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Effect of Irrigation Levels and Sulfur Rates on Maize Productivity in North Sinai, Egypt

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Abstract: A field experiment was conducted during 2018 and 2019 growing seasons at Al-Arish Agric. Res. Station (33.82 E, 31.12 N and 4.10 m altitude above mean sea level), North Sinai Governorate, Egypt. The trial aimed to investigate the effect of three irrigation water levels (I_1: 120%, I_2: 100% and I_3: 80% ETc) and three sulfur rates (0, 200 and 400 kg fed^{-1}) on maize yield, yield components and some crop-water relations. A split-plot design with three replicates was adopted. The results revealed that, most of the studied maize parameters (ear weight per plant (g), 100-grain weight (g), stalk and grain yields (t fed^{-1}), N, P and K contents, chlorophyll, total carbohydrate and protein (%)) were significantly affected by the adopted irrigation water levels in 2018 and 2019 seasons. Increasing irrigation water level from 80% to 100% or 120% ETc resulted in gradual increase in the abovementioned parameters. The adopted sulfur rates applications exerted significant effects on all investigated maize parameters and chemical constituents as well. The highest sulfur rate (400 kg fed^{-1}) exhibited the highest figures of the abovementioned characters compared with the other two rates in 2018 and 2019 seasons. The interaction of the highest irrigation water level (120% ETc) and applying sulfur at 400 kg fed^{-1} resulted in the highest significant values of the investigated maize yield, yield components and chemical constituents in 2018 and 2019 seasons. Average values of applied irrigation water (AIW) and water productivity (WP) under I_1, I_2 and I_3 treatments were 3517, 2537 and 2552 m^3 fed^{-1}. Average WP values were 0.90, 0.82 and 0.80 kg/m^{-3} for the same respective treatments. It is recommended to apply 120% ETc and 400 kg fed^{-1} sulfur to obtain highest maize grain yield under Al-Arish conditions.

Key words: Maize yield · Irrigation water level · Sulphur rate · Yield and yield components · Water productivity

INTRODUCTION

In Sinai Peninsula, Egypt, the soil is sandy and calcareous. In many sites of these areas, farmers use saline ground water for irrigation due to the limited fresh water sources. Such water contains a variety of dissolved and suspended substances of salts, organic and soil particles that affects its quality [1].

Water availability for irrigation is the most limiting factor for production of crops in the hot and dry summer season of arid and semiarid regions. By the year 2050, it is predicted that there will be a yearly worldwide water deficiency of 640 billion cubic meters and irregular rainwater delivery over the years, produced by change of climate, has been a main factor accountable for water deficiencies in the tropics. Substantial improvement had previously been made in enhancing investments in irrigation water throughout the use of drip irrigation methods; on the other hand, combating the impending water emergency needs more optimization of drip irrigation management [2, 3].

Thus, new techniques are needed to stun the decrease of production and to raise water use efficiency. One of such methods is irrigation modern systems, particularly the drip irrigation method which has numerous benefits over other irrigation systems [4].

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Abd El-Wahed and Ali [5] concluded that, the drip irrigation system leads to maximum water use efficiency and maize grain yield compared with other irrigation systems. Payero *et al*. [6] noticed that, soil moisture stress at any cycle of the plant growth can be a reason of the decrease in maize growth and yield. Unavailability of water restricted the growth of maize crop by decreasing the macro-nutrients uptake [7]. EL-Hendawy *et al*. [8] tested the response of the maize hybrid cultivars to four drip irrigation rates. The results revealed that, drip irrigation rates affected soil water contents and the reserved soil water, dependent on soil deepness. The influence of irrigation incidence on grain yield was highly significant as the extreme yields were noted at irrigation frequency of two and third days. Furthermore, they found that, water stress led to low irrigation frequencies (once in four and five days) caused a significant decrease in maize crop yield by 51% and 40% respectively, compared with irrigation after two days. Water productivity increased with raising irrigation frequency and reached the extreme values at higher irrigation level.

Khatab *et al*. [9] noticed that the increasing applied irrigation water to 2400 m^3fed^{-1} led to high contents of chlorophyllous, carbohydrate and protein% in grains and highest values of the investigated chemical constituents which tended to be reduced reduction as the irrigation water level decreased.

Sulfur plays a major role on regulating soil salinity hazards under the irrigation with saline water. It contributes to refining soil properties, plant arrangement and crop yields production [1]. Sulfur is an important element for plant nutrient. It is essentially for all crops since it helps in peptides synthesis, which contains cysteine like glutathione, numerous secondary metabolites and chlorophyll. Sulfur additions significantly improved total uptake of nitrogen, phosphorus and potassium as well as improved crop production and plant composition of wheat growing in sandy soil [10-12].

In Egypt, maize is one of the important cereals, since it ranks the third after wheat and rice. It is used as an animal feed and human food. Maize is involved in the manufacturing of dry feed (up to 70%) and also in certain manufactures such as glucose extraction, fructose and oil [13]. It is a high water consuming crop and sensitive to water stress [14]. Irrigation and fertilization are vital factors for fruitful founding of annual food crops such as cereal crops [15].

The aim of the study was to determine the effect of irrigation water levels and sulfur rates and their interactions on maize yield, yield components, some chemical constituents and crop-water relations.

MATERIALS AND METHODS

A field experiment was conducted during the summer seasons of 2018 and 2019 at the experimental farm of El-Areish Agricultural Research station (33.82 longitude, 31.12 latitude and 4.10 m altitude above mean sea level), North Sinai Governorate, Egypt.

Soil samples from surface layer (0–60cm) were collected before conducting the experiment to determine main soil physical (particle size distribution and soil texture), hydro-physical (bulk density, field capacity, wilting point and available soil moisture) as well as some chemical parameters (pH, EC, $CaCO_3$ %, cations, anions and some macro-elements). Main irrigation water chemical parameters were also determined. Analysis of soil and water samples were done according to Ryan *et al.* [16] and the obtained values are listed in Tables 1, 2 and 3.

Experimental Design and Tested Treatments: A split plot experimental design with three replicates was used to implement the field experiment. Three irrigation water levels assigned to the main plots and three sulfur rates assigned to the subplots as follows:

Irrigation water levels (IWL) (main plots):

I_1: 120% ETc
I_2: 100% E Tc
I_3: 80% ETc

Sulfur rates (Agricultural sulfur) (sub-plots):

S_1: Zero (control)
S_2: 200 kg fed^{-1}
S_3: 400 kg fed^{-1}

Cultural Practices: Maize grains (Single-Cross 10 hybrid) were sown using 15 kg fed^{-1} seeding rate on the 1st and 3rd of June 2018 and 2019 summer seasons, respectively. To assure full germination, 50mm of irrigation water was applied for all plots at sowing. After 10 and 20 days from sowing, two applications (50mm each) of irrigation water were applied for complete establishment of seedlings. Irrigation was executed at 4 days interval along the growing season. Sulfur rates were applied during soil preparation in the form of agricultural sulfur. Fertilization was managed according to the recommendation of the Ministry of Agriculture in Egypt, where the mineral fertilizers superphosphate at 30 kg P_2O_5 fed^{-1} and potassium sulphate at 48 kg K_2O fed^{-1} were applied in soil before ridging. Nitrogen fertilizer at 120 kg N fed^{-1} as

Table 1: Soil physical and chemical characteristics at the experimental site

Character		2018	2019
Particle size distribution and textural class	Coarse sand (%)	12.20	10.75
	Fine sand (%)	53.20	51.10
	Silt (%)	33.88	37.40
	Clay (%)	0.72	0.75
	Textural class	Sandy loam	Sandy loam
pH (1:2.5)		8.46	7.80
$CaCO_3$ (%)		18.52	20.10
EC_e (dS m^{-1}), soil paste extract		3.20	2.84
Soluble cations (meqL^{-1})	Ca^{2+}	7.2	4.4
	Mg^{2+}	9.6	8.1
	Na^+	13.5	14.2
	K^+	1.8	1.5
Soluble anions (meq L^{-1})	HCO_3^-	8.6	9.8
	Cl^-	13.2	11.5
	SO_4^{2-}	10.3	6.9
Macro- elements (ppm)	N	33.45	31.9
	P	4.06	3.86
	K	128.4	126.9

Table 2: Chemical analysis of the irrigation water at the experimental site

Characters		2018	2019
pH		7.3	7.2
EC (dS m^{-1})		5.08	5.28
Soluble cations (meq L^{-1})	Ca^{2+}	8.1	8.7
	Mg^{2+}	5.2	5.4
	Na^+	37.3	38.5
	K^+	0.1	0.1
Soluble anions (meq L^{-1})	HCO_3^-	4.9	4.3
	Cl^-	39.2	41.3
	SO_4^{2-}	6.6	7.1

Table 3: Soil hydro-physical constants and bulk density at the experimental site

	Bulk density (g cm^{-3})		Field Capacity (%, w/w)		Wilting Point (%, w/w)		Available soil water (%, w/w)	
Soil depth (cm)	2018	2019	2018	2019	2018	2019	2018	2019
00-15	1.47	1.45	11.40	10.10	5.8	5.5	5.6	4.6
15-30	1.66	1.61	10.90	10.30	5.6	5.3	5.3	5.0
30-45	1.72	1.68	9.70	9.10	4.9	4.6	4.8	4.5
45-60	1.82	1.80	9.40	9.30	4.0	3.8	5.4	5.5

ammonium sulfur (20.6 %N) was applied in four equal portions (20, 35, 50 and 65 days after sowing, DAS). The adopted N fertilizer dose was thoroughly dissolved in a proper water quantity and the supernatant was injected into the irrigation system. The other common cultural practices for maize production were executed.

Harvest was executed on the 23rd and 25 th of September 2018 and 2019 seasons, respectively. Ten plants were chosen randomly from the two inner rows of each sub-plot and 100-grain weight (g), ears and grain weight (g) per plant were recorded. In addition, stover and grain yields (t fed^{-1}) were determined based on the whole area of sub-plots. At 75 DAS chlorophyll pigments content (mg dm^{-2}) were determined as described by Moran [17]. Protein % in grains was estimated via multiplying N% by 5.75. Total carbohydrate % was determined as percentage described by Dubasit *et al*. [18].

Total nitrogen of maize grains and stovers was determined by wet oxidation using Kjeldahl digestion and distillation procedures [19]. Phosphorous was determined calorimetrically using ammonium molybdate and ammonium metavanadate as described by Ryan *et al.* [16]. Potassium was determined using the flame spectrophotometer method [20].

Table 4: Average monthly agro-meteorological data and the calculated ETo for North Sinai Governorate during 2018 and 2019 maize growing seasons.

		Temperature (°C)					
Month	Year	*T.max	T.min	T.mean	Relative Humidity (%)	Wind speed (m sec^{-1})	ETo (mm day^{-1})
June	2018	37.0	19.8	28.4	35.7	4.2	6.34
	2019	35.3	19.0	27.1	40.4	4.2	6.30
July	2018	38.1	21.1	29.6	38.8	3.8	6.46
	2019	38.2	21.1	29.6	37.4	3.7	6.39
August	2018	38.4	21.9	30.1	41.4	3.6	6.20
	2019	39.7	23.8	31.7	40.7	4.0	6.08
September	2018	35.4	20.6	28.0	45.8	3.5	5.24
	2019	36.2	19.8	28.0	44.2	3.6	5.03

* Temperature

Table 5: Reference evapotranspiration (ETo mm/period) and crop coefficients for different growth periods of maize crop

Growth stage	Period	ETo (mm/period)	Kc
Initial	1 - 20 Jun.	126.8	0.35
Development	21 Jun. - 30 Jul.	63.4	0.75
		193.8	
Mid-season	31 Jul. to 8 Sep.	6.46	1.1
		192.2	
		41.92	
Late-season	9 Aug. to 22 Sep.	78.6	0.8

The irrigation system at the experimental site was surface drip irrigation. Drip lateral lines of 16mm were connected to the manifold line. Each cultivated row was served with one lateral line of about 20m long. The lateral lines were equipped with built-in emitters of 3.4 L h^{-1} discharge and spaced at 25 cm apart.

Crop-Soil-Water Relations:

Reference Evapotranspiration (Eto): The reference evapotranspiration (ETo) in mm $month^{-1}$ was calculated using the monthly averages of El-Arish metrological data and FAO Penman-Monteith equation as presented in the CROPWAT 8.0 model [21]. The agro-meteorological data and the calculated ETo values are recorded in Table 4.

Crop Evapotranspiration (ETc): The actual evapotranspiration (ETc) values were calculated using crop coefficient values (Kc) for the initial, development, mid- and late-season growth stages of maize crop (Table 5) according to the equation reported by FAO [22] as follows:

Etc = ETo × Kc.

where:
ETc: crop evapotranspiration (mm day^{-1})
ET_o: reference crop evapotranspiration (mm day^{-1})
Kc: crop coefficient, as reported by FAO [23].

Applied Irrigation Water (AIW): The amounts of applied irrigation water were calculated according to the equation given by Vermeiren and Jopling [24] as follows:

$$AIW = \frac{ETc \times I}{Ea(1 - LR)}$$

where:
AIW : depth of applied irrigation water (mm)
ETc : crop evapotranspiration (mm day^{-1}).
I : irrigation interval (days)
Ea : Irrigation application efficiency for the drip irrigation system (˜ 90% at the experimental site).
LR : leaching requirements: the extra amount of applied water needed for salt leaching under the current experimental conditions.

Crop Water Productivity (WP): The WP is defined as crop yield per a unit of applied irrigation water according to Zhang [25] and is given as follows:

WP = Maize yield (kg/fed)/Applied irrigation water (m^3/fed).

Statistical Analysis: Data collected for the studied variables were subjected to statistical analysis using MSTATC computer package to calculate F ratio according to Snedecor and Cochran [26]. The means were compared using Least Significant Difference (LSD) at 5% level according to Waller and Duncan [27].

RESULTS AND DISCUSSION

Yield and its Components: The effect of tested variables on values of ear weight per plant (g), grain weight per plant (g), 100-grain weight (g) and stover and grain yields (t fed^{-1}) during the two growing seasons for each treatment are presented in Table 6. Results indicated that most yield parameters were significantly affected by the adopted irrigation rates in 2018 and 2019 seasons. The highest values of yield parameters were recorded with I_1 (120% ETc) treatment, whereas the lowest values were detected from irrigation at 80% ETc in both seasons. The highest average values of ear weight and grain weight per plant, 100-grain weight and stover and grain yields were 262.8 g, 139.9 g, 28.33 g, 2.860 t/fed and 3.531 t/fed and 242.4 g, 122.7 g, 26.32 g, 2.586 t/fed and 2.894 t/fed for the 120% ETc irrigation treatment in 2018 and 2019 seasons, respectively. Such findings may be due to the fact that maize is very sensitive to water stress and the less availability of water has been reported to limit maize production throughout the growth stages. Also, proper soil moisture availability in plant root zone during the growing season enhances all growth parameters. The obtained results are in agreement with those reported by Abdallah *et al.* [1]; Awe *et al*. [4]; El-Hendawy *et al.* [8] and Ahmed *et al.* [10].

Regarding to the effect of sulfur rates (S_1: Zero (control), S_2: 200 and S_3: 400 kg fed^{-1}) on maize yield and its components are presented in Table 6. Results indicated that, the adopted sulfur rates significantly affected all the studied maize yield parameters in 2018 and 2019 seasons. In general, the highest figures of the yield parameters were recorded with sulfur additions at 400 kg fed^{-1} rate (S_3), followed by 200 kg fed^{-1} (S_2) and S_1 (control) and reduced with decreasing sulfur rates. Such findings may be due to the role of sulfur fertilizer in decreasing soil and water salinity and releasing nutrients required for plant growth. These results may be attributed to the direct effect of sulfur efficiency on the sustainability of crop yields in sandy soil.

Also, when sulfur is deficient in soil; full yield potential of the crop cannot be realized regardless of other nutrients even under good crop husbandry practices. Moreover, the role of elemental sulfur on controlling the hazards of soil salinity under the use of saline irrigation water and its contribution on improving ears weight per plant, grain weight per plant, 100-grain weight and stalk and grain yields. The obtained results are in harmony with those obtained by Ahmed [10].

With respect to the interaction effect of irrigation water levels and sulfur rates, results in Table 6 showed that yield component parameters were significantly affected in 2018 and 2019 seasons. The highest averages of yield component parameters were detected for the 120% ETc and the S_3 (400 kg fed^{-1}) sulfur rate treatment. On the contrary, the lowest averages were obtained from the 80% ETc and S_1 (control) treatment in 2018 and 2018 seasons.

Some Chemical Constituents

Macronutrients Content in Maize Grains and Stalk: The effect of tested variables on N, P and K% in maize grains and stalk during the two growing seasons is shown in Table 7. In general, N, P and K% contents in maize grains and stalk were significantly increased due to the adopted 120% ETc irrigation treatment as compared with the other treatments in 2018 and 2019 seasons. These results may be attributed to the fact that the soil moisture in the root zone was more available under the highest irrigation water level that helps increased nutrient contents in grains and stalks of maize which consequently enhanced chemical constituents of maize plants. The obtained results are in agreement with by Gutierrez *et al.* [7].

Results in Table 7 indicated that the highest values of the studied chemical parameters were obtained from applying S_3 sulfur treatment in 2018 and 2019 seasons. While, without addition of sulfur (S_1) produced the lowest values of such parameters in both seasons. This may be due to the salinity of the irrigation water, which led to the unavailability of the elements in maize grains and stalk. These results may be due to the effectiveness of sulfur in stimulating building of amino acids and growth hormones as well, which in turn gave positive action on genetic factors that control the various metabolic processes and have shown that S deficiency can reduce N, P and K use efficiency in grains and stalk. The obtained results were in agreement with those reported by Ahmed *et al.* [10] and EL-Kholy *et al.* [11]. Fismes *et al.* [28] concluded that the highest N grains uptake was recorded with increasing levels of sulfur which progressively enhanced the total N maize uptake.

Results indicated significant effect of the interaction between irrigation water levels and sulfur rates on N, P and K% in maize grains and stalk (Table 7) in two growing seasons. The highest averages of N, P and K% parameters were detected for the 120% and 100% ETc levels as interacted with 400 and 200 kg fed^{-1} sulfur rates in 2018 and 2018 seasons. On the contrary, the lowest averages were obtained for the interaction between 80% ETc (I_3) and zero sulfur (S_1) in 2018 and 2018 seasons.

Table 6: Effect of irrigation levels and sulfur rates and their interactions on yield and yield components of maize in 2018 and 2019 growing seasons

Irrigation level	Sulfur rate	Ears weight per plant	Grain weight per plant	100- grain weight (g)	Stalk yield ($t\ fed^{-1}$)	Grain yield ($t\ fed^{-1}$)	Ears weight per plant	Grain weight per plant	100- grain weight (g)	Stalk yield ($t\ fed^{-1}$)	Grain yield ($t\ fed^{-1}$)
				2018 Season					2019 Season		
I_1:120%	S_1	249.1	128.1	25.87	2.783	3.439	231.3	113.8	24.35	2.514	2.690
	S_2	264.8	141.7	28.42	2.855	3.271	243.3	123.0	26.43	2.595	2.926
	S_3	274.7	149.9	30.71	2.941	3.884	252.7	131.2	28.17	2.649	3.066
Mean		262.8	139.9	28.33	2.860	3.531	242.4	122.7	26.32	2.586	2.894
I_2:100%	S_1	234.2	117.8	22.25	2.374	2.376	234.0	104.9	21.18	2.293	2.215
	S_2	245.0	127.1	25.38	2.452	2.640	225.0	112.7	24.27	2.342	2.382
	S_3	253.8	134.7	28.05	2.561	2.804	238.2	122.0	26.07	2.381	2.586
Mean		244.3	126.5	25.23	2.462	2.607	232.4	113.2	23.84	2.339	2.394
I_3:80%	S_1	218.7	105.2	21.38	2.156	1.990	208.4	95.78	20.61	2.125	1.881
	S_2	230.4	114.5	23.67	2.227	2.178	216.9	102.9	22.33	2.163	2.068
	S_3	237.1	120.0	25.94	2.269	2.238	222.1	107.1	24.05	2.196	2.014
Mean		228.7	113.2	23.66	2.217	2.135	215.8	101.9	22.33	2.161	1.988
Sulfur mean											
S_1 (Zero)		234.0	117.0	23.17	2.438	2.750	224.6	104.8	22.05	2.311	2.262
S_2 (200 kg fed^{-1})		246.7	127.8	25.82	2.511	2.696	228.4	112.9	24.34	2.367	2.459
S_3 (400 kg fed^{-1})		255.2	134.8	28.23	2.590	2.827	237.7	120.1	26.10	2.409	2.556
L.S.D at 0.05											
I		10.01	10.48	0.498	0.0585	0.0716	2.097	2.924	2.324	0.01054	0.07169
S		15.99	13.99	1.018	0.0324	0.0726	4.707	11.50	2.565	0.01491	0.07956
I x S		27.69	24.23	1.763	0.0562	0.1258	8.152	19.92	1.442	0.02582	0.1378

Table 7: Effect of irrigation levels and sulfur rates and their interaction on N, P and K% in maize grains and stalk in 2018 and 2019 growing seasons

		Grains			Stalk			Grains			Stalk		
Irrigation level	Sulfur rate	N	P	K	N	P	K	N	P	K	N	P	K
								(%)					
				2018 season						2019 season			
I_1:120%	S_1	1.790	0.400	0.360	0.61	0.54	1.450	1.710	0.3700	0.3300	0.58	0.48	1.45
	S_2	1.860	0.440	0.370	0.66	0.57	1.470	1.770	0.4000	0.3400	0.61	0.50	1.41
	S_3	1.890	0.490	0.390	0.69	0.59	1.520	1.790	0.4500	0.3700	0.66	0.53	1.58
Mean		1.847	0.443	0.373	0.65	0.57	1.48	1.757	0.4067	0.3467	0.62	0.50	1.48
I_2:100%	S_1	1.720	0.360	0.350	0.55	0.52	1.410	1.660	0.3400	0.2900	0.51	0.46	1.36
	S_2	1.750	0.420	0.380	0.58	0.55	1.440	1.700	0.3800	0.3100	0.56	0.47	1.40
	S_3	1.800	0.450	0.370	0.63	0.59	1.460	1.750	0.4000	0.3400	0.60	0.50	1.42
Mean		1.757	0.410	0.366	0.59	0.55	1.44	1.703	0.3733	0.3133	0.56	0.48	1.39
I_3:80%	S_1	1.610	0.340	0.310	0.51	0.46	1.330	1.570	0.3100	0.2700	0.47	0.42	1.33
	S_2	1.670	0.380	0.360	0.52	0.50	1.350	1.610	0.3700	0.3000	0.50	0.45	1.32
	S_3	1.690	0.410	0.340	0.55	0.52	1.390	1.650	0.3900	0.3500	0.520	0.47	1.37
Mean		1.657	0.376	0.336	0.53	0.49	1.36	1.610	0.3567	0.3067	0.50	0.45	1.340
Sulfur mean													
S_1 Zero		1.707	0.366	0.340	0.55	0.50	1.39	1.647	0.3400	0.2967	0.52	0.45	1.41
S_2 200 kg fed^{-1}		1.760	0.413	0.370	0.58	0.54	1.42	1.693	0.3833	0.3167	0.55	0.47	1.37
S_3 400 kg fed^{-1}		1.793	0.450	0.366	0.62	0.56	1.45	1.730	0.4133	0.3533	0.59	0.50	1.42
L.S.D at 0.05													
I		0.1492	0.0413	0.0585	0.04	0.001	0.001	0.04139	0.04139	0.04139	0.004	0.004	0.041
S		0.1299	0.0649	0.0726	0.03	0.032	0.032	0.04593	0.04593	0.03248	0.032	0.032	0.045
I x S		0.2250	0.112	0.1258	0.05	0.056	0.056	0.07956	0.07956	0.05626	0.056	0.056	0.079

Chlorophylls, Total Carbohydrate and Protein %: Results in Table 8 showed that chlorophyll contents in maize leaves as well as total carbohydrate (%) and protein (%) in maize grains were significantly influenced by the adopted irrigation water levels in 2018 and 2019 seasons. Results indicated also that, the 120% ETc irrigation treatment recorded the highest significant values of the chlorophyll pigments, total carbohydrate (%) and protein (%). The tested traits were reduced as the irrigation water level decreased in both seasons. These results may be attributed to that the soil moisture in the root zone was more available under the highest irrigation water level that increased water availability to chlorophyll in leaves as well as total carbohydrate and protein (%0 in maize grains, which in consequence enhanced the growth, yield and chemical constituents of maize plants. These results were in agreement with those obtained by Khatab *et al.* [9].

Results in Table 8 indicate that, the highest significant values of the studied total chlorophyll, carbohydrate and protein (%) were obtained from applying 400 kg of sulfur/fed (S_3), while the lowest values were obtained from the control treatment (S_1) in 2018 and 2019 seasons. These results may be due to the influence of sulfur in stimulating amino acids buildings and growth hormones as well, which in turn gave positive action on genetic factors that control the various metabolic processes while S deficiency can reduce total chlorophyll, carbohydrate and protein (%) in maize grains. The obtained results were in agreement with hose reported by Ahmed *et al.* [10] and EL-Kholy *et al.* [11]. The results agreed also with the finding of Bhagyalakshmi *et al.* [29], who stated that adequate sulfur is required for carbohydrate formation; also it has a role in photosynthesis by influencing the formation of chlorophyll.

Table 8: Effect of irrigation level and sulfur rate and their interaction on Chlorophyll, Total carbohydrate and Protein% in grains in 2018 and 2019 growing seasons

Irrigation level	Sulfur rate	Total chlorophyll	Total carbohydrate (%)	Protein (%)	Total chlorophyll	Total carbohydrate (%)	Protein (%)
			2018 season			2019 season	
I_1:120%	S_1	3.772	72.15	10.29	3.665	71.407	9.833
	S_2	3.966	73.73	10.70	3.814	74.830	10.18
	S_3	4.087	74.48	10.87	3.923	75.843	10.29
Mean		3.942	73.45	10.62	122.7	74.027	10.10
I_2:100%	S_1	3.456	71.94	9.890	3.238	72.220	9.543
	S_2	3.748	73.12	10.06	3.535	74.053	9.777
	S_3	3.833	74.33	10.35	3.625	76.280	10.06
Mean		3.679	73.13	10.10	113.2	74.184	9.794
I_3:80%	S_1	3.238	70.32	9.257	3.069	68.277	9.030
	S_2	3.352	72.87	9.603	3.219	72.763	9.260
	S_3	3.437	73.63	9.717	3.317	74.547	9.490
Mean		3.342	72.27	9.526	101.9	71.862	9.260
Sulfur mean							
S_1 Zero		3.489	71.47	9.813	3.324	70.634	9.469
S_2 200 kg/fed.$^{-1}$		3.689	73.24	10.12	3.523	73.882	9.739
S_3 400 kg/fed.$^{-1}$		3.785	74.15	10.31	3.631	75.557	9.949
L.S.D at 0.05							
I		0.09255	1.879	0.8502	0.03162	1.89	0.2551
C		0.04593	4.853	0.7484	0.02582	4.95	0.2659
I x C		0.07956	8.405	1.296	0.04472	8.250	0.4605

Table 9: Actual crop evapotranspiration (mm) as affected by irrigation treatments throw different stages during 2018 and 2019 growing seasons

Growth stage	Period	Etc 120%	100%	80%
		2018 season		
Initial	1 to 20 Jun.	53	44.38	35.504
Development	21 Jun. to 30 Jul.	57	47.55	38.04
		174	145.35	116.28
Mid-season	31 Jul. to 8 Sep.	9	7.106	5.6848
		254	211.42	169.136
		55	46.112	36.8896
Late-season	9 to 22 Sep.	75	62.88	50.304
Total (mm)		678	565	452
		2019 season		
Initial	3 to 20 Jun.	53	44.1	35.28
Development	21 Jun. to 30 Jul.	58	47.925	38.34
		173	143.775	115.02
Mid-season	31 Jul. to 8 Sep	8	7.029	5.6232
		249	207.328	165.8624
		53	44.264	35.4112
Late-season	9 to 25 Sep.	72	60.36	48.288
Total (mm)		666	555	444

Table 10: Applied irrigation water (m^3 fed^{-1}) as affected by irrigation treatments at different growth stages during 2018 and 2019 growing seasons

Growth stage	Period	120%	100%	80%
		2018 season AIW (m^3 fed^{-1})		
Initial	1 to 20 Jun.	630	630	630
Development	21 Jun. to 30 Jul.	1080	900	721
Mid-season	31 Jul. to 8 Sep.	1482	1235	988
Late-season	9 to 22 Sep.	352	293	235
Total (m^3 fed^{-1})		3544	3058	2574
		2019 season		
Initial	3 to 20 Jun.	630	630	630
Development	21 Jun. to 30 Jul.	1073	895	716
Mid-season	31 Jul. to 8 Sep	1448	1208	965
Late-season	9 to 25 Sep.	338	282	225
Total (mm)		3489	3015	2536

Table 11: Applied irrigation water and water productivity as affected by irrigation treatments during 2018 and 2019 growing seasons

Irrigation levels	Sulfur rate	Applied irrigation water (AIW)	Grain Yield (kg fed^{-1})	Crop water productivity (WP)	Applied irrigation water (AIW)	Grain Yield (kg/fed^{-1})	Crop water productivity (WP)
			2018 season			2019 season	
I_1:120%	S_1	3544	3884	1.10	3489	2690	0.771
	S_2		3271	0.92		2926	0.839
	S_3		3439	0.97		3066	0.879
Mean		3531	0.99		2894	0.82	
I_1:100%	S_1	3058	2376	0.78	3015	2215	0.735
	S_2		2640	0.86		2382	0.790
	S_3		2804	0.92		2586	0.858
Mean		2607	0.85		2394	0.79	
I_1:80%	S_1	2574	1990	0.77	2536	1881	0.742
	S_2		2178	0.85		2068	0.815
	S_3		2238	0.87		2014	0.794
Mean		2135	0.83		1988	0.78	

Results in Table 8 revealed that, the highest averages of total chlorophyll in maize leaves, carbohydrate (%) and protein (%) of maize grains were recorded from 120% and/or 100% ETc treatments as interacted with 400 or 200 kg/fed^{-1} sulfur rate in 2018 and 2019 seasons. On the contrary, the lowest averages were obtained from the interaction of 80% ETc and without applying sulfur in the two seasons. These results were in agreement with those obtained by Khatab *et al.* [9].

Crop-Soil-Water Relations

Actual Evapotranspiration (ETc): Results in Table (9) revealed that the average mean season under 120%, 100% and 80% of ETc were 678, 656 and 452 mm in 2018 and 666, 555 and 444 mm in 2019, respectively.

Applied Irrigation Water (AIW): The effect of irrigation treatments on the amounts of applied irrigation water is presented in Table (10). Results indicated that, total amounts of applied irrigation water (AIW) for the whole growth seasons were 3544, 3058 and 2574 m^3/fed in 2018 season and were 3489, 3015 and 2536 m^3/fed in 2019 season, for the 120%, 100% and 80% ETc treatments, respectively. Results revealed also that, irrigation amounts in 2018 season were higher than those of 2019 due to the effect of air temperature, relative humidity and wind speed parameters used to calculate ETo values.

Crop Water Productivity (WP): Water productivity values for maize crop (kg grains/m^3 of applied water) as affected by the amounts of applied irrigation water and sulfur rates are presented in Table (11). In general, the average water productivity values differed considerably due to irrigation treatments. The WP values increased with increasing amounts of irrigation water in the two seasons. Average WP values were higher under the 120% ETc than those of 100% and 80% ETc in the two seasons. The WP values ranged from 0.83 to 0.99 kg/m^3 and from 0.78 to 0.82 kg/m^3 in 2018 and 2019 seasons, respectively.

Results indicated also that, increasing sulfur rate increased WP values in both seasons. The interaction effect of I_1 (120% ETc) and S_3 (400 kg/fed) resulted in the highest WP values of 0.97 and 0.879 kg grain/m^3 applied water in the 2018 and 2019 growing seasons, respectively. The results agreed also with the finding of Abd El-Latif and Abdelshafy [30], who stated that adequate water productivity (WP) values were higher under drip system (2.66 and 2.62 kg/m^{-3}) in the two respective seasons.

CONCLUSION

From the obtained results, it could be concluded that, it is recommended to apply I_1 (120% ETc) and S_3 (400 kg/fed) treatment to obtain highest maize yields under the saline irrigation water of North Sinai conditions.

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