Impact of Biochar and Phosphogypsum Addition on Soil Physical Properties, Physiological Traits and Productivity of Maize under Water Deficit Conditions

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ABSTRACT: Egypt has a severe water shortage, made worse in recent years by the building of the Renaissance Dam. Thus, the purpose of this research is to assess the role of soil amendments in mitigating the negative influences of water stress and improving maize productivity. A field experiment was carried out at El-Gemmieza Agriculture Research Station, El-Gharbia Governorate, during the two successive summer seasons of 2021 and 2022 to study the influence of three levels of available soil moisture depletion (AVSMD) and soil amendments biochar (BC) and phosphogypsum (PG) on soil physical proprieties, some physiological traits and maize productivity (TWC 368). The experiment was laid out in a split-plot design with four replicates. The main plots were occupied by three levels of (AVSMD) irrigation at 50 % of AVSMD,I_1(moist);irrigation at 65 % of AVSMD,I_2 (medium) and irrigation at 80 % of AVSMD, I3 (dry). Whereas subplots contained six treatments of BC and PG singly or in combination, i.e., (T_1: control, T_2: 2 ton BC fad^{-1}, T_3: 4 ton BC fad^{-1}, T_4: 2 ton PG fad^{-1}, T_5: 4 ton PG fad^{-1} and T_6: 2 ton BC fad^{-1} plus 2 ton PG fad^{-1}).The results indicated that, increasing soil moisture stress up to (I_3) significantly decreased total porosity (Tp), soil hydraulic conductivity (Hc), organic matter (OM), available N, P, K, chlorophyll a (chl. a), b, shoot dry weight, leaf area (LA), leaf relative water content (LRWC),days to 50 % silking, plant height, antioxidant enzymes, ear length, 100- kernel weigh and grain yield, Whereas, bulk density (Bd),soil pH, chl. a/b ratio, proline and water measurements significantly increased in both seasons. Application (T_6) significantly increased all mentioned traits except Bd, pH, chl. a/b ratio, proline, water applied (WA) and water consumptive use (WCU). From the interaction between water stress treatments and soil amendments addition, It can be summarized that irrigation of maize plants at I_1 or I_2 with T6 improved pH, OM, available P and K, as well as achieved the highest values for chl. a, LA, LRWC, days to 50% silking, plant height, ear length, 100-kernel weight, grain yield, as well as improved water use efficiency (WUE) and water productivity (WP). While applying (I_2) with (T_6) recorded the highest values of Hc and antioxidant enzymes.

***Keywords**:* Maize, water stress, biochar, phosphogypsum, soil proprieties ,physiological**,** grain yield traits**.**

INTRODUCTION

Maize (Zea mays L.) is one of the most important grain crops cultivated worldwide and plays a crucial role in meeting global food needs. In Egypt, the total cultivated area of maize amounted to 2.8 million faddan, with an annual production of approximately 9.2 million ton, sufficient for 48–50% of our needs. This gap is filled through imports (Economic Affairs Sector, Agriculture Ministry). Water stress is considered one of the main obstacles to global agricultural production, especially in Egypt, in light of the increasing water challenges it faces due to population growth, climate change and the Ethiopian Renaissance Dam. Maize is one of the most sensitive to water shortage (**Li *et al*., 2021**), which can result in a yield reduction of 25–30% (**Kimm *et al*., 2020**).

Drought stress is a series of abiotic stresses that induce morphological, physiological, and biochemical changes responsible for a substantial reduction in crop yield (**Liang *et al*., 2020; Latif *et al*., 2022**), which increases leaf senescence, decreases chlorophyll synthesis and enhanced the overproduction of radical oxygen species, ROS (**Vijayaraghavareddy *et al*., 2022**), that damages proteins, lipids, DNA and enzymatic reactions (**Cui *et al*., 2017**) for this pervious reasons photosynthesis and crop productivity were reduced a substantial (**Ma *et al*., 2021**). Therefore, it is crucial to create techniques that may improve the soil's capacity for holding water and nutrients, increasing crop production under water deficit. Examples of such techniques are the use of biochar or Phosphogypsum.

Biochar (BC) is composed of plant-based materials that have been charred through a procedure known as pyrolysis in which there is no or less oxygen **(Wu *et al*., 2023).** It is abundant in carbon-based compounds. The use (BC) as a soil amendment improves plant development and nutrient use efficiency. It also improves the soil's ability to retain nutrients like calcium, phosphorus, and nitrogen while having a higher pH and greater moisture-holding capacity. In recent studies indicated that integrated application of (BC) with mineral fertilizer caused to improving soil structure and productivity of maize **Tufa *et al*. (2022)** and increasing soil physicochemical properties such as pH, cation exchange capacity, water retention capacity, and influencing microbial soil activity (**Mosharrof *et al*., 2021**).

Phosphogypsum (PG) is a by-product of the phosphate fertilizer industry, due to the manufacturing of phosphoric acid from rock phosphate (fluorapatite). Globally, around 160 Mt of phosphogypsum are manufactured yearly and it is mainly removed in big stocks or discharged into Waterways **(Saadaoui *et al*., 2017).** Given that it is primarily made up of $CaSO_4$ and $2H_2O$, it can serve as a source of calcium for agricultural soils, which are one of the main sources of this element globally.

According to **Mahmoud *et al*., (2017)** reported that the combination of BC and PG at a rate of 10 Mg ha^{-1} with recommended nitrogen fertilizer for maize plants could be considered as an ameliorating material to reclaim compacted soils such as some physical-chemical characteristics and to improve the yield of maize plants.

Therefore, the objective of this investigation was to determine whether drought harm can be minimized by using soil amendments like BC and PG to reduce water stress and thus improve physiological traits and the productivity, as well as WUE and WP.

MATERIALS AND METHODS

A field experiments was layout out at El-Gemmeiza Agricultural Research Station Farm (located between Latitude 30° 58′ 56″ N and Longitude 30° 57′ 8″ E), Egypt during the two summer seasons of 2021 and 2022 to study the influence of water stress and soil amendments i.e.biochar (BC) and Phosphogypsum (PG) on soil physical proprieties, some growth parameters and productivity of maize plants (Three Ways Cross 368, "TWC 368").The experimental unit area was 28.8 m^2 (4.8 x 6 m) including 6 ridges (6m length and 80cm width).Grains of the tested maize treatments were obtained from Maize Department, Field Crops Research Institute, Agriculture Research Center, Egypt. TWC 368 was sown on 20^{th} and 25^{th} May in the first and the second seasons, respectively, as recommended for maize in the area. The experiment was laid out in a split plot design with four replications where the irrigation treatments were allocatedin the main plots whereas the sub plots contained application of BC and PG, which mixed with the soil surface layer (0-30 cm depth) before cultivation. Every agricultural practice was implemented in accordance with the guidelines provided by Egypt's Ministry of Agriculture.

The treatments were as follows:

I - Main Plots (Irrigation Treatments)

A- Irrigation at 50 % of available soil moisture depletion (AVSMD) (moist, I_1).
B- Irrigation at 65 % of AVSMD (medium, I_2).
C- Irrigation at 80 % of AVSMD (dry, I_3).

II -Sub-plots Application of biochar (BC) and phosphogypsum (PG)

1- Without treatment (control, T_1)
2- Biochar (2 ton BC fad^{-1}, T_2)
3- Biochar (4 ton BC fad^{-1}, T_3)
4- Phosphogypsum (2 ton PG fad^{-1}, T_4)
5- Phosphogypsum (4 ton PG fad^{-1}, T_5)
6- (2 ton BC fad^{-1} plus 2 ton PG fad^{-1},T_6)

Meteorological tables play an important role in cases of water deficit of various crops due to their close connection to the processes of transpiration and evaporation from the soil surface (Table, 1).

Table 1: Meteorological data in 2021 and 2022 growing season Month for Gharbia Governorate.*

Month	T - Max		T - Min		T-mean		Relative Humidity (%)	
	2021	2022	2021	2022	2021	2022	2021	2022
June	36.89	37.83	19.48	21.11	28.19	29.47	41.40	50.85
July	39.02	38.94	22.47	22.05	30.75	30.50	41.50	51.13
August	39.45	38.64	22.95	23.16	39.05	30.90	43.13	54.04
September	35.75	37.05	20.96	22.15	28.36	32.71	51.16	54.57
October	31.52	31.78	17.72	19.40	24.62	25.59	55.18	59.94

*Source: Water Requirement and Field irrigation Res., Dept.

The physical and chemical properties of the soil samples before application of soil amendments, where the soil samples (0-30 cm) were air dried, crushed and passed through a 2 mm sieve and kept for soil chemical and physical properties analysis as shown in Table (2 and 3).

Table 2: Chemical and physical properties of the experimental soils.

Season	pH (1:2.50)	EC $dScm^{-1}$	NPK available (mg kg^{-1})			OM
			N	P	K	
2021	8.01	0.81	42.85	3.05	425.00	1.29
2022	8.09	0.95	45.85	3.35	485.25	1.38

Season	Particle size distribution (%)				Tex. class	HC	CEC (Cmol kg^{-1})
	C. sand	F.sand	Silt	Clay			
2021	7.35	12.61	30.61	49.43	Clay	1.19	44.92
2022	7.03	12.06	31.65	49.26	Clay	1.26	46.32

OM= organic matter, C.sand= corease sand, F.sand= fine sand, Hc= hydraulic conductivity. CEC= cation exchange capacity

Table 3: Field capacity, permanent wilting point, available moisture and bulk density were determined for the experimental sit.

depth	season 2021				season 2022			
	FC	WP	AW	Bd	FC	WP	AW	Bd
0-15 cm	43.81	22.69	21.12	1.19	43.02	22.09	20.93	1.16
15-30 cm	42.65	22.01	20.64	1.22	41.99	21.86	20.10	1.23
30-45 cm	39.86	19.99	19.87	1.27	38.89	19.79	19.10	1.30
45-60cm	37.39	19.03	18.36	1.36	36.93	18.73	18.2	1.35
Average	40.93	20.93	20.00	1.26	40.21	20.62	19.58	1.26

FC= Field capacity, wp= water point, Aw= available water, Bd= bulk density.

Soil sampling analysis:

Soil sample were randomly made in the experimental site to measure soil physical properties. Soil texture was determined using the pipette method (**Gee and Bauder 1986)** at 0-30 cm depths for soil. Bulk density was determined by the core method (**Blake and Hartage 1986)** for soil. Soil water content was determined from soil samples taken at the same locations using the gravimetric method. Field capacity and permanent wilting points were considered at 0.3 and 15.0 bars, respectively (**Klute 1986**). Hydraulic conductivity saturated (Ksat) was determined for each tested soil and calculated by Darcy, slow according to **Black *et al*. (1965)**. Available NPK of soil were determined according to **Page *et al*. (1982).** Organic matter content was determined using Walkley and Black rapid titration method according to **Soil Laboratory Staff (1984)**. Soil pH was determined in 1:2.5 (soil: water) suspension using Beckman pH meter as out lined by **Soil Laboratory Staff (1984**). Total soluble salts were measured as dS m^{-1} using electrical conductivity (EC) in soil paste extract. Sample of BC and PG were air-dried and ground, 1.0 g weight of manure and digested then, the digest was diluted with distilled water to a volume of 100 ml. Aliquots from this digest was analyzed for the content macronutrients according to **Cottenie *et al*. (1982)**. PH value was determined in 1:10 (soil amendments: water) suspension using glass electrode pH-meter according to **Jodic *et al*. (1982).**

Table 4: Some characteristics of biochar and phosphogypsum used in this study.

Properties	pH (1:10)	Total N (%)	Total P (%)	Total K (%)	Total Ca (%)	Total Mg (%)	Total S (%)	OC (%)
Biochar	9.15	1.65	0.58	1.25	0.38	0.19	0.22	58.00
Phosphogypsum	5.08	0.29	0.71	0.19	20.01	0.21	15.91	4.05

Growth and physiological traits:

Leaf chlorophyll content:

Chlorophyll a and b content in fresh leaves (as mg/g fresh weight) at 70 days after sowing were determined and calculated according to **Moran (1982)**

At 90 days after sowing five guarded plants from each plot were chosen randomly to determine plant height, leaf area and shoot dry weight, then the data were averaged and recorded. The leaf area in cm^2 (LA) was calculated as follows:

Individual leaf area= Leaf length × Leaf width × 0.73 according to **Stewart and Dwyer (1999**).

Leaf relative water content (LRWC %):

LRWC % was estimated according to (**Salgado-Aguilar *et al*., 2020**) as follows:

RWC % = (Fw- Dw)/ (Tw- Dw) X 100

Where Fw, Tw and Dw are fresh weight, turgid weight and dry weight, respectively.

Antioxidant enzymes activity of leaves

Peroxidase activity was according to **Allam** and **Hollis (1972)** and Polyphenol oxidase activity was determined as described by **Matta** and **Dimond (1963)**.

Proline content of leaves:

Proline in leaves was determined according to **Bates *et al*. (1973).** The results were calculated in mg / g dry weight.

Days to 50 % silking (**DTS):** was determined.

Harvesting took place 7 October, 2021 and 12 October, 2022 in the first and second seasons, respectively. At harvest time, ten individual guarded plants were randomly taken from one row in each sub-plot to determine: Ear length (cm), 100- kernels weight (g) and Grain yield (GY) ard. fad^{-1}, was calculated from two ridges in each sub-plot.

Water consumptive use (WCU):

In order to determine the soil moisture content, soil samples were taken with a regular auger at planting time, 48 hours after each irrigation and at harvest time. Duplicate soil samples were collected at depths of 0–15, 15–30, 30-45, and 45–60 cm and their moisture contents were computed by weighting.

Moisture content and water consumptive use per unit area was calculated according to the equation described by **Israelsen and Hansen (1962)**.

$$\text{WCU (cm)} = \frac{\text{Q2} - \text{Q1}}{100} \text{ X Bd X ERZ}$$

Where: WCU = Water Consumptive use (WCU) (cm). Bd = Bulk density of soil layer (g cm^{-3}).

Q1 = Soil moisture content (%,wt/wt) just before the next irrigation

Q2 = Soil moisture content (%, wt / wt) 48 hrs after irrigation.

ERZ = Effective root zone depth (cm).

Q = CA (2gH) 0.5

Where: Q = orifice flow discharge C = discharge coefficient t = 0.6 Range (0.6 & 0.8) A = cross-sectional area of orifice or pipe (ft^2) g = acceleration due to gravity (32.2 ft/s^2) H = effective head on the orifice (measured from center of orifice to water surface).

Water use efficiency (WUE):

Water use efficiency was calculated accordance with **Jensen (1983)** as follows:

WUE = Grain yield (kg fad^{-1})/seasonal water consumption in m^3 fad^{-1}.

Water Productivity (WP):

Water productivity was calculated according to **(Ali *et al*., 2007)** as kg grains m^{-3} water applied: WP (kg m^{-3}) = Gy/I Where: Gy = Grain yield (kg fad^{-1}) I = Irrigation water applied m^3 fad^{-1}.

Statistical analysis

Data of the two seasons were subjected to statistical analysis of variance according to **Steel and Torrie (1980)** by using (**Costat, 2005**). Means of the studied traits were compared using LSD at 5% probability level.

RESULTS AND DISCUSSION

1- Impact of water stress, applications BC, PG either alone or in combination and their interaction on soil physical properties.

Data presented in Table (5) show that irrigation treatments had a significant impact on Bd, Tp, and Hc efficiency in both seasons. According to the results, Bd significantly increased when soil depletion moisture was increased from (I_1) to (I_3), on the other side Tp and Hc were decreased in both seasons. Irrigation at (I_1) or (I_2) were similar in previous traits except for Hc in the second season. In comparison to I_3, irrigation treatment (I_1) resulted in a decrease in Bd by (3.48 and 3.31%) and an increase in Tp and Hc by (2.72, 3.31%) and (19.62, 25.63%), respectively, over the course of two seasons. The current study supports the findings of **Zhang *et al*. (2019)**, who found that Bd in the 0–10 cm soil layer was increased, but Tp and Hc were significantly decreased by drought stress. This may be due to lower fine root biomass and residue input from understory vegetation in the surface layer.

Table 5: Effect of irrigation treatments, biochar and phosphogypsum, as well as their interaction on soil physical properties during 2021 and 2022 seasons.

Treatments		Bd (g cm^{-1})		TP (%)		HC (cm hr^{-1})	
		2021	2022	2021	2022	2021	2022
Irrigation levels							
I_1		1.15	1.12	56.65	57.65	1.58	1.51
I_2		1.16	1.13	56.33	57.30	1.56	1.42
I_3		1.19	1.17	55.11	55.74	1.27	1.12
$LSD_{0.05}$		**0.014**	**0.015**	**0.53**	**0.54**	**0.11**	**0.046**
Biochar and phosphogypsum							
T_1		1.22	1.20	53.88	54.63	0.72	0.68
T_2		1.17	1.16	55.76	56.31	1.23	1.13
T_3		1.14	1.12	56.77	57.78	1.52	1.39
T_4		1.18	1.16	55.34	56.06	1.46	1.35
T_5		1.15	1.14	56.43	57.15	1.81	1.60
T_6		1.11	1.07	58.03	59.46	2.08	1.94
$LSD_{0.05}$		**0.019**	**0.017**	**0.73**	**0.62**	**0.13**	**0.11**
interaction							
I_1	**T_1**	1.20	1.18	54.72	55.47	0.89	0.97
	T_2	1.16	1.13	56.23	57.36	1.23	1.28
	T_3	1.13	1.10	57.36	58.49	1.71	1.55
	T_4	1.17	1.15	55.85	56.60	1.58	1.53
	T_5	1.15	1.12	56.60	57.74	1.84	1.7
	T_6	1.09	1.05	58.87	60.38	2.21	1.99
I_2	**T_1**	1.21	1.19	54.34	55.09	0.73	0.66
	T_2	1.15	1.15	56.60	56.60	1.28	1.23
	T_3	1.14	1.11	56.98	58.11	1.53	1.41
	T_4	1.17	1.16	55.85	56.23	1.58	1.35
	T_5	1.15	1.13	56.60	57.36	2.05	1.73
	T_6	1.11	1.06	58.11	60.00	2.18	2.14
I_3	**T_1**	1.25	1.24	52.83	53.21	0.53	0.41
	T_2	1.21	1.19	54.34	55.09	1.17	0.89
	T_3	1.16	1.14	56.23	56.98	1.31	1.22
	T_4	1.21	1.19	54.34	55.09	1.23	1.16
	T_5	1.16	1.16	56.23	56.23	1.53	1.38
	T_6	1.14	1.11	56.98	58.11	1.83	1.69
$LSD_{0.05}$		**NS**	**NS**	**NS**	**NS**	**NS**	0.13

Regarding BC and PG either alone or in combination had significant effect on Bd, Tp and Hc in both seasons (Table, 5). Adding (T_6) achieved the highest values of Tp by (7.70, 8.84 %) and Hc by (188.89, 185.29 %), but it recorded the lowest values of Bd by (9.02 and 10.83 %) respectively, in the first and second seasons compared to untreated plants (T_1). The results showed that the mixture of BC and PG led to increased soil porosity, water aggregate stability and decreased soil bulk density. Moreover, the generation of macrospores and channels by root penetration through soil tends to form preferential flow paths, thus enhancing soil infiltration (**Benegas *et al*., 2014**). These results agree with **Mahmoud *et al*. (2017)**, who found that Bd and Hc significantly increased as a result of the addition of 10 Mg BC ha^{-1} plus 10 Mg PG ha^{-1}. Even worse, there is little research about the extent of the effect of BC adding for short periods of time to soils with medium to high soil organic content (SOM). In this regard **Lehmann *et al*. (2011)** illustrated that BC can change soil physicochemical parameters that increase root biomass and crop productivity by improving the soils' hydrologic properties that include increasing the soils' water-holding capacity and available water content, changing the hydrophobicity of the soil and altering the hydraulic conductivity of the soil. Also, **Agbede and Adekiya (2020)** found that application of BC at 10, 20, and 30 t ha^{-1} reduced Bd by 9.7%, 19.40%, and 28.8%, respectively, as the average for both seasons compared with the control. **Filho *et al*. (2016)** found that the combined application of lime and (PG) effectively increased the organic carbon content in different classes of aggregates as well as lower soil bulk density and penetration resistance.

The interaction effect between water stress and soil amendments was significant on Hc in the second season only. The maximum value of Hc were recorded in response to treating maize plants by (I_2×T_6), but (I_3×T_1) recorded the lowest value.

2- Impact of water stress, applications BC, PG either alone or in combination and their interaction on soil chemical properties.

Data obtained in Table (6) revealed that increasing soil moisture depletion from (I_1) up to (I_3) caused a significant reduction in OM, N, P and K available, but soil pH increased in both seasons. In this concern, the relative increases were 4.58 and 5.06% for OM, 12.89 and 9.22% for N available, 18.45 and 14.06% for P available and 7.54 and 7.73% for K available compared with I_3 in the first and second seasons, respectively. The corresponding decrease in soil pH was 0.75 and 1.00% with I_1 as compared to I_3 for the first and second seasons, respectively. These findings concur with **El-Gamal *et al*. (2021**), who observed that irrigation at 40% of water depletion improved pH, OM, available N, P, and K in soil when compared to irrigation at 60 and 80% of water depletion. This could be explained by the fact that as soil drought stress increased, microbial activity weakened and declined, changing the soil's structure and degrading soil ecosystem productivity.

It is clear that BC and PG mixture augmented significantly OM, N, P and K available over control by about 40.46, 49.38, 65.64 and 14.73% as compared to control in the first season, respectively. While, the second season increased by 39.42, 46.73, 87.66 and 11.71% with BC and PG mixture as compared to control at the same previous properties respectively. The results illustrated in Table (6) showed that the applied of BC with PG gradually decreased soil pH by 2.95 and 3.09 % as compared to control in the first and second season, respectively. These results concur with **Yang *et al*. (2022),** who reported that adding BC enhanced the amount of available nutrients (N, P, and K) and OM and improvements in these indices were generally correlated with the amount of BC added; moreover, adequate moisture can also provide more nutrients from the root zone.

It is known that soil pH affects the availability of nutrients and how the nutrients react with each other. The current investigation demonstrated that the addition of BC and PG has a positive effect on lowering PH. These results agree with **Liu and Zhang (2012)** who reported that adding BC produced a decreasing for pH trend. The alkaline soil used for the study had a pH of 7.9, which could have prevented any BC liming effect. Thus, the addition of BC to the soil may benefit the environment by preventing nutrients loss and thereby protecting water resources. Application of PG led to lowering soil pH that may be attributed to release of phosphoric acid and sulfuric acid contained by PG and that enhanced soil fertility, through improving soil available nutrients. These results were confirmed with **Kim*et al*. (2021)**. Also **Vicensi *et al*., (2016)** reported that adding (PG) improving the chemical conditions enabled greater root development and improved root distribution throughout the soil profile to enhance their ability to take up water and nutrients.

As for interaction effect between water deficit and soil amendments (BC, PG) was found to be a significant effects on soil pH and OM in the two seasons and P and K available in the second season only (Table, 6). The data showed that the treatment (I_1×T_6) provided the lowest value for soil pH and the highest values for P and K. Irrigation of maize plants at I_1 or I_2 with T_6 gave the maximum value for OM.

3-Impact of water stress, applications of BC, PG either alone or in combination and their interaction on chlorophyll a, b and a/b ratio.

Data are given in Table (7) illustrated that Ch. a, Ch. b and Ch. a/b ratio were significantly affected by irrigation treatments in the two season. Increasing soil moisture depletion from (I_1) up to (I_3) resulted in significantly reduction in Ch. a, Ch. b but Ch. a/b ratio was increased. Irrigation at (I_1) gave the highest values of Chl. a and b this may be attributed to the abundance irrigation water which encourage the absorption of water and nutrients by cells that prompted their volume and photosynthesis efficiency. While water stress has a negative effect on chlorophyll due to damage to the chlorophyll mechanism and the destruction of the photosynthesis system due to the lack of water absorption and nutrients from the soil and their transfer to the various plant organs. Our results agreed with those obtained by **(Ali** and **Abdelaal, 2020 and Rusmana *et al*., 2021). Kaya *et al*. (2020)** confirmed that deficit irrigation led to lower RWC, which in turn caused stomatal closure, limiting CO_2 availability, and reduced rates of photosynthesis and antioxidant /reactive oxygen species. Furthermore under drought stress the reduction of Chl b is greater than that of Chl a, thus, transforming the ratio in favor of Chl a (**Jaleel *et al*. 2009**). On the other hand, **Shafiq *et al*. (2021)** found that under drought stress circumstances, the chl. a/b ratio remained constant.

Concerning the impact of application of BC, PG either alone or in combination, there were significant differences on Ch. a, Ch. b and Ch. a/b ratio as presented in Table 7 in the two season. Results pointed out that application of (T_6) on the soil scored the maximum values of Ch. a and b followed by treated with (T_3) with a significant difference between such two treatments. On the other side addition (T_6) or (T_3) gave the minimum value for Ch. a/b ratio. As well as BC and PG mixture improved significantly soil physical and chemical properties as shown in Tables (5 and 6).

The increases in leaves chlorophyll content as a result of BC addition which may be due to what was reported by **Wu *et al.* (2023)** who referred that adding BC to soil improved soil structure, soil organic matter, soil aggregate stability, water and nutrient holding capacity, and the activity of both beneficial microbes and fungi, that improved leaf water

Table 6: Effect of irrigation treatments, biochar and phosphogypsum, as well as their interaction on soil chemical properties during 2021 and 2022 seasons.

Treatments		pH (1:2.50)		OM (%)		N available		P available		K available	
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Irrigation levels											
I1		7.98	7.94	1.60	1.66	46.07	48.35	4.75	3.65	394.9	426.7
I2		8.01	7.96	1.60	1.64	44.80	48.23	4.41	3.25	380.6	407.5
I3		8.04	8.02	1.53	1.58	40.81	44.27	4.01	3.20	370.0	396.1
$LSD_{0.05}$		**0.021**	**0.014**	**0.054**	**0.055**	**0.94**	**0.69**	**0.21**	**0.055**	**7.38**	**6.41**
Biochar and phosphogypsum											
T1		8.13	8.09	1.31	1.37	35.30	38.03	3.26	2.35	355.9	387.9
T2		8.09	8.04	1.63	1.65	43.84	47.12	3.80	2.76	382.2	411.7
T3		8.08	8.03	1.78	1.83	49.59	52.54	4.29	3.11	397.8	422.8
T4		7.96	7.94	1.42	1.46	39.74	42.56	4.52	3.66	368.9	398.9
T5		7.94	7.89	1.50	1.55	42.15	45.64	5.07	3.90	377.8	406.1
T6		7.89	7.84	1.84	1.91	52.73	55.80	5.40	4.41	408.3	433.3
$LSD_{0.05}$		**0.032**	**0.048**	**0.068**	**0.070**	**1.41**	**1.25**	**0.15**	**0.084**	**7.83**	**7.91**
Interactions											
I1	**T1**	8.13	8.11	1.33	1.39	36.75	38.65	3.63	2.54	366.0	398.7
	T2	8.08	8.03	1.69	1.73	45.88	48.36	4.2	2.94	398.3	428.3
	T3	8.03	7.99	1.80	1.85	52.23	54.78	4.83	3.27	413.3	441.7
	T4	7.92	7.88	1.41	1.45	42.19	44.12	4.8	3.98	376.7	415.0
	T5	7.9	7.86	1.48	1.53	44.11	46.22	5.27	4.13	388.3	418.3
	T6	7.84	7.78	1.89	2.00	55.27	57.96	5.78	5.06	426.7	458.3
I2	**T1**	8.13	8.07	1.32	1.38	35.66	39.33	3.23	2.30	355.0	388.3
	T2	8.09	8.01	1.65	1.64	44.6	48.55	3.74	2.75	380.0	406.7
	T3	8.1	8.01	1.82	1.87	51.17	53.17	4.23	3.00	403.3	420.0
	T4	7.95	7.93	1.43	1.47	40.65	44.24	4.60	3.36	363.3	398.3
	T5	7.92	7.88	1.48	1.54	43.12	46.78	5.20	3.82	376.7	406.7
	T6	7.88	7.84	1.91	1.95	53.61	57.28	5.45	4.24	405.0	425.0
I3	**T1**	8.14	8.10	1.29	1.33	33.49	36.10	2.94	2.22	346.7	376.7
	T2	8.10	8.10	1.53	1.59	41.04	44.43	3.48	2.58	368.3	400.0
	T3	8.11	8.10	1.71	1.77	45.37	49.68	3.81	3.05	376.7	406.7
	T4	8.01	8.00	1.42	1.46	36.4	39.32	4.15	3.63	366.7	383.3
	T5	7.97	7.94	1.53	1.58	39.21	43.92	4.73	3.75	368.3	393.3
	T6	7.94	7.9	1.73	1.77	49.32	52.17	4.98	3.93	393.3	416.7
$LSD_{0.05}$		**0.034**	**0.030**	**0.056**	**0.071**	**NS**	**NS**	**NS**	**0.23**	**NS**	**6.84**

Table 7: Effect of irrigation treatments, biochar and phosphogypsum, as well as their interaction on chlorophyll a, b and a/b ratio of maize hybrid TWC 368 during 2021 and 2022 seasons.

Treatments		Chl. a		Chl. b		Chl. a/b	
		2021	2022	2021	2022	`2021	2022
Irrigation levels							
I_1		15.64	16.07	5.886	6.303	2.673	2.574
I_2		14.28	14.88	4.908	5.295	2.951	2.844
I_3		11.96	12.23	3.721	4.031	3.275	3.074
LSD $_{0.05}$		**0.37**	**0.44**	**0.130**	**0.358**	**0.076**	**0.138**
Biochar and phosphogypsum							
T_1		12.43	12.86	3.926	4.326	3.269	3.066
T_2		13.75	14.54	4.802	5.243	2.913	2.818
T_3		14.80	15.09	5.362	5.540	2.795	2.758
T_4		13.49	13.92	4.434	4.839	3.110	2.927
T_5		13.84	14.16	4.603	5.060	3.063	2.856
T_6		15.48	15.80	5.903	6.248	2.647	2.559
LSD $_{0.05}$		**0.45**	**0.55**	**0.316**	**0.321**	**0.182**	**0.219**
Interactions							
I_1	T_1	15.02	15.25	5.283	5.578	2.847	2.781
	T_2	15.68	16.18	5.935	6.371	2.654	2.55
	T_3	16.06	16.53	6.288	6.575	2.557	2.519
	T_4	15.34	15.69	5.513	5.912	2.786	2.66
	T_5	15.39	15.73	5.61	6.158	2.75	2.567
	T_6	16.36	17.03	6.688	7.223	2.447	2.366
I_2	T_1	12.22	13.04	3.779	4.289	3.258	3.098
	T_2	13.99	14.76	4.796	5.236	2.925	2.832
	T_3	15.26	15.92	5.516	5.738	2.77	2.775
	T_4	13.66	14.35	4.493	4.952	3.053	2.909
	T_5	14.49	14.57	4.717	5.131	3.076	2.853
	T_6	16.09	16.66	6.148	6.424	2.623	2.601
I_3	T_1	10.04	10.28	2.716	3.106	3.705	3.319
	T_2	11.58	12.67	3.676	4.128	3.162	3.072
	T_3	13.09	12.81	4.282	4.306	3.058	2.981
	T_4	11.46	11.73	3.296	3.653	3.49	3.213
	T_5	11.64	12.17	3.483	3.894	3.365	3.147
	T_6	13.98	13.72	4.875	5.098	2.87	2.711
LSD $_{0.05}$		**0.73**	**0.84**	**0.481**	**0.634**	**NS**	**NS**

status and reduced ROS damage, which increased chlorophyll synthesis and photosynthetic rate, reducing the negative impacts of water shortage on carbon assimilation and photosynthesis, that is linked with boosted chlorophyll synthesis **Wang *et al.* (2021)**. Also **Bossolani *et al.*, (2021**) stated that PG improves root system by increasing rate of multiplication and expansion of the root throughout the soil profile which in turn increased plant uptake of water and nutrients. These changes are reflected in greater synthesis of chlorophylls that, it an important part on Calvin cycle and is responsible for harvesting sunlight during plant photosynthesis (**Busch, 2020**).

The interaction effects between water stress and application of BC and PG on chl. a, b and chl. a/b ratio are shown in Table 7. Results cleared that application of BC and PG had a significant effect on chl. a and b in the two seasons. In both seasons, treatment of (I_1×T_6) produced the best value for chl. a, followed by (I_2×T_6) with presence insignificant differences. As well as, (I_1×T_6) recorded the highest value for chl. b followed by (I_1×T_3), which had insignificant differences between them in both seasons. Whereas, worst values of chl. a and b were observed by plants under water stress (I_3) and unfertilized (T_1) during the two seasons.

4-Impact of water stress, applications of BC, PG either alone or in combination and their interaction on shoot dry weight plant^{-1}, leaf area, plant height and leaf relative water content

Data presented in Table (8) showed that shoot dry weight plant^{-1}, LA ,plant height and LRWC %

were significantly affected by irrigation treatments in both seasons. There are gradual reductions in each mentioned traits by exposing maize plants to drought stress (I_3) compared to the other treatments in both seasons .Irrigation treatments (I_1), increased shoot dry weight plant^{-1} and LA by (38.81 and 46.95 %) and (30.14 and 27.13 %) in the first and second season, respectively compared to maize plants under drought stress (I_3). In the same time, increasing plant height by (25.42 and 29.44 %) and LRWC by (13.13 and 13.81 %) in the first and second seasons, respectively in response to irrigated plants (I_1) compared to (I_3). Reduction in soil water potential as a result of water stress caused the inability of the plant to absorb water and nutrients in the critical growth stages of plants, that led to the congestion of soluble carbohydrates, proline, and osmotic regulation (which helps cell division and elongation), thus a decrease in the number and length of nodes, which reflected negatively on plant height. On the other hand, the LA decreased due to water stress, that reduced the size of chloroplasts and deterioration of the internal chloroplast membranes, and thus decreased total chlorophyll, thereby resulted in lower photo-assimilates and less dry matter accumulation. These results are in accordance with those of **(Laskari *et al.*, 2022 and Seham Mohamad *et al.*, 2023).**

With respect the effects of applying soil amendments (BC & PG), data in Table (8) pointed out that shoot dry weight plant^{-1}, LA, plant height and LRWC were affected positively by BC and PG application either alone or in combination in the 1st and 2nd seasons. Where, (T_6) appeared significantly increasing in all mentioned traits compared with the other treatments in both seasons. Adding T_6 treatment to soil improved shoot dry weight plant^{-1} and LA by (54.65 and 49.28 %) and (25.56 and 24.21 %) in both seasons, respectively compared to control (T_1). In the same trend, plant height was increased by (26.35 and 26.13 %) and LRWC by (12.88 and 12.90 %), in the two seasons, respectively compared to (T_1). The current study shows that maize plants treated with BC amended soil resulted in increased LRWC (Table 8), which could be attributed to the significantly increased for water uptake from soil to maintain the plants' water status and, as a result, encourage photosynthesis, which has positive effect on shoot dry weight plant^{-1} and grain yield. The present results were in agreement with the findings by **(Abideen *et al.*, 2022; and Ali *et al*. 2021)**. Most plant growth parameters may have improved as a result of the application of BC to the soil, which enhances the biological, chemical, and physical properties of the soil that increases its ability to retain water and nutrients **(Mavi *et al.*, 2018).** In the same trend, **Gharred *et al.*, (2022)** reported that addition of BC to the soil may be caused an improvement in plant nutrition rather than by increasing water uptake and increased soil-available potassium (K) and enhanced its uptake and then tolerance plant to water stress. Moreover, **Bossolani *et al*. (2021)** reported that application of Lime plus PG improved root development, which reflected on increasing water and nutrients uptake by plants, increased photosynthesis and better regulation of oxidative stress led to higher shoot dry matter and grain yield of maize.

As for interaction effect between water deficit and soil amendments (BC& PG) was found to be a significant effect on shoot dry weight plant^{-1} and LRWC in the two growing seasons and LA and plant height in the first season only (Table 8). Data confirmed that the maximum values of shoot dry weight plant^{-1}, LA and plant height were recorded by treatments ($I_1 \times T_6$) or ($I_1 \times T_3$) compared to other treatments. On the other hand, the highest values of LRWC was obtained when soil treated with (T_6) under treatment (I_1) followed by (T_6) under irrigation treatment (I_2) with insignificant difference between them in the both seasons. It could be confirmed that growth parameters such as plant height, LA and shoot dry weight were significantly reduced under water deficit, while the addition of BC and PG improved such traits under normal irrigation and minimized the harmful impact of water stress.

5-Impact of water stress, applications BC PG either alone or in combination and their interaction on antioxidant enzymes and proline content.

Data are given in Table (9) illustrated that, antioxidants enzyme i.e., peroxidase and polyphenol oxidase increased significantly in response to increasing water deficit from (I_1) to (I_2), but by increasing water deficit up to (I_3), antioxidants enzymes began reduced in both seasons. Also, the accumulation of proline increased significantly in both seasons by raising the soil moisture depletion level from (I_1) to (I_3) in both seasons. It is known that antioxidants production increased in tissues under stress conditions such as drought in order to protect the plant from over production of ROS, which might damage different macromolecules and cellular structures, thus this plant is forced to secrete more amounts of total phenols and proline to resist these ROS (**Gharibi *et al.*, 2016** and **Hafez *et al.*, 2021**) but with the continuing stress conditions for a long time, the production of antioxidant enzymes decline.

Regarding the effect of soil amendments of BC, PG and their combination, it cleared that soil amendments of BC, PG significantly increased peroxidase and polyphenol oxidase, but proline was decreased in leaves of maize plants as compared to other treatments. The highest values of antioxidants enzymes were achieved by maize plants fertilized at (T_6) followed by addition of (T_3) while lowest values was observed with untreated plants (control). In contrary the maximum value of proline was scored with untreated plant

Table 8: Effect of irrigation treatments, biochar and phosphogypsum,as well as their interaction on shoot dry weight plant^{-1}, leaf area, plant height and leaf relative water content of maize hybrid TWC 368 during 2021 and 2022 seasons.

Treatments		Shoot dry weightplant^{-}		Leaf area		Plant height		LRWC	
		2021	2022	2021	2022	2021	2022	2021	2022
Irrigation levels									
I_1		280.1	301.8	695.7	745.4	248.6	235.4	74.05	76.58
I_2		234.8	252.5	628.2	686.8	223.6	212.5	71.32	72.95
I_3		171.4	160.1	486.0	543.2	185.4	166.1	64.33	66.00
LSD $_{0.05}$		**6.5**	**20.0**	**29.4**	**29.3**	**13.3**	**10.6**	**1.13**	**0.89**
Biochar and phosphogypsum									
T_1		184.6	195.0	538.4	593.5	195.8	183.7	66.25	67.99
T_2		222.1	231.8	596.9	650.6	216.0	200.2	69.43	70.96
T_3		253.9	262.5	635.3	685.2	233.1	214.3	71.62	74.01
T_4		207.6	220.3	575.8	631.9	208.4	196.3	68.00	69.80
T_5		218.6	228.2	597.6	652.6	214.3	202.0	69.31	71.55
T_6		285.5	291.1	676.0	737.2	247.4	231.7	74.78	76.76
LSD $_{0.05}$		**19.5**	**15.5**	**34.6**	**39.0**	**16.4**	**16.01**	**1.89**	**1.83**
Interactions									
	T_1	245.8	264.1	635.8	683.3	230.1	221.0	71.18	74.28
	T_2	277.8	300.5	697.0	757.8	247.0	231.3	74.55	76.25
	T_3	305.3	333.2	720.1	769.9	256.3	242.3	75.19	77.88
I_1	**T_4**	257.9	279.0	667.0	722.8	244.5	229.5	72.33	75.14
	T_5	262.5	283.4	684.5	729.4	246.8	232.3	72.78	76.28
	T_6	331.3	350.9	770.0	809.3	266.8	256.0	78.29	79.67
	T_1	185.3	204.9	563.6	623.0	194.5	188.3	66.85	68.36
	T_2	223.2	242.1	618.5	675.4	220.5	211.3	70.05	71.65
	T_3	260.6	273.8	670.2	712.1	241.3	220.5	73.15	75.47
I_2	**T_4**	213.3	237.8	599.9	664.3	210.8	205.0	69.82	70.72
	T_5	230.1	244.2	625.5	680.1	219.5	208.8	71.92	72.9
	T_6	296.5	311.9	691.7	766.1	255.0	241.5	76.14	78.62
	T_1	122.9	115.9	415.8	474.2	162.8	141.8	60.73	61.34
	T_2	165.3	152.8	475.4	518.5	180.5	158.0	63.70	64.98
	T_3	196.0	180.5	515.7	573.5	201.8	180.0	66.51	68.69
I_3	**T_4**	151.7	144.1	460.5	508.6	170.0	154.3	61.86	63.54
	T_5	163.4	156.9	482.7	548.3	176.5	165.0	63.25	65.46
	T_6	228.9	210.5	566.4	636.2	220.6	197.7	69.93	72.00
LSD $_{0.05}$		**31.2**	**26.4**	**66.5**	**NS**	**26.3**	**NS**	**3.07**	**2.83**

Table 9: Effect of irrigation treatments, biochar and phosphogypsum, as well as their interaction on peroxidase, polyphenol oxidase and proline of maize hybrid TWC 368 during 2021 and 2022 seasons.

Treatments		Peroxidase content (mg/g/f.wt)		Polyphenol oxidase (mg/g/f.wt)		Proline content (mg/g/d.wt)	
		2021	2022	2021	2022	2021	2022
Irrigation levels							
I_1		1.692	1.756	0.181	0.245	1.222	1.281
I_2		2.062	2.183	0.374	0.405	1.451	1.502
I_3		1.428	1.492	0.142	0.182	1.759	1.858
LSD 0.05		0.071	0.048	0.023	0.025	0.030	0.048
Biochar and phosphogypsum							
T_1		1.475	1.572	0.154	0.170	1.643	1.752
T_2		1.743	1.803	0.224	0.257	1.495	1.542
T_3		1.852	1.941	0.279	0.343	1.398	1.437
T_4		1.668	1.732	0.187	0.242	1.537	1.667
T_5		1.708	1.808	0.230	0.252	1.461	1.523
T_6		1.918	2.006	0.320	0.401	1.331	1.361
LSD 0.05		**0.057**	**0.078**	**0.022**	**0.036**	**0.058**	**0.058**
Interaction							
I_1	T_1	1.421	1.592	0.144	0.163	1.315	1.400
	T_2	1.71	1.751	0.173	0.214	1.236	1.288
	T_3	1.831	1.862	0.198	0.300	1.165	1.202
	T_4	1.675	1.661	0.160	0.212	1.281	1.376
	T_5	1.62	1.751	0.175	0.220	1.193	1.246
	T_6	1.897	1.919	0.235	0.360	1.143	1.177
I_2	T_1	1.815	1.887	0.228	0.250	1.607	1.730
	T_2	2.068	2.167	0.366	0.387	1.455	1.497
	T_3	2.224	2.359	0.456	0.495	1.371	1.385
	T_4	1.945	2.067	0.297	0.352	1.514	1.614
	T_5	2.046	2.184	0.374	0.373	1.444	1.467
	T_6	2.276	2.434	0.523	0.575	1.318	1.323
I_3	T_1	1.188	1.237	0.090	0.098	2.008	2.127
	T_2	1.451	1.492	0.134	0.168	1.793	1.843
	T_3	1.503	1.601	0.183	0.233	1.656	1.725
	T_4	1.384	1.468	0.103	0.161	1.815	2.011
	T_5	1.458	1.489	0.142	0.162	1.747	1.856
	T_6	1.583	1.664	0.201	0.267	1.532	1.584
LSD 0.05		**0.114**	**0.122**	**NS**	**0.067**	**0.105**	**NS**

control followed by addition of (T_4). These findings confirmed those of **Wu *et al*. (2023)**, who found that adding BC to soil enhances the production of antioxidant enzymes (peroxidase and catalase), which may be related to improved plant metabolic function, cell growth, and a decrease in ROS production, which protects the plants from the adverse effects of drought stress and thus improves plant growth under this condition **(Zulfiqar *et al* (2022)**.

Data in Table (9) show that the interaction between soil moisture stress and application of BC, PG had a significant effects on peroxidase enzyme in both seasons and polyphenol oxidase in the second season while proline content in the first season only. The results indicated that maize plants treated with $I_2 \times T_6$ scored the highest values of peroxidase enzyme and polyphenol oxidase. On the other hand, the lowest value of proline was recorded by ($I_1 \times T_6$) or ($I_1 \times T_3$).

6-Impact of water stress, applications BC, PG either alone or in combination and their interaction on days to 50 % silking, ear length, 100-kernel weigh and grain yield.

In both seasons findings showed that days to 50 % silking, ear length, 100-kernel weigh and grain yield were significantly affected by irrigation treatments (Table 10). It could be observed that increasing soil moisture depletion from (I_1) up to (I_3) resulted in reduction in former mentioned traits. Irrigation treatment (I_1) increased days to attain 50 % silking and ear length by (6.37 and 6.15%) and (27.66 and 28.58%) in both seasons, respectively as comparison to maize plants exposed to drought stress (I_3). In the same trend (I_1) caused to increasing 100- kernels weigh and grain yield by (18.00, 17.35 %) and (30.58, 30.82 %) in the first and the second, respectively compared with irrigation regime (I_3). Maize plants reduce the time it takes to reach 50% silking in order to escape unfavorable conditions. These findings are consistent with those of **El-Gamal *et al*. (2021)** and **Seham Mohamad *et al*. (2023).** The decrease in ear length under water stress during plant growth stages may be due to lowering speed of photosynthesis and decreased absorption of nutrients, which was negatively affected on cell growth, consequently declined ear length. These results are in accordance with **(Sathish *et al.*, 2022).**

The depression in 100- kernels weigh and grain yield obtained herein by prolonging the irrigation intervals which may be due to the significant reduction in the growth characters such as shoot dry weight plant^{-1} and leaf area as well as the physiological constituents in the leaves (chlorophyll content and LRWC) discussed previously in Tables 5 and 6, respectively. Our results are in line with **Hafez *et al*. (2021)** who found that irrigation every 18 days decreased 100-grain weight and grain yield compared to irrigation every 12 days. These findings are consistent with those of **(Dina Ghazi and El-Sherpiny, 2021)** and **Ariyanto *et al*. (2023).**

Data shown in Table (8) demonstrated that days to 50% silking, ear length, 100-kernel weigh and grain yield were significantly impacted by the addition of BC and PG in both seasons. It is evident that fertilized maize plants with (T_6) increased days to 50 % silking by (4.44 and 5.73 %), ear length by (25.30 and 21.70 %) in the first and the second, respectively compared to untreated plants. In the same trend 100-kernel weigh and grain yield were increased by (18.05 and 17.53 %) and (20.24 and 21.16 %) in both seasons, respectively. **Tufa *et al*. (2022)** reported that delayed phenological parameters of maize as a result of adding BC with mineral NPS addition might be due to improving soil fertility, increasing essential nutrients uptake of plant, leading to production of more vegetative growth. According to **Al-Kadem (2022),** the increase in 1000 -grains weight is attributed to the effect of BC, which was the main store for nutrients and good moisture content, which encouraged the plant to form a large leaf area and then increasing the leaf area index, consequently elevating chlorophyll content, that resulted in a longer and larger reception of solar rays, increasing photosynthetic activity, flow speed, and the accumulation of vital matter downstream grains.

Results in Table (10) show that the interaction effect between soil moisture stress and soil amendments was found to be significant on all mentioned traits in both seasons, except for days to 50 % silking in the first season only. Days to 50 % silking and ear length, 100-kernel weigh and grain yield recorded the highest values in response to irrigation at (I_1) or (I_2) with fertilized maize plants at (T_6), however, unfertilized maize plants under water regime (I_3) gave lowest values for the same traits in both seasons.

8- Impact of water stress, applications BC, PG either alone or in combination and their interaction on water measurements.

Data in Table (11) showed that the values of WA, WCU, water use efficiency (WUE) and water productivity (WP) were significantly affected by irrigation treatments. The irrigated plants at (I_1) and (I_2) gave the maximum values of WA and WCU, with significant variation between them. Similarly, irrigation at (I_1) or (I_2) resulted in the highest values for WUE and WP. On the other hand, irrigation at (I_3) had the lowest values for all the attributes listed. The high water consumptive use for the moist treatment is due to the abundance of moisture in the soil, so the plants tend to grow without stress. These results are similar to those of **(Taha and Kasem, 2022)**, Who demonstrated that when maize was grown under sole cultivation, irrigation at 80% ETo (evapotranspiration) gave the lowest values for WA, WCU, WUE and WP compared to irrigation at 100 and 120% ETo.

In regard with the results presented in Table(11) application of soil amendments significantly affected on water measurements in both seasons. The combined of BC and PG decreased significantly WA and WCU by (9.80, 8.94 %), (8.66, 7.28%), while increased WUE and WP by (33.33, 32.38 %) and (32.17,30.07%) compared to control in the two seasons respectively. Results showed that the use of a mixture of PG and BC improved the soil's hydro-physical and chemical properties, resulting in less evapotranspiration losses, making water available for crops for a longer period which protecting the crop against water stress and consequently, increasing WUE and WP. Our results concur with **(Faloye *et al*., 2020, Bossolani *et al*., 2021** and **Zahra *et al*., 2021).** Studies show that BC has a high porosity and surface area which leading to an increase in the general soil porosity and water content, reducing water stress for plants **(Batista *et al*., 2018)**. The WUE was lowered by 45 and 50% by using 4% biochar and 40% plant water requirements (PWR) irrigation respectively. (**Ngulube *et al*., 2018**).

The interaction effect between water treatment and soil amendments were significantly on WA and WUE in the two seasons while WP significantly affected in the second season only. The maximum value of WA was obtained from

(I_1×T_1) treatment, but when treated maize plants by (I_3×T_6) recorded the lowest value. Whereas treated maize plants by (I_2×T_6) resulted in the maximum value of WUE while, WP recorded the highest value in response to treated maize plants by I_1 or I_2 with T_6 but the lowest values were obtained when maize plants received (I_3×T_1) treatment.

Table 10: Effect of irrigation treatment , biochar and phosphogypsum, as well as their interaction on days to 50 % silking, ear length, 100- kernel weigh and grain yield of maize hybrid TWC 368 during 2021 and 2022 seasons.

Treatments		Days to 50 % silking		Ear length (cm)		100- kernel weigh (g)		Grain yield (ard fad^{-1})	
		2021	2022	2021	2022	2021	2022	2021	2022
Irrigation level									
I_1		65.00	65.58	24.19	25.68	36.77	37.53	32.80	33.71
I_2		63.71	64.42	22.77	23.92	34.08	34.59	30.37	31.91
I_3		60.86	61.55	17.50	18.34	30.15	31.02	22.77	23.32
LSD 0.05		**1.54**	**0.60**	**0.84**	**0.68**	**0.70**	**1.05**	**0.80**	**0.45**
Biochar and phosphogypsum									
T_1		61.97	62.50	19.41	20.60	30.90	31.60	26.28	26.94
T_2		63.22	63.67	21.16	22.48	33.68	33.92	28.23	29.44
T_3		63.63	64.50	22.77	24.03	35.64	35.96	30.01	31.05
T_4		62.72	62.83	20.34	21.56	32.44	33.49	27.59	28.40
T_5		62.88	63.53	20.92	22.15	32.85	34.17	28.19	29.42
T_6		64.72	66.08	24.32	25.07	36.48	37.14	31.60	32.64
LSD 0.05		**1.07**	**1.23**	**0.84**	**0.91**	**1.14**	**0.91**	**0.81**	**0.57**
Interactions									
I_1	T_1	64.25	64.75	22.50	24.20	35.23	36.03	31.04	31.54
	T_2	65.25	65.25	24.13	25.68	37.19	37.49	32.98	33.93
	T_3	65.50	65.50	25.06	26.55	38.18	38.36	33.68	34.39
	T_4	64.50	65.25	23.23	24.85	35.64	36.94	31.95	32.74
	T_5	64.50	65.25	23.90	25.33	35.67	37.48	32.26	33.35
	T_6	66.00	67.50	26.32	27.50	38.69	38.88	34.92	36.33
I_2	T_1	62.75	63.00	20.53	21.31	30.77	31.15	27.96	29.00
	T_2	63.75	64.50	22.25	23.68	34.03	34.26	29.62	31.70
	T_3	64.00	65.25	24.35	25.50	36.45	36.69	32.08	33.90
	T_4	63.25	63.50	21.48	22.70	32.87	32.99	29.13	30.65
	T_5	63.50	63.50	21.98	23.43	32.90	34.14	29.74	31.16
	T_6	65.00	66.75	26.05	26.90	37.44	38.31	33.72	35.03
I_3	T_1	58.90	59.75	15.20	16.29	26.69	27.61	19.85	20.28
	T_2	60.65	61.25	17.10	18.09	29.81	30.01	22.09	22.67
	T_3	61.4	62.75	18.92	20.05	32.30	32.84	24.29	24.86
	T_4	60.4	59.75	16.32	17.14	28.81	30.53	21.68	21.80
	T_5	60.65	61.83	16.87	17.69	29.99	30.91	22.58	23.76
	T_6	63.15	64	20.59	20.81	33.31	34.24	26.15	26.55
LSD 0.05		**NS**	**1.98**	**1.56**	**1.52**	**1.89**	**1.75**	**1.33**	**1.12**

Table11: Effect of irrigation treatments, biochar and phosphogypsum, as well as their interaction on water measurements of maize hybrid TWC 368 during 2021 and 2022 seasons.

Treatments	(WA) (m^3 fad^{-1})		WCU ($m^3 fad^{-1}$)		WUE (kg m^{-3})		WP (kg m^{-3})	
	2021	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**
Irrigation levels								
I_1	3372	3311	2625	2558	1.75	1.84	1.36	1.43
I_2	3148	3114	2458	2391	1.73	1.87	1.35	1.44
I_3	2956	2892	2300	2243	1.39	1.46	1.08	1.14
$LSD_{0.05}$	**41.47**	**38.47**	**28.97**	**22.72**	**0.06**	**0.04**	**0.06**	**0.04**
Biochar and phosphogypsum								
T_1	3325	3231	2567	2472	1.43	1.53	1.11	1.17
T_2	3166	3129	2458	2391	1.61	1.72	1.25	1.32
T_3	3088	3067	2412	2357	1.74	1.84	1.36	1.42
T_4	3200	3147	2506	2452	1.54	1.62	1.21	1.26
T_5	3174	3117	2479	2419	1.59	1.70	1.24	1.32
T_6	2999	2942	2344	2292	1.89	1.99	1.48	1.55
$LSD_{0.05}$	**75.49**	**54.24**	**40.25**	**34.36**	**0.06**	**0.05**	**0.06**	**0.04**
interaction								
I_1 T_1	3591	3440	2753	2637	1.58	1.67	1.21	1.28
I_1 T_2	3350	3303	2630	2550	1.76	1.86	1.38	1.44
I_1 T_3	3260	3240	2557	2510	1.84	1.92	1.45	1.49
I_1 T_4	3443	3393	2670	2623	1.68	1.75	1.30	1.35
I_1 T_5	3433	3350	2637	2570	1.71	1.82	1.32	1.39
I_1 T_6	3157	3137	2503	2460	1.95	2.07	1.55	1.62
I_2 T_1	3260	3220	2553	2473	1.53	1.64	1.20	1.26
I_2 T_2	3162	3133	2437	2400	1.70	1.85	1.31	1.42
I_2 T_3	3127	3090	2397	2350	1.87	2.02	1.44	1.54
I_2 T_4	3157	3110	2547	2433	1.60	1.76	1.29	1.38
I_2 T_5	3147	3110	2497	2397	1.67	1.82	1.32	1.40
I_2 T_6	3037	3023	2317	2290	2.04	2.14	1.55	1.62
I_3 T_1	3123	3033	2393	2307	1.16	1.23	0.89	0.94
I_3 T_2	2987	2952	2306	2223	1.34	1.43	1.04	1.08
I_3 T_3	2877	2870	2283	2210	1.49	1.57	1.18	1.21
I_3 T_4	3000	2938	2300	2300	1.32	1.33	1.01	1.04
I_3 T_5	2943	2890	2303	2290	1.37	1.45	1.07	1.15
I_3 T_6	2803	2667	2213	2127	1.65	1.75	1.31	1.39
$LSD_{0.05}$	**74.35**	**53.81**	**NS**	**NS**	**0.14**	**0.11**	**NS**	**0.10**

CONCLUSION:

It is clear that water stress has a negative effect on the soil physical properties, physiological traits and productivity of maize plants. But the application of BC and PG has an important role in improving most soil properties, including water holding capacity and nutrients. Therefore, it reflects improving plant growth and increasing productivity.

It could be concluded that irrigation of maize plants up to 65% of AVSMD with the addition of 2 tons BC fad^{-1} plus 2 tons PG fad^{-1} improved the physical and chemical properties of the soil, increasing plant uptake of water and nutrients, improving plant growth and productivity, lowering WCU, and improving WUE.

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الملخص العربى

تأثير إضافة البيوشار والفوسفوجيبسينيوم على الخصائص الفيزيائية للتربة والصفات الفسيولوجية وإنتاجية الذرة الشامية تحت ظروف نقص الماء

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تعاني مصر من نقص حاد في المياه، والذي تفاقم في السنوات الأخيرة بسبب بناء سد النهضة. وبالتالي فإن الهدف من هذا البحث هو تقييم دور محسنات التربة في التخفيف من التأثيرات السلبية لنقص الماء وتحسين إنتاجية الذرة الشامية. تم إجراء تجربة حقلية بمحطة البحوث الزراعية بالجميزة بمحافظة الغربية بجمهورية مصر العربية خلال موسمي الصيف المتتاليين لعامى 2021 , 2022 م لدراسة تأثير ثلاثة مستويات من الماء الميسر مع إضافة محسنات التربة (البيوشار والفوسفوجيبسينيوم) منفردة او مجتمعه علي الخصائص الفيزيائية للتربة وبعض الصفات الفسيولوجية والانتاجية لمحصول الذرة الشامية (هجين ثلاثي368). تم تنفيذ التجربة بنظام القطع المنشقة مرة واحدة في أربعة مكررات, مساحة الوحدة التجريبية 28,8 م2 (4,8 × 6 م) متضمنة 6 خطوط (طول 6 م وعرض 80 سم. تم شغل القطع الرئيسية بثلاثة مستويات من الري وهي الري عند فقد 50 ,65 , 80٪ من الماء الميسر,بينما اشتملت القطع الشقية على ستة معاملات من البيوشار والفوسفوجيبسينيوم وهي:

1) بدون تسميد (الكنترول)
2) 2 طن بيوشار للفدان
3) 4 طن بيوشار للفدان
4) 2 طن فوسفوجيبسينيوم للفدان،
5) 4 طن فوسفوجيبسينيوم للفدان
6) 2 طن بيوشار + 2 طن فوسفوجيبسينيوم للفدان.

أشارت النتائج إلى أن زيادة الإجهاد الرطوبي في التربة حتى 80٪ من الماء الميسر أدى إلى انخفاض معنوي في المسامية الكلية والتوصيل الهيدروليكي للتربة، المادة العضوية، المتاح من النيتروجين والفوسفور والبوتاسيوم ، كلوروفيل أ و ب ، الوزن الجاف للمجموع الخضري، مساحة الورقة ، المحتوى المائي النسبي للورقة ، عدد الأيام حتي طرد 50٪ من الحريرة ، ارتفاع النبات ، نشاط انزيمي البيروكسيديز و البوليفينول أوكسيديز، طول الكوز، وزن الـ 100 حبة و إنتاجية الفدان من الحبوب ، لكن وجدت زيادة معنوية في الكثافة الظاهرية ، الرقم الهيدروجيني , نسبة كلوروفيل أ / ب والبرولين في كلا الموسمين.

أدى اضافة 2 طن بيوشار + 2 طن فوسفوجيبسينيوم للفدان إلى زيادة معنوية في جميع الصفات المدروسة باستثناء الكثافة الظاهرية، الرقم الهيدروجيني ، نسبة كلوروفيل أ / ب ، البرولين ، كمية الماء المضافة وكمية الماء المستهلك.

وتشير نتائج التفاعل بين معاملات الإجهاد المائي ومحسنات التربة علي نباتات الذرة عند فقد 50 أو 65 ٪ من الماء الميسر مع اضافة 2 طن بيوشار + 2 طن فوسفوجيبسينيوم أدي الي تحسين الرقم الهيدروجيني، زيادة المادة العضوية , زيادة المتاح من الفوسفور والبوتاسيوم, كماسجلت أعلى القيم للكلوروفيل أ ، مساحة الورقة ، محتوى الماء النسبى للورقة ، عدد الأيام حتى طرد 50٪ من الحريرة ، ارتفاع النبات ، طول الكوز، وزن الـ 100 حبة وإنتاجية الحبوب للفدان ، وتحسين كفاءة استخدام الماء و إنتاجية الماء. بينما أدى الري عند فقد 65 % من الماء الميسر مع اضافة 2 طن بيوشار+ 2 طن فوسفوجيبسينيوم للفدان الي تسجيل أعلى قيم للإنزيمات المضادة للأكسدة و التوصيل الهيدروليكى.