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Ameliorating Effect of Biochar on some Physical Properties of Sandy Soil and Water use Efficiency of Tomato (*Solanum lycopersicum L.*) Plant Grown under Drip Irrigation

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ABSTRACT

Field experiments were conducted in two successive seasons (2018 and 2019) to investigate the effect of biochar application rates on weight basis (0.0 % (BC_0), 0.2 % (BC_1), 0.4 % (BC_2) and 0.6 % (BC_3)) on soil some physical properties, yield productivity and water use efficiency of tomato grown in sandy soil under drip irrigation. The results indicated that the soil physical properties, yield component and water use efficiency of tomato were significantly and positively affected ($P < 0.05$) by biochar application treatments. Marked lowering in bulk density, saturated hydraulic conductivity, infiltration rate and cumulative infiltration depth of the sandy soil in both the two growing seasons as results of increasing application rate of biochar. In addition , increasing rate of biochar application resulted in significant increase of total porosity, mean weight diameter (MWD) , soil moisture constants (i.e., saturation percentage (SP), field capacity (F.C.), and wilting point (W.P.)), and soil water retention of sandy soil in both the two growing seasons. The measured available water content (AWC, %) showed a significant increase with increasing rate of biochar application which can be arranged in the order: $BC_3>BC_2>BC_1>BC_0$. The results showed that the highest yield of tomato (32.4 and 31.9 ton.fed^{-1}) was obtained due to BC_2 treatment in both seasons. The maximum values of WUE (10.7 and 10.5 kg / m^3) were associated with BC_2 treatment (0.4 wt. % biochar) in both seasons. Consequently, under sandy soil conditions, application of biochar might be a promising amendment for ameliorating soil physical properties and subsequently enhancing tomato plant productivity.

Keywords: Tomato, Sandy soil, Biochar, Soil Physical Properties, Water use efficiency

INTRODUCTION

Biochar is one of many soil amendments that can enhance soil sustainability and productivity. It is the product of pyrolysis of organic wastes in the absence of oxygen and at high temperature (Adekiya *et al.* 2019 and Lehmann and Joseph, 2009).

The decomposition of soil organic matter is too high especially under arid and semiarid conditions due to high temperature, and low precipitation. Therefore biochar provides an additional soil amendment option, where it can remain for several years in the soil (Jien and Wang, 2013). Also biochar has a good physical properties i.e. large surface area and high porosity (Kolb *et al.*, 2007). The use of biochar improves the physical, chemical, and biological properties of soil (Busscher *et al.* 2010; Sun and Lu 2014; Karhu *et al.* 2011; He *et al.* 2016)and therefor have direct effects on soil productivity for crop production (Benjamin *et al.* (2003)). Biochar has been shown to improve the physical properties of soil such as soil structure, soil aggregate stability, porosity, water-holding capacity, tensile strength , penetration resistance, soil infiltration , reduce runoff and decrease erosion (Jien and Wang 2013; Kimety and Lehmann 2010 ; Liang *et al.* 2006 ; Harvey *et al.* 2006 ; Joseph *et al.* 2010 ; Chan *et al.* 2007 and Asai *et al.* 2009) .

Recently, biochar has the potential to increase soil water holding capacities of sandy soils. But, studies of biochar impact on improving a soils saturated hydraulic conductivity have reported mixed results (Novak *et al.* 2016). The addition of biochar to sandy soils increased the available soil moisture by 18% after adding 45% of biochar by volume, while no changes were observed in loamy soil, while in clayey soil, the available soil moisture decreased with increasing coal additions. Therefore, improvements of soil water retention by biochar additions may only be expected in coarse-textured soils or soils with large amounts of macro pores (Tryon, 1948 and Arthur and Ahmed 2017).

Tomato is one of the most important vegetable crop in Egypt. It's grown all year round in Egypt. The area of cultivated tomato in Egypt is about 2400 hectares produced 10.5 million tons (2008-2009 statistics) . the estimated annual growing of tomatoes was increasing with rate of 5-7% . El-Nubaria region ranks the first in terms of production and area. The area of tomatoes accounts for 40% of the area of vegetable crops. Tomato crop is one of the crops that are consumed fresh and processed. It is also an important export crop and is being exported to European and Gulf countries.(the Egyptian Ministry of Agriculture and Land Reclamation (MALR))

Gamareldawla *et al.* (2017), found that applying biochar had significantly ($P <0.05$) increased on the height of tomato plants, number of leaves, and yield relative to the control (without biochar). Harel *et al.* (2012), reported that plant heights were significantly greater in the two biochar treatments (1 and 3%) at each measurement as compared with the control, with no difference between the two levels of biochar amendment.

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The objectives of the present work were: (1) to evaluate the effect of biochar application on soil some physical properties of sandy soil; (2) to investigate the effect of biochar amendments on yield, yield components of tomato crop and water use efficiency.

MATERIALS AND METHODS

1. Field experimental site:

Two field experiments were conducted at El-Bostan area, Aly Mubark Experimental Farm south Tahrir region (30^0 54 N, 29^0 52 E, and 25 m above sea level) during two successive seasons: 2018 and 2019, to study the effect of biochar application on soil physical properties of sandy soil and yield component of tomato (*Solanum lycopersicum L.* var.) plant grown under drip irrigation system. The physical and chemical properties of the experimental soil were analyzed according to Jackson, (1973) and Page et. al., (1982) and the results obtained are shown in Tables 1 and 2. The chemical composition of irrigation water was analyzed according to Jackson, (1973) and the results obtained are shown in Tables 3. The source of irrigation is well water. In addition , the mean monthly weather conditions at the experimental location were obtained from the following website: https://power.larc. nasa.gov/ data-access-viewer during 2018 and 2019 growth seasons and this data are shown in Table 4.

Table 1. The mean values of some physical properties of experimental soil.

Soil depth , cm	F.C. * , %	WP** , %	AW*** , %	D_b**** ,Mg/m^3	Particle size distribution,% Sand	Silt	Clay	Texture class
0-15	16.5	3.3	13.2	1.62	90.4	5.2	4.4	Sandy
15-30	14.1	2.9	11.2	1.68	91.2	5.3	3.5	Sandy
30-45	12.3	2.3	10.0	1.72	91.6	4.1	4.3	Sandy
45-60	12.0	2.2	9.8	1.74	92.1	3.6	4.3	Sandy

F.C. * = field capacity W.P. ** = wilting point A.W. *** = available water D_b**** =Bluk density

Table 2. The mean values of chemical properties of experimental soil.

Soil depth , cm	EC ,dS/m	pH	Soluble cations, meq/l Ca^{+2}	Mg^{+2}	Na^+	K^+	Soluble anions, meq/l CO_3^-	HCO_3^-	SO_4^-	CL^-
0-15	0.46	8.11	1.32	0.81	1.82	0.65	0.16	1.18	0.50	2.76
15-30	0.42	8.20	1.30	0.70	1.71	0.49	0.15	1.13	0.50	2.42
30-45	0.40	8.25	1.29	0.62	1.65	0.44	0.11	1.21	0.48	2.20
45-60	0.38	8.31	1.25	0.60	1.59	0.36	0.13	1.23	0.53	1.91

Table 3 . The mean values of chemical composition of irrigation water (well water)

EC_w dS/m	pH	Soluble cations (meq/L) Ca^{+2}	Mg^{+2}	Na^+	K^+	Soluble anions (meq/L) $CO3^-$	HCO_3^-	Cl^-	SO_4^-	SAR**
0.63	7.82	2.45	1.27	2.07	0.51	n.d.*	2.99	1.42	1.70	1.52

* n.d. : not detected SAR** : sodium adsorption ratio

Table 4. The overall mean values of monthly weather conditions at the experimental location during the two growing seasons (2017/2018 and2018/ 2019).

Months	Temperature (c^0) Maximum	Minimum	Mean	Relative humidity(%)	Precipitation (mm)	Wind speed (m/hr)	Sun shine (hr.)	ET_0, mm /day
Mar.	23.4	10.2	16.8	55.7	1.46	3.5	11.2	4.42
Apr.	28.0	13.0	20.5	47.8	2.84	3.8	12.2	4.76
May	32.0	16.4	24.2	45.6	0.0	4.0	12.6	5.67
June	35.1	19.4	27.3	46.4	0.0	4.2	13.2	6.25
July	36.4	21.2	28.8	49.2	0.0	4.0	13.4	6.50
Aug.	36.4	21.9	29.1	51.6	0.0	3.9	12.7	6.19
Sep.	34.2	20.9	27.5	53.7	0.0	3.9	12.2	5.52

2. Preparation of Biochar:

The used biochar in this experiment was made of corn cob (as a feed stock) which was produced using pyrolysis treatment at a final temperature of 450 C^0 with a retention time of 2 hours. The biochar was ground and sieved (< 0.5 mm), prior to use and subjected to characteristics analysis. Some physical and chemical properties of this biochar are shown in Table 5. The amounts of biochar required for the experimental treatment was distributed and mixed during the preparation of the soil during the month of February.

3. Tomato cultivation:

Seeds of "super strain B" tomato cultivar were obtained by the Egyptian Agricultural Ministry. The seeds were sown in nursery on first of February every season. The transplants were set on one side of the ridges between the furrows with 1 meter width and 5m long, with 30 cm between transplants. Each experimental unit consisted of 4 furrows as the plot area was 20 m^2. The recommended agricultural practices for growing tomato in El-Nubaria region were applied. Super phosphate fertilizer (15.5 % P_2O_5) at a rate of 200 kg. Fed^{-1}, ammonium sulfate fertilizer (20 % N) at a rate of 200 kg. Fed^{-1} and potassium sulfate fertilizer (48.52 % K_2O) at a rate of 100 kg. Fed^{-1} were applied in equal dose during the growing season.

Table 5. The main different physicochemical properties of the used biochar.

SSA m^2/g	Density ,Mg/m^3	O.C, %	pH	N, %	P, %	K^+, Cmol.kg^{-1}	CEC, Cmol.kg^{-1}	C/N
8.47	0.23	68.3	7.0	0.93	0.5	36.5	128.4	73.4

SSA: Specific surface area ($m^2.g^{-1}$) O.C: Organic carbon (%)

4. Experimental Layout:

The experiment was laid out in a randomized complete block design using four applications. The rates of biochar (0, 0.2, 0.4 and 0.6 % wt./wt.) were applied with three replicates as shown in Table 6.

Table 6. Summary of the experimental treatments.

T_0	BC_0	0 % biochar (control)
T_1	BC_1	0.2 wt % biochar
T_2	BC_2	0.4 wt % biochar
T_3	BC_3	0.6wt % biochar

BC : Biochar made of Corn cob

The drip irrigation system, used in this farm included, an irrigation pump connected to sand and screen filters, and a hydraulic fertilizer injection pump. The main line is made of a PVC pipe of 63 mm diameter. Laterals of 16 mm diameter are connected to sub main line. Each later is 50 m long with standard drippers of 4 l/h discharge rate, spaced at 0.5m apart. One lateral served each row of tomato plant.

Applied irrigation water (AIW):

The amount of water applied per each irrigation (Table 7) was calculated according to the following equation under drip irrigation system (Vermeiren and Jopling, 1984):

$$AIW = \frac{ET0 \times Kc \times Kr}{Ea} + LR \qquad (1)$$

Where:

AIW = Applied irrigation water depth (mm).
ET_0 = Reference crop evapotranspiration (mm/day) was estimated using CROPWAT model (Smith, 1991).
K_c = Crop coefficient.
K_r = Reduction factor that depends on ground cover. It equals 0.7 for mature plants.
E_a = Irrigation efficiency (%) = 0.85 (Ismail, 2002).
LR = Leaching requirements = 10 % of the total amount of applied irrigation water.

Table 7. Mean of applied water (m^3 /one irrigation), number of irrigation for tomato plants during the two growing seasons in sandy soil.

Month	ET_0, mm/day	Monthly ET_0, mm	No. of Irrigation	Applied water, m^3/one irrigation
Apr.	4.76	142.8	15	32
May	5.67	175.8	16	36
June	6.25	187.5	15	42
July	6.50	201.5	16	42
Aug.	6.19	191.9	16	42
∑		899.5	75	3026.4

5. Water use efficiency (WUE) :

It was calculated according to the following equation according to (Vites, 1962 and Stanhill, 1986).

$$\mathrm{WUE} = \frac{Ya}{AIW} \qquad (2)$$

Where:

WUE is the water use efficiency (kg/m^3).
Y_a is the actual yield (kg/ fed.)
AIW is the amount of applied irrigation water (m^3/fed)

6. Determination of physical properties

Bulk density*:* Soil bulk density is mass of dry soil per unit of bulk volume and it was determined in situ using a sharp-edged cylindrical soil sampler, 10-cm long with an inside diameter of 4.7 cm (Black, 1965).

Total porosity (E_a) was extrapolated from the bulk density using relationship described by Hillel (2004) as follows :

$$E_a = 1 - \frac{Db}{Ds} \qquad (3)$$

Where:

E_a : the soil total porosity,
D_b : the soil bulk density and
D_s: the soil particle density assumed to be 2.65 Mg/m^3.

7. Saturated hydraulic conductivity coefficient (Ks)

It was determined for each tested soil samples under a constant water head and calculated by Darcy law (Klute , 1986) as follows:

$$K_s = \frac{QZ}{Ath} \qquad (4)$$

Where:

K_s = Hydraulic conductivity coefficient (cm/h);
Q= Volume of water (cm^3);
Z= Gravitational head (cm) =length of soil column (cm);
A= Cross sectional area of sample (cm^2);
T= time (hour); and h= hydraulic head (cm)

Infiltration rate:

It was determined by using double ring cylinder at each treatment by applying 15 cm depth of water in the field, then, the infiltration time was recorded for each plot and after that, the average of these values was calculated for each treatment.

Cumulative infiltration (I) was calculated using the Kostiakov infiltration equation as follows:

$$I = KT^n \qquad (5)$$

Where:

T is the time elapsed for the experiment. I is the Cumulative infiltration. K, and n are empirical constants that are site specific and depend on soil conditions such as soil texture, moisture content, bulk density and other soil properties

Soil aggregate stability (Mean weight diameter (MWD))

Aggregate stability is critical for infiltration, root growth, and resistance to water and wind erosion. Aggregate stability is an indicator of organic matter content, biological activity, and nutrient cycling in soil. Soil aggregate stability was determined using wet sieving with vertical oscillation (30 oscillations per minutes), according to the method described by (van Bavel, 1953). Mean weight diameter (MWD) was calculated by the formula as follows:

$$\mathrm{MWD} = \sum_{i=1}^{n} x_i w_i$$

Where i x is the mean diameter of any particular size range of aggregates separated by sieving, and wi is the weight of aggregates in that size range as a fraction of the total dry weight of soil used.

Moisture Constants and Soil Moisture Characteristic Curve

Saturation percentage (SP) was determined according to American Society for Testing and Materials (ASTM) standards (1992), (ASTM, D 2325-68, and ASTM, D 3152-72). Field capacity (FC) and wilting point (WP) were determined from the soil moisture-retention curve. Soil moisture- retention curve was determined by the method outlined by ASTM (1992) and Soil Moisture Equipment Crop (SMEC, 1993) The apparatus models used were Model No. 1000, pressure membrane extractor, Model No. 1500 GI, 15-bar pressure plate extractor with cells, and Model No. 1600 GI, 5-bar extractor with cells.

7. Growth Parameters and Yield.

Plant growth and yield characters were evaluated in-situ from five randomly selected plants through the measurement of the following observations:

Plant height (cm): It was measured from the soil surface to the tip of the main stem;

Stem girth (cm): It was measured using a Vernier-caliber at third node;

Leaf area index ($cm^2.cm^{-2}$): It was calculated according to Breda (2003);

The average fruit weight (g), Total yield .plant^{-1} (kg) and Fruit yield. Fed^{-1}: were calculated for over all plants in the plot.

Statistical analysis:

The obtained data were statistically analyzed and separated as well as combined analysis variances were carried out. Comparisons among means were done according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

1. Effect of Biochar rates on Soil Physical Properties:

Bulk density (D_b)

It is clear from Table 8 that soil bulk density (D_b) decreased significantly ($p < 0.05$) with increasing rate of biochar application ,i.e, biochar rates decreased the D_b from 1.58 $Mg.m^{-3}$ in the control soil(BC_0) to 1.42 ,1.26 and 1.11$Mg.m^{-3}$ in the soil treated with 0.2% (BC_1), 0.4% (BC_2) and 0.6% (BC_3) on weight basis, respectively. The lowest D_b value was observed due to 0.6 % (BC_3) treatment compared to the other treatments. Fig.1 shows results of regression of the bulk density ($Mg.m^{-3}$) against percent biochar applied. It is clear that, for all treatments of biochar application, the D_b strongly fit a linear equation of the form:

$$y = -0.157\,x + 1.735 \qquad R^2=0.9998 \qquad (7)$$

Where, y is D_b ($Mg.m^{-3}$) and x is application biochar rate (%) with markedly high determination coefficients approaching nearly 1.0 (0.9998). Głąb *et al.* (2016) and Liu *et al.* (2016a) showed that, as the amount of biochar is increased, bulk density decreased linearly .Also, many researchers reported that, application of biochar can decrease the bulk density of soils (Abel *et al.* 2013; Githinji 2014; Herath *et al.* 2013; Jien and Wang 2013; Oguntunde *et al.* 2008; Lei and Zhang 2013; Ayodele *et al.* 2009; Busscher *et al.* 2011; Novak *et al.* 2012).

Table 8. Mean values of bulk density (D_b) , total porosity (E_a), mean weight diameter of soil aggregates (MWD) and saturated hydraulic conductivity (K_s) expressed for the two growing seasons .

Treatments	Rate of biochar , (w/w) %	D_b , $Mg.m^{-3}$	E_a ,%	MWD , mm	K_s ,$cm.h^{-1}$
BC_0	0.0	1.58 a	40.38 d	1.375 c	0.644 a
BC_1	0.2	1.42 b	46.42 c	1.540 b	0.594 b
BC_2	0.4	1.26 c	52.45 b	1.678 b	0.554 b
BC_3	0.6	1.11 d	58.11 a	1.856 a	0.495 c
$LSD_{0.05}$		0.06	5.20	0.151	0.043

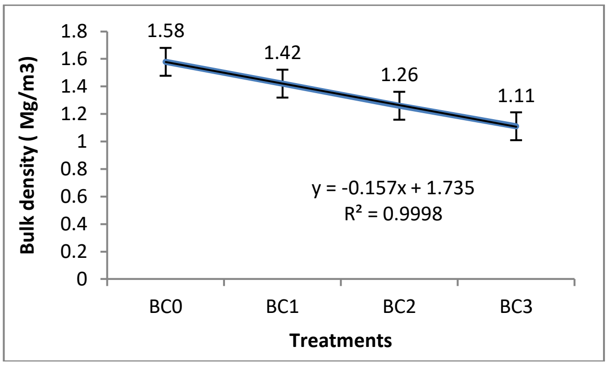

Fig. 1. Effect of biochar rates on the means of bulk density ($Mg.m^{-3}$) for the two growing seasons.

Total porosity (Ea)

Decreasing in soil bulk density as the result of biochar application to sandy soil affected its total porosity . The application of biochar showed a significant ($P < 0.05$) change in total porosity (E_a) among due to the different rates of application treatments (Table 8). The results of E_a were 46.42, 52.45 and 58.11 % for BC_1, BC_2 and BC_3 respectively, compared to BC_0 treatment as the control (40.38 %). The biochar applications performed as follow, regarding total porosity: 0.2%, 0.4% and 0.6 % (wt. /wt.) led to a +14.96%, +29.89% and + 43.90% effects, all measured relative to BC_0 treatment (the control), respectively. Soil porosity increased linearly with an increase in biochar application (Fig.2). The regression equation for total porosity as a function of biochar application rate was determined as shown in the following equation:

$$y = 5.922\,x + 34.535 \qquad R^2 = 0.9998 \qquad (8)$$

Where, y is E_a (%) and x is application biochar rate (%) with markedly high determination coefficients approaching nearly one. Reduced bulk density and higher porosity of soil treated with biochar is mainly due to the lower density of biochar compared to the bulk density of the soil. Herth *et al.* (2013) noticed that, the total porosity of soil increased by application of biochar but this increase in porosity was depend on type of biochar used and soil type where biochar was applied. Mukherjee *et al.* (2013) showed that, this increase in soil porosity was due to high porous nature of biochar. The findings of recent studies agree with that reviewed by Omondi *et al.* (2016), who reported that biochar addition increased soil porosity by 8.4%.

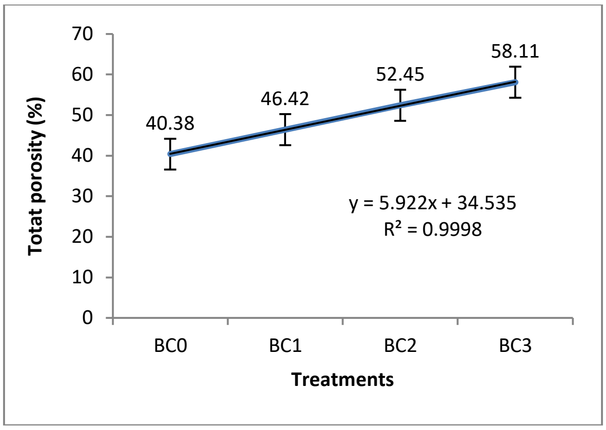

Fig. 2. Effect of biochar rates on the means of total porosity (%)for the two growing seasons .

Mean weight diameter (MWD)

Table 8 showed that, the mean weight diameter (MWD) increased significantly in biochar-treated soil compared with the control (BC_0). Biochar application rates increased the MWD from 1.375 mm in the control soil to 1.540, 1.678 and 1.856 mm in the soil treated with 0.2%, 0.4% and 0.6 % (wt. /wt.) rates of the corn cob biochar, respectively. The highest value of MWD was observed due to 6.0 wt. % (BC_3) treatment compared to the other treatments. Fig.3 shows the results of regression of the mean weight diameter against percent biochar added. It is noticeable that, for all treatments of application biochar, the MWD strongly fits linear equation of the form:

$$y = 0.1581x + 1.217 \qquad R^2 = 0.9979 \qquad (9)$$

Where, y is MWD (mm) and x is application biochar rate (%).

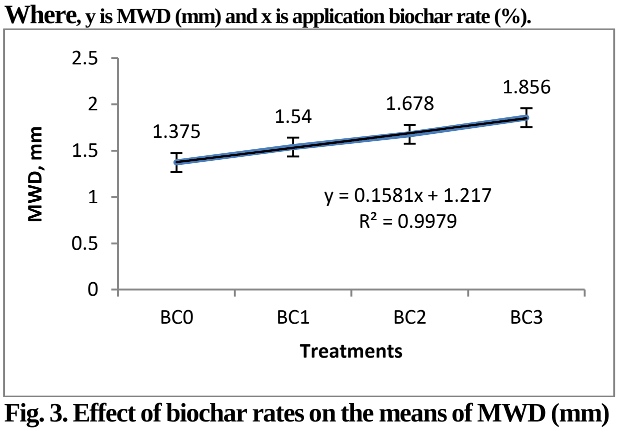

Fig. 3. Effect of biochar rates on the means of MWD (mm) for the two growing seasons.

MWD indicates prevalence of larger and more stable aggregates and therefore is an index of soil aggregate stability and quality (Amezketa, 1999; Arshad and Coen, 1992). The increased MWD for soils treated with biochar could be due to increase in binding organic substances from the biochar, thereby improving the aggregate cohesion among the soil particles (Aggelides and Londra, 2000; Dexter *et al*., 2008). Biochar has been shown to improve soil structure, soil aggregate stability and porosity (Kimetu and Lehmann, 2010. Jien and Wang, 2013 and Liang *et al*. 2006).

Saturated hydraulic conductivity (Ks)

Saturated hydraulic conductivity was significantly affected by biochar treatments (Table 8). It decreased from 0.644 to 0.594, 0.554 and 0.495 cm. h^{-1} as a result of treatment by 0% (control), 0.2%, 0.4% and 0.6 % , respectively. The lowest K_s were recorded with BC_3 treatment compared to the other treatments. Reynods el al. (2000) reported that, K_s is an important soil property for many engineering, agronomic and environmental activities . For example, it is being essential in water solute transport and crop growth models. One of the most important disadvantages of sandy soils is the loss of water at a high speed due to its high saturated hydraulic conductivity (K_s) value. The results obtained (Table 8) showed that, the value of K_s decreased by a percentage ranging from 7.8% to 23.1% as the result of increased additions of biochar. A resulting decrease of hydraulic conductivity is of main importance especially in sandy soils. . The linear function was obtained as a relationship between hydraulic conductivity and biochar application rates and represented by the following:

$$y = -0.0487x + 0.6935 \quad R^2 = 0.9948 \qquad (10)$$

Where, y is K_s (cm.h^{-1}) and x is biochar application rate (%) with markedly high determination coefficients approaching nearly one. Barnes *et al.* (2014) and Liu *et al.* (2016) showed that, biochar application to sandy soil increased the tortuosity of the porous media and reduced interpore size and pore throat size, which resulted in a decrease in saturated hydraulic conductivity.

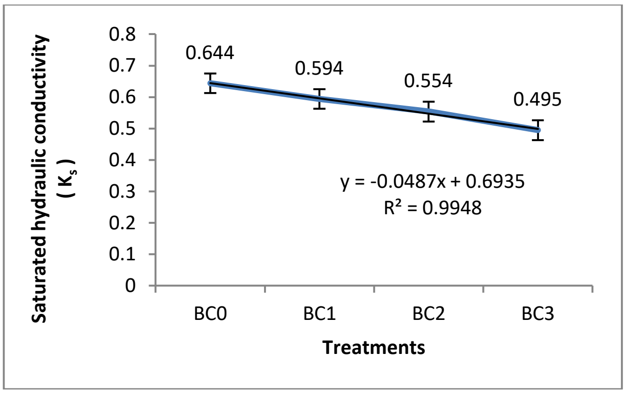

Fig. 4. Effect of biochar rates on mean values of Saturated hydraulic conductivity (K_s cm.h^{-1}) for the two growing seasons.

Infiltration Rate (IR)

Infiltration is a measure of the amount of water that penetrates the ground surface and is an important process that determines how much water gets to plant roots as well and how much runoff takes place. The results on infiltration rate followed a similar trend to that of saturated hydraulic conductivity. Table 9 showed that infiltration rates (IR) were significantly affected by biochar application and were at the highest values at the beginning of the experiments, then decreased steadily at different rates. Basic infiltration rates occurred between 150 mins and 180 mins. The recorded means of the basic infiltration rates (IR) were 3.6, 3.1, 2.4 and 2.0 cm.h^{-1} for BC_0, BC_1, BC_2 and BC_3 treatments, respectively for the tow growing seasons (Table 9 and Fig. 5). The results of infiltration rate revealed a decreasing trend with increasing rate of biochar application. The lowest value of the basic infiltration rates (IR) was observed due to BC_3 treatment (0.6 wt. % biochar) with decrease ratio of (IR) to be 44.4 % followed by 33.3% and 13.9% for BC_1 and BC_2 treatments, respectively compared to the control (BC_0).

The observed improving in the physical properties of in sandy soil such as decreasing of hydraulic conductivity (K_s) and infiltration rate (IR) due to biochar application may have been associated with the influence of soil organic matter (SOM) (Mukherjee and Lal, 2014).The improvements of IR due to biochar application reduced macro pore size and aggregation formation,, which resulted in a decrease in infiltration rate (Uzoma *et al*., 2011 and Ouyang *et al*., 2013).

Table 9. Effect of biochar rate on the mean values of infiltration rate (IR, cm.h^{-1}) for two growing seasons 2018 and 2019.

Time (min.)	Treatments BC_0	BC_1	BC_2	BC_3
5	24.0	20.4	18.4	14.4
10	16.0	13.6	11.2	9.6
15	13.6	11.6	9.5	8.2
20	12.0	10.2	8.4	7.2
25	11.9	10.1	8.3	7.0
30	10.4	8.8	7.3	6.2
40	8.6	7.3	6.0	5.2
50	7.6	6.5	5.3	4.6
60	6.8	5.8	4.8	4.1
75	6.1	5.1	4.3	3.7
90	5.5	4.7	3.9	3.3
120	4.0	3.4	2.8	2.4
150	3.6	3.1	2.5	2.0
180	3.6	3.1	2.4	2.0

BC_0= 0% (wt.) biochar BC_1 =0.2% (wt.) biochar
BC_2 =0.4% (wt.) biochar BC_3=0.6% (wt.) biochar

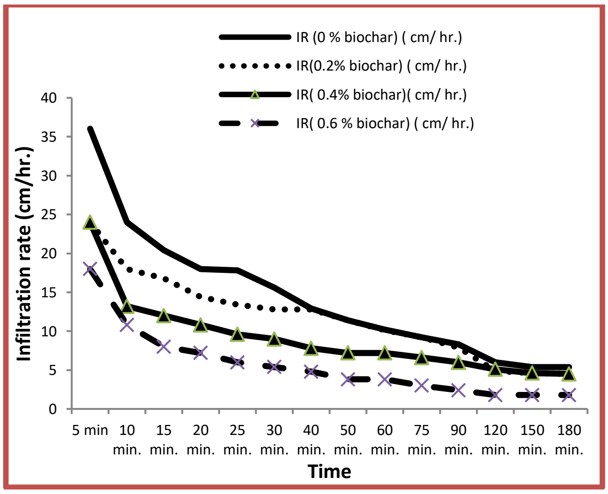

Fig. 5. Effect of biochar rates on the mean values of infiltration rate (cm.h^{-1}) for the two growing seasons 2018 and 2019.

1.6. Cumulative infiltration depth

Biochar treatments significantly affected cumulative infiltration depth (Cum.Inf.) as compared to the control (BC_0). The decrease of cumulative infiltration depth varied from 20.4 cm for the control treatment (BC_0) to 12.2 cm for BC_3 treatment (Table 10 and Fig.6). The recorded means of cumulative infiltration depth were 20.4, 17.8, 14.4 and 12.2 cm for BC_0, BC_1, BC_2 and BC_3 treatments, respectively for the two growing seasons. The results of cumulative infiltration depth revealed a decreasing trend with increasing rate of biochar application (Fig.6). The lowest value of Cum.Inf. depth was observed in BC_3 treatment (0.6wt. % biochar) with decrease the ratio of (IR) to be 40.2 % followed by 29.4% and 12.7 for BC_1 and BC_2 treatments, respectively compared to the control (BC_0). Blanco-Canqui (2017) reported that biochar application to sandy soil resulted in a decrease in the infiltration rate and cumulative infiltration due to the improvement of the bonding of sand particles with the increase of SOM, increasing soil cohesiveness and adsorbing water. Also, some unstable biochar particles may rapidly disintegrate, cement, and clog the soil macropores, reducing the infiltration rate within the soil and the cumulative infiltration depth.

Table 10. Effect of biochar rate on mean values of cumulative infiltration depth (cm) for two growing seasons 2018 and 2019.

Time (min.)	Treatments			
	BC_0	BC_1	BC_2	BC_3
5	2.0	1.7	1.5	1.2
10	3.3	2.8	2.4	2.0
15	4.4	3.9	3.2	2.7
20	5.4	4.8	3.9	3.3
25	6.4	5.6	4.6	3.9
30	8.1	7.1	5.8	4.9
40	9.5	8.3	6.8	5.8
50	10.8	9.4	7.6	6.6
60	11.9	10.4	8.4	7.3
75	13.4	11.7	9.5	8.2
90	14.8	12.9	10.5	9.0
120	16.8	14.6	11.9	10.2
150	18.6	16.2	13.2	11.2
180	20.4	17.8	14.4	12.2

BC_0= 0% (wt.) biochar BC_1 =0.2% (wt.) biochar
BC_2 =0.4% (wt.) biochar BC_3=0.6% (wt.) biochar

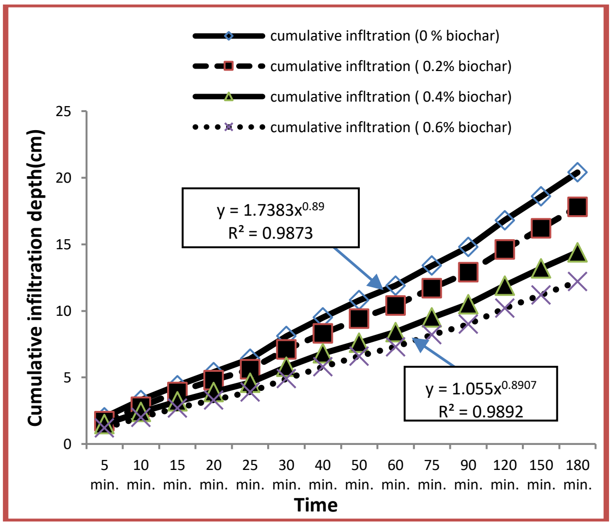

Fig. 6. Effect of biochar rates on themean values of cumulative infiltration (cm) for the two growing seasons 2018 and 2019.

Moisture Constants and Soil Moisture Characteristic Curve

The soil water retention characteristics as influenced by biochar application rate are shown in Table 11 and Fig 7. The results showed that values of moisture percentage, θ_V % (volume basis) were increased with increasing application rate of biochar which can be arranged in the order : BC_3>BC_2>BC_1>BC_0 (Table 11 and Fig 7). Less water was retained in BC_0 treatment than in the other treatments .The moisture percentages (volume basis) at saturation (SP), field capacity (F.C.) and wilting point (W.P.) of the soil treated with biochar rate can be calculated by the data shown in fig 7,which values of moisture content (θ_V %) corresponding to tension 0, -0.1 and -15 bar , respectively. The results showed that the highest mean values of S.P., F.C. and W.P (62.1 , 48.6 and 8.7 %, respectively) were recorded due to BC_3 treatment, while the lowest mean values (33.2 , 17.2 and 2.6 %) were recorded due to BC_0 treatment (the control). The BC_3 treatment has the highest water content at FC (48.6%) followed by BC_2 treatment (42.5%) as compared with BC_0 treatment (17.2%). It is clear, therefore , that application increased water contents of sandy soil at saturation, field capacity, and wilting point and these characteristic of water contents were increased with the increase in biochar application rate .Similar results have been reported Blanco-Canqui(2017) and Zhou *et al.*(2019). Brandstaka *et al.* (2010) reported that, higher soil moisture content in plots treated by 15 tons ha^{-1} of biochar as compared with the control. Rawls *et al.* (2003) pointed that soil water retention was increased with increasing SOM which is in agreement with the results obtained in this study.

The mean values of degree of saturation (D.S., %) as influenced by biochar application rate are shown in Fig 8.The degree of saturation had the same trend of the soil water retention characteristics curve which were increased with increasing application rate of biochar but values of D.S. due to BC_2 treatment (0.4 wt. % biochar) were higher than the other treatments which can be arranged as follows: BC_2> BC_3> BC_1>BC_0 (Fig 8).

Table 11. Mean values of soil moisture – tension data for the application rate of biochar during the two growing seasons 2018 and 2019.

Tension	Treatments											
	0 % Biochar			0.2 % Biochar			0.4 % Biochar			0.6 % Biochar		
	θ_v, %	D.S. ,%	AW.,%	θ_v, %	D.S. ,%	AW., %	θ_v, %	D.S. ,%	AW., %	θ_w, %	D.S. ,%	AW., %
0.0	33.2	100		42.1	100		52.3	100		62.1	100	
0.103	17.2	51.8		31.1	73.9		42.5	81.3		48.6	78.3	
0.310	14.7	44.3		26.4	62.7		34.1	65.2		40.3	64.9	
0.517	11.8	35.5		21.5	51.1		30.4	58.1		33.4	53.8	
0.826	10.2	30.7		18.3	43.5		24.4	46.7		28.2	45.1	
1.033	9.2	27.7	14.6	15.2	36.1	26.2	20.3	38.8	34.4	21.9	35.3	39.9
3.099	6.8	20.5		12.5	29.7		15.4	29.4		20.1	32.3	
5.165	5.5	16.6		11.0	26.1		13.8	26.4		16.8	27.1	
8.264	3.8	11.4		7.4	17.6		11.9	22.8		12.5	20.1	
10.330	3.1	9.3		6.5	15.4		8.8	16.8		11.1	17.9	
15.495	2.6	7.8		4.9	11.6		8.4	16.1		8.7	14.0	

The available water content (AWC, %) was calculated as the difference between θ_V at −0.1 and −15 bar for every treatment (Fig 7). The results showed that AWC revealed increasing trend with increasing rate of biochar application (Fig.9). as biochar application rates increased the mean value of AWC has increased from 16.4% in BC_0 treatment to 26.2, 34.4 and 39.9 % in the soil treated with 0.2, 0.4 and 0.6 wt. % biochar treatments, respectively. Regarding AWC biochar applications performence led to a +59.8%, +109.8% and + 143.3% due to 0.2%, 0.4% and 0.6 wt. % biochar against BC_0 treatment (the control), respectively. The effect of adding biochar to soil is boosting the ability of the soil to retain water, and hence increasing its content of available water. Therefore, the effect appeared more pronounced for BC_3 treatment (0.6 wt. % biochar) when compared to the other treatments. A higher

AWC due to BC_3 and BC_2 treatments can be ascribed to high SOM and favorable structural properties (Uzoma *et al*., 2011)

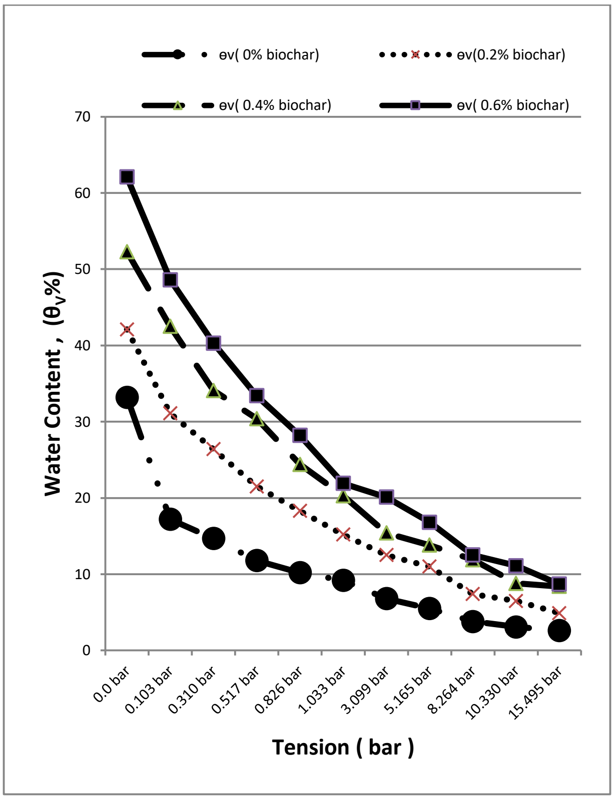

Fig. 7. Effect of biochar rate on mean values of soil moisture characteristic curve for the two growing seasons 2018 and 2019.

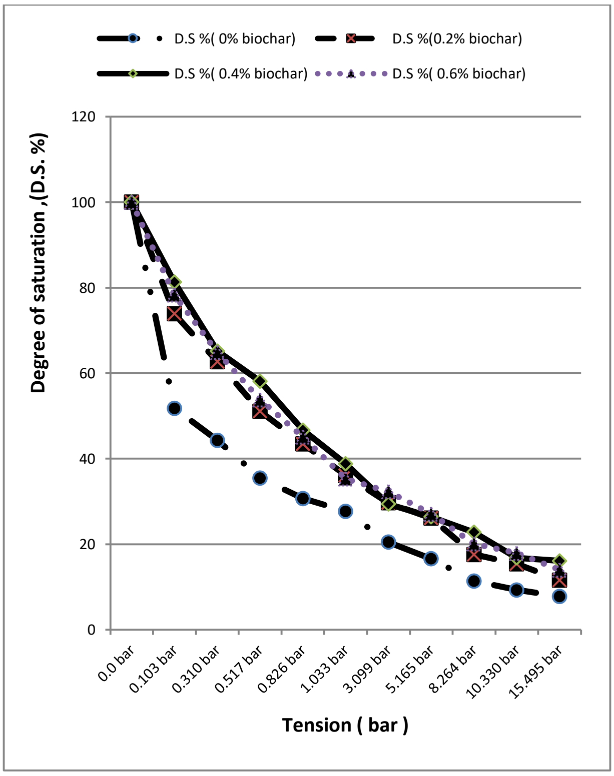

Fig. 8. Effect of biochar rate on the mean values of degree of saturation (D.S., %) for the two growing seasons 2018 and 2019.

It has been reported that the increase of moisture limits might be mainly attributed to the increase of fine pores between particles of soil and the porosity of the biochar, and the increase in soil water retention might be highly related to the strong water binding capacity of the biochar (Zhang *et al*., 2016; Zhang and You ,2013). A lot of research has confirmed that, using of biochar as an amendment to improve the soil physical properties, especially its ability to retain water, is due to the increase in soil porosity as well as the increase in the inner surface area (Hina *et al*., 2010; Liang *et al*., 2006; Kishimoto and Sugiura, 1985; Van Zwieten *et al*., 2009).

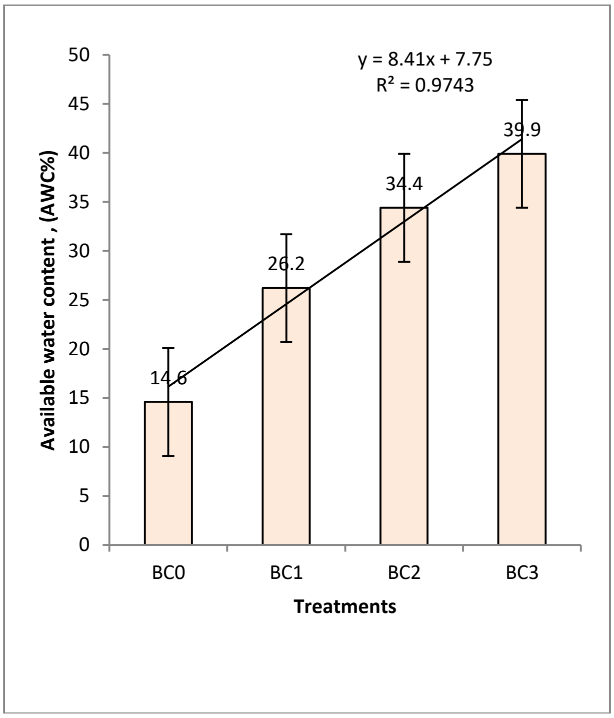

Fig. 9. Effect of biochar rate on the mean values of available water content (AWC, %) for the two growing seasons 2018 and 2019.

2.Growth Parameters and Yield Components

Table 12 indicated that biochar application significantly affected all growth parameters of tomato plants during the two growing seasons. The mean values of the highest significant values were obtained as a result of BC_2 treatment (0.4 wt. % biochar) followed by BC_3 treatment (0.6 wt. % biochar) with non-significant differences between both. However, the lowest values were obtained as result of BC_0 treatment (the control).

The mean values of plant height of tomato were 58.3 , 72.1 , 100.7 and 94.3cm as result of the treatments : BC_0,BC_1,BC_2 and BC_3 ,respectively for the first growing season (2018) and were 62.6 , 74.8 , 102.3 and 95.2 cm as result of the treatments : BC_0,BC_1,BC_2 and BC_3 ,respectively for the second growing season (2019) .

The mean values of stem girth (Table 12) were 2.8,3.5,4.6 and 4.1cm as result of the treatments : BC_0,BC_1,BC_2 and BC_3 ,respectively for the first growing season (2018) and 3.1,3.8,5.2 and 4.3cm for the same treatments, respectively for the second growing season (2019) .

The highest values of leaf area index (5.71 and 5.85 $m^2.m^{-2}$) were obtained due to BC_2 treatment in the two growing seasons, respectively. On other hand, the lowest values of leaf area index (3.32 and 3.35 $m^2.m^{-2}$) were recorded due to D_3B_1 treatment in the two growing seasons, respectively.

Table 12. Mean values of growth parameters, yield components of tomato plant and water use efficiency due to application rate of biochar during the two growing seasons 2018 and 2019.

Treatments	Height plant, cm	Stem girth, cm	Leaf area index, $m^2.m^{-2}$	Average fruit weight, gm.	Total yield/ plant kg	Yield, ($Ton.fed^{-1}$)	Water Use Efficiency, $Kg.m^{-3}$
2018							
BC_0	58.3	2.8	3.32	62.0	1.62	19.8	6.5
BC_1	72.1	3.5	4.41	88.1	2.25	22.4	7.4
BC_2	100.7	4.6	5.71	111.8	3.26	32.4	10.7
BC_3	94.3	4.1	4.86	97.6	2.82	28.6	9.5
$LSD_{0.05}$	18.1	0.8	0.99	18.8	0.68	4.1	1.9
2019							
BC_0	62.6 b	3.1	3.35	65.4	1.74	19.8	6.5
BC_1	74.8 b	3.8	4.38	86.1	2.13	23.1	7.6
BC_2	102.3 a	5.2	5.85	110.6	3.22	31.9	10.5
BC_3	95.2 a	4.3	4.93	98.2	2.91	29.4	9.7
$LSD_{0.05}$	17.8	0.8	0.95	17.5	0.64	4.3	1.8

Table 12 showed that biochar application significantly increased yield components i.e., average fruit weight (gm) and total yield / plant and yield ($ton.fed^{-1}$). It is clear that BC_2 and BC_3 treatments recorded the highest average fruit weight, total yield / plant and yield ($ton.fed^{-1}$) compare to the control treatment (BC_0). The highest fruit tomato yield was obtained as a result of BC_2treatment (0.4 wt. % biochar), which recorded32.4 and 31.9 $ton.fed^{-1}$, respectively for the two growing season 2018 and 2019. The lowest tomato yield was obtained as a result of BC_0 treatment (without biochar), which recorded 19.8 $ton.fed^{-1}$ for both the two growing seasons. The obtained results are in agreement with those obtained by Gamareldawla *et al*. (2017) and Harel *et al*.(2012) .

3. Water Use Efficiency (WUE):

Table 7 showed that the values of reference or potential evapotranspiration (ET_0 or ET_p) are affected by the climatic factors, with increased ET_0 in July (6.5 $mm.day^{-1}$). The number of irrigations during a single growing season was approximately 75 times, and the number of irrigations per month ranged between 15-16 times (Table 7). The mean value of applied water for tomato plant recorded 32 to 42 m^3 for every one irrigation. Total applied water for tomato plants recorded 3026 m^3 per every growing season (Table 7).

Tables 12 showed that the values of water use efficiency (WUE) were significantly affected by rate of biochar application. The maximum values of WUE were 10.7 and 10.5 kg tomato / m^3 applied irrigation water, in the first and second growing seasons, respectively, and were obtained as a result of BC2 treatment (0.4 wt. % biochar). The lowest value of WUE was (6.5 kg tomato /m^3) in 2018 and 2019 growing seasons which was obtained by the BC_0 treatment (control treatment).

CONCLUSION

Sandy soils are characterized by low water holding capacity, high infiltration rate and consequently low available water content . This is attributed to high percentage of sand fraction and extremely low organic matter content .Application of biochar as a source of organic carbon and high Cation exchange capacity can improve the physical properties of sandy soil. Biochar application at a rate 0.4 or 0.6 wt. % significantly improved total porosity , mean weight diameter , saturation percentage , field capacity and soil water retention of sandy soil as compared to the biochar untreated soil. As a result , the tomato yield significantly increased due to treatment by 0.4 or 0.6 wt. % biochar . This is also was recorded for water use efficiency by tomato plant. This study indicates that biochar application to sandy soil is a valuable amendment for ameliorating and enhancing plant productivity grown in sandy soil.

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التأثير المحسن للفحم الحيوي على بعض الخواص الفيزيائية للتربة الرملية وكفاءة استخدام المياه لمحصول الطماطم المنزرع تحت الري بالتنقيط

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إجريت تجارب حقلية لموسمين زراعيين متتاليين بهدف دراسة تاثير معدلات مختلفة من البيوتشار(0.0 %, 0.2 % , 0.4 % , 0.6 %) على أساس الوزن للفدان على كلا من خواص التربة الفيزيائية و إنتاجية المحصول وكفاءة إستخدام المياة لمحصول الطماطم المنزرع فى التربة الرملية تحت نظام الرى بالتنقيط. أوضحت النتائج تأثر كلا من خواص التربة الفيزيائية و إنتاجية المحصول وكفاءة إستخدام المياة تاثيرا معنويا نتيجة معدلات البيوتشار المختلفة . وجد إنخفاض ملحوظ فى قيم كلا من الكثافة الظاهرية والتوصيل الهيدروليكى المشبع ومعدل التسرب وكذلك عمق التسرب التجميعى نتيجة الاضافات المتزايدة من البيوتشار. على الجانب الأخر فإن زيادة الأضافات من البيوتشار أدى إلى زيادة معنوية فى كلا من المسامية الكلية ومتوسط القطر الموزون والمحتوى الرطوبى للتربة عند التشبع والسعة الحقلية ونقطة الذبول المستديم وكذلك قدرة التربة الرملية على الأحتفاظ بالماء للتربة فى كلا موسمى النمو . أوضحت النتائج زيادة الماء المتاح فى التربة نتيجة الاضافات المتزايدة من البيوتشار و يمكن ترتيب المعاملات ترتيبا تنازليا حسب كمية الماء المتاح كالتالى : 0.6 % >0.4 %>0.2 %>0.0 % (بيوتشار على أساس الوزن). كان أقصى محصول طماطم عند تطبيق معاملة 0.4 % على أساس الوزن بيوتشار حيث سجلت 32.4 و 31.5 طن / فدان خلال موسمى النمو (2018) و (2019) على الترتيب. أرتبطت القيم القصوى لكفاءة إستخدام المياة لمحصول الطماطم بالمعاملة 0.4 % على أساس الوزن بيوتشار حيث سجلت 10.5 و 10.7 كجم / م^3 خلال موسمى النمو. وبالتالى , فأنة فى ظل خصائص التربة الرملية قد يكون إضافة البيوتشار حلا واعدا لتحسين خصائص التربة وبالتالى تعزيز إنتاجية النبات .