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Research Article

Evaluation of remobilization rate, grain yield and antioxidant content of maize in reaction to biochar and humic acid amounts under water deficiency stress

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Abstract

In order to investigate the effect of biochar and humic acid on the rate of remobilization, grain yield and antioxidant content of maize under water deficiency stress, an experiment was conducted as asplit-split plot in the form of a randomized complete blocks design with three replications in Ahvaz, southwest of Iran. The main plot involved water stress with three irrigation levels after depleting 30, 40 and 50% of field capacity, non-stress, moderate stress, and severe stress, respectively, asubplot withbiochar with 2 control levels (no use of biochar) and application of 4 tons in biochar hectares and another subplot having humic acid with 4 control levels (no use of humic acid) and application of 2, 4 and 6 liters per hectare of humic acid. The results showed that the effect of water deficit stress, biochar and humic acid on grain yield, remobilization rate, current photosynthesis, share of current photosynthesis, catalase and superoxide dismutase enzymes was significant at the level of 1% probability. The highest grain yield was related to irrigation treatment after depleting 40% of field capacity and application of 4 tons per hectare of biochar. In total, the use of 4 liters per hectare of humic acid in moderate moisture stress conditions due to its positive role on the growth and hence on the 42% increase in the yield, compared to severe stress treatment and no consumption of humic acid, can be recommended under arid and semi-arid conditions to save water consumption, and reduce the effects of water deficit stress.

Keywords: antioxidant activity; catalase enzyme; grain yield; photosynthesis; water stress

Introduction

Corn (*Zea mays* L.) is one of the most important crops that ranks first in terms of production among cereals (FAO, 2018). Water deficit stress is one of the limiting factors of production in crops such as corn. Some plant growth stages are highly sensitive to water deficiency. With regard to corn, the stages of seedling, pollination and grain filling are more sensitive to water deficiency (Lobell *et al.*, 2014). Water stress causes a range of physiological and biochemical reactions in plants. Water stress disrupts crop growth by disrupting plant water relations, altering carbohydrate metabolism, and changing enzyme structure (Anjum *et al.*, 2017; Amiri *et al.*, 2017). The researchers stated that when the plant suffers from stresses caused by food and

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moisture, the current photosynthesis decreases. In order to compensate for this, the plant increases the transfer of dry matter to the seeds (Bahrani *et al.*, 2011; Hosseinzadeh *et al.*, 2016). Restriction of soil moisture by decreasing leaf area and consequently reducing current photosynthesis increases the dependence of crop yield on dry matter remobilization sharingprocesses in the grain filling stage (Haghjoo and Bahrani, 2015; Hosseinzadeh and Ahmadpour, 2018).

One of the reasons that environmental stresses such as dehydration decrease the growth and the ability of the plant is the imbalance between the production of oxygen free radicals and the defense mechanisms that eliminate these radicals. This in turn would lead to the accumulation of reactive oxygen species (ROS), induce oxidative stress, and also would end up in damaging proteins, lipids and other cellular components.

Organic matter is one of the important soil modifiers and improves the physical, chemical, and biological properties of soils. Biochar is a carbon-rich product that is produced during the thermal decomposition of biomasses such as wood, fertilizers, leaves, straw and stubble residues, and agricultural waste under anaerobic or low-anaerobic conditions, which is calledpurolysis (Lehmann *et al.*, 2006; Ahmadpour and Armand, 2020). The amount of water absorbed depends directly on the specific level of biochar, and therefore the application of biochar in the soil causes the absorption of large amounts of water (Karim *et al.*, 2020). By providing the amount of water required for the growth and production of dry matter, biochar reduces the rate of plant remobilization by increasing biomass and synthetic production and allocating these materials to shoots and seeds (Ullah *et al.*, 2018).

The use of natural fertilizers without harmful environmental effects can be fruitful in order to increase plant yield, especially under changing environmental conditions. Among these nature-friendly natural fertilizers are thehumic substances (Pakdaman *et al.*, 2018). In a study examining the effect of humic acid consumption on corn yield and yield components of maize, it wasreported that organic compound such as humic acid and fulvic acid as an organic acid play a very important role in increasing moisture retention, grain yield, and other quantitative and qualitative traits in crops (Azeem *et al.*, 2021). Attarzadeh et al. (2013) suggested that consuming higher amounts of humic acid in terms of producing more leaf area and increasing material stored in the stem increased the transfer rate compared to lower amounts of humic acid consumption.

In this context, the aim of the present study is to investigate the effects of humic acid and biochar on the rate of remobilization and water use efficiency of maize in water deficit stress conditions.

Materials and Methods

Experimental design, treatments, and crop management

This experiment was performed in the city of Ahvaz located in southwestern Iran with a latitude (31º20'52" North and 48º40'31" East) and an altitude of 22.5 meters above sea level. This region has a hot and humid climate and hot summers and Mediterranean winters. The average annual rainfall is 250 mm. The minimum temperature in winter is 3 °C and the maximum temperature in summer is 49 °C (Figure 1).

In order to determine the physical and chemical properties of the soil in the area, before planting, random sampling was done from three points of the field from a depth of zero to 30 cm. Then, the samples were transferred to the soil laboratory for chemical and physical analysis and the desired parameters in the soil were determined using conventional laboratory methods.

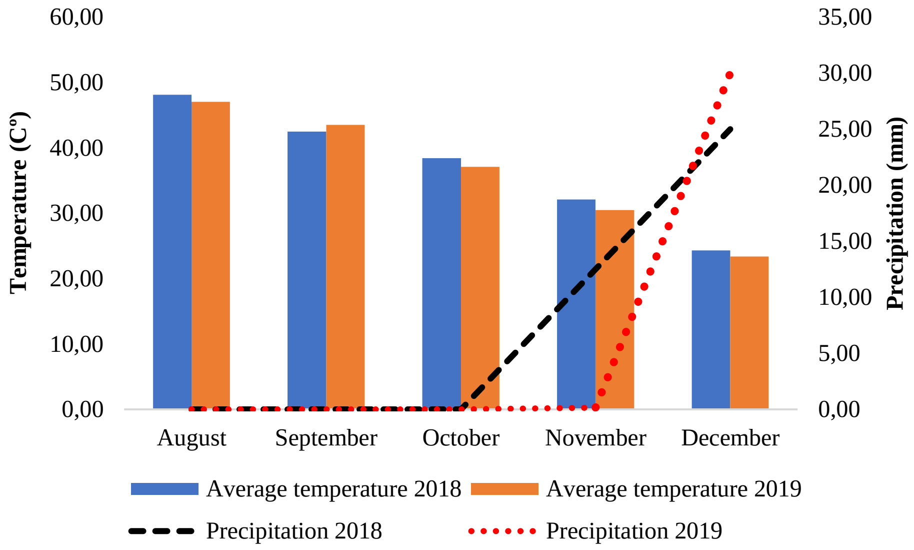

Figure 1. Meteorological data of Ahwaz (2018-2019)

Biochar was produced in such a way that sugarcane bagasse, after preparation, was washed several times with water and dried in the open air. After grinding, it was poured into special containers with lids and placed in the oven for four hours at a rate of 20 degrees Celsius per minute, then the oven was set at 300 degrees Celsius and the sugarcane bagasse was converted to biochar at this temperature (Yuan *et al.*, 2011). Physical and chemical properties of test soil and biochar are presented in Tables 1 and 2.

Table 1. Chemical characteristics and some other important properties of the soil of tested field

Crop year	Depth of soil	Soil texture	pH	EC	Organic matter	K	P	N	Z	Fe
	(cm)			(dc/m)	(%)	(ppm)				
2017-2018	0-30	Sandy Loam	7.51	3.94	0.73	188	12.2	0.42	0.7	1.2
2018-2019	0-30	Sandy Loam	7.12	3.74	0.62	175	11.04	0.38	0.51	1.14

Table 2. Chemical characteristics and some other important properties of biochar

pH	EC	Organic carbon	H	N
	(ds.m^{-1})	(%)		
4.83	3.88	64.45	4.88	0.53

This study was conducted as a split-split plot in the form of a randomized complete blocks design with three replications in maize in the summer of two cropping years 2017-18 and 2018-19. Main plot consists of water shortage stress with three irrigation levels after depleting 30, 40 and 50% of field capacity, optimum irrigation, moderate stress, and severe stress, respectively, subplot including biochar with 2 control levels (no use of biochar) and application of 4 tons in biochar hectares and sub-plots having humic acid with 4 control levels (no use of humic acid), application of 2, 4 and 6 liters per hectare of humic acid. The experiment consisted of 72 plots. Each experimental plot was six meters long and had seven planting lines with a distance of 75 cm and a plant spacing of 17 cm with a density of 75,000 plants per hectare. The distance between the two sub-plots was one meter (equivalent to one planting line) and the distance between the main plots was 1.5 meters.

Irrigation planning

Up to the five-leaf stage, irrigations were performed based on depleting 30% of moisture from the soil field capacity according to the depth of root development (50 cm) in all treatments and from this stage onwards, water stress treatments were applied in the field. The stress application time took about 60 days starting from 30 days after planting to about 25 days before harvest. In order to determine the exact time of irrigation in each treatment, 48 hours after each irrigation, sampling was done using field soil agar at the depth of root development. Irrigation was done when the weight moisture of the soil in different treatments reached the desired percentage, then the volume of irrigation water required for each treatment was calculated from the following equation (Hoffman *et al.*, 1990). V= (Fc-m)×pb×Droot×A/Ei The parameters are: V = Volume of irrigation water in cubic meters, Fc = percentage of weight moisture at field capacity, ϴm = percentage of weight moisture before irrigation, Pb = bulk density of soil in grams per cubic centimetre, A = Irrigated area in square meters, Droot = depth of root development in meters.

Measuring traits

The maturity of the grains was determined by creating a black layer at the base of the grains and the final harvest was done by removing 50 cm from the beginning and end of the lines from a surface equivalent to two square meters. In order to measure the grain yield in each experimental plot, after removing 0.5 m from both ends of the lines, all the ears in the three middle lines with a length of two meters were harvested manually and after drying in the oven, the grains were separated manually, and cleaning was done with 14% weight moisture. The antioxidant enzymes activity was measured at the full flowering stage. The samples were prepared from fresh leaves and then frozen in liquid N and stored at -80 °C till biochemical analysis. The catalase activity was measured by Boominathan and Doran method (2002), at the flowering stage.

Plants are possessed with an effective defense system to deal with oxidative stress, which encompasses catalase and superoxide dismutase (Gill and Tuteja, 2010).

The amount and share of remobilization and the amount and share of current photosynthesis were also calculated from the following formulas (Papakosta and Gagianas, 1991). Dry weight of vegetative organs in stage – maximum dry matter yield of vegetative organs (g/m^2) = amount of dry matter in physiological remobilization (g/m^2). Share of remobilization process in grain yield (%) = Dry matter weight in remobilization process (g/m^2)/grain yield (g/m^2) × 100. Weight of dry matter in remobilization process (g/m^2) - grain yield (g/m^2) = Weight of dry matter resulting from current photosynthesis (g/m^2). Share of remobilization in grain yield - 100 = share of current photosynthesis in grain yield. Water use efficiency was calculated using the following formula (Hoffman *et al.*, 1990). Economic efficiency of water consumption (kg/m^3) = Grain yield (kg/hec)/Total volume of water consumption (m^3/hec).

Statistical analysis

At the end of this study, in order to analyse the combined variance of the data after Bartlett test, the statistical model of split plot design in site per year was used. Data analysis of variance was performed by SAS statistical software and LSD test was used to compare the means at the level of 5% probability.

Results and Discussion

According to the analysis of variance of grain yield, the grain yield of water shortage stress, biochar and humic acid treatments and their interactions showed a significant response (Table 3). The highest grain yield was obtained from the application of 4 tons per hectare of biochar under irrigation conditions after 30% of field capacity (which did not show any statistically significant difference from the application of 4 tons per hectare of biochar in terms of irrigation after depleting 40% of field capacity), and the lowest grain yield was obtained from the non-application of biochar in irrigation conditions after depleting 50% of field capacity, which showed a decrease of 40% compared to the maximum treatment (Figure 2). In this study, the plant in moderate water stress conditions, compared to suitable irrigation conditions through biochar, was able to tolerate the lack of available water well without reducing yield. Biochar with its many pores on its surface helps to better retain water, hence it is possible to use biochar instead of irrigation after depleting 30% of crop capacity, and irrigation after depleting 40% of crop capacity can be used to grow corn. Application of 10 tons per hectare of biochar, compared to its non-application, increased grain yield by 56%, improved soil properties and increased wheat biomass (Mahmoud *et al.*, 2019). The highest grain yield was obtained from irrigation treatment after the depletion of 30% of field capacity and application of 6 liters per hectare of humic acid, which increased by 42% compared to irrigation treatment after the depletion of 50% of field capacity and non-application of humic acid (Table 4).

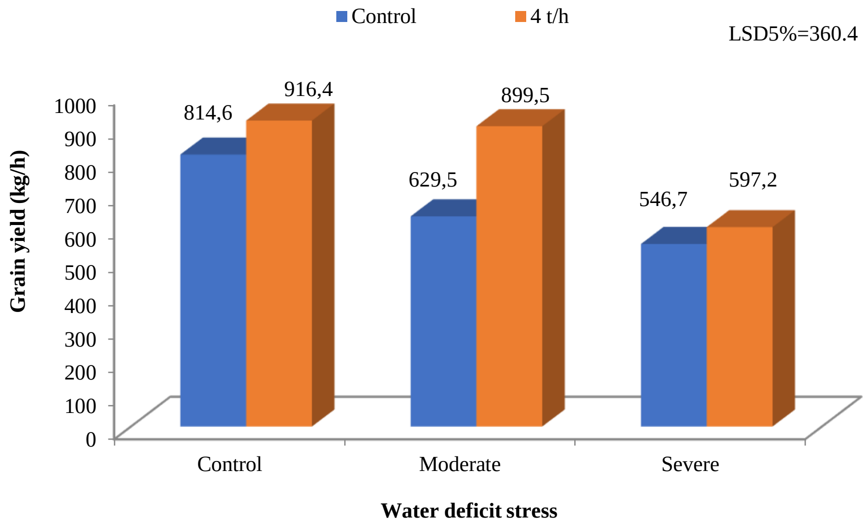

Figure 2. Interactions effects of water deficit stress and biochar on grain yield

Table 3. Analysis of variance for the effects of year (Y), replication (R), water deficit stress (ws), biochar rates (b) and humic acid (h) on grain yield (GY), water use efficiency (WUE), catalase (CAT), superoxide dismutase (SOD), current photosynthesis (CP), current photosynthesis contribution (CPC), remobilization (R) and remobilization contribution (RC) in corn in two crop years.

Treatments	Levels	Grain yield (g/m^{-2})	WUE (g/m^2)	CAT (uM H_2O_2/mg protein)	SOD (U/mg protein)	CP (g/m^2)	CPC (%)	R (g/m^2)	RC (%)
Years	2018	665.8	1.40	115.8	501.5	507.7	76.26	158.1	23.74
	2019	802.2	1.68	85.8	367.3	628.6	78.36	173.6	21.64
LSD 0.05		71.05	0.11	3.31	23.2	30.17	2.5	2.98	0.63
Drought stress(D)	Control	900.34	1.82	71.1	334.7	733.9	81.5	166.4	18.5
	Moderate	727.01	1.58	100.3	431.0	548.5	75.4	178.6	24.6
	Severe	575.06	1.23	131.0	537.3	420.0	72.9	155.6	27.1
LSD 0.05		45.17	0.07	4.85	19.13	34.0	1.17	3.11	0.88
Biochar (t/h)	0	647.5	1.30	128.7	525.2	473.0	73.1	175.5	26.9
	4	820.5	1.78	72.9	343.6	661.3	80.6	159.2	19.4
LSD 0.05		71.05	0.11	3.31	23.2	30.17	1.23	2.98	0.63
Humic acid	0	560.05	1.19	66.9	304.1	403.5	71.9	157.2	28.1

(t/h)	2	601.03	1.34	90.7	400.2	440.9	73.3	160.4	26.7
	4	880.01	1.81	121.3	514.2	706.1	80.3	174.1	19.7
	6	895.2	1.82	124.6	519.1	719.2	80.3	176.1	19.7
LSD 0.05		18.2	0.05	4.52	27.83	33.1	1.01	3.01	0.46
Analysis of variance									
Years (Y)		P≤0.01	P≤0.01	P≤0.01	P≤0.01	P≤0.01	ns	P≤0.01	P≤0.01
Drought stress(D)		P≤0.01	P≤0.01	P≤0.01	P≤0.01	P≤0.01	P≤0.01	P≤0.01	P≤0.05
Biochar(B)		P≤0.01	P≤0.01	P≤0.01	P≤0.01	P≤0.01	P≤0.01	P≤0.01	P≤0.05
Humic acid (H)		P≤0.01	ns	P≤0.01	P≤0.01	P≤0.01	P≤0.01	P≤0.01	P≤0.05
Y×D		ns	ns	ns	ns	ns	ns	ns	ns
Y×B		ns	ns	ns	ns	ns	ns	ns	ns
D×B		P≤0.01	P≤0.01	P≤0.01	P≤0.01	ns	ns	ns	ns
Y×H		ns	ns	ns	ns	ns	ns	ns	ns
D×H		P≤0.01	P≤0.01	P≤0.01	P≤0.01	ns	ns	ns	ns
B×H		ns	ns	ns	ns	ns	ns	ns	ns
Y×D×B		ns	ns	ns	ns	ns	ns	ns	ns
Y×D×H		ns	ns	ns	ns	ns	ns	ns	ns
Y×B×H		ns	ns	ns	ns	ns	ns	ns	ns
D×B×H		ns	ns	ns	ns	ns	ns	ns	ns
Y×D×B×H		ns	ns	ns	ns	ns	ns	ns	ns
Coefficient of variation (%)		16.0	17.1	9.9	11.2	12.3	5.5	6.7	18.3

*P≤0.05; **P≤0.01; ns, not significant.

Table 4. Grain yield (GY), water use efficiency (WUE), catalase (CAT)and superoxide dismutase (SOD) of corn influenced by water deficit stress × humic acid

Drought stress	Humic acid (t/h)	Grain yield (g/m^{-2})	WUE (g/m^2)	CAT (uM H_2O_2/mg protein)	SOD (U/mg protein)
Control	0	736.2	1.60	65.2	310.11
	2	800.04	1.67	72.19	330.04
	4	924.3	1.81	88.06	381.45
	6	970.03	1.83	91.25	386.1
Moderate	0	610.5	1.50	89.38	394.06
	2	660.32	1.54	96.04	457.3
	4	732.91	1.70	117.56	483.25
	6	967.42	1.81	120.2	495.13
Severe	0	561.83	1.14	102.35	438.04
	2	596.05	1.24	110.02	480.16
	4	621.27	1.33	127.25	527.02
	6	629.1	1.41	130.14	530.11
LSD 0.05		33.06	0.06	4.02	31.43

Increased grain yield indicates the ability of humic acid to affect the reproductive process of the plant in water stress conditions. It seems that different levels of humic acid increased grain yield by providing nutrients (Wang *et al.*, 2014). The trend of the grain yield increase under water deficiency stress in response to humic acid may be related to the increased chlorophyll content, changes in minerals, and the protective role of membranes that increase plant tolerance to water stress damage (Hoekman *et al.*, 2012), which was consistent with the results of this study.

According to the results of the combined analysis of variance (Table 3), the effect of water deficit stress, biochar and humic acid and the interaction of the effects of water shortage stress and biochar and water shortage stress and humic acid on the economic efficiency of water consumption were significant at the level of 1% probability. The lowest economic efficiency of water consumption was obtained from irrigation treatment after the depletion of 50% of field capacity, which compared to irrigation after the depletion of 30% of field capacity decreased by about 32% (Table 3). The reason for the decrease in economic and biological efficiency of water consumption under moisture stress conditions was the decrease in grain yield and biological yield under these conditions. In water deficit stress conditions, water use efficiency is affected by stress and decreases since the leaf to stem ratio increases and leaves become small and thick. In this regard, Song et al. (2019) stated that the decrease in water use efficiency under moisture stress conditions is due to a greater reduction in photosynthesis compared to plant respiration. The researchers attributed this to damage to leaf mesophyll due to moisture stress.

In this study, the application of 4 tons per hectare of biochar in irrigation conditions after 30% of field capacity had the highest water use and the lowest water use efficiency was obtained from not using biochar in irrigation conditions after depleting 50% of field capacity (Figure 3). In this study, the addition of biochar to the soil increases the amount of soil water at moderate stress levels. Water holding capacity is due to the high adsorption capacity and porous structure of biochar. Therefore, the use of biochar significantly increases the water status of the plant, which has improved water use efficiency (Hafez *et al.*, 2018). Increasing water use efficiency by adding biochar is also one of the cases reported by other researchers (Kaman *et al.*, 2011). The highest economic efficiency of water consumption in irrigation was after the depletion of 30% of field capacity with consumption of 6 liters per hectare of humic acid and the lowest water use efficiency of irrigation was observed to be after the depletion of 50% of field capacity and no use of humic acid (Table 4). In this study, humic acid molecules form bonds with soil minerals to form an interconnected network that is able to store large volumes of water. The lighter the soil texture, the better the effect. This increases water storage capacity and improves water use efficiency in crops (Azeem *et al.*, 2021).

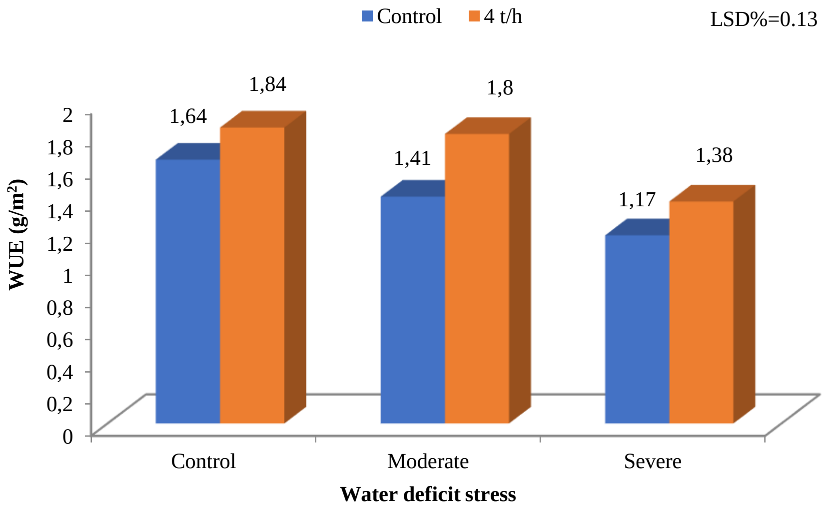

Figure 3. Interactions effects of water deficit stress and biochar on WUE

Two-year combined analysis of variance showed that the effects of water deficit stress, biochar and humic acid and the interaction of water stress and humic acid and water stress and biochar on catalase activity were significant (Table 3). Water deficit stress (irrigation after discharge of 50% of field capacity) increased catalase activity by 45.73% compared to optimal irrigation conditions (Table 3). Mean comparison of the interaction of water deficit stress and biochar on catalase activity showed that the highest catalase activity was obtained from non-application of biochar in irrigation conditions after the depletion of 50% of field capacity and the lowest amount of catalase activity was observed in irrigation conditions after the depletion of 30% of field capacity and application of 4 tons per hectare of biochar (Figure 4).

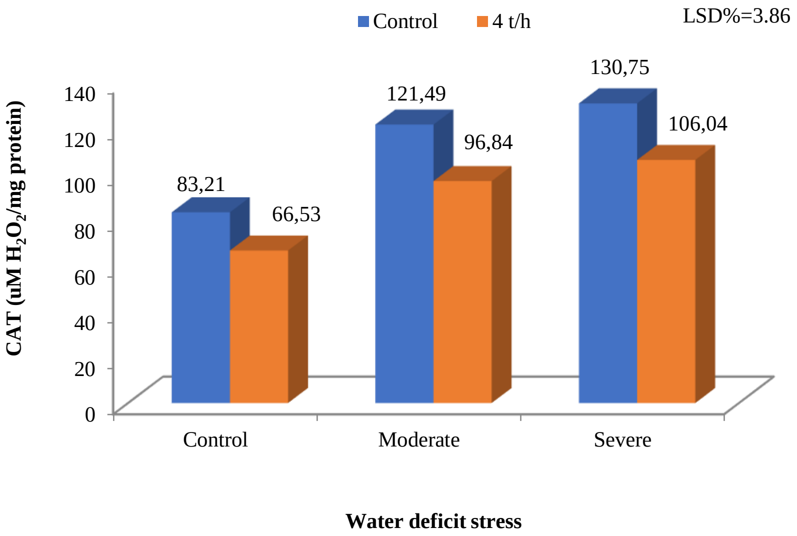

Figure 4. Interactions effects of water deficit stress and biochar on CAT

The catalase enzyme with high molecular weight and a polymeric structure is located in peroxisome and is activated in plant cells when the amount of hydrogen peroxide in the environment is high (Gill and Tuteja, 2010). Excess hydrogen peroxide may inhibit peroxidase activity; hence catalase activity is likely to be under severe stress to maintain peroxidase activity (Ashraf, 2010). Other researchers also report an increase in the enzyme catalase under water deficit stress conditions, which is consistent with the findings of this study (Movludi *et al.*, 2014). Based on the research information on plants in biochar-treated soils, the activity of the antioxidant enzymes such as catalase under water deficit stress increase (Cui *et al.*, 2013). In this study, the highest catalase activity was obtained from irrigation treatment after 50% of field capacity and application of 6 liters per hectare of humic acid (there was no statistically significant difference with irrigation treatment after 50% of field capacity and application of 4 liters per hectare of humic acid), which increased by 49% compared to irrigation treatment after draining 30% of field capacity and non-application of humic acid (Table 4). By increasing the amount of humic acid, the plant's antioxidant system becomes more active and the plant can also resist the damage caused by water shortage stress as the activity of catalase enzyme, which is the first defense barrier against oxygen radicals, increases (Halek *et al.*, 2013). It can be said that, underwater deficit conditions, humic acid increases the amount of catalase as enzymes that convert hydrogen peroxide to water and molecular oxygen in leaves and roots (Tsanaktsidis *et al.*, 2013).

In current research, the highest activity of superoxide dismutase was retrieved from non-application of biochar in irrigation conditions after 50% of field capacity, on the other hand, the lowest activity of superoxide dismutase was obtained in conditions of irrigation after 30% of field capacity and application of 4 tons per hectare of biochar (Figure 5).The effects of water deficit stress was decreased by adding biochar to the soil which was the result of reduced water evaporation and moisture retention in the root environment. This happened largely because if the presence of large biochar pores or improved soil texture which was the result of free radical levels of oxygen and hydrogen peroxide, that in turn ended up in decreasing antioxidant activity (Seyed Sharifi *et al.*, 2020). The highest activity of superoxide dismutase enzyme was obtained from irrigation treatment after depletion of 50% of field capacity and application of 6 liters per hectare of humic acid. When compared to irrigation treatment after depletion of 30% of field capacity and non-application of humic acid increased by

41.5% (Table 7). The increase of antioxidants under the influence of humic acid in water stress conditions reveals the fact that humic acid in stress conditions increases superoxide dismutase as a protective factor and reduces the effects of water deficiency, and therefore the use of humic acid in stress conditions is more useful than using biochar (Pullen and Saeed, 2012).With increasing the amount of humic acid , the plant's antioxidant system becomes more active and by increasing the activity of superoxide dismutase enzyme as the first defense barrier against oxygen radicals, it makes the plant resistant to damage caused by water shortage stress (Halek *et al.*, 2013).

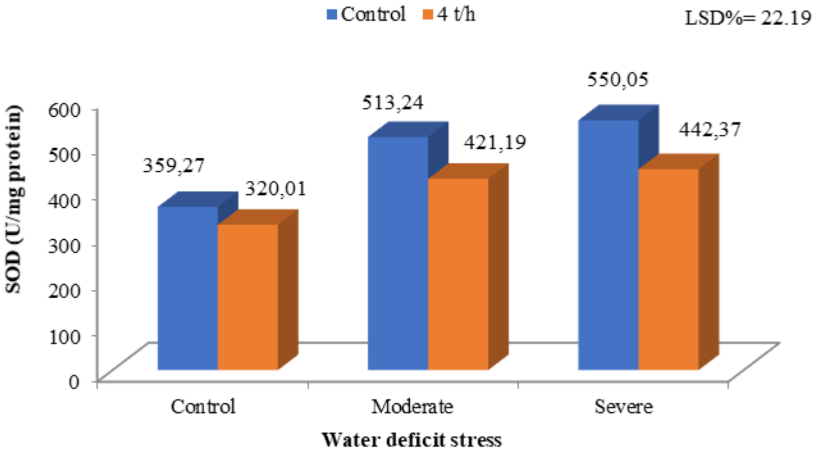

Figure 5. Interactions effects of water deficit stress and biochar on SOD

In this study, the rate of current photosynthesis under the simple effect of water shortage stress, biochar and humic acid stress was significant at the level of 1% probability (Table 3). The highest amount of current photosynthesis was allocated to irrigation treatment after the depletion of 30% of field capacity and the lowest amount of current photosynthesis was allocated to irrigation after the depletion of 50% of field capacity (Table 3). When the plant is exposed to stresses from food and moisture, current photosynthesis decreases and the plant increases the transfer of dry matter to the seeds to compensate for it (Bahrani *et al.*, 2011). Other researchers' observations also point to a decrease in current photosynthesis under water shortage stress conditions (Haghjoo and Bahrani, 2015), which is consistent with the findings of this study. The results showed that the highest rate of current photosynthesis was obtained from the application of 4 tons per hectare of biochar, which showed an increase of about 24% compared to the absence of biochar (Table 3). In this study, the high rate of current photosynthesis in the application of biochar can be attributed to the improvement of soil physical properties, storage of and access to nutrients, and the strengthening of soil biological activities, which leads to increased plant growth and leaf area index. (Abrishamkesh *et al.*, 2017). The highest rate of current photosynthesis was obtained from the treatment of 6 liters per hectare, which was not significantly different from the treatment of 4 liters per hectare of humic acid, while the lowest rate of current photosynthesis was obtained from the non-use of humic acid (Table 3). In this trait, with increasing humic acid, a considerable upward trend was seen in the process of increasing the current photosynthesis. Humic acid increases the current photosynthesis due to the production of more leaf area and its longer persistence by delaying leaf aging (Attarzadeh *et al.*, 2013).

The results showed that the share of current photosynthesis under the effects of water shortage stress, biochar and humic acid was significant at the level of one percent probability (Table 3). The share of current photosynthesis in irrigation conditions after depleting 50% of field capacity compared to non-stress showed about 9% reduction (Table 3). In this study, the share of current photosynthesis in grain yield increases under optimal conditions, but when unfavourable conditions such as drought stress occur, the share of current photosynthesis decreases and the share of photosynthetic remobilization in grain yield increases so that the remobilization functions as modulator and partially compensates for the damage caused by the loss of current photosynthesis. According to Haghjoo and Bahrani (2015), the amount of photosynthetic material produced under stress conditions in the vegetative stage was probably sufficient for the plant, in which case the need for remobilization was reduced, which is consistent with the results of this study. Based on the results of mean comparison (Table 3), the maximum share of current photosynthesis was obtained from 4 tons per hectare of biochar, which increased by about 4% compared to the non-application of biochar. In this study, in the treatment of biochar application, due to the better water and nutrient retention, soil fertility and better plant nutrition, current photosynthesis has the largest share in the weight of the maize kernels, and therefore the use of biochar had the largest share of current photosynthesis as compared to the non-application of biochar. In this regard, Babaei *et al.* (2017) reported that under favourable conditions and access to sufficient resources, as current photosynthesis increases, the balance between source and sink is largely maintained and the materials produced by the source can be used in the sink. However, in stressful conditions such as water constraints, lack of access to nutrients may upset the balance between source and sink. As such, the sink is stronger than the source and due to physiological relations between the source and the sink, the source increases the transfer rate of the dry matter so that it may be able to meet part of the urgent needs of the sinks (grains), which is consistent with the results of this study. The highest share of current photosynthesis was obtained from the treatment of 6 liters per hectare of humic acid, whereas the lowest share of current photosynthesis was obtained from the treatment of no application of humic acid (Table 3). It seems that with the increase of humic acid, more biomass is produced in plant and the share of the reserves of vegetative parts increases and the share of current photosynthesis decreases in the same proportion, which was consistent with the results of Attarzadeh *et al.* (2013).

According to the results of the combined analysis of variance in Table 3, the rate of dry matter remobilization under the effects of water deficit, biochar and humic acid stress treatments was significant at the level of one percent probability. The highest rate of remobilization was obtained from irrigation after the depletion of 30% of field capacity, which increased by about 12.8% compared to irrigation treatment after the depletion of 50% of field capacity (Table 3). In plants under non-stress and irrigation after the depletion of 50% of field capacity (severe stress), high photosynthesis and low storage, respectively, reduced the rate of dry matter remobilization. The efficiency of vegetative parts in dry matter remobilization depends on the dry weight of these organs at the pollination stage. Dry weight of most vegetative parts at this stage leads to greater participation of stored dry matter in remobilization of material into the seeds and improvement of yield under moisture stress conditions (Mahrokh, 2017). The highest rate of remobilization was due to the treatment of 4 tons per hectare of biochar and the lowest rate of remobilization was attributed to the treatment of non-consumption of biochar which decreased by about 8% compared to the treatment of biochar (Table 3). In this research, biochar was able to increase the amount of plant remobilization by providing the amount of water required for the growth and production of dry matter, by increasing biomass and synthetic products and allocating these materials to shoots and seeds. On the other hand, by adding biochar to the soil, the water holding capacity in the soil increases and the plant has access to water for a longer period of time. Moreover, biochar absorbs the nutrients needed by plants and gradually releases them and supplies them to the plant, thus preventing the leaching of these elements, so the conditions for improving biomass in water stress conditions are provided and this increases the rate of plant remobilization, which was consistent with the results of Ullah *et al.* (2018). The highest rate of remobilization was obtained from the treatment of 6 liters per hectare of humic acid and the lowest rate of remobilization was obtained from the non-application of humic acid (Table 3). In this study, with the increase of humic acid, a significant upward trend was seen in the trend of increasing the redistribution rate. Application of humic acid accelerates leaf growth and storage of photosynthetic material and is transferred to the seed when filled. At lower levels of fertilizer, leaf growth is slow and it is not possible to increase the rate of remobilization.

In this study, the share of remobilization under the effects of water deficit, biochar and humic acid stress treatments was significant at the level of 5% probability (Table 3). The highest share of remobilization was obtained in irrigation conditions after the depletion of 50% of field capacity, whereas the lowest share of remobilization was achieved in irrigation conditions after the depletion of 30% of field capacity that decreased by about 26% compared to severe stress treatment (Table 3). This situation indicated that the share of storage material in the vegetative organs to the seed increased when the plant was exposed to water deficit stress due to the reduction of current photosynthesis. It seems that in favourable conditions and access to sufficient resources, since the current photosynthesis increases, the balance between source and sink is largely maintained and the source-produced material can be used in the sink; however, in stress conditions such as water resource limitation and lack of access to nutrients, the balance of the resource and the sink might be disrupted, and in such cases the sink is stronger than the source and due to the physiological relationship between the source and the sink, the source increases the amount of the dry matter transfer so that it may be able to meet part of the severe needs of sinks (Babaei *et al.*, 2017). The highest share of remobilization was obtained from non-application of biochar and the lowest share of remobilization was obtained from the use of 4 tons per hectare of biochar, which decreased by 13.5% compared to the control treatment (Table 3). In this study, it can be stated that in the case of non-application of biochar, the share of dry matter remobilization increased, while with the application of biochar, due to the provision of sufficient moisture and nutrients for the plant, more dry matter was produced and while increasing the grain yield through current photosynthesis, the share of remobilization decreased and more photosynthetic material was stored in vegetative organs. The highest share of remobilization was obtained from the non-application of humic acid and the lowest share of transfer was obtained from the treatment of 6 liters per hectare which did not show any statistically significant difference from the treatment of 4 liters per hectare of humic acid (Table 3). With increasing consumption of humic acid, the share of redistribution after the silking stage in grain yield decreased. With increasing leaf area from the pollination stage to physiological maturity and dependence of seeds on storage materials, the vegetative part was restricted for remobilization of materials at high levels of humic acid. Reports (Attarzadeh et al. 2013) were also consistent with the results of this study.

Conclusions

In general, the experimental results showed that under favourable moisture conditions, increasing the amount of humic acid was associated with a significant increase in grain yield and remobilization, and the use of biochar had a very positive effect on grain yield. In severe water stress conditions (irrigation after the depletion of 50% of the field capacity), the reduced uptake and increased waste of the humic acid fertilizer due to water deficit in the soil reduced the positive effect of increasing humic acid on increasing grain yield. Biochar was also able to reduce the effects of water deficit stress due to its porous structure, high specific surface area and negative surface loads. Since humic acid did not show any adverse effects on the maize plant and yield increase, if the plant is exposed to limited irrigation conditions during the growing season, it seems better to use biochar and humic acid for the plant in order to increase its yield. Therefore, based on the obtained results, due to the important role of humic acid and biochar on the root system in the transfer of water and nutrients to the shoots, the use of 4 liters per hectare of humic acid along with the consumption of 4 tons per hectare of biochar in moderate water stress conditions, due to their positive effect on the growth and yield increase, can be recommended in arid and semi-arid conditions to save water consumption and reduce the effects of water deficit stress.

Authors' Contributions

AC, MM, SL, TS, and MD conceived, designed, and did the project;
AC wrote the paper. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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