The data collected were statistically analyzed with the procedures described by **(Snedecor and Cochran, 1980).** Three replicates were used for each treatment. Duncan's multiple range test was outlined by SPSS software, version 15, also, it was used to conducted the statistical analyses. The Fisher's test (least significant difference LSD) used to assessment the statistical significance.

3. RESULTS AND DISCUSSION

3.1. The effect of soil organic conditioners addition on some soil physical characteristics under deficit irrigation treatments

3.1.1. Soil dry bulk density

Table 2 showed that the initial values of some the soil physical and chemical characteristics. Soil texture is heavy clayey soil, and the soil is calcareous. The clay fraction values increased with depth increment. The study soil has decreasing in pore spaces between the soil particles, low permeability, poor soil structure, low available water content and the subsurface layer more compacted, due to the soil have a high content of the clay fraction. These soils well be required the correctly integrated management of water and soil to get the highest productivity of these soils. Soil pH values ranged between (7.35 - 7.52), and ECe values ranged between 3.66 dS m^{-1} at surface layer of the soil (0-20 cm) to 5.51 dS m^{-1} in subsurface layer of the soil (20-40 cm).

Table 4 showed that the lowest value of soil bulk density (SBD) was 1.23 g cm^{-3}, and it recorded at full irrigation I_1 (100% of ETc) and vermi-compost application (I_{100} × VC) under surface layer of the soil (0-20 cm). The lowest value of the SBD was recorded at full irrigation I_1 (100% of ETc) and vermi-compost application under surface soil layer (0-20 cm) might be attributed to improvement in soil structure under full irrigation I_1 and vermi-compost applications. These results are compatible with those outlined by **Twum and Nii-Annang (2015).** Also, at surface layer of the soil (0-20 cm), the mean values of the SBD significantly increased by 1.59 and 3.17% when the deficit irrigation treatments increased from I_1 to I_2 and I_3, respectively. These results are parallel with those concluded by **Gautam *et al.***

(2022), who recorded that the SBD was linearly correlated and negatively with increasing water content at the field capacity and the wilting point.

Under surface soil layer (0-20 cm), SBD values significantly decreased by 7.52, 5.26 and 6.77% at full irrigation (I_1) and by 6.71, 5.22 and 5.97% at deficit irrigation (I_2) and by 5.93, 4.65 and 5.19% at deficit irrigation (I_3), with addition each of vermi-compost, biochar and (½ vermi-compost + ½ biochar), respectively, as compared with control. The SBD values were decreased when applied full irrigation I_1 with vermi-compost application as a soil organic conditioner added to heavy clay soil. Vermi-compost application had a superior effect on SBD values as compared to other applications of soil organic conditioners. This benefit effect is attributed to more accumulation of organic matter at the vermi-compost application and enhance the soil biological activities, which led to enhancing soil structure, aeration and permeability, and decreases in SBD values in heavy clay soil. These results are in compatible with those indicated by **Neupauer *et al.* (2023).**

3.1.2. Total porosity of the soil

Table 4 indicated that, the highest value of the soil total porosity was 53.41%, and it recorded with full irrigation I_1 (100% of ETc) and vermi-compost applications under surface layer of the soil (0-20 cm). These results might be due to the improvement in SBD, and soil structure under full irrigation I_1 and increasing the organic matter content after application the vermi-compost. These results are compatible with those concluded by **Yuan *et al.* (2018).** Also, at layer surface of the soil (0-20 cm), the mean values of the soil total porosity significantly decreased by1.09 and 2.36% when the deficit irrigation treatments increased from I_1 to I_2 and I_3, respectively. These results attributed to low biological activity and poor structure under deficit irrigation I_3. These results are parallel with those concluded by **Abd El-Mageed *et al.* (2021)** who recorded that the decreasing in SBD values was related to increases in the soil total porosity. Under surface layer of the soil (0-20 cm), total porosity values of the soil significantly increased by 7.64, 5.38 and 6.87% at full irrigation treatment (I_1), and by 6.93, 5.22 and 6.15% at deficit irrigation (I_2), and by 6.20, 4.67 and 5.44% at deficit irrigation (I_3),, with addition each of vermi-compost, biochar and (½ vermi-compost + ½ biochar), respectively, as compared to control. It is clear that, the increases in total porosity values of the soil under full irrigation treatment (I_1) more than under deficit irrigation treatments.

Table 4. Effect of soil organic conditioners application on the values of soil dry bulk density and soil total porosity under deficit irrigation treatments (as average values of two seasons)

Treatment	Soil bulk density (g cm^{-3}) at depth		Total porosity of soil (%) at depth	
	0-20 cm	20-40 cm	0-20 cm	20-40 cm
Irrigation (I)	**	**	**	**
$I_{100\%}$	1.26±0.012c	1.36±0.003c	52.08±0.448a	48.70±0.098a
$I_{80\%}$	1.28±0.009b	1.37±0.003b	51.51±0.359b	48.30±0.093b
$I_{60\%}$	1.30±0.011a	1.38±0.002a	50.85±0.406c	47.92±0.090c
Soil conditioner (SC)	**	**	**	**
Control	1.34±0.003a	1.38±0.003a	49.24±0.119d	47.92±0.134c
Vermicompost (VC)	1.25±0.007d	1.36±0.004bc	52.65±0.234a	48.44±0.179ab
Biochar (BC)	1.27±0.005b	1.37±0.003b	51.77±0.172c	48.31±0.123b
½VC + ½ BC	1.26±0.007c	1.36±0.002c	52.27±0.220b	48.56±0.072a
I × SC interaction	NS	NS	**	**
I_{100} × Control	1.33±0.003b	1.37±0.003bc	49.62±0.116h	48.30±0.173c
I_{100} × VC	1.23±0.006i	1.35±0.006e	53.41±0.127a	49.10±0.084a
I_{100} × BC	1.26±0.003fg	1.36±0.003cd	52.27±0.103d	48.70±0.097b
I_{100} × (½VC + ½ BC)	1.24±0.006hi	1.36±0.00de	53.03±0.021b	48.70±0.035b
I_{80} × Control	1.34±0.003ab	1.38±0.003ab	49.24±0.055i	47.92±0.153d
I_{80} × VC	1.25±0.006gh	1.37±0.003bcd	52.65±0.166c	48.30±0.055c
I_{80} × BC	1.27±0.003ef	1.37±0.003bcd	51.89±0.040e	48.30±0.123c
I_{80} × (½VC + ½ BC)	1.26±0.003fg	1.36±0.003cd	52.27±0.086d	48.68±0.079b
I_{60} × Control	1.35±0.003a	1.39±0.003a	48.86±0.088j	47.55±0.151e
I_{60} × VC	1.27±0.003de	1.38±0.003ab	51.89±0.177e	47.92±0.092d
I_{60} × BC	1.29±0.003c	1.38±0.003ab	51.14±0.116g	47.92±0.069d
I_{60} × (½VC + ½ BC)	1.28±0.003cd	1.37±0.003bcd	51.52±0.065f	48.30±0.047c

Where: $I_{100\%}$, $I_{80\%}$ and $I_{60\%}$ are the deficit irrigation treatments 100%, 80% and 60% of crop evapotranspiration.

The vermi-compost added treatment had a superior effect on total porosity values of the soil as compared to other applications of the soil organic conditioners. The effect of soil organic conditioners on total porosity values of the soil could be descending order as the following: vermi-compost > (½ vermi-compost + ½ biochar treatments) > biochar > control. Biochar application decreasing the SBD values, and mitigates soil salinity by enhancing soil porosity. Biochar improving soil healthy by increasing water retention, water absorption, organic matter content, nutrient holding capacity, and the microbial activity. The vermi-compost added treatment had a superior effect on the values of soil total porosity when compared with other applications of soil organic conditioners. These results are compatible with those conducted by **Kumar *et al.* (2023) and Neupauer *et al.* (2023).** Biochar application decreasing the SBD values, and mitigates soil salinity by enhancing soil porosity. Biochar improving soil healthy by increasing water retention, water absorption, organic matter content, nutrient holding capacity, and the microbial activity. This improvement due to biochar's high porosity value, adsorptive properties, negative surface charge, ash content, slow nutrient release by chelation, increased soil organic carbon and facility of habitat to microorganisms **(Niraj and Mahat, 2024).**

3.1.3. Void ratio of the soil

Table (5) showed that the highest value of the void ratio in soil was 1.146, and it recorded at full irrigation I_1 (100% of ETc) and vermi-compost application under surface soil layer (0-20 cm). These results might be attributed to application vermi-compost under full irrigation I_1 increasing organic matter content in surface layer of the soil, and led to improvement in the SBD, total porosity, and soil structure when compared to irrigation treatments I_2 and I_3. Also, at surface layer of the soil (0-20 cm), the mean values of the void ratio of the soil significantly decreased by 2.30 and 4.87% when the deficit irrigation treatments increased from I_1 to I_2 and I_3, respectively. These results due to vermi-compost application increased the organic matter content and improving the SBD, total porosity, and soil structure as compared with deficit irrigation treatments I_2 and I_3. These results are compatible with those concluded by **Yuan *et al.* (2018)** and **Abd El-Mageed *et al.* (2021).**

Under surface layer of the soil (0-20 cm), the values of soil void ratio significantly increased by 16.35, 11.68 and 14.62% at full irrigation (I_1) treatment and by 14.64, 11.24 and 12.89% at deficit irrigation (I_2) treatment and by 12.98, 9.63 and 11.31% at deficit irrigation (I_3) with addition each of vermi-compost, biochar and (½ vermi-compost + ½ biochar), respectively, as compared to control. It is clear that the increases in soil void ratio values under full irrigation treatment (I_1) more than under deficit irrigation treatments. The vermi-compost added treatment had a superior effect on the soil void ratio values as compared to other applications of the soil organic conditioners. The effect of using organic conditioners on soil void ratio values could be descending order as the following: vermi-compost > (½ vermi-compost + ½ biochar) > biochar > control. These results are parallel with those conducted by **Kumar *et al.* (2023).**

3.1.4. Saturated hydraulic conductivity of the soil

Table 5 indicated that, the highest value of the hydraulic conductivity of soil was 0.33 cm h^{-1} and it recorded at full irrigation I_1 (100% of ETc) and vermi-compost application under surface layer of the soil (0-20 cm). These results due to improvement in the soil total porosity, void ratio and soil structure. Also, at surface layer of the soil (0-20 cm), the mean values of hydraulic conductivity of the soil significantly decreased by 8 and 16% when the deficit irrigation treatments increased from I_1 to I_2 and I_3, respectively. The soil hydraulic conductivity significantly decreased when the deficit irrigation treatments increased from I_1 to I_2 and I_3 at surface layer. These results due to low soil aggregates and poor soil structure at the irrigation treatment I_2 and I_3, which achieved low irrigation water as compared with full irrigation treatment (I_1). These results are parallel with those concluded by **Gautam *et al.* (2022) and Farag *et al.* (2024).**

Table 5. Effect of soil organic conditioners application on the values of soil void ratio and soil hydraulic conductivity under deficit irrigation treatments (as average values of two seasons)

Treatment	Void ratio in the soil at depth		Soil hydraulic conductivity (cm h^{-1}) at depth	
	0-20 cm	20-40 cm	0-20 cm	20-40 cm
Irrigation (I)	**	**	**	**
$I_{100\%}$	1.09±0.019a	0.95±0.003a	0.25±0.029a	0.10±0.006a
$I_{80\%}$	1.06±0.015b	0.93±0.003b	0.23±0.024b	0.09±0.004a
$I_{60\%}$	1.04±0.017c	0.92±0.003c	0.21±0.027c	0.08±0.006b
Soil conditioner (SC)	**	**	**	**
Control	0.97±0.005d	0.92±0.004c	0.08±0.003d	0.06±0.002b
Vermicompost (VC)	1.11±0.010a	0.94±0.007ab	0.30±0.008a	0.10±0.004a
Biochar (BC)	1.07±0.007c	0.93±0.004b	0.26±0.007c	0.09±0.003a
½VC + ½ BC	1.10±0.010b	0.94±0.003a	0.28±0.008b	0.10±0.005a
I × SC interaction	**	**	NS	NS
I_{100} × Control	0.99±0.001h	0.93±0.002c	0.09±0.003f	0.06±0.003e
I_{100} × VC	1.15±0.002a	0.96±0.002a	0.33±0.006a	0.11±0.006a
I_{100} × BC	1.09±0.004d	0.95±0.003b	0.28±0.006c	0.10±0.003ab
I_{100} × (½VC + ½ BC)	1.13±0.004b	0.95±0.005b	0.30±0.006b	0.11±0.003a
I_{80} × Control	0.97±0.007i	0.92±0.003d	0.08±0.003f	0.06±0.003e
I_{80} × VC	1.11±0.003c	0.93±0.005c	0.30±0.006b	0.10±0.003ab
I_{80} × BC	1.08±0.005e	0.93±0.003c	0.26±0.003d	0.09±0.003bc
I_{80} × (½VC + ½ BC)	1.10±0.003d	0.95±0.005b	0.28±0.006c	0.10±0.003ab
I_{60} × Control	0.96±0.001j	0.91±0.003e	0.07±0.003f	0.05±0.003e
I_{60} × VC	1.08±0.002e	0.92±0.003d	0.28±0.003c	0.09±0.003cd
I_{60} × BC	1.05±0.001g	0.92±0.003d	0.23±0.006e	0.08±0.003cd
I_{60} × (½VC + ½ BC)	1.06±0.002f	0.93±0.004c	0.25±0.006d	0.08±0.003d

Where: $I_{100\%}$, $I_{80\%}$ and $I_{60\%}$ are the deficit irrigation treatments 100%, 80% and 60% of crop evapotranspiration.

Under surface layer of the soil (0-20 cm), the values of soil hydraulic conductivity significantly increased by 230, 180 and 200% at full irrigation (I_1), and by 234, 188 and 211% at deficit irrigation (I_2) and by 211, 156 and 178% at deficit irrigation (I_3), when addition each of vermi-compost, biochar and (½ vermi-compost + ½ biochar), respectively, when compared with control. The effect of soil organic conditioners on the soil hydraulic conductivity values could be descending order as the following: vermi-compost > (½ vermi-compost + ½ biochar) > biochar > control. The vermi-compost application had a superior effect on the values of soil hydraulic conductivity as compared to other applications treatments of soil organic conditioners (like biochar), due to it rich in organic matter, nutrition, low C/N ratio, and it improve the soil structure and soil porosity especially the macro pores and enhancing the soil microbial activity and soil health. These results are compatible with those observed by **Major *et al.* (2010)** who observed that the application of biochar resulted increases in the values of hydraulic conductivity from 2.7 to 13.4

cm/h. Also, **Blanco-Canqui (2017)** found that the biochar application causes an alteration in hydraulic conductivity and infiltration that depending on the soil texture.

3.1.5. The pore size distribution of soil

Figure (2) indicated that, the values of each of total porosity (TP), the quickly drainable pores (QDP), volume drainable pores (VDP), the water holding pores (WHP), and useful pores (UP) were decreased when deficit irrigation treatments increased from I_1 (100% of ETc) to I_2 (80% of ETc) and I_3 (60% of ETc). While, the fine capillary pores (FCP) values were increased when deficit irrigation treatments increasing from I_1 to I_2 and I_3.

The results showed that at surface layer of the soil (0-20 cm), and full irrigation treatment I_1, the values were increased by 27.62, 18.57 and 22.30% for VDP, and by 9.63, 7.82 and 7.57% for WHP, and by 7.17, 4.44 and 4.59% for UP, when application each of vermi-compost, biochar and (½ vermi-compost + ½ biochar), respectively, as compared to control. The full irrigation (I_1) had a superior effect on the values of volume drainable pores (VDP), and useful pores (UP) when compared with deficit irrigation treatments I_2 and I_3. Also, at surface layer of the soil (0-20 cm) and deficit irrigation treatment I_2, the values were increased by 16.77, 10.95 and 13.34% for VDP, and by 12.44, 10.96 and 11.88% for WHP, and by 6.36, 5.71 and 6.06% for UP, when application each of vermi-compost, biochar and (½ vermi-compost + ½ biochar), respectively, as compared to control In addition, at the surface layer of the soil (0-20 cm), and deficit irrigation treatment I_3, the values were increased by 13.63, 8.38 and 10.81% for VDP, and 12.68, 6.29 and 12.01% by for WHP, and by 6.51, 4.15 and 4.98% for UP, when application each of vermi-compost, biochar and (½ vermi-compost + ½ biochar), respectively, as compared to control. It is clear that, the full irrigation (I_1) had a superior effect on the VDP and UP values when compared to deficit irrigation treatments I_2 and I_3.

Also, the vermi-compost application treatment had a superior effect on the pore size distribution (TP, QDP, VDP, WHP, and UP) values as compared to other applications of soil organic conditioners. The application effect of soil organic conditioners on the pore size distribution could be descending order as the following: vermi-compost > (½ vermi-compost + ½ biochar) > biochar > control. This benefit impact attributed to more accumulation of organic matter with vermi-compost application and enhancing in the soil biological activities, which led to improve in the values of soil total porosity, and pore size distributions in the heavy clay soil. These results are in agreement with those obtained by **Goyal and Kahlon (2022).**

3.2. The application effect of soil organic conditioners on some soil chemical characteristics under deficit irrigation treatments

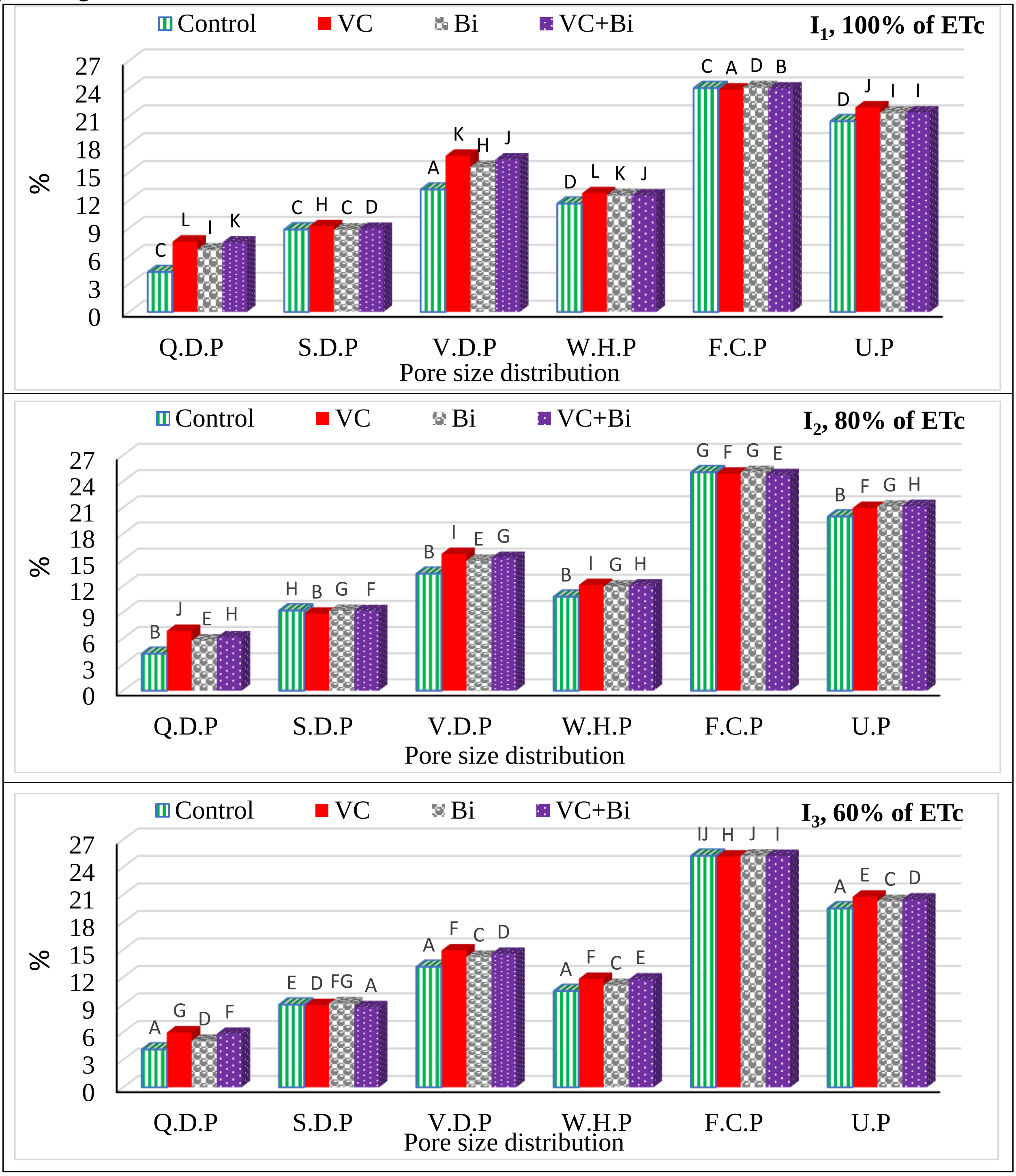

Fig. 2. Effect of deficit irrigation treatments and soil organic conditioners addition on the soil pore size distribution values (%) under surface layer of the soil (0-20 cm) (as average values of two seasons). Where, VC is the vermi-compost, BC is the biochar, T.P is the total porosity, Q.D.P is the quickly drainable pores, S.D.P is the slowly drainable pores, V.D.P is the volume drainable pores, W.H.P is the water holding pores, F.C.P is the fine capillary pores and U.P is the useful pores.

3.2.1. Soil salinity (EC)

Table (6) showed that the increased deficit irrigation treatments from I_1 (100% of ETc) to I_2 (80% of ETc) and I_3 (60% of ETc) resulted significant increases in the values of soil salinity (ECe) at different applications of soil organic conditioners. Under surface layer of the soil (0-20 cm), the lowest values of soil ECe was 2.71, 3.45 and 4.12 dS m^{-1}, and they recorded at irrigation treatments I_1, I_2 and I_3, respectively and with biochar applications. The results showed that the ECe values increased at the deficit irrigation treatment (I_3) as compared the full irrigation treatment (I_1). At surface layer of the soil (0-20 cm) the mean values of the soil ECe significantly increased by 20.52 and 42.35% when the deficit irrigation treatments increased from I_1 to I_2 and I_3, respectively. Low soil salinity (ECe) values at full irrigation treatment (I_1) might be due to increasing the irrigation water applied at this treatment which led to more leaching the soil salts from the surface soil layer, and led to improve the soil physical characteristics, i.e., soil porosity and macro pores, void ratio and soil permeability, as compared to other deficit irrigation I_2 and I_3. These results are in cope with those concluded by respectively **El-Garawany and Albaloushi (2015).**

Under surface layer of the soil (0-20 cm) the results clear that the soil ECe values were significantly decreased by 22.57, 10.00 and 16.86% at full irrigation treatment (I_1), and by 13.32, 5.53 and 9.80% at deficit irrigation treatment (I_2), and by 11.40, 5.16 and 7.74% at deficit irrigation treatment (I_3), when application each of vermi-compost, biochar and (½ vermi-compost + ½ biochar), respectively, when compared with control. The soil organic conditioners effect of on decreasing the soil ECe values could be ascending order as the following: vermi-compost < (½ vermi-compost + ½ biochar) < biochar < control. Vermi-compost application improve the soil structure and macro pores in the soil which led to more leaching the soluble salts, and it enhance the soil microbial activities in the surface soil layer, which led to enhance the soil physical characteristics and decreasing soil salinity as compared to biochar and (½ vermi-compost + ½ biochar) treatments. The application of vermi-compost and biochar enhancing the agricultural efficiency and nutrient content. Also, with the addition of vermi-compost or biochar, the organic matter and NPK percentages were increased in the soil, though the pH values decreased of the soil. These results are compatible with those outlined by **Alfadil *et al.* (2021), Ngalani *et al.* (2023),** and **Hegab (2024).**

3.2.3. The soil organic matter content

Data in Table (6) showed that, under surface layer of the soil (0-20 cm) the highest values of the soil organic matter content were 1.70, 1.59 and 1.45%, and they recorded at deficit irrigation treatments I_1, I_2 and I_3, respectively, with vermi-compost application. At surface layer of the soil (0-20 cm) the mean values of the soil organic matter content significantly decreased by 7.69 and 12.82% when the deficit irrigation increased from I_1 to I_2 and I_3, respectively. The maximum values of soil organic matter percentage were recorded at full irrigation treatment I_1 with vermi-compost application due to increasing in the microbial activities in the surface soil layer and it receive the optimum irrigation water quantity. In addition to, the vermi-compost application treatment had a superior effect on the values of soil organic matter content when compared with biochar and (½ vermi-compost + ½ biochar) treatments applications.

Under surface layer of the soil (0-20 cm), organic matter content values were significantly increased by 29.77, 20.61 and

Table 6. Effect of soil organic conditioners application on the values of soil salinity (ECe) and soil organic matter under deficit irrigation treatments (as average values of two seasons)

Treatment	Soil salinity (ECe, dSm^{-1}) at soil depth:		Organic matter (%) at soil depth:	
	0-20 cm	20-40 cm	0-20 cm	20-40 cm
Irrigation (I)	**	**	**	**
$I_{100\%}$	3.07±0.089a	4.81±0.058a	1.55±0.045a	1.16±0.029a
$I_{80\%}$	3.69±0.060b	5.40±0.058b	1.44±0.030b	1.10±0.019b
$I_{60\%}$	4.37±0.058c	5.53±0.054c	1.36±0.037c	1.06±0.023c
Soil conditioner (SC)	**	**	**	**
Control	4.04±0.167d	5.51±0.105d	1.25±0.017d	0.98±0.009d
Vermicompost (VC)	3.43±0.204a	5.01±0.106a	1.58±0.036a	1.18±0.023a
Biochar (BC)	3.77±0.182c	5.31±0.111c	1.46±0.028c	1.12±0.016c
½VC + ½ BC	3.59±0.199b	5.16±0.120b	1.50±0.033b	1.15±0.015b
I × SC interaction	**	**	**	**
I_{100} × Control	3.50±0.006e	5.10±0.006d	1.31±0.003j	1.01±0.009g
I_{100} × VC	2.71±0.006a	4.60±0.006b	1.70±0.006a	1.26±0.006a
I_{100} × BC	3.15±0.003c	4.87±0.006c	1.57±0.006d	1.18±0.006c
I_{100} × (½VC + ½ BC)	2.91±0.006b	4.68±0.006b	1.63±0.006b	1.20±0.006b
I_{80} × Control	3.98±0.006h	5.65±0.006k	1.25±0.009k	0.98±0.006h
I_{80} × VC	3.45±0.003d	5.12±0.006e	1.59±0.006c	1.18±0.006c
I_{80} × BC	3.76±0.006g	5.48±0.006i	1.43±0.007g	1.10±0.006e
I_{80} × (½VC + ½ BC)	3.58±0.007f	5.35±0.006g	1.47±0.006e	1.15±0.006d
I_{60} × Control	4.65±0.006l	5.79±0.006l	1.19±0.006l	0.95±0.006i
I_{60} × VC	4.12±0.006i	5.31±0.006f	1.45±0.006f	1.10±0.006ef
I_{60} × BC	4.41±0.006k	5.58±0.006j	1.39±0.006i	1.08±0.006f
I_{60} × (½VC + ½ BC)	4.29±0.006j	5.44±0.006h	1.41±0.006h	1.10±0.006e

Where: $I_{100\%}$, $I_{80\%}$ and $I_{60\%}$ are the deficit irrigation treatments 100%, 80% and 60% of crop evapotranspiration.

24.43% with full irrigation (I_1), and by 27.20, 14.40 and 17.60%Under surface layer of the soil (0-20 cm), organic matter content values were significantly increased by 29.77, 20.61 and 24.43% with full irrigation (I_1), and by 27.20, 14.40 and 17.60% with deficit irrigation (I_2), and by21.85, 16.81 and 18.49% with deficit irrigation (I_3), when application each of vermi-compost, biochar and (½vermi-compost + ½ biochar), respectively, when compared with control. Soil organic matter content values were increased when applied full irrigation I_1 with vermi-compost application as soil organic conditioners in the heavy clay soil.

Effect of soil organic conditioners on increasing the values of soil organic matter content could be descending as the following order: vermi-compost > (½ vermi-compost + ½ biochar) > biochar > control. Also, these results are due to the improving in the soil physiochemical characteristics. The effect of the soil organic conditioners on increasing soil organic matter content values could be descending order as the following: vermi-compost > (½ vermi-compost + ½ biochar) > biochar > control. These results are in compatible with those observed by **Gautam *et al.* (2022).**

4. CONCLUSION

Soil organic conditioners application and deficit irrigation treatments had an effective effect on the properties of the heavy clay soils. The lowest values of SBD and soil salinity (ECe) were recorded at I_1 with VC application. While the highest values of total porosity, void ratio, hydraulic conductivity and organic matter were recorded at I_1 with VC application. The effect of organic conditioners on the soil total porosity, void ratio, hydraulic conductivity, ECe and organic matter values could be descending order as the following: VC > (½ VC + ½ BC) > BC > control. I_1 treatment with vermi-compost application improved each of quickly drainable pores and useful pores. It could be recommended that, using full irrigation treatment (I_1) with vermi-compost application as SOCs to achieve the optimum soil productivity and enhance the soil physiochemical characteristics of the heavy clayey soils.

REFERENCES

Abd El-Mageed, T.A., Rady, M.O., Semida, W.M., Shaaban, A., Mekdad, A.A. 2021. Exogenous micronutrients modulate morpho-physiological attributes, yield, and sugar quality in two salt-stressed sugar beet cultivars. J. Soil Sci. Plant Nutr., 21:1421–1436.

Alfadil A.A., Xia, J., Shaghaleh, H., Hamoud, Y.A., Ibrahim, J.N., Hamada, A.A., Rahim, S.F., Sheteiwy, M.S. and Wu, T. 2021. Wheat straw biochar application improves the morphological, physiological, and yield attributes of maize and the physicochemical properties of soil under deficit irrigation and salinity stress. J. Plant Nutr., 44(16):1-22.

Ararso, G.T. 2023. Effects of vermi-compost and nitrogen fertilizer rates on yield and yield components of onion (*allium cepa* L.) and soil physicochemical properties under irrigation in Bena-Tsemay district, Southern Ethiopia. Plant Horticultural Sci.

Baghbani-Arani, A., Ali, S., Modarres-Sanavy, M. and Poureisa, M. 2021. Improvement the soil physicochemical properties and fenugreek growth using zeolite and vermi-compost under water deficit conditions. Home J. Soil Sc. Plant Nutr., 21:1213-1228.

Blanco-Canqui, H. 2017. Biochar and soil physical properties. Soil Sci. Soc. Amer. J., 81(4):687-711.

Cao, X.C., Shu, R., Guo, X.P. and Wang, W.G. 2019. Scarce water resources and priority irrigation schemes from agronomic crops. Mitigation and Adaptation Strategies for Global Shange, 24:399-417.

Chen, L., Chen, X., Yang, X., Bi, P., Ding, X., Huang, X. and Wang, H. 2020. Effect of calcium carbonate on the mechanical properties and microstructure of red clay. Adv Mater Sci Eng., 5298186, 8 https://doi.org/10. 1155/2020/5298186

Christian, K., Renuka P.S., Stephan, H.M., Nicola, S. and Eva-Maria P. 2021. Impact of biochar on nutrient supply, crop yield and microbial respiration on sandy soils of northern Germany. Europ J. Soil Sci., 72:1885-1901.

da Silva, J.A., de Carvalho, L.G. and Ribeiro, A.F. 2022. Gas exchange and water stress index in soybean cultivated under water deficit and soil compaction. Soils and Plant Nutr. Rev. Ceres 69 (2), Mar-Apr.

De Leehneer, H. and De Boodt, M. 1965. (Ed.). Soil Physics. International Training Centre for Postgraduates Soil Scientists, Ghent, Balgium.

Doorenbos, J. and Pruitt, W.O. 1992. Guidelines for Prediction of Crop Water Requirements. FAO Irrigation and Drainage Paper No. 24 Rome, Italy.

El-Garawany, M.M. and Albaloushi, N.S. 2015. Deficit irrigation effects on soil chemistry properties yield and, yield components and fruit firmness of cucumber and (*Cucumis sativus* L.) under arid condition of Al-Hassa, Saudi Arabia JKAU: Met., Env. Arid Land Agric. Sci., 26 (1):57-68.

Faloye, O.T., Alatise, M.O., Ajayi, A.E. and Ewulo, B.S. 2019. Effects of biochar and inorganic fertilizer applications on growth, yield and water use efficiency of maize under deficit irrigation. Agric. Water Manage., 217:165-178.

Farag, A.A., Abdelfattah, A. and Fahmy E.F. 2024. Impact of soil amendments under water stress on growth, fruit production and high quality of Wonderful pomegranate variety. Curr Sci Inter., 13 (10), March.

Farid, Y.I., Mohamed, I., Abdelhafez, A.A. and Abbas, M.H. 2025. Enhancing wheat productivity in salt-affected soils using traditional and acidified biochars: A sustainable solution. Egypt. J. Soil Sci. 65(1):121 - 134.

Gautam S.K., Kautilya, C. and Rakesh, K. 2022. Effect of long term nutrients management on physical properties of soil during pearl millet-fallow cropping system under dry land conditions. Indian J Ecol. 49(6):2055-2062.

Ghahrie, M., Taghavi. M., Masir, M.N. and Sourestani, M.M. 2025. Effect of hydrogel and zinc on growth indices of Menth in a calcareous soil. Soil Manage Sustain Prod. 14(4), 1-27.

Goyal, R. and Kahlon, M.S. 2022. Soil physico-chemical properties and water productivity of maize as affected by biochar application under different irrigation regimes in northwest India, Communications in Soil Sci. Plant Anal. 1-17.

Haider, F.U., Coulter, J.A., Liqun, C.A., Hussain, S., Cheema, S.A., Jun, W.U. and Zhang, R. 2022. An overview on biochar production, its implications, and mechanisms of biochar-induced amelioration of soil and plant characteristics. Pedosphere, 32:107-130.

Hegab, R.H. 2024. Impact of integrating between mineral nitrogen, vermicompost and biochar on nitrogen-use efficiency and productivity of panicum plants grown on sandy soil. Egypt. J. Soil Sci., 64(3):1273-1284.

Idbella, M., Baronti, S., Giagnoni, L., Renella, G., Becagli, M., Cardelli, R., Maienza, A., Vaccari, F.P. and Bonanomi, G. 2024. Long-term effects of biochar on soil chemistry, biochemistry, and microbiota: Results from a 10-year field vineyard experiment. Appl Soil Ecol, 195, 105217.

Israelsen, O.W. and Hansen, V.C. 1962 (edt). “Irrigation Principles and Practices. “ John Wiley Sons Inco., New York, U.S.A.

Jin, H., Y. Xie, M. Li, Y. Liu, D. He, W. Feng, et al. 2016. Effects of annual continuous tillage on soil water conservation and crop yield in lime concretion black soil farmland. Sci Agric Sin. 49(16), 3239–3250.

Keller, J. and Karmeli, D. 1975. Trickle irrigation design rain bird sprinkler manufacturing crop. Glendor. Calfi., 91740, USA, 24-26.

Kiran, S. 2019. Effects of vermi-compost on some morphological, physiological and biochemical parameters of lettuce (*Lactuca sativa* var. crispa) under drought stress. Notulae Botanicae, Horti Agrobotanici, Cluj-Napoca, 47(2):352-358.

Klute, A. (ed.) 1986. Methods of Soil Analysis. Part-I: Physical and Mineralogical Methods. (2nd.). Amer. Soc. of Agronomy, Madison, Wisconsin, U.S.A.

Kumar, M., Bharose, R., Thomas, T. and Raj, N.I. 2023. Influenced of vermi-compost and bio-fertilizer on physico-chemical properties of soil under hybrid maize (*Zea may* L.). Int J Plant 35(15):336-342.

Kumar, T. and Kahlon M.S. 2022. Sensor-based irrigation scheduling, soil physical properties and wheat productivity under different organic amendments. Commun in Soil Sci. Plant Anal

Major, J., Rondon, C., Molina, D., Riha, S.J., and Lehmann, J. 2010. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. Plant Soil. 333 (1-2):117-128.

Nagaz, K., El Mokh, F., Masmoudi, M.M. and Mechlia, N.B. 2017. Soil Salinity under deficit drip irrigation of potato and millet in an arid environment. J. Agric. Environ. Int. Devel 111 (1):207-223.

Neupauer, J., Kovacik, P., Gazo, J. and Smolen, S. 2023. Effect of vermi-compost and lumbricus terrestrison soil parameters and maize growth. Fresenius Environ Bulletin. 32(02):831-840.

Ngalani, G.P., Kagho, F.D., Peguy, N.N., Prudent, P., Ondo, J.A. and Ngameni, E. 2023. Effects of coffee husk and cocoa pods biochar on the chemical properties of an acid soil from West Cameroon. Arch Agron Soil Sci. 69(5):1-15.

Niraj, K.C. and Mahat, B. 2024. A Review article on the effect of biochar on soil properties. J. Wastes Biom Manage. 6(2):77-81.

Page, A.I., Miller R.H. and Keeney, D.R. (Eds) 1982. Methods of Soil Analysis part 2: Chemical and Microbiological Properties. 2nd ed. Am. Soc. Agron. Madison, Wisconsin, U.S.A.

Park, J-H., Yun, J.-J., Kim, S.-H., Park, J.-H., Acharya, B.S., Cho J.-S. and Kang, S.-W. 2023. Biochar improves soil properties and corn productivity under drought conditions in South Korea. Springer Link, 5, article number 66.

Şahin, C.B., Akçalı, C.T. and Tiryakioğlu, M. 2024. The effect of some soil conditioners on yield and water use efficiency in soybean (*Glycine max* L.) grown under water stress conditions. Commun Soil Sci Plant Anal. 55(9).

Snedecor, G.W. and Cockran, W.G. 1980. “Statistical Methods”. (7th ed.). lowa State Univ., lowa, U.S.A.

Twum, E.K. and Nii-Annang, S. 2015. Impact of soil compaction on bulk density and root biomass of *Quercus petraea* L. At reclaimed post-lignite mining site in lusatia, Germany, Appl Environ Soil Sci. 504603

Wani, S.P., Sudi, R. and Pardhasardhi, G. 2021. Scaling-up land and cropmanagement solutions for farmers through participatory integrated demonstrations “seeing is believing” approach. Scaling-up Solutions for Farmers, Springer, Cham, pp. 149-203.

Yuan, C., Feng, S., Wang, J., Huo, Z. and Ji, Q. 2018. Effects of irrigation water salinity on soil salt content distribution, soil physical properties and water use efficiency of maize for seed production in arid Northwest China. Int J Agric Biol Eng. 11(3):137.

Yuan, C., Wang, X. and Zhou, M. 2024. Influence of deficit irrigation on soil water distribution and water use efficiency of waxy maize under rain-shelter cultivation. J Biosyst Eng. 49:52-60.

Zahra, P., Etedali, H.R. and Kaviani, A. 2021. Effects of applying biochar and straw on nitrate leaching and maize yield production. Water Environ J. 35(3):943-950.

Zhang, X., Qu, J., Li, H., La, S., Tian, Y. and Gao, L. 2020. Biochar addition combined with daily fertigation improves overall soil quality and enhances water-fertilizer productivity of cucumber in alkaline soils of a semi-arid region. Geoderma 363.