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RESPONSE OF WATER STRESSED TOMATO PLANTS TO SOIL ORGANIC AMENDMENTS

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ABSTRACT

Two field trials were conducted during successive two summer seasons of 2019 and 2020 at the experimental farm, Fac. Environ. Agric. Sci., Arish Univ., North Sinai, Egypt to investigate the influence of drought stress (100% of crop evapotranspiration "ETc" (full irrigation "D_0"), 85% ETc (low drought stress "D_L"), 75% ETc (medium drought stress "D_M") and 55% ETc (high drought stress "D_H") and organic amendments (biochar "BCH" and barley straw "ST") on soil water relation as well as growth, yield and quality of tomato. Biochar+barley straw treatment exhibited the highest increment under all water levels of the three water relation, *i.e.*, field capacity (FC), plant permanent wilting point (PWP) and plant available water content (AWC) traits with insignificant differences between biochar and biochar+ barley straw treatments. The highest yielding treatments under high drought stress (55% ETc, D_H) level were both BCH and BCH+ST treatments. As for stress tolerance indices, BCH+ST followed by BCH treatment recorded the highest Relative drought index "RDI", Stress Tolerance Index "STI", Geometric mean productivity "GMP", Yield Index "YI", Drought resistance index "DI", Modified Stress Tolerance Index 1"K_1STI" and Modified stress tolerance index2 "K_2STI" suggesting more stress tolerance mechanism. Based on the yield category, treatments classified into three groups: high, moderate and low yield/feddan. Comparison between the two drought stress levels (D_H and D_M) shows the extent of improvement in the 75% ETc (D_M). Construction of dendrogram based on 12 drought tolerance indices under non-stress and both high and moderate drought conditions were involved. Based on Fruit yield (ton/fed) under non-stress and high drought stress, the 4-amendment treatments split into two main clusters. Cluster I contained stress tolerant treatment that had low value of stress susceptibility (Biochar and Biochar+ST) indicating the best cluster for both growth conditions. Cluster II performed poorly in the reverse trend of tolerant-group. So, this study confirms the contribution of biochar to the sustainability of agriculture and water conservation.

INTRODUCTION

Tomato is an important vegetable crop in Egypt, which occupied the largest cultivation area as well as consumes large quantities of water among vegetables. In arid and semi-arid conditions water apportionment for agriculture is reducing steadily and adequate of irrigation water is not available in many parts of the world. Water scarcity denotes serious problems to world food security, where most of irrigated agricultural areas of the world are predicted to face hazard water crisis in the future. Thus, in semi-arid Mediterranean regions studied new irrigation strategies which can reduce consumption of water irrigation and increase productivity of agriculture and

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other sectors depending on water (**Costa** ***et al.*****, 2007**). Tomato crop is highly sensitive to water stress, furthermore water deficit by 15% and 30% resulting in reduce net profits by 15% and 22%, respectively (**Obreza** ***et al.*****, 1996**) through influencing physiological processes involving photosynthesis and transpiration. However, available water is important restriction for plant productivity, generally affecting growth of roots and leaves, dry matter accumulation, photosynthesis and stomata conductance (**Blum, 1997**). Soils of Arish region is, in general, characterized as sandy soil, which is very poor in mineral nutrients, single grain structure, low moisture holding capacity, susceptibility to erosion as well as low levels of organic matter content and microorganisms. Many researchers studied many methods to solve these problems. Organic additions are capable to improve soil properties and plant growth in addition, applying biochar amendment enhanced nutrient availability, soil water holding capacity, soil physical and chemical properties as well as plant productivity (**Ahmad** ***et al*****., 2017**). Therefore, depending on the intrinsical characteristics of each biochar type, its application has the potential to modify some soil properties, *i.e.*, soil pH, nutrients availability, water-holding capacity, bulk density and soil aggregation (**Lehmann** and **joseph, 2015; Mary** ***et al*****., 2016**). The optimal application rate of biochar is not yet established, as it will vary between biochar types, soil types and target species. Moreover, under saline irrigation water, **She** ***et al*****. (2018)** reported that biochar amendment increased vegetative growth, quality parameters and yield. One recent example is the increase in tomato plant growth and quality of fruit, which showed a darker red color and higher sugar, acid, and vitamin C content after soil amendment with bamboo biochar produced at different temperatures (**Suthar** ***et al.*****, 2018**). Furthermore, biochar amendments increase growth, quality, and crop yield under stress conditions such as salt and drought (**Ali** ***et al*****., 2017; Akhtar** ***et al*****., 2018; She** ***et al*****., 2018**). Presently applications of organic amendments have become a more sustainable and current approach for increasing crop productivity under these conditions.

Straw application can supply nitrogen to the soil, reducing fertilizer nitrogen rates, so nitrogen pollution of agricultural ecosystems could be somewhat relieved (**Watanabe** ***et al*****., 2009**). The decomposition of straw consumes inorganic soil nitrogen, reduces soil nitrogen leaching losses, and also, can reasonably maintain the soil C/N ratio (**Pan** ***et al*****., 2013**) and improve soil structure, especially in high-fertilizer-input fields (**Yang** ***et al*****., 2018**). Straw is rich in cellulose, which is an ideal source of carbon and hydrogen for microorganisms inhabiting the soil (**Chirak** ***et al*****., 2017**). **Wyszkowska** ***et al*****., (2021**) confirmed the significant impact of an organic substance (finely ground barley straw) on organotrophic bacteria, oligotrophic spore-forming bacteria and actinobacteria.

Therefore, this study aims to determine the effects of water stress and organic soil amendments on some physical properties of soil, growth, yield and quality of tomato to maximize productivity and water saving under Arish region.

MATERIALS AND METHODS

Two field trials were carried out during successive two summer seasons of 2019 and 2020 at the Experimental Farm, Fac. Environ. Agric. Sci., Arish University, North Sinai, Egypt to study the influence of drought stress (100% ETc (D_0), 85% ETc (D_L), 75% ETc (D_M) and 55% ETc (D_H) and organic amendments *viz.*, biochar (BCH), and barley straw (ST) on soil physical properties as well as growth, yield and quality of tomato. Biochar (BCH) prepared from citrus wood (CWB) in a traditional charcoal kiln (lump charcoal) was obtained from a local market **(Elad *et al.*, 2010; Qayyum *et al.*, 2015).** Briefly, a porous black solid (consisting of an amorphous form of carbon) obtained as a residue when Citrus pruning offal is heated in the absence of air and it is figuratively called biochar. The biochar (73.4% C, 0.63% N, 2.3% H, and 26.4% O) has been ground into a size of ≤ 2.0 mm (**Suthar *et al.*, 2018**). The prepared BCH was stored in clean plastic bags until use (**Younis *et al.*, 2015**). Seedlings of tomato *cv.* GS-12 F_1 (produced by the Swiss Company Syngenta) were obtained from a commercial nursery (Arish, Egypt) at 40 to 50 days after seeding and transplanting was done on 15th April. Organic amendments were applied after soil preparation and mixed in 15-20 cm of sandy loam soil surface (7.5% pH, 0.16% organic matter (OM), 58.75% Coarse sand, 19.6% Fine sand, 12.84% silt, and 9.25% clay) at rates of 1.5 and 4.0 ton/fed for crashed barley straw (ST) and biochar (BCH), respectively. However, after 15 days from transplanting, irrigation treatments were started. Treatments were all the combinations of four drought stress levels (100% ETc (D_0), 85% ETc (D_L), 75% ETc (D_M) and 55% ETc (D_H)) and four organic amendments, *i.e.*, without amendments (Am_0) as control, crashed barley straw (Am_S), CWB biochar (Am_{CWB}) and crashed barley straw + CWB biochar (Am_{S+CWB}). Treatments were arranged in a split-plot system with three replications in a Randomized Complete Block Design. Each replication comprised 16 sub-plots (four irrigation levels were randomly assigned to the main plots, where four amendment treatments were randomly arranged in the sub-plots) as shown in Table 1. The experimental unit area was 21.6 m^2 (3 dripper lines × 6 m length × 1.2 m width), seedlings transplanted on dripper line 1.2 m apart and 0.5 m spaced between plants in the same line. One line was used to determine the morphological and physiological traits and the other two lines were used for yield determinations. In addition, one row, as guard area, was left between each two plots to avoid the overlapping infiltration of irrigation water. The normal agricultural practices of the commercial tomato production were done as needed. However, over two seasons mean of chemical analysis of irrigation water had EC 3.15 dS/m and pH 7.5.

Recorded Data

Vegetative growth

After 90 days from transplanting, 5 plants from each experimental unit were randomly taken to record plant height (cm), leaf area/plant (m^2) and both fresh and dry total weight of plant.

Leaf carotenoid and chlorophyll content

The contents were extracted and measured by spectrophotometric **(Marker and Jinks, 1982).**

Fruit yield

It was calculated as average fruit weight (g), and total fruit yield (ton/fed)**.**

Fruit quality

At ripe stage (red color), random sample of ten fruits were taken from each treatment to determine TSS %, firmness (Kg/cm^2) and fruit dry matter (%) according to **AOAC (1990**).

Leaves N, P and K contents

N was determined using a microkjeldahl method (**Jones *et al.*, 1991**), the total content of K, and P were determined using a flame photometer device and the colorimetric method, respectively.

Stress tolerance indices

For each amendment treatment, twelve stress tolerance indices were calculated based on average yield under normal irrigation (Yn) and both medium and high drought stress (Ys) levels over the two seasons. The names, equations and references of the stress tolerance indices are shown in Table 2. A dendrogram was constructed based on “Euclidean distance" procedure. Amendment treatments were clustered using unweighted pair group method (UPGMA) using arithmetic average as outlined by **Kovach (1995**).

Table 1. Irrigation regimes and organic amendments treatments used in this study

Main plot	**Sub plot**			
Irrigation regimes	**Organic amendments**			
100% Etc (D_0)	(Am_0)	(Am_S)	(AmCWB)	(Am_S+CWB)
80 % Etc (D_L)	(Am_S+CWB)	(AmCWB)	(Am_0)	(Am_S)
75 % Etc (D_M)	(AmCWB)	(Am_S)	(Am_S+CWB)	(Am_0)
55 % ETc (D_H)	(Am_0)	(Am_S+CWB)	(Am_S)	(AmCWB)

D_0: Full irrigation (control), **D_L, D_M** and **D_H**: Low, medium and high drought stress, respectively

Am_0: without any amendments **Am_S:** straw, **Am_{CWB}:** Biochar, **Am_{S+CWB}:** straw+ Biochar treatments

Table 2. List of the drought stress tolerance indices and formula.

A. The high values of these indices indicated to stress tolerance

Index	**Geometric mean productivity**	**Relative drought index**	**Stress Tolerance Index**	**Yield Index**	**Drought resistance index**	**Modified Stress Tolerance Index 1**	**Modified stress tolerance index 2**
Abbr.	**GMP**	**RDI**	**STI**	**YI**	**DI**	**$STIK_1$**	**$STIK_2$**
Formula	$\sqrt{Yn \times Ys}$	$\frac{(Ys/Yn)}{(\bar{Y}s/\bar{Y}n)}$	$(Ys \times Yn)/(\bar{Y}n)^2$	$Ys/\bar{Y}s$	$(Ys \times (Ys/Yn))/\bar{Y}s$	$[(Yn)^2/(\bar{Y}n)^2] \times STI$	$[(Ys)^2/(\bar{Y}s)^2] \times STI$
References	**Fernandez (1992)**	**Fischer and Wood (1979)**	**Fernandez (1992)**	**Gavuzzi *et al.* (1997)**	**Lan (1998)**	**Farshadfar and Sutka (2002)**	

B. The high values of these indices indicated to stress susceptibility

Index	**Stress tolerance index**	**Stress susceptibility index**	**Relative decrease in yield**	**Abiotic tolerance index**	**Stress Susceptibility percentage index**
Abbr.	**TOL**	**SI**	**RDY**	**ATI**	**SSPI**
Formula	$Yn - Ys$	$\frac{1-(Ys/Yn)}{1-(\bar{Y}s/\bar{Y}n)}$	$100-(Ys/Yn \times 100)$	$[(Yn-Ys)/(\bar{Y}n/\bar{Y}s)] \times \sqrt{Yn \times Ys}$	$[(Yn-Ys)/(2 \times \bar{Y}n)] \times 100$
References	**Rosielle and Hamblin (1981)**	**Fischer and Maurer (1978)**	**Farshadfar *et al.*(2013)**	**Moosavi *et al.* (2008)**	**Moosavi *et al.* (2008)**

Ys and Yn: Yield of each amendment treatment under stress and non-stress conditions, respectively.

$\hat{Y}s$ and $\hat{Y}n$: Mean of yield overall treatments under stress and non-stress conditions, respectively.

Statistical analysis of the obtained data was carried out according to **Snedecor and Cochran (1980)**. Duncan's multiple range tests was used for comparison among means (**Duncan, 1955**).

RESULTS AND DISCUSSION

Effect of Irrigation Regimes

Results in Table 3 and Fig. 1 indicate that irrigation treatments had significant effect on plant height, both fresh and dry plant weights and leaf area of tomato in the two seasons.

It could be inferred that full water levels (100 % ETc) produced the maximum plant height, both fresh and dry weight of plant and leaf area as vegetative growth traits, fruit firmness (Kg/cm^2) and fruit dry matter (%) as fruit quality as well as both average fruit weight and total fruit yield of tomato in both seasons with no significant differences among 100, 85 and 75% ETc irrigation levels at both seasons for vegetative traits and 1st one for both average fruit weight and firmness. Water deficit treatment improved the TSS % of tomato fruits (Fig. 2) compared with full irrigation treatment, this result is in accordance with that of **Singh *et al.* (2019**). **Agbna *et al.* (2017)** reported a insignificantly increase in TSS% of tomato fruits and water stressed plants had higher values for most quality traits compared with the unstressed plants. On the contrary, the lowest values of all vegetative and yield previously mentioned parameters were recorded under high drought stress (55% ETc), where, the decreases in total yield (average of two seasons) were about 18.8, 36.6 and 46.9% due to irrigation with 85, 75 and 55 % ETc than full irrigation (100 %ETc). High drought stress (55% ETc) caused a reduction in all studied plant growth characters, and this may be due to that water stress causes losses in tissues content of water which led to reduce the turgor pressure in the cells, thereby inhibition enlargement and cell division as concluded by **Hsiao *et al.*, (1974**). Water stress causes an increase in Abscisic Acid (ABA) / Cytokinin (CYT) ratio, which in turn decreased plant growth (**Marschner, 1995**), where ABA is decreasing, under sufficient water conditions, with increasing in CYT, Gibberellic Acid (GA) and Indole Acetic Acid (IAA) reflecting good growth and dry matter content (Fig. 2).

The increment in water supply led to increase the soil moisture content and caused no suffering of plants to get their water requirements, where primarily irrigation improves leaves growth which in turn increases net assimilation of organic nutrients and subsequently plant growth and yield.

Results showed that, low water supply content resulted in decreased root growth and inhibited leaf enlargement rate associated with increase in ABA concentration in leaves as reported by **Smith and Dale (1988**) and decreasing CYT production and export (**Atkin *et al.*, 1973**). Also, harmful effect of drought could be due to negatively effects on cell division and enlargement, reduces photosynthetic rate, delay cellular growth, and finally this in turn affect the growth and yield of tomato plants (**Hafez *et al.*, 2020**). Increasing yield with increasing irrigation level might be due to the increase of total chlorophyll content and/or the increment of leaf transpiration, which correlates with the increasing water supply results in a positive effect on yield *via* the enhancing gases exchange and photosynthesis process (**Foti *et al.* 1995**).

Effect of Soil Amendments

Application of biochar and barley straw (alone or in combination) significantly increased vegetative growth traits (both fresh and dry total plant weight and leaf area) and total fruit yield of tomato (Table 4 and Fig. 3). Biochar plus barley straw (BCH+ST) treatment exhibited the highest value for all abovementioned traits followed by BCH alone with no significant differences between BCH and ST in all these traits, except total plant fresh weight and total fruit yield at both seasons and first one, respectively.

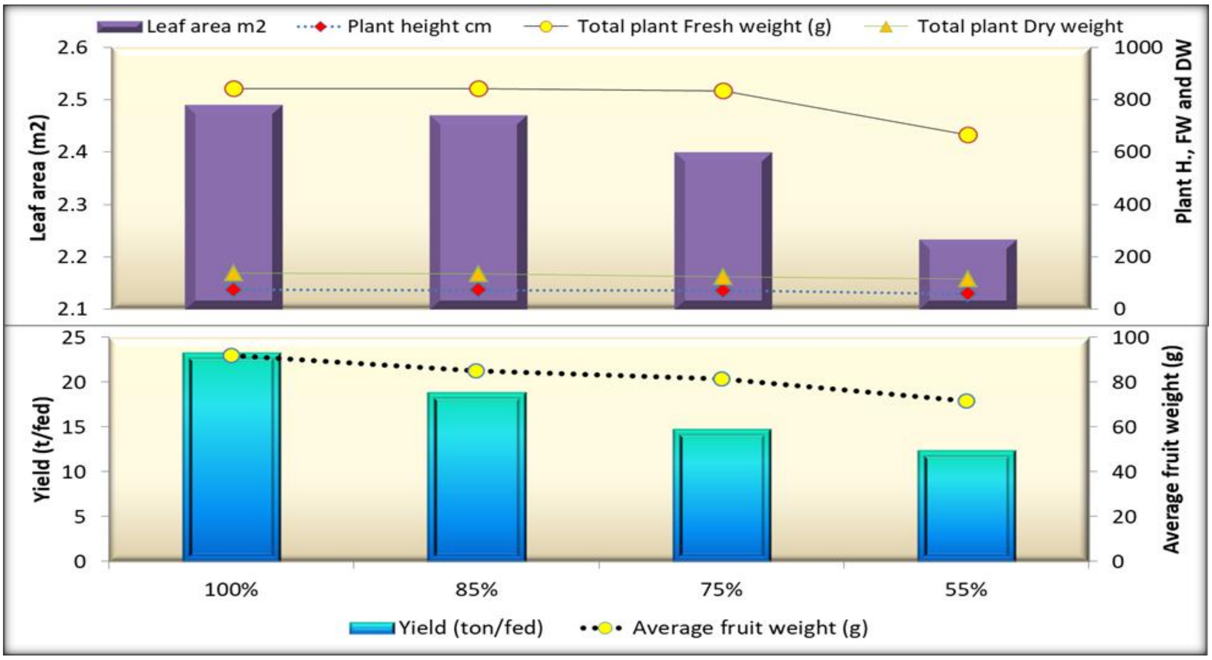


Fig. 1. Vegetative growth (Upper), average fruit weight (g) and fruit yield (ton/fed) (Down) traits of tomato as affected by irrigation regimes (average of two seasons)

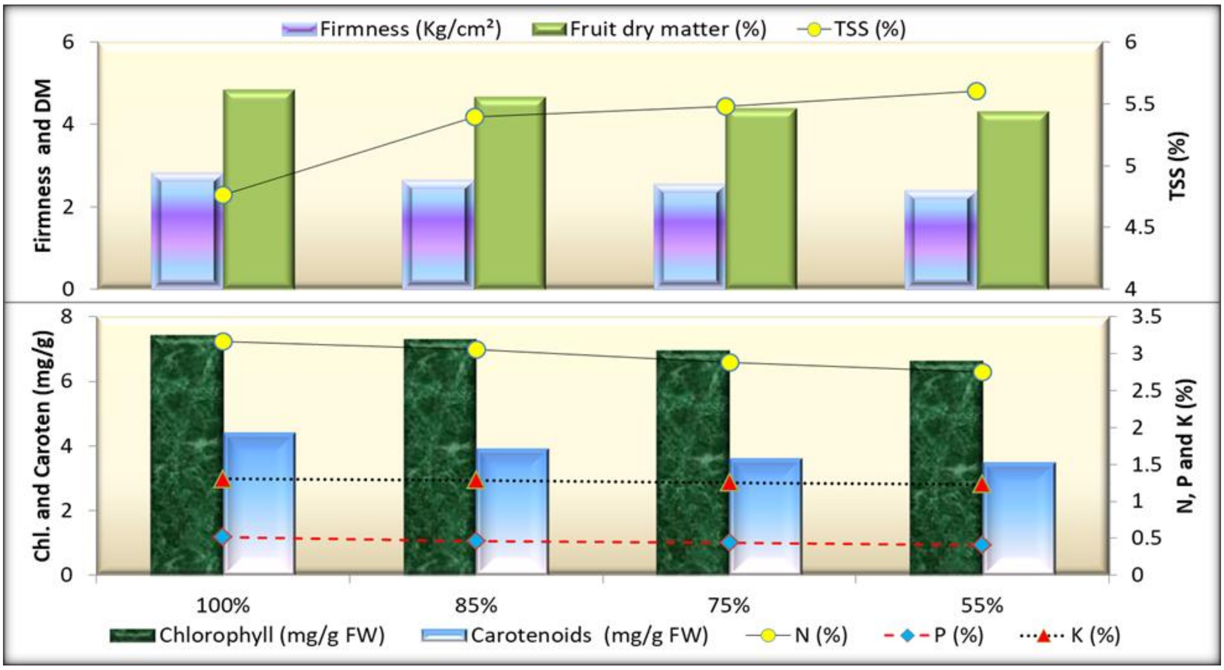


Fig.2. Tomato fruit quality (Upper), leaf content of chlorophyll and carotenoids as well as chemical constituent (Down) as affected by irrigation regimes (average of two seasons).

Table 3. Vegetative growth, average fruit weight (g) and fruit yield of tomato (ton/fed.) as affected by irrigation regimes during two seasons

Irrigation regimes	Plant height (cm)	Total plant weight (g)		Leaf area (m^2)	Average fruit weight (g)	Total fruit yield (ton/fed)
		Fresh	Dry			
1st season						
100%	73.16a	843.08a	136.36a	2.48a	92.16a	22.37a
85%	70.71a	838.48a	133.37a	2.46a	83.64ab	17.93b
75%	69.46a	831.44a	122.57ab	2.39a	80.75ab	13.72c
55%	55.05b	663.86b	112.81b	2.22b	67.91b	11.52c
2nd season						
100%	74.77a	845.36a	139.28a	2.50a	91.78a	24.23a
85%	73.18a	844.78a	136.09a	2.48a	86.12a	19.93b
75%	71.36a	835.54a	126.23ab	2.41a	82.32a	15.85c
55%	59.51b	668.95b	116.19b	2.25b	75.41a	13.27c

- Values having the same alphabetical letter(s) did not significantly differ at 0.05 level of probability according to Duncan’s multiple range test.

Table 4. Vegetative growth, average fruit weight (g) and fruit yield of tomato (ton/fed) as affected by organic amendments during two seasons

Organic amendments	Plant height (cm)	Total plant weight (g)		Leaf area (m^2)	Average fruit weight (g)	Total fruit yield (ton/fed)
		Fresh	Dry			
1st season						
Control	56.47c	739.18c	111.69c	1.99c	77.18a	13.58c
ST	63.28bc	777.79b	122.61b	2.37b	81.55a	15.46d
BCH	69.22b	819.56a	131.72ab	2.42b	82.55a	17.20b
BCH+ST	79.42a	840.34a	139.10a	2.76a	83.19a	19.31a
2nd season						
Control	59.94b	741.52a	114.67c	2.01c	79.94a	15.62c
ST	65.44b	782.07a	126.27b	2.39b	83.12a	17.46b
BCH	71.40ab	826.75a	134.67ab	2.44b	85.67a	19.03b
BCH+ST	82.02a	844.28b	142.18a	2.79a	86.89a	21.19a

- Values having the same alphabetical letter(s) did not significantly differ at 0.05 level of probability according to Duncan’s multiple range test.

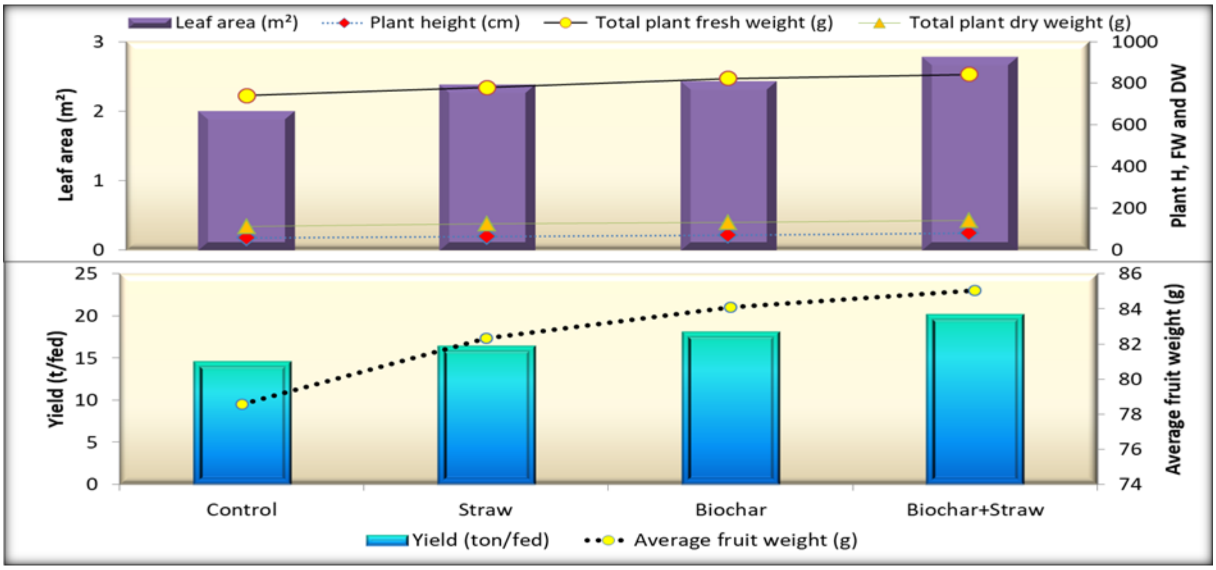


Fig. 3. Tomato vegetative growth (Upper), average fruit weight (g) and fruit yield (ton/fed) (Down) traits as affected by organic amendments (average of two seasons)

It was reported that biochar application, also gradually and insignificantly improved the fruit TSS (%) (**Singh *et al.*, 2019**). Leaves content of total chlorophyll, carotenoids and chemical constituents as well as fruit quality (firmness, TSS% and dry matter) are shown in Fig.4. results showed significant effects for soil amendment treatments on all studied traits in both seasons, except, leaves content of chlorophyll in the first season. The highest content of photosynthetic pigments (chlorophyll and carotene) were recorded with application of biochar plus barley straw without significant differences than application of biochar alone in both seasons.

The positive effect of biochar can be attributed to the fact that biochar increases the soil content of elements such as carbon that improves soil quality and leads to an increase in the relative water content and enhancement of plant traits. This result of biochar application was similar to the results obtained by **Wei *et al.* (2020)**. The increase in these traits may be due to the important role of biochar in enhancing nutrient and water use efficiency, the mechanisms responsible for increasing nutrient availability, increased cation exchange capacity and surface area leading to nutrient retention or direct release from the elements adsorbed from the biochar surfaces (**Mukome *et al.*, 2013**). As well as more effective of biochar or straw in reducing soil temperature compared to the control (**Chakraborty *et al.*, 2008**).

Drought Stress and Organic Amendments Interaction (D × Am):

As previously mentioned, the plants that received 55% ETc water irrigation (D_H) showed the minimum vegetative growth values and yield traits (Table 3) compared with the plants received 75% ETc (D_M) and 85% ETc (D_L) deficit irrigations and well-watered plants (100% ETc). However, treated stressed plants with biochar and/or barley straw significantly increased most vegetative growth traits as well as total fruit yield/fed under drought conditions in the

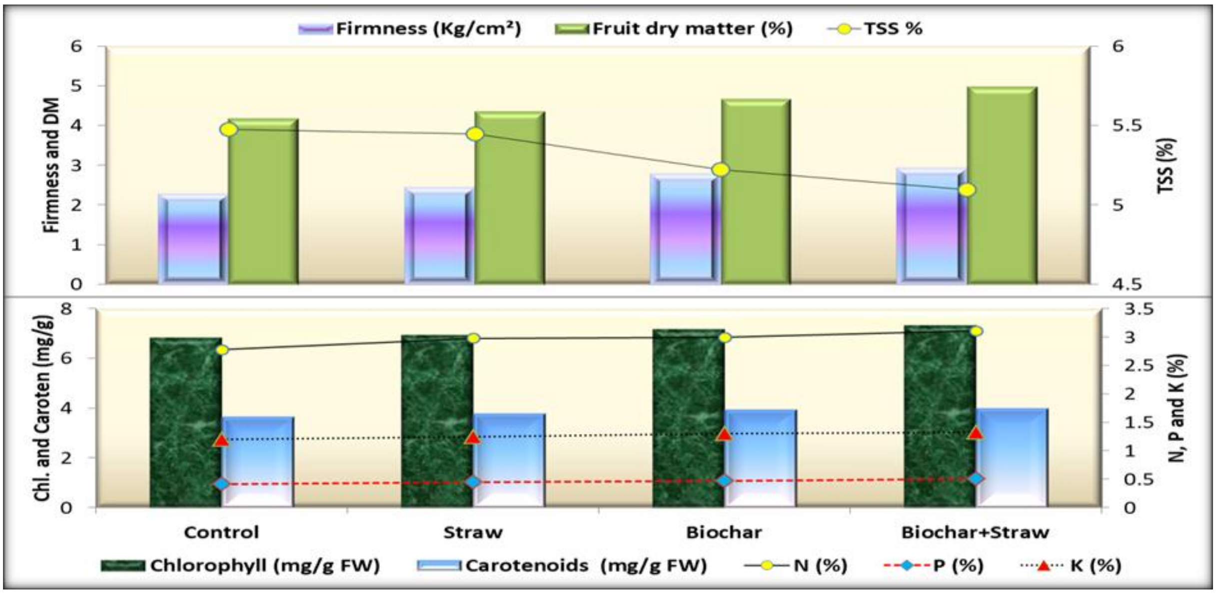


Fig. 4. Tomato fruit quality (Upper), leaf content of chlorophyll and carotenoids as well as chemical constituent (Down) as affected by irrigation regimes (average of two seasons)

two seasons (Figs. 5 and 6). Among all treatments, the high values were recorded in the stressed tomato plants which treated with biochar plus barley straw (Am_{CWB+S}) followed by biochar (Am_{CWB}) alone comparing with corresponding control (stressed untreated plants) in both seasons. However, no significant difference between the interaction of organic amendments and drought stress treatments (D×Am) with the control (well-watered plants) was observed for average fruit weight in the two seasons. The lowest values of vegetative growth and yield traits were recorded with the interaction between untreated plants and 55% ETc stressed plants ($Am_0 \times D_H$) for all traits in both seasons.

As mentioned above, the fruit yield and firmness traits values (Figs. 6 and 7) of tomato plants significantly increased with application of biochar (Am_{CWB}) and biochar plus straw (Am_{CWB+ST}) as well as fruit dry matter in case of Am_{CWB+ST} where the increase was significant in the stressed (55 and 75% ETc) treated plants compared with stressed (55 and 75% ETc) untreated plants. These results could be attributed to the important role of organic amendments in improving plant growth, increase nutrients uptake, enhance the concentrations of phytohormones (**Hussain *et al.*, 2008**), and consequently improve yield characters **(Langeroodi *et al.*, 2019).** However, TSS performed in the same trend where plants of amended soil exposed to water stress treatments had higher values compared with the unstressed plants.

Soil Water Relation

Field capacity (FC), plant permanent wilting point (PWP) and plant available water content (AWC) as soil moisture parameters were evaluated and compared to quantify soil water holding capacity. Significant increases in FC and AWC were observed in the three organic amendments (crashed barley straw, biochar and crashed barley straw + biochar) treatments, where the wilting point only slightly increased. However, biochar + barley treatment exhibited the highest increment under all water levels of the three water relation traits with no significant differences between biochar and biochar + barley straw treatments (Fig. 8).

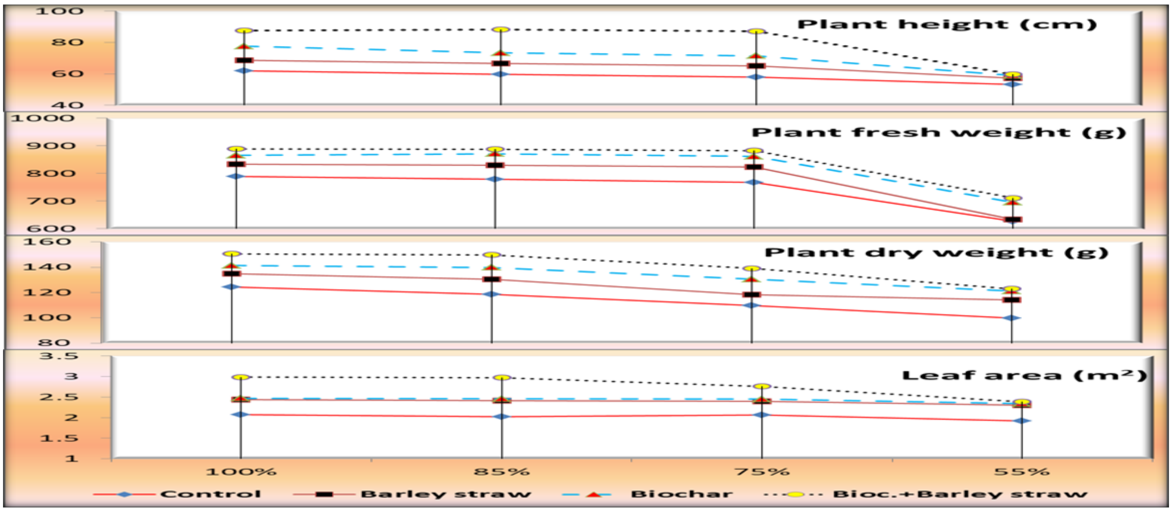


Fig.5: Vegetative growth traits of tomato plants as affected by the interaction between irrigation regimes and amendments (average of both seasons).

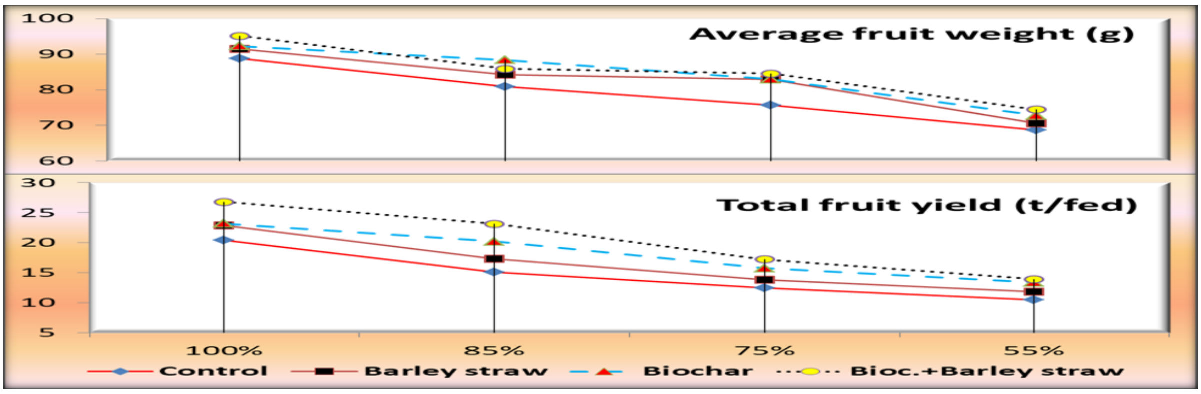


Fig.6. Yield traits of tomato plants as affected by the interaction between irrigation regimes and amendments (average of both seasons)

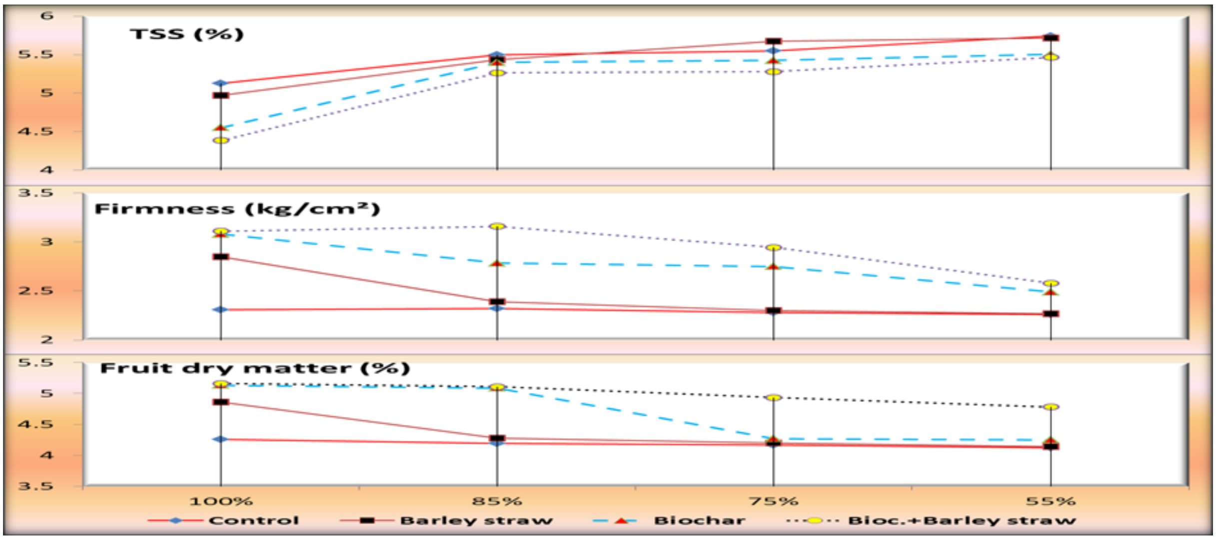


Fig.7. Fruit quality traits of tomato as affected by the interaction between irrigation regimes and amendments (average of both seasons)

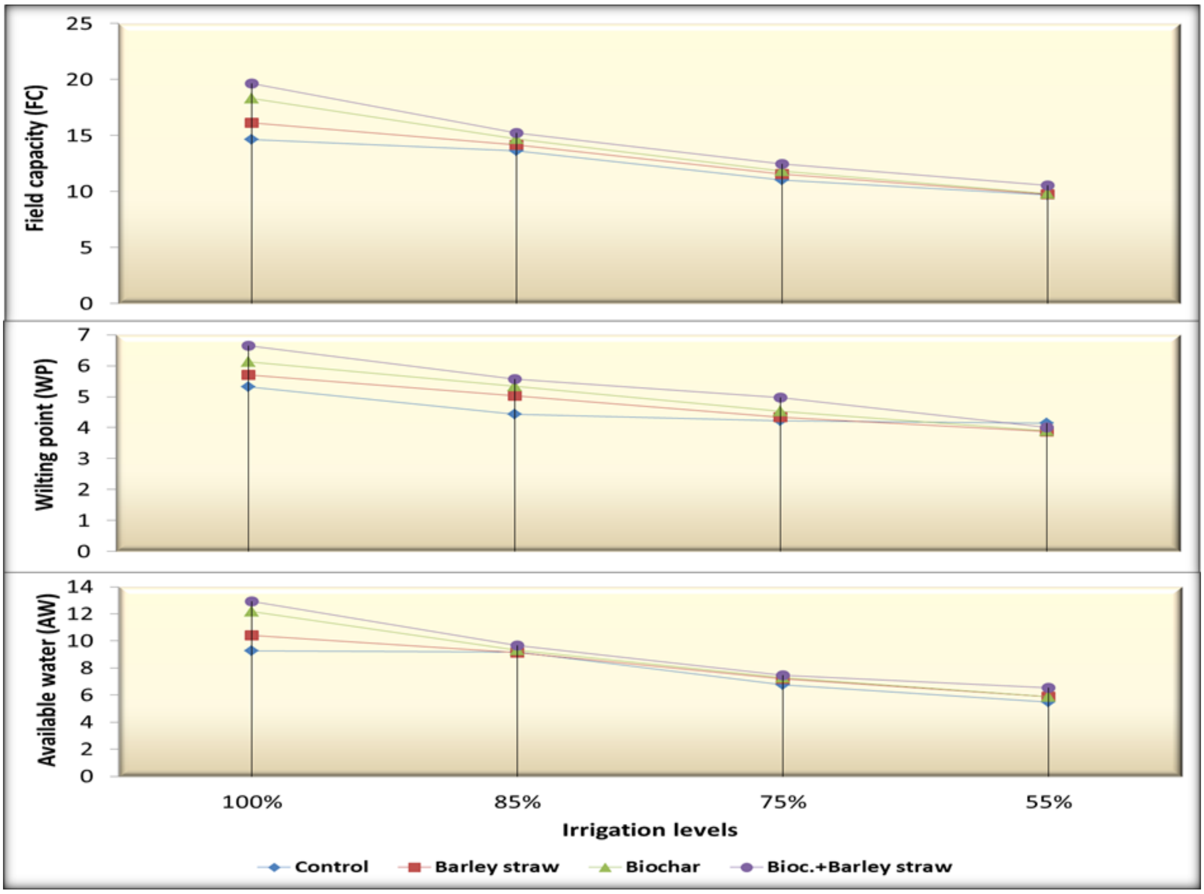


Fig. 8. Soil field capacity (%) "Upper", wilting point(%) "Middle" and available water (%) "Down"as affected by irrigation regimes (average of both seasons)

The plant permanent wilting point (PWP) is closely related to the specific surface area of soil, whereas the plant available water content (AWC) does not depend on it (**Petersen *et al.*, 2016**). Fig. 8 show that AWC of the experimental soil (sandy loam) was about 11.21% as average of both seasons that is in line with **Li *et al.*, (2021)**.

Any methods to improve field capacity and reduce the wilting point will increase the water available to plants (modifying the soil structure towards higher porosity with smaller pore sizes (**Li *et al.*, 2021**). It has been reported that biochar additions can transform the drainable pores between soil particles into water-retaining pores, and thus, the plant AWC of sandy loam soils with biochar additions was significantly increased (**Petersen *et al.*, 2016**). The increase in AWC was affected by the amount of biochar added and the biochar particle size. There is strong controversy regarding the effects of biochar as an additive to sandy soils. Several studies have shown positive effects of biochar on soil water retention and others have failed to provide promising results. Biochar can change the texture of sandy soils and soil moisture parameters and provide a water storage mechanism. Because of the inconsistent research results, it is worth understanding the functions and mechanisms of biochar in modulating water retention and nutrition for sandy soils from a fluid mechanics point of view (**Li *et al.*, 2021**).

Stress Tolerance indices

Results of Fig. 6 show that the highest yielding treatments under normal irrigation (100% ETc) were BCH (23.165 ton/fed) and BCH+ST (26.77 ton/fed), whereas ST alone had the least value (22.845 ton/fed). However under water stress (55% ETc), both BCH (13.36 ton/fed) and BCH+ST (13.91 ton/fed) treatments had the highest fruit yield. Meanwhile, barley straw (ST) treatment gave the least value (11.87 ton/ fed) with the highest reduction percentage (42.9%) comparing with control treatment (without amendments, 20.43 ton/fed). According to the mean productivity index (MP), the highest value of MP recorded by BCH+ST treatment (17.17 ton/fed) as average of both normal and water deficit conditions, whereas, the least value was expressed by barley straw (ST) treatment alone. Treatments that had high yield under normal and stressed irrigation condition, had high values of MP index (**Farshadfar and Sutka, 2002**), while, **Shirazi *et al.* (2009)** stated that the higher yield in the non-stress condition resulted in an increase in the MP index and cannot be considered a valid indicator for identifying treatments that reduce the effect of stress. As shown in Fig. 9 and Table 5, BCH+ST amendment treatment followed by BCH treatment recorded the highest RDI, STI, GMP, YI, DI, K_1STI and K_2STI as compared with other amendment treatments suggesting more stress tolerance mechanism, where, treatments exhibited high values of STI showed high MP and GMP. Moreover, STI was more useful index in order to select favorable treatments under stress and non-stress conditions (**Moghaddam and Hadi-Zadeh 2002**). Therefore, selection based on STI might lead to high-yielding treatments (**Abdelghany *et al.*, 2016)**.

Based on the STI under drought tolerance of 55% of ETc, treatments were classified into three groups: highly tolerant to drought stress (2, HT), susceptible (1, S) and highly susceptible (1, HS) (Table 5). The stress tolerance index (STI) does not take into account the low relative yield under drought stress, thus a treatment classified as highly tolerant based on the STI value may have a high percentage of yield decrease under drought stress which is undesirable. Therefore, the classification of the three classes of drought tolerance based on the STI value was improved by incorporating the relative decrease in yield under the drought (RDY) index (Table 6).

The selection methods involving the two selection criteria, STI and RDY are presented in Table 6. Based on this selection mode of the 4 treatments evaluated (including the control), two were drought tolerant and two highly drought susceptible. Based on the yield category, treatments classified into three groups: high (2, BCH and BCH+ST), moderate (1, ST) and low (1, without amendments) yield/ feddan.

As for moderate drought stress condition (75% ETc), based on the stress tolerance indices values and productivity (Fig.10), the treatments exhibited more improvements under 75% ETc drought stress condition comparing with 55% ETc. Comparison between the two drought stress levels (D_H and D_M) shows the extent of improvement in the 75% ETc (D_M). However, the yield of ST, BCH and BCH+ST treated under 75% ETc increment by 16.26, 17.7 and 23.62%, respectively compare with their productivity under 55% ETc (D_H) drought stress which caused it to be improved to a higher yield categories level (Table 5 and Fig. 10).

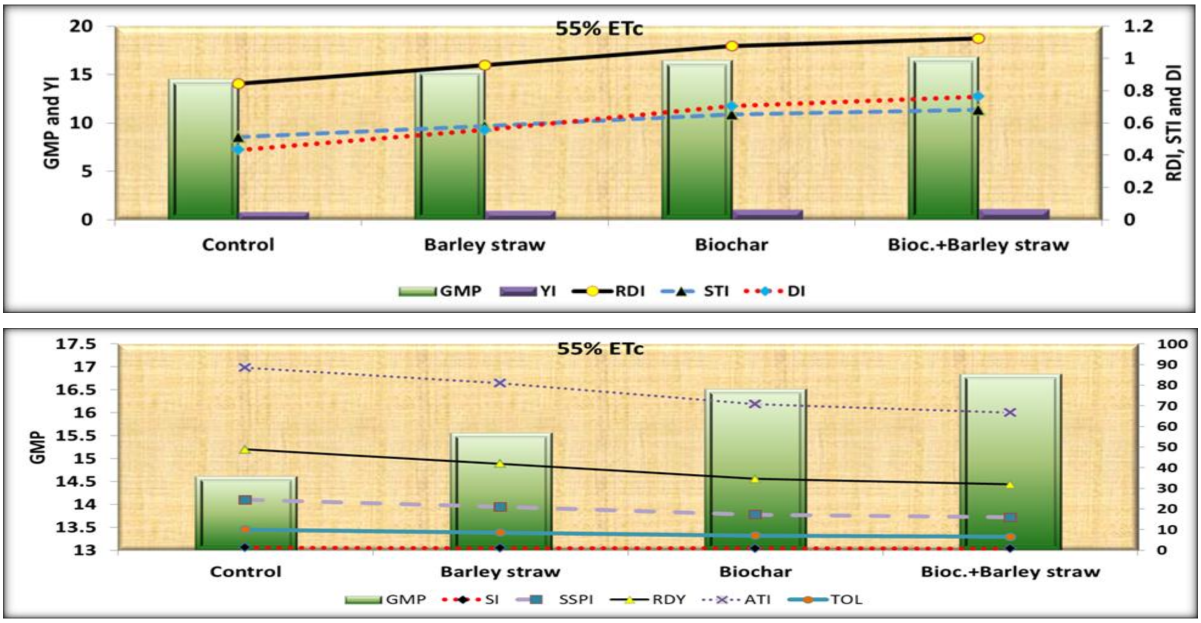


Fig. 9. Drought tolerance indices of yield under non-stress and 55% ETc drought stress (average of both seasons)

Table 5. Drought tolerance indices for leaf area (m^2), average fruit weight (g) and total fruit yield (ton/fed.) under high drought, D_H (55% ETc) stress conditions (average of both seasons)

Item	RDI	STI	GMP	TOL	YI	DI	SSPI	RDY	ATI	K_1STI	K_2STI	SI
Leaf area (m^2)												
Control	0.86	0.46	1.41	1.12	0.86	0.4	26.93	53.86	0.84	0.46	0.34	1.16
ST	1.03	0.55	1.54	0.93	1.03	0.57	22.34	44.69	0.76	0.55	0.59	0.96
BCH	1.05	0.56	1.55	0.91	1.05	0.59	21.86	43.72	0.75	0.56	0.62	0.94
BCH+ST	1.06	0.57	1.56	0.89	1.06	0.61	21.50	43.00	0.75	0.57	0.64	0.93
Average fruit weight (g)												
Control	0.96	0.77	78.16	20.04	0.96	0.74	11.28	22.56	1,263.39	0.77	0.71	1.17
ST	0.99	0.79	79.18	18.23	0.99	0.78	10.26	20.53	1,164.56	0.79	0.77	1.06
BCH	1.02	0.82	80.41	16.02	1.02	0.83	9.02	18.04	1,039.28	0.82	0.85	0.93
BCH+ST	1.04	0.84	81.33	14.35	1.04	0.87	8.08	16.15	941.26	0.84	0.91	0.84
Total fruit weight(ton/fed.)												
Control	0.84	0.51	14.61	9.98	0.84	0.43	24.41	48.83	88.47	0.51	0.36	1.24
ST	0.96	0.58	15.57	8.56	0.96	0.56	20.95	41.9	80.9	0.58	0.53	1.07
BCH	1.08	0.65	16.52	7.07	1.08	0.70	17.30	34.61	70.89	0.65	0.76	0.88
BCH+ST	1.12	0.68	16.86	6.52	1.12	0.76	15.96	31.91	66.70	0.68	0.86	0.81

Table 6. Mode for classifying treatments into four classes of drought resistance degree

STI classification	Range of RDY	Selection
HT	<25 %	Highly drought Tolerant
	>25<50 %	Tolerant
	>50<75 %	Susceptible
	>75<100 %	Highly susceptible
T	<25 %	Tolerant
	>25<50 %	Susceptible
	>50<75 %	Highly susceptible
	>75<100 %	Highly susceptible
S	<25 %	susceptible
	>25<50 %	Highly susceptible
	>50<75 %	Highly susceptible
	>75<100 %	Highly susceptible
HS	<25 %	Highly susceptible
	>25<50 %	Highly susceptible
	>50<75 %	Highly susceptible
	>75<100 %	Highly susceptible

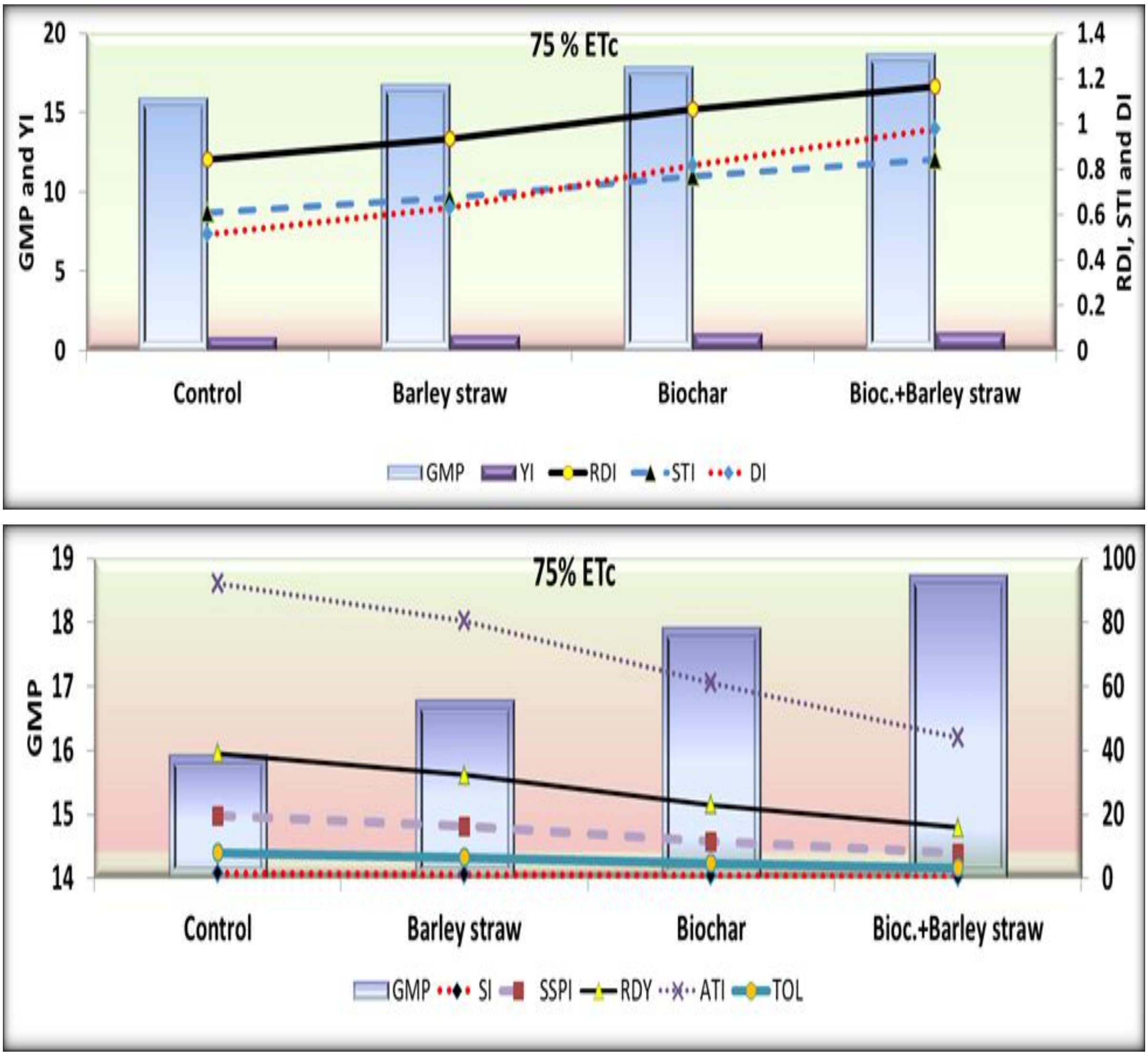


Fig. 10. Drought tolerance indices of yield under non-stress and 75% ETc stress conditions (average of both seasons)

Cluster Analysis

Construction of dendrogram based on 12 drought tolerance indices, leaf area, average fruit weight and fruit yield (ton/fed) under non-stress, D_H (55% ETc) and D_M (75% ETc) drought conditions was illustrated in Fig. 11. As for fruit yield (ton/fed) under non-stress and D_H drought (55% ETc) conditions, the 4-amendment treatments splited into two main clusters (Fig. 11, down). Cluster I contained stress tolerant treatments that had low value of stress susceptibility (ATI, TOL, SI and SSPI as well as RDY >25<50) and high value of GMP, DI, MK_1, MK_2, YI, RDI and STI tolerance indices (Biochar and Biochar + ST) in which the yield of amended drought treatments (13.36 and 13.91 ton/fed) exceeded corresponding control of stress one (10.455 ton/fed) by 27.8 and 33%, respectively (Figs. 6 and 11), where the GS-12 genotype in cluster I had a moderate performance in both environments than any other treatments tested in this study. Moreover, both amendment treatments exhibited moderate yield (under the two conditions) and dependable drought tolerance indices such as STI, GMP, YI, DI and MP. Therefore, this group was considered as the most desirable cluster for both growth conditions. This implies that selecting for those indices will provide preference of the plant with those amendment treatments in this cluster over others (**Ene *et al*., 2016**). However, this classification was in accordance with the results of **Farshadfar *et al*., (2012)** as well as **Eid and Sabry, 2019).** Cluster II in the reverse trend of tolerant-group contained both ST and the control as highly sensitive treatment. These treatments were characterized by low-yield performance and moderate for both leaf area and average fruit weight under non-stress conditions. Both amendments clustered in cluster II had high values of SSPI, ATI, SI and TOL low values of STI and GMP. Therefore, they were identified as high-sensitive treatments to moisture stress with least stability performance. Hence, plants clustered in this group performed poorly under both growth conditions. However, this classification was in paralleled with the results of **Farshadfar *et al.* (2012**). As for 75% ETc moderate drought stress (D_M), construction of dendrogram based on abovementioned 12 drought tolerance indices and yield under non-stress and 75% ETc drought conditions (D_M) was illustrated in Table 7 and Figs. 10 and 11 (Right).

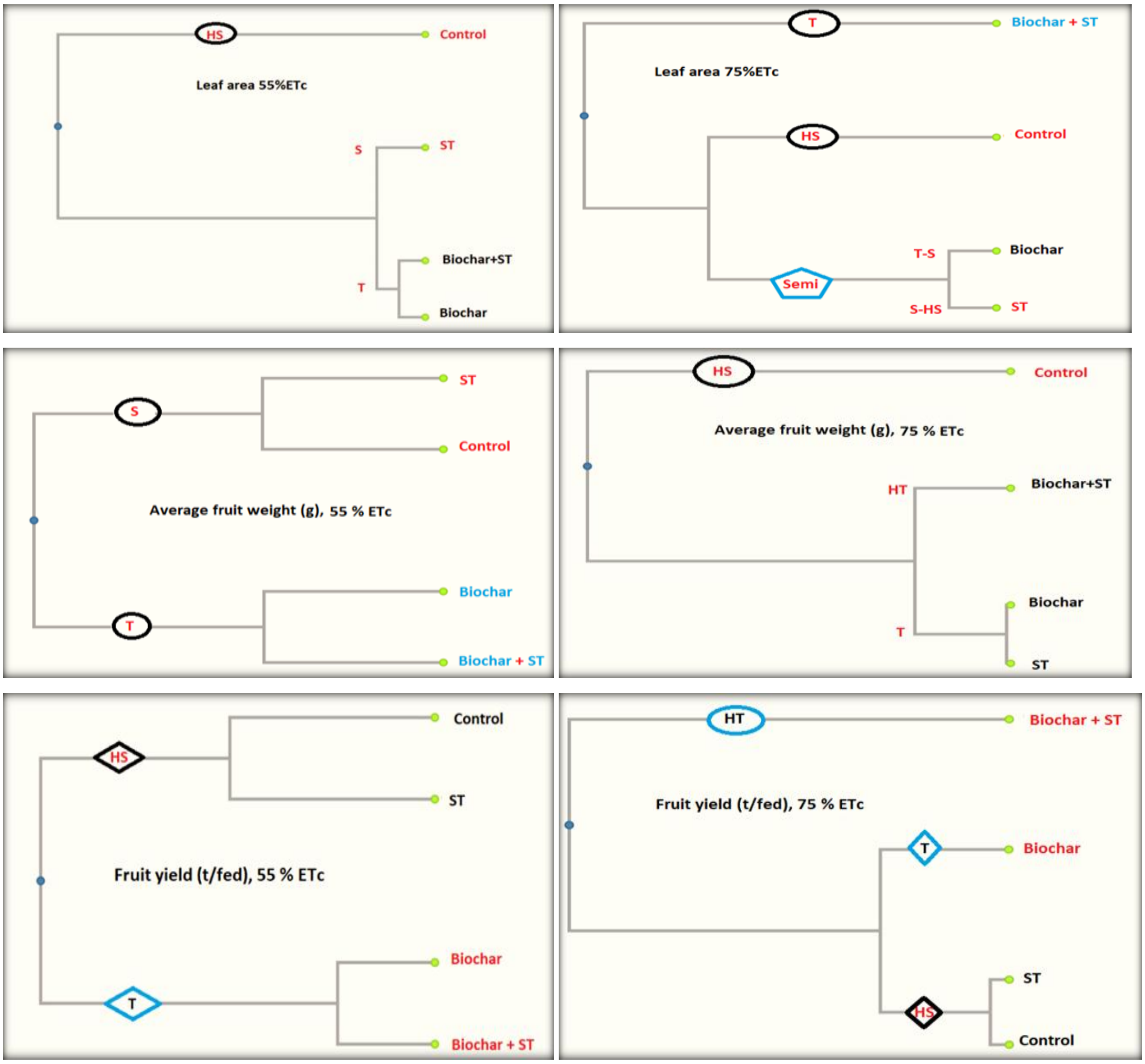
The four amendment treatments split into three main clusters. Cluster I contained high tolerant amendment treatments that had low value of stress susceptibility (TOL, SSPI, RDY (<25), ATI and SI) and high value of DI, YI and STI, K_1STI, K_2STI, GMP and tolerance indices (Fig. 11), *i.e.*, Biochar+ barly straw treatment (improved from T under D_H to HT under D_M). The amendment treatments in this cluster exhibited a higher performance in both environments than any other treatment tested in this study.

Moreover, these treatments had high yield under both conditions as well as dependable drought tolerance indices such as GMP, STI, YI and DI. Therefore, this group was considered as the most desirable cluster for both growth conditions. This implies that selecting for those indices will provide preference of the biochar plus barley straw amendment treatment in this cluster over others (**Ene *et al*., 2016**). However, this classification was in accordance with the results of **Farshadfar**

***et al*. (2012)** as well as **Eid** and **Sabry (2019).** Cluster II contained tolerant (Biochar) treatment that had high value of tolerance indices (DI, YI, STI and RDY <25), while cluster III include both barley straw (ST) and control treatments those had high values of stress susceptibility (ATI, TOL, SSPI and RDY >25<50). Treatment with biochar alone had median values of yield under both moisture regimes (100% and 75% ETc). Only two treatments made the cluster III, including the highly sensitive effect of drought, with the lowest performance in terms of stability. Hence, plants grouped in this cluster gave low yield under both growing conditions. Cluster analysis has been used in many studies to classify treatments according to their plants' response to drought. Several authors such as **Farshadfar *et al*. (2013)** and **Mursalova *et al*. (2015)** concluded that cluster analysis based on indicators of drought tolerance and yield under drought stress and non-stress conditions is appropriate for selecting drought-tolerant crops.

Table 7. Drought tolerance indices for leaf area(m^2), average fruit weight(g) and total fruit yield (ton/fed.) under moderate drought, D_M (75% ETc) stress conditions (average of both seasons)

Item	RDI	STI	GMP	TOL	YI	DI	SSPI	RDY	ATI	K_1STI	K_2STI	SI
						Leaf area (m^2)						
Control	**0.87**	0.51	1.48	1.02	0.87	0.44	24.52	49.03	0.88	0.51	0.39	1.18
ST	**0.99**	0.58	1.57	0.88	0.99	0.57	21.14	42.27	0.81	0.58	0.56	1.02
BCH	**1.01**	0.59	1.59	0.85	1.01	0.59	20.53	41.06	0.79	0.59	0.60	0.99
BCH+ST	**1.14**	0.66	1.69	0.70	1.14	0.75	16.79	33.57	0.69	0.66	0.86	0.81
						Average fruit weight (g)						
Control	**0.93**	0.85	82.00	13.11	0.93	0.79	7.38	14.76	986.57	0.85	0.73	1.80
ST	**1.02**	0.93	85.80	5.93	1.02	0.95	3.34	6.67	466.72	0.93	0.96	0.81
BCH	**1.02**	0.93	85.84	5.85	1.02	0.95	3.30	6.59	461.40	0.93	0.97	0.80
BCH+ST	**1.04**	0.95	86.68	4.22	1.04	0.99	2.38	4.76	336.20	0.95	1.03	0.58
						Total fruit yield (ton/fed.)						
Control	**0.84**	0.61	15.94	7.99	0.84	0.51	19.55	39.11	92.21	0.61	0.43	1.42
ST	**0.93**	0.68	16.79	6.63	0.93	0.63	16.23	32.45	80.59	0.68	0.59	1.18
BCH	**1.06**	0.77	17.92	4.71	1.06	0.82	11.51	23.03	61.05	0.77	0.87	0.83
BCH+ST	**1.16**	0.84	18.74	3.24	1.16	0.98	7.92	15.83	43.89	0.84	1.14	0.57



D_H **D_M**

Fig. 11. Dendrogram of four amendment treatments based on cluster analysis showing classification based on leaf area, average fruit weight and total fruit yield as well as both 55%(D_H) and 75%(D_M) ETc drought tolerance indices

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الملخص العربي

استجابة نباتات الطماطم تحت الإجهاد المائي لمحسنات التربة العضوية

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أجريت تجربتان حقليتان خلال موسمين صيفيين متتاليين لعامي 2019 و2020 بالمزرعة البحثية لكلية العلوم الزراعية البيئية، جامعة العريش، شمال سيناء لدراسة تأثير إجهاد الجفاف (100% و85% و75% و55% من الاحتياجات المائية) والمحسنات العضوية للتربة (الفحم الحيوي وتبن الشعير) على علاقة التربة بالمياه وكذلك نمو وإنتاجية وجودة الطماطم. تم تقييم ثلاث قياسات رئيسية لرطوبة التربة. وقد أظهرت معاملة الفحم + قش الشعير أعلى زيادة تحت جميع مستويات الرى لصفات علاقة الماء الثلاثة مع عدم وجود فروق معنوية بين معاملتى الفحم و(الفحم+القش). كما كانت معاملتي الفحم و(الفحم + القش) هي أعلى المعاملات محصولا ثمريا في ظل الإجهاد المائي (55٪ ETc). أما بالنسبة لمؤشرات تحمل الإجهاد، فقد سجلت معاملة الفحم + القش يليها معاملة الفحم بمفرده أعلى مستويات RDI وSTI وGMP وYI وDI وK_1STI وK_2STI مما يشير إلى مزيد من آلية تحمل الإجهاد. بناءً على فئة المحصول، تم تصنيف المعاملات إلى ثلاث مجموعات: عالي، متوسط، منخفض المحصول/ فدان. كانت اعلى إنتاجية للطماطم صنف جى اس ١٢ في تربة طينية رملية تحت الري بنسبة 75٪ من ETc أعطت زيادة في المحصول مقارنة مع إنتاجيتهم تحت إجهاد الجفاف بنسبة 55 ٪ ETc الذي تسبب في تحسينه إلى عائد أعلى مستوى الفئات. تم استخدام التحليل العنقودي لتصنيف المعاملات وفقًا لاستجابة نباتاتها للجفاف. وتم إنشاء مخطط شجري بناءً على 12 مؤشراً لتحمل الجفاف تحت ظروف الري العادي (عدم الإجهاد) وظروف الجفاف المرتفعة (55٪ ETc) والمتوسطة (75٪ ETc) وقد أكد التحليل العنقودي مدى مطابقة النتائج وتوضيح مدى التحسن عند الزراعة في مستوى 75٪ ETc. بناءً على محصول الثمار (طن/ فدان) في ظل مقارنة الري العادي مع جفاف مرتفع (55٪ ETc)، وانقسمت معاملات تعديل التربة الأربعة إلى مجموعتين رئيسيتين. احتوت المجموعة الأولى على معاملة تحمل الإجهاد وهي المعاملة الى اعطت قيم منخفضة للحساسية للاجهاد (الفحم، الفحم والقش معا) واعتبرت المجموعة الأكثر استحسانًا لكل من ظروف النمو. اما المجموعة الثانية فكانت في الاتجاه العكسي للمجموعة المتحملة وكان أداؤها ضعيفًا في ظل ظروف النمو. لذلك، تؤكد هذه الدراسة مساهمة البيوتشار في استدامة الزراعة والحفاظ على المياه.

الكلمات الاسترشادية: طماطم، الاجهاد المائي، الفحم الحيوى، قش الشعير.

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