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Addition biochar to enhanced soil quality and sugar beet crop grown under water stress treatments in salt-affected soils

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Abstract

Biochar amendment as agro-management technique could play an important role in growing crops for high profit, enhancing the availability of water and nutrients in the root zone environment, and maintaining soil fertility. The present study aims to evaluate the benefit effects of biochar applications on some soil properties and in mitigating the adverse effects induced by drought on sugar beet plants grown in salt-affected soils. Therefore, field experiment was carried out in Demo farm, Faculty of Agriculture, Fayoum University, Fayoum, Egypt. Three deficit irrigation regimes (i.e. I_{100}= 100%, I_{80}= 80% and I_{60}= 60% of crop evapotranspiration (ETc) and three application rates of biochar (i.e. B_0 = zero addition (control), B_{10} =10 (t ha^{-1}) and B_{20} = 20 (t ha^{-1}) were applied. The experimental treatments were arranged in a complete randomized block design split-split plot with three replicates. Sugar beet seeds (*Beta vulgaris L.*, Baraca) was planted in two successive winter seasons along two years (2019/2020 and 2020/2021) in salt affected soils (E_{Ce} =10.94 dS/m). The obtained results revealed that biochar amendment improved soil moisture retention characteristics. Biochar addition by 20 t ha^{-1} caused significant reduction in soil bulk density, hydraulic conductivity, soil EC_e by 2.94, 16.04 and 12.49 % respectively. Meanwhile under high level of biochar addition 20 (t ha^{-1}), field capacity (FC), available water content (AW), cation exchangeable capacity and organic matter content were significantly increased by 18.03, 31.10and 11.76% respectively compared with control. In addition sugar beet growth parameters (root length, root diameter, leaves number, leaves area and dry matter) and physiological attributes (relative water content, membrane stability index and SPAD) were significantly affected by the applied deficit water regimes and biochar application levels.

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However, sugar roots yield (t ha^{-1}) and biomass yield (t ha^{-1}) were reduced by 11.67 and 15.01% at (I_{80}) and by 33.78 and 33.22% at (I_{60}), respectively, compared with full irrigation treatment. However, harvest index (HI) and water productivity (WP) recorded their maximum values 0.68 and 18.18 (kgm^{-3}), respectively, under moderate irrigation regime (I_{80}). Thus, the application of biochar treatments could be efficiently used to produce high productivity of sugar beet crop and reduce the hazardous effects induced by salinity and drought stresses on both growth and yield of sugar beet crop. In addition, the use of irrigation regime (I_{80}) in combination with biochar application rate (B_{20}) could found to be a favorable agro-management strategy to save 20% of the applied irrigation water and slightly decrease in yield of sugar beet crop (11.67%) under Fayoum conditions.

Keywords:

Biochar, deficit irrigation, soil properties, soil salinity, sugar beet, water productivity.

Introduction

Drought stress and soil salinity are the most a biotic stress elements that directly threaten the global food security, especially in arid and semi-arid regions Yang, et al., 2016; Yang et al., 2020.

Drought adversely affects leaf water content and turgor loss, resulting in stomata close (Sahin et al. 2018; Parkash and Singh 2020). The closure of stomata which is one of the earliest responses of the plant to drought stress triggers the accumulation of the reactive oxygen species (ROS) (He et al., 2021; Pridgeon et al., 2021. However, under salinity stress, the plant struggle two key stresses, (i.e., osmotic stress and ionic stress) Lamers, et al., 2020. Osmotic stress induced by the increased accumulation of salts in the soil solution in the root zone, resulting decrease in plant water uptake Acosta-Motos et al., 2017. Ionic stress resulted from the accumulation of ions in plants' tissues beyond the threshold limits at which the ions cause toxic effects Acosta-Motos et al., 2017. The detrimental effects on metabolic and physiological activities metabolic and physiological induced by the drought and salinity stresses are similar, such as reduced enzyme activity, CO_2 assimilation disruption, protein synthesis inhibition, and decrease in leaf water status and reduction in photosystem. Overall, drought and salinity stresses produce detrimental effects on plant physiology, growth, and yield.

Therefore, to mitigate the adverse effects of drought and salinity stresses, it is imperative to adopt more efficient agro-management practices that have a great potential to improve soil moisture and nutrient retention capacity, ameliorate and remove excess of soluble salts from the soil solution Saifullah et al., 2018; Parkash and Singh 2020.

Organic soil amendments such as farm-yard manure, poultry manure, press mud and compost, are extensively used to improve the physical, chemical, and biological properties of the salt-affected soils to enhance the crop productivity (Srivastava et al., 2016; Amin and Baque, 2020). However these organic amendments incorporate a high amount of decomposable organic substrates, requiring their frequent reapplication Pandey et al., 2016; Al-Wabel et al., 2019. Meanwhile the biochar, is a highly stable organic material, has not yet extensively used to estimate its ameliorative impact on salt-affected soils. Biochar is a carbon-rich material with a strong anti-decomposability characteristic. Biochar is ordinarily generated by thermal degradation (pyrolysis) of biomass, especially agricultural residues under limited supply or the absence of oxygen in a closed furnace Wang et al., 2017; Rani et al., 2019. Biochar could enhance crop productivity via improving the soil physical properties (bulk density, porosity, aggregate stability, water holding capacity and saturated hydraulic conductivity), chemical properties (cation exchange capacity (CEC), soil nutrient retention, pH and EC), and soil biodiversity Blanco-Canqui, 2017; Haider et al., 2020; Zhang et al., 2020b. Biochar due to its high surface area and CEC is a suitable soil amendment for salt-affected soils (Tomczyk et al., 2020. Biochar amendments also reduce heavy metal toxicity in crops (Medy´nska-Juraszeket al., 2020.

Sugar beet is important sugar crop, provides approximately 35% of the world sugar needs, which is widely cultivated particularly in arid and semi-arid regions (Wu et al., 2013).

In Egypt the sugar industry is based on both sugar cane and sugar beet crops Mehareb, et al., 2021. Sugar beet is one of the main strategic crops, providing about 50% of sugar production by 1.255 million tons FAOSTAT, 2016. However, Egypt faces difficulties to decrease the gap between sugar production and sugar consumption which reaches about one million ton/year Zaida, 2014.

Thus, our study was carried out to evaluate the ameliorative effect of biochar application rates on some soil physical and chemical properties. Also, to determine the detrimental effects of water stress on growth, physiological response and yield of sugar beet crop. In addition, to estimate the beneficial effects of biochar applications in mitigating the adverse effects induced by drought on sugar beet cultivated in salt-affected soils.

3. Materials and Methods

3.1. Field environmental conditions

3.1.1. Climate

The current investigation was implemented at the experimental farm at Demo of Faculty of Agriculture, Fayoum University, Egypt, (29◦29_N latitude, 30◦91_E longitude). From Table (1) clear that experimental site is arid, hot in summer months with high temperatures and little or absent rainfall in winter. The highest value of maximum temperature 33.0 ˚C was observed in Oct. 2020, minimum temperature 8.3 ˚C was observed in Fib. 2021. The maximum and minimum values of Pan evaporation 4.8 and 5.2 (mm day^{-1}) were achieved in the of Oct. and Apr. months respectively, while the lowest 1.45 and 1.55 (mm day^{-1}) were observed in Dec. and Jan. months respectively, as averages humidity were 43 and 34%, respectively. The pan evaporation rates were in line with the changes in temperature, while the maximum mean value of pan evaporation was 4.80 of two seasons in April month.

Table (1). The meteorological data of experimental site.

Month	Year	Temperature C°			Relative humidity (%)	Wind speed (m sec^{-1})	Pan evaporation (mm day^{-1})	Mean values of pan evaporation (mm day^{-1})
		Max.	Min.	Mean				
October	2019	32.3	18.6	25.4	38	2.0	4.5	4.65
	2020	33.0	21.6	27.3	39	1.9	4.8	
November	2019	26.2	13.4	19.8	41	1.9	2.3	2.20
	2020	28.1	15.6	21.9	42	1.7	2.1	
December	2019	23.6	12.7	18.2	43	1.8	1.4	1.45
	2020	21.1	9.5	15.3	42	1.9	1.5	
January	2020	21.3	9.4	15.4	43	2.2	1.5	1.55
	2021	20.4	8.5	14.5	42	1.8	1.6	
February	2020	23.4	9.7	16.6	41	1.9	1.5	1.90
	2021	22.0	8.3	15.1	42	2.0	2.3	
March	2020	29.4	12.7	21.1	37	2.2	4.0	3.75
	2021	26.7	12.7	19.7	37	2.1	3.5	
April	2020	21.1	9.2	15.2	36	2.2	4.4	4.80
	2021	31.2	15.6	23.4	34	2.2	5.2	

3.1.2 Soil

The field work was conducted in newly reclaimed soils with sandy loam in texture. Soil salinity (ECe) was 10.98 dS m^{-1}. As shown in Table (2), soil physical properties were measured as described by Klute 1986. The soil bulk density and hydraulic conductivity values were 1.57 Mg m^{-3} and 1.93 cm h^{-1}, respectively, as averages in soil depth (0-60 cm). Soil moisture constants, i.e., field capacity and wilting point averaged 21.83 and 10.45% respectively at the same soil depth. Soil chemical analysis were measured as described by Page et al. 1982, e.g., soil pH (1: 2.5 soil-water extracts), organic matter content (Walkley and Black,s), cation exchangeable capacity and $CaCO_3$ amounted 7.52, 0.68%, 9.29 cmole kg^{-1} and 7.2% respectively, as averages in soil depth (0-60 cm).

Table (2). Some initial physico- chemical characteristics of the experimental soil.

Depth (cm)	Particle size distribution, %			Texture class	ρ_b Mg m^{-3}	K_{sat} cm h^{-1}	F.C %	W.P %	A.W %	EC (dS/m)	pH	O.M %	CEC cmole kg^{-1}	$CaCO_3$ %
	Sand	Silt	Clay											
0-20	75.8	11.5	12.7	S.L.	1.55	2.04	22.63	10.76	11.87	11.21	7.49	0.75	9.31	7.54
20-40	76.6	12.5	10.9	S.L.	1.57	1.97	21.82	10.42	11.4	10.54	7.51	0.65	8.57	6.21
40-60	79.9	9.6	10.5	S.L.	1.58	1.77	21.04	10.18	10.86	11.19	7.56	0.64	9.99	7.89
Mean	77.4	11.2	11.4	S.L.	1.57	1.93	21.83	10.45	11.38	10.98	7.52	0.68	9.29	7.21

EC is the electrical conductivity, O.M = organic matter content, SL= sandy loam, ρ_b = bulk density, K_{sat}= hydraulic conductivity, F.C= field capacity, W.P = wilting point and A.W = Available water.

3.2. Treatments

The experimental treatments were implemented in a split plot based on randomized complete blocks design including three treatments of deficit irrigation and three application rates of biochar amendment with three replicates. Deficit irrigation (I_{100}, I_{80} and I_{60} representing 100, 80 and 60 of ETc) were arranged. Main plot area was and bounded with dikes (2 m width). Each main plot was divided into 3 sub main plots which occupied by three biochar application rates (i.e., B_0, B_{10} and B_{20} representing non addition, 10 and 20 t ha^{-1}). Sub main plot area was 10.5 m^2 (3 × 3.5 m).

3.3. Irrigation water applications

The three main plots were received, three different deficit irrigation treatments, sugar beet plants were irrigated every 10 days' intervals by different amounts of irrigation water applied (IWA) and was determined as a percentage of the crop evapotranspiration (ET_c) representing one of the following three treatments: I_1= 100%, I_2= 80% and I_3= 60% of ETc. The daily ET_o values were computed according to Eq. (3.1) (Allen et al., 1998**)** as follows:

$$\mathbf{ET_o = E_{pan} * K_{pan}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where: E_{pan} is evaporation from the Class A pan (mm day^{-1}) and K_{pan} is the pan evaporation coefficient.

The actual amount of water applied to sugar beet plants of each irrigation treatment depended mainly upon the reference evapotranspiration (ETo). Monthly mean weather data for years in two seasons were obtained from Agricultural Manager station, Fayoum, Egypt.

The crop evapotranspiration (ETc) values were calculated from the flowing equation according to Doorenbos and Pruitt (1992)**,** Eq. (3.2).

$$\mathbf{ETc = ET_o \times Kc} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

Where: ET_o is the "Reference ET" (the amount of full water use by a well irrigated, mowed grass), ET_o varies daily with changes in temperature, relative humidity, solar radiation and wind speed, Kc is "Crop Coefficient" (A factor that is used to convert ETo to potential vineyard ETc).

The amounts of irrigation water application (IWA) values to each plot during the irrigation regime were determined by using the following equation (Eq. 3.3), Abd El-Wahed and Ali (2013)**.**

$$\mathbf{IWA = \frac{A \times ETc \times Ii}{Ea \times 1000}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

Where: IWA is the irrigation water application (m^3), A is the area (m^2), ETc is the crop evapotranspiration (mm day^{-1}), Ii is the irrigation intervals (day), and Ea is the application efficiency of irrigation (%). The amount of IWA was controlled through plastic pipe (spiles) of 50 mm in diameter and 80 cm in length.

One spile per plot was used to convey irrigation water for each plot. The amount of water delivered through a plastic pipe (spiles) was calculated according to the following equation (Eq. 3.4), Israelsen and Hansen (1962).

$$\mathbf{Q = CA}\sqrt{2gh} \times 10^{-3} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.4)$$

Where: Q is the discharge of irrigation water (l $sec.^{-1}$), C is the coefficient of discharge, A is cross-section area of irrigation pipe (cm^2), g is gravity acceleration (cm s^{-2}) and h is the average of effective head of water (cm) above pipe.

3.4. Biochar analysis

The used biochar amendment is produced by the pyrolysis process of burning trees with plant wastes in the absence of oxygen or under limited oxygen at a temperature degree (600 – 700). Table (3) shows the chemical analysis of the applied biochar amendment.

Table (3). Chemical characteristics of the biochar.

EC (dS/m)	pH	O.C. %	CEC cmol$^+$ kg^{-1}	N %	P g kg^{-1}	C/N ratio	K g kg^{-1}	Ca g kg^{-1}	Mg g kg^{-1}	θ %
4.10	7.80	45.10	400	0.90	3.05	50.11	5.15	30	36	41

3.5. Plant under study

Biochar amendment was applied manually to experimental soil before sowing. Seeds of sugar beet crop (*Beta vulgaris L.*, Baraca) was planted in the 1st of Oct. in two successive winter seasons along two years 2019/2020 and 2020/2021. Sugar beet seeds were planted manually in hills, 20 cm apart from each other with 60 cm distance between rows. Sugar beet plants harvested after 190 days from planting in each season. Nitrogen fertilization (urea 46.5% N) was added at the rate of 109 kg N ha^{-1} in two equal doses, the first applied after thinning (at 4 leaves stage /plant) and the second dose was applied 4 weeks later. At sowing phosphor fertilization (Supper Phosphate 15.5% P_2O_5) was applied by rate 70 kg P_2O_5 ha^{-1} Potassium fertilization (Potassium Sulfate 48% K_2O) by 60 kg K_2O ha^{-1} was applied after thinning. However, all the other Agronomic cultural practices, disease, pest management for sugar beet crop were carried out as local commercial sugar beet production.

3.6 Growth parameters and yield of the sugar beet crop

At harvest, randomly ten plants were collected from each plot then separated into tops and roots. Root length, diameter, and weight were estimated using a meter scale and digital balance. To measure root and biological yields, plants of each plot were harvested. Harvest index (HI) was calculated on a dry mass basis by using the following formula HI = yield of roots (t ha^{-1})/ [root yield (t ha^{-1}) + top yield (t ha^{-1})]. Digital planometer (Planix 7) was used for measuring leaf area per plant. Total soluble solids percentage (T.S.S) was determined by using Digital Refractometer Model (ATAGO PR-32). Sucrose percentage (pol %) was polarimetically determined on a lead acetate extract of fresh macerated root according to the method of Mustafa et al. 2013. Potassium and sodium were determined by Flame photometer apparatus. Juice purity: was calculated as the formula Juice purity = Sucrose % / T.S.S. White sugar yield was expressed = root yield / white sugar (%) and loss sugar yield were computed using this formula loss sugar yield = root yield × loss sugar (%). According to McGinnus 1971, α-amino N (meq/100 g of the root) was determined using automatic sugar polarimeter. White sugar contents were calculated by linking the K, Na and α-amino N (meq/100 g of the root) according to Harvey and Dotton (1993). The water productivity (WP) values as kg root yield per m^3 of applied water.

3.7 Physiological measurements:

3.7.1. The relative chlorophyll concentration (SPAD chlorophyll) was determined using (SPAD502, KONICAMINOLTA. Inc., Tokyo). At harvest (188 and 186 DFP) in both seasons, respectively, 10 individual plants of each sub-plot were sampled randomly.

3.7.2 Relative water content (RWC %) was estimated according to (Hayat et al., 2007) and calculated using the following formula:

$$RWC (\%) = \{(FW - DW) \times 100\} / (TW - DW) \text{ …….. (3.5)}$$

Where: FW is fresh weight (g) was determined within two hours after excision of leaves. TW is turgid weight (g) was estimated by soaking leaves in distilled water at room temperature for 16-18 hours then soaked leaves rapidly and carefully blotted dry by tissue paper to express turgid weight. DW is dry weight (g) obtained after oven dry for 72 hours at 65 °C.

3.7.3. Membrane stability index (MSI %) was measured using the method of Premchandra et al. (1990) and calculated by the following equation.

$$MSI = [1 - (C_1/C_2)] \times 100 \text{ ………………………….. (3.6)}$$

Where: MSI% is the membrane stability index, C_1: is the electrical conductivity of the solution at 40 °C and C_2: is the electrical conductivity of the solution at 100 °C. Shoots fresh of plants were weighed and then placed in an oven at 70 ± 2 °C till a constant weight to measure their dry weights.

3.8. Water productivity (WP) of sugar beet crop

The water productivity was expressed as kg roots yield of sugar beet m^{-3} of water consumed. The values have been used to evaluate the variation between different treatments in producing maximum yield from water unit consumed by the grown sugar beet plants. The WP values were calculated according to Jensen et al. (1990) as following equation:

$$\mathbf{WP}\ (kg\ m^{-3}) = \text{Roots yield } (kg\ ha^{-1}) / \text{Actual crop ETc } (m^3\ ha^{-1}) \text{ …….. (3.7)}$$

3.9 Statistical and data analysis

The complete randomized blocks (spilt plot) design with three replicates was used and the collected data were statistically analyzed using the procedures outlined by Snedecor and Cochran (1980).

4. Results and Discussions

4.1. Effect of biochar on physico-chemical properties of the studied soils.

From Table (4) showed that the beneficial effects of biochar amendment addition on soil physico-chemical properties. Biochar indeed improved soil bulk density, pore size distribution, water movement and soil moisture retention characteristics. Increasing the application rate of biochar amendment from control (B_0) to 10 (B_1) and 20 (B_2) t ha^{-1} caused significant reduction by 1.15 and 2.94% in soil dry bulk density values and by 13.37 and 16.04% in soil hydraulic conductivity values, respectively. The lower bulk density and higher porosity of biochar materials than the soil could be responsible for increasing the pore volume of soil, resulting decreases in soil bulk density values, thus, biochar addition probably reduces soil bulk density through the mixing or dilution effect. The reduction of soil hydraulic conductivity in response to biochar addition might be caused by the filling or clogging of soil macro-pores with fine biochar particles, resulting in an increase in water holding pores. However, the decrease in soil bulk density due to biochar application was associated with an increase in soil total porosity (TP). The lowest value of soil TP 40% was determined for non-amended plots and increased gradually by 1.70 and 4.34% with the gradual increase of biochar application at 10 and 20 t ha^{-1}, respectively. The increase in TP in correspondence to biochar addition might be refer to the reduction of soil packing, improving soil aggregation and reduction of soil bulk density.

Table (4). Effect of biochar amendment application rates on physico- chemical characteristics of the experimental soil.

Biochar Appl. rates	ρ_b Mg m^{-3}	TP %	WHP %	UP %	F.C %	A.W %	K_{sat} cm h^{-1}	ECe (dS/m)	pH	O.M %	CEC cmol kg^{-1}
B_0	1.58a	0.40c	12.48c	17.50c	22.18c	11.48c	1.87a	8.57^a	7.44^b	0.85^c	12^c
B_{10}	1.56b	0.41b	14.66b	19.09b	24.93b	14.72b	1.62b	7.71^b	7.65^a	0.88^b	14^b
B_{20}	1.53c	0.42a	15.51a	21.76a	26.18a	15.05a	1.57c	7.50^c	7.65^a	0.95^a	15^a

Where: ρ_b: bulk density, TP: total porosity %, WHP: water holding pores % and UP: useful pores %.

Furthermore, biochar amendment not only enhanced soil total porosity, but also caused some alterations in pore size distribution, which directly linked with water and air flow in soil domain. Water holding pores WHP recorded their maximum value 15.51% with biochar application rate 20 t ha^{-1} and by increasing rate 24.33% higher than control (B_0). The improvement in WHP due to biochar application, it could be attributed to the soil particles rearrangement. Increasing the proportion of meso-pores and decreasing the ratio of drainable pores enhances the soil pore homogeneity. Similarly, the increasing application rates of biochar from 0 (control) to 10 and 20 t ha^{-1} significantly increased the field capacity (FC) by 12.40 and 18.03% respectively; also available water content (AW) increased by 28.22 and 32.10% respectively under the same biochar application rates as compared with zero addition of biochar (B_0). The high specific surface area of biochar particles, as well as its high ability to retain water, and its beneficial effect on pore homogeneity could be responsible for the improvement of available water content. The obtained results are in agreement with many researchers respecting to the positive impacts of biochar on soil physical properties Omondi et al. 2016; Agbna et al. 2017; Sedlak, 2018; Fu et al. 2019; Yang et al. 2020.

Furthermore, biochar application caused significant decrease in soil salinity (ECe). The ECe value at control of biochar application was 8.57 dSm^{-1} and this value decreased to 7.71 and 7.50 dSm^{-1} with application rates of biochar increased to 10 and 20 t ha^{-1}, respectively. The greatest reduction in soil ECe by 12.49% was observed with biochar application level (B_{20}) as compared with control (B_0), which reflecting the ameliorative effect of biochar on soil salinity. The reduction in ECe may be attributed to leaching of salts due to the improvement in soil porosity and hydraulic conductivity. In addition the decrease in soil ECe values with biochar applications it might be refer to the adsorption of soluble salts, especially Na ions on the surfaces of biochar particles, or as a result of physical capture of salt ions in fine pores of biochar Hammer et al., 2015. In contrast, soil pH, cation exchangeable capacity and organic matter content were significantly increased by 2.82, 25 and 11.76%, respectively, with increasing biochar addition from (B_0) to (B_{20}). The increase in soil pH might be attributed to the initial high-pH of added biochar material (pH = 7.80) in comparison to the soil pH (7.5) Rasse et al., 2017. The increase in soil CEC could be referring to the higher surface area and CEC of used biochar (Rahman et al., 2018). Similarly, biochar contains high organic carbon resulting in increases in soil organic carbon content.

4.2. Effect of biochar treatments and water stress on sugar beet growth attributes.

Sugar beet growth attributes (e.g. root length, root diameter, leaves number, leaves area and dry matter) were significantly affected by the applied deficit water regimes and biochar treatments Table (5). Water stress under moderate (I_{80}) and high (I_{60}) intensity levels resulted reduction in root length by (4.45 and 16.16%), root diameter by (4.74 and 17.62%), leaves number by (10 and 40%), leaves area by (17.61 and 18.08%) and dry matter by (20.02 and 63.87%) respectively, as compared with full irrigation treatment. However, the biochar applications mitigated the negative effects induced by draught stress. Application biochar amendment enhanced all growth traits of both water stressed and non-stressed sugar beet plants. The higher biochar application rate (B_{20}) gives the highest values of root length (27.11 cm), root diameter (16.77 cm), leaves number (55), leaves area (96.7 dm^{-2}) and dry matter (835 g) respectively. The above mentioned growth traits under the high level of biochar amendment (B_{20}) were higher by 29.77, 49.73, 37.50, 29.03 and 131.94%, respectively as compared with non- amended soil (B_0).

Respecting to the observed detrimental effects of drought stress on growth of sugar beet plants, it could be related to the adverse effects of drought on cell division and enlargement. The lower turgidity and dehydration of plant cells under drought disrupts protoplasmic functions and cell metabolic processes which leads to decrease in cell division causing suppression in plant growth rate Abd El-Mageed et al. 2019; Islam et al. 2020; Seleiman et al. 2021. The improvement of soil water retention and decrease in soil salinity content induced by biochar application could be enhanced the availability of water and nutrients, resulting in better root water and nutrient uptake under moderate and high water stress levels. Thus, the growth of sugar beet plants exhibited positive response to biochar addition. The positive effects of the biochar addition under water stress conditions on growth of several crops have been widely reported by Durukan et al., 2020 and Haider et al., 2020 who concluded that the application of biochar amendment increased growth and biomass of drought-stressed plants.

Table (5). Effect of biochar amendment application rates and deficit irrigation treatments on sugar beet growth attributes under two successive seasons.

Source of variation	Root length, cm	Root diameter, cm	No. of leaves	dry matter, g	Leaves area, dm^{-2}
Season (S)	NS	NS	NS	NS	NS
S_I	24.32	14.44	41.67	0.64	82.62
S_{II}	24.30	14.40	41.62	0.63	82.60
Irrigation	**	**	**	**	**
$I_{100\%}$	26.11^a	15.60^a	50^a	0.894^a	93.78^a
$I_{80\%}$	24.95^b	14.86^b	45^b	0.715^b	77.26^b
$I_{60\%}$	21.89^c	12.85^c	30^c	0.323^c	76.82^c
biochar	**	**	**	**	**
B_0	20.89^c	11.20^c	40^c	0.360^c	74.94^c
B_{10}	24.95^b	15.34^b	45^b	0.737^b	76.22^b
B_{20}	27.11^a	16.77^a	55^a	0.835^a	96.70^a
S × I	NS	NS	NS	NS	NS
S × B	NS	NS	NS	NS	NS
I × B	**	**	**	**	**
S × I × B	NS	NS	NS	NS	NS

Where: Different letters within each treatment indicate significant differences for Fisher LSD test, (LSD) at $p \leq 0.05$. **and * indicate respectively differences at $P \leq 0.05$ and $P \leq 0.01$ probability level, NS indicates not significant difference.

4.3. Effect of water stress and biochar treatments on physiological responses of sugar beet plants

The leaves relative water content (RWC), membrane stability index (MSI) and SPAD showed significant differences ($P \leq 0.05$), respecting to the applied deficit water treatments and biochar amendment application rates for both seasons (Table, 6). The RWC, MSI and SPAD were declined by (12.89, 10.59 and 17.28% at I_{80}) and by (28.29, 23.00 and 27.07% at I_{60}) relative to adequate irrigation regime (I_{100}). In contrast, biochar addition improved the physiological responses of drought and well watered sugar beet plants. With high biochar application level (20 t h^{-1}), RWC, MSI and SPAD increased by 20.57, 14.83 and 12.82% respectively, higher than control (B_0). The reduction in plant relative water content induced by water stress it might be attributed to some dehydration in protoplasm. In addition, drought stress stimulates the synthesis of the reactive oxygen species (ROS), which induce the lipid oxidation and membrane injury, accordingly increase in leakage of ions Abd El-Mageed et al. 2019; Hu et al. 2020; Xia et al. 2020. The reduction in SPAD parameter indicates photo-disruption induced by draught for water stressed sugar beet plants. On the other hand, the improved sugar beet physiological traits with biochar it might be refer to the ameliorative effect of biochar amendment which not only enhanced soil moisture content but also alleviated the osmotic pressure of soil solution, thus augmenting the plant water status and photosynthetic function. The obtained results respecting the beneficial effects of biochar amendment on physiological responses of sugar beet plants were in line with those reported by (Ali et al. 2017; Abbas et al. 2018; Palansooriya et al. 2019), they found that the application of biochar enhanced the photosynthesis, improved the contents of chlorophyll, photosynthetic rate, stomatal conductance, relative water contents (RWC) of drought-stressed plants.

Table (6). Effect of water stress and biochar amendment application treatments on plant physiological responses of sugar beet in during two successive seasons.

Source of variation	SPAD	RWC%	MSI%
Season (S)	NS	NS	NS
SI	62.52	73.18	68.17
SII	60.50	72.20	68.15
Irrigation regime(I)	*	*	*
I100%	73.36[a]	84.83[a]	76.77[a]
I80%	60.68[b]	73.89[b]	68.64[b]
I60%	53.52[c]	60.83[c]	59.11[c]
biochar	*	*	*
B0	56.62[c]	65.17[c]	63.09[c]
B1	61.34[b]	75.81[b]	68.98[b]
B2	63.88[a]	78.58[a]	72.45[a]
S × I	NS	NS	NS
S × B	NS	NS	NS
I × B	**	**	**
S × I × B	NS	NS	NS

Where: Different letters within each treatment indicate significant differences for Fisher LSD test (LSD) at $p \leq 0.05$. **and * indicate respectively differences at $P \leq 0.05$ and $P \leq 0.01$ probability level, NS indicates not significant difference.

4.4. Effect of water stress and biochar application treatments on sugar beet yield, yield components and water productivity

Water stress and soil organic amendment of used biochar caused significant effect on yield parameters of sugar beet crop Table (7). The greatest root yield 67.07 t ha^{-1} and biomass yield 111.01 t ha^{-1} were produced with full irrigation regime. Root yield and biomass yield were reduced by 11.67 and 15.01% at (I_{80}) and by 33.78 and 33.22% at (I_{60}) respectively, comparable with control. However, harvest index (HI) and water productivity (WP) recorded their maximum values under moderate irrigation regime. Harvest index was insignificantly differed between high irrigated and severely stressed sugar beet plants. Also, WP showed insignificant differences between I_{80} and I_{60}. However, sugar beet yield, HI and WP significantly increased as well as biochar application dose increased. The reduction in yield of sugar beet under drought stress could be attributed to the negative effects of drought on plant growth, water and nutrient uptake and activity of photosynthesis which depressing the yield and quality of sugar beet crop Moosavi et al. 2017; Abd El-Mageed et al. 2019; Aksu & Altay 2020a; Islam et al. 2020. Meanwhile, biochar amendment could be enhanced water holding capacity and soil nutrient retention. Furthermore enriching soil with biochar improves soil microbial activities, resulting in better environment for crop production of drought affected sugar beet plants.

Table (7). Effect of water stress and biochar application treatments on yield, yield components and water productivity of sugar beet plants grown in salt affected soils during two successive seasons.

Source of variation	Root fresh weight (kg plant^{-1})	Root yield (t ha^{-1})	Biomass yield (t ha^{-1})	HI	WP
Season (S)	NS	NS	NS	NS	NS
S_I	1.61	64.54	97.94	0.66	17.61
S_{II}	1.59	64.60	97.86	0.66	17.60
Irrigation	**	**	**	**	**
$I_{100\%}$	2.229^a	76.07^a	116.71^a	0.65^b	16.47^b
$I_{80\%}$	1.789^b	67.19^b	99.19^b	0.68^a	18.18^a
$I_{60\%}$	0.800^c	50.37^c	77.93^c	0.65^b	18.17^a
biochar	**	**	**	**	**
B_0	0.894^c	43.29^c	71.65^c	0.60^c	11.71^c
B_{10}	1.835^b	72.11^b	107.41^b	0.67^b	19.51^b
B_{20}	2.089^a	78.24^a	114.77^a	0.68^a	21.17^a
S × I	NS	NS	NS	NS	NS
S × B	NS	NS	NS	NS	NS
I × B	**	**	**	**	**
S × I × B	NS	NS	NS	NS	NS

Where: Different letters within each treatment indicate significant differences for Fisher LSD test (LSD) at $p \leq 0.05$. **and * indicate respectively differences at $P \leq 0.05$ and $P \leq 0.01$ probability level, NS indicates not significant difference.

4.5. Effect of water stress and biochar treatments on sugar technological properties and quality of sugar beet

Data presented in Table (8) showed that the measured sugar technological quality of sugar beet crop were remarkably effected via the applied irrigation treatment and/or biochar application. Increasing deficit irrigation level caused significant reduction in TSS, sodium content of beet roots, as well as purity percentage Abd El-Mageed et al. 2019; Aksu & Altay, 2020b; Abd El-Mageed et al. 2021. On the other hand, sucrose percentage, beet roots potassium content and Alpha amino nitrogen were positively influenced under water stress compared with control. Biochar amendment enhanced TSS and sucrose percentage, but decreased the percentage of sugar purity Durukan et al. 2020; Zhang et al. 2020a.

Table (8). Effect of water stress and biochar treatments on sugar technological properties and quality of sugar beet grown during two successive seasons.

Source of variation	T.S.S	Sucrose percentage (pol %)	Sodium (meq/100 g of beet).	Potassium (meq/100 g of beet).	Alpha amino nitrogen (meq/ 100 g of beet)	Purity percentage, %
Season (S)	NS	NS	NS	NS	NS	NS
SI	36.74	21.25	2.67	4.81	3.75	55.71
SII	36.70	21.24	2.65	4.80	3.76	55.70
Irrigation regime (I)	*	*	*	*	*	*
$I_{100\%}$	48.55[a]	20.74[c]	2.69[c]	4.13[c]	3.27[c]	58.48[a]
$I_{80\%}$	31.28[b]	21.27[b]	2.78[a]	5.11[b]	3.77[b]	57.23[b]
$I_{60\%}$	30.39[c]	21.73[a]	2.55[b]	5.18[a]	4.21[a]	51.42[c]
biochar	*	*	*	*	*	*
B_0	25.37[c]	18.81[c]	2.89[a]	5.04[a]	3.52[c]	79.34[a]
B_{10}	38.96[b]	21.74[b]	2.65[b]	4.55[c]	3.89[a]	50.49[b]
B_{20}	45.89[a]	23.20[a]	2.48[c]	4.84[b]	3.84[b]	37.29[c]
S × I	NS	NS	NS	NS	NS	NS
S × B	NS	NS	NS	NS	NS	NS
I × B	**	**	**	**	**	**
S × I × B	NS	NS	NS	NS	NS	NS

Where: Different letters within each treatment indicate significant differences for Fisher LSD test (LSD) at $p \leq 0.05$. **and * indicate respectively differences at $P \leq 0.05$ and $P \leq 0.01$ probability level, NS indicates not significant difference.

Conclusion

With increasing water scarcity, the biochar amendment as agro-management technique could play an important role in growing crops for high profit, enhancing the availability of water and nutrients in the root zone environment, and maintaining soil fertility. The applied biochar amendment improved soil moisture retention characteristics. Biochar addition caused significant reduction in soil bulk density, hydraulic conductivity and soil ECe, meanwhile increased field capacity (FC), available water content (AW), cation exchangeable capacity and organic matter content. As a result of the improvement of some physical and chemical properties of the salt affected soil due to biochar application led to an improvement in sugar beet growth, yield, yield quality and physiological attributes. Sugar beet growth parameters (i.e., root length, root diameter, leaves number, leaves area and dry matter) and physiological attributes (i.e., relative water content, membrane stability index and SPAD) were significantly affected by the applied deficit water regimes and biochar application levels. Enriching soil with biochar application rate 20 (t ha^{-1}) and applying irrigation according to (I_{80}) achieved the highest crop water productivity, which could be used as a favorable agro-management strategy to save 20% of the applied irrigation water and slightly decrease in yield of sugar beet crop (11.67%) under Fayoum conditions.

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أضافة الفحم الحيوي لتحسين جودة التربة ومحصول بنجر السكر النامي تحت معاملات الاجهاد المائي في الأراضي المتأثرة بالأملاح

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الملخص

أن أضافة الفحم الحيوي كتقنية من تقنيات الخدمة والإدارة الأرضية الجيدة للتربة تلعب دورا هاماً في نمو المحاصيل لكي تحقق عائدا اقتصاديا كبيرا وتعمل على توفير وتيسر المياه والمغذيات بمنطقة انتشار المجموع الجذري للنباتات والحفاظ على خصوبة التربة. تهدف الدراسة الحالية إلى تقييم الآثار المفيدة لتطبيقات الفحم الحيوي على بعض خصائص التربة وفي التخفيف من الآثار الضارة الناجمة عن الجفاف على نمو محصول بنجر السكر المنزرع في التربة المتأثرة بالأملاح. لتحقيق أهداف هذه الدراسة، تم إجراء تجربة حقلية في المزرعة التجريبية بدمو بكلية الزراعة جامعة الفيوم بالفيوم مصر. وتم استخدام ثلاث معاملات مختلفة للري المتناقص كنسبة مئوية من البخر نتح الفعليETc)) لمحصول بنجر السكر وهي كالاتي:

$I_{100} = 100\%$ ، $I_{80} = 80\%$ و $I_{60} = 60\%$ من ETc. وقد تم استخدام ثلاثة مستويات من المصلح العضوي للتربة (الفحم الحيوي) ، وهي بدون إضافة (B_0) ، و 10 طن للهكتار (B_{10}) ، و 20 طن للهكتار (B_{20}). مع تطبيق ثلاثة مكررات من جميع المعاملات تحت التجربة مع استخدام تصميم القطاعات الكاملة العشوائية (القطع المنشقة مرة واحدة). تمت زراعة بذور بنجر السكر (*Beta vulgaris L.*) صنف Baraca في موسمين شتويين متتاليين على مدار عامي (2020/2019 و 2021/2020) في تربة متأثرة بالأملاح(ECe = 10.98 ds/m.) وقد تمت زراعة البذور في 1 أكتوبر والحصاد في 10 أبريل. وكان موسم النمو 180 يوما". أظهرت النتائج المتحصل عليها أن أضافة الفحم الحيوي يحسن خصائص احتفاظ التربة بالماء. إضافة الفحم الحيوي بمقدار20 طن للهكتار أدى الى انخفاض معنوي في الكثافة الظاهرية للتربة، التوصيل الهيدروليكي، وملوحة التربة بنسبة 2.94 ، 16.04 و 12.49٪ على التوالي بالمقارنة الكنترولB_0)). بينما تحت المستوى العالٍ من إضافة الفحم الحيوي20) طن للهكتار) ارتفعت السعة الحقلية، محتوى الماء الميسر، ومحتوى المادة العضوية بشكل معنوي بنسبة 18.03 و 31.10 و 11.76٪ على التوالي مقارنة مع الكنترول. بالإضافة إلى ذلك، تأثرت صفات نمو نباتات بنجر السكر (طول الجذر، قطر الجذر، عدد الأوراق، مساحة الأوراق، المادة الجافة) والخصائص الفسيولوجية (المحتوى المائي النسبي) بشكل معنوي لكل من معاملات الرى المتناقص ومستويات تطبيق الفحم الحيوي. أيضا، انخفض محصول الجذر طن للهكتار ومحصول الكتلة الحيوية طن للهكتار بنسبة 11.67 و 15.01٪ عند (I_{80}) وبنسبة 33.78 و 33.22٪ عند (I_{60}) على التوالي مقارنة بمعاملة الرى الكنترول (I_{100}). وسجل مؤشر الحصاد (HI) وإنتاجية المياه (WP) قيمهما القصوى 0.68 و 18.18 كجم م $^{-3}$ على التوالي، في ظل معاملة الرى (I_{80}). وبالتالي يمكن استخدام معالجات الفحم الحيوي المطبقة بكفاءة لتحقيق إنتاجية عالية لمحصول بنجر السكر وتقليل الآثار الخطرة الناجمة عن الاجهاد الملحي والجفاف على نمو وإنتاجية محصول بنجر السكر. بالإضافة إلى أن استخدام معاملة الريI_{80})) مع اضافة الفحم الحيوي (B_{20}) يمكن أن يكون استراتيجية إدارة زراعية مناسبة لتوفير 20٪ من مياه الري المطبقة والحفاظ على إنتاجية عالية من محصول بنجر السكر تحت ظروف الفيوم.

الكلمات الدالة: الفحم الحيوي، الري المتناقص، خواص التربة، ملوحة التربة، بنجر السكر، إنتاجية المياه.