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Effect of Water Deficit on the Productivity of Four Bread Wheat Cultivars under Calcareous Soil Conditions in Egypt

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ABSTRACT

Irrigation reduction is the main problem facing wheat production especially in calcareous soil in Egypt. Four bread wheat cultivars (Giza 171, Shandaweel 1, Sids 14 and Sakha 95) were studied under 100 %, 60 % and 40 % of full irrigation in calcareous soil conditions. Three irrigation treatments were distributed in the horizontal strips, and the four bread wheat cultivars were distributed in vertical strip. Results showed that full irrigation (100%) which used 2476 and 2357 m^3/fed in the in the first and second season, produced the highest values of all studied traits, followed by irrigation treatment 60% then irrigation with 40% of full irrigation. Data cleared the superiority of Sakha 95 in grain, biological yield and harvest index percentage. Moreover, Sakha 95 was the best cultivar under all irrigation treatments. On the other hand, the worst cultivar was Sids 14 for grain and biological yield. Genotype by environment interaction (GGE) Biplot analysis revealed that Shandaweel 1 was the most stable cultivar regardless of its grain yield. Meanwhile, Sakha 95 was the most superiority cultivar with moderate tolerance to reduced irrigation. On the contrary, Sids 14 had reasonable stability and was the worst cultivar for grain yield. Moreover, Giza 171 was the most unstable cultivar under these conditions. Irrigation water productivity (IWP) values increased with increasing water deficit for all wheat cultivars. The highest IWP values were 2.90 and 3.10 kg/m^3 in first and second season by using water stress treatment 40% from full irrigation with Sakha 95, respectively. While, the lowest values were 1.14 and 1.41 kg/m^3 were obtained from Sids 14 with 100% irrigation treatment in the first and second season, respectively. The study recommends cultivation of the cultivar Saka 95 under reduced irrigation in the calcareous soil.

Keywords: *Bread wheat, Triticum aestivum L., water deficit, stress tolerance index*

1. INTRODUCTION

Wheat (*Triticum aestivum*, L.) is the most important crop in Egypt and worldwide. Wheat production in Egypt, does not meet the current demands. Thus, efforts have been devoted by the Egyptian government to reduce imported wheat quantity to less than 50% of the total consumption (Abdrabbo and Gaaver 2012). Many efforts are continuously paid for increasing wheat productivity to decrease the gap between production and consumption. This included vertical and horizontal expansion. The vertical increase can be achieved by breeding programs to improve yield and apply the optimum cultural practices, including irrigation. Within the arid and semi-arid regions, water deficiency is the major limitation for crop production. Wheat crop needs sufficient available water to achieve optimum yields. Over the last decades, several studies have been conducted on the regulation of watering in arid and semi-arid regions (De Juan *et al.*, 1999 and Li *et al.*, 2001). Wajid *et al.* (2002) reported that, wheat produced the highest grain yield by

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applying irrigation at definite growth stages. Moreover, Mirbahar *et al.* (2009) indicated that water stress had significantly reduction on plant height, spike length, spikelet per spike, grains per spike and 1000 kernels weight for 25 wheat varieties. In addition, Abdelraouf *et al.* (2013) showed that decreasing the irrigation requirements (IR) from 100% to 50% had significantly decreased from 1.91 to 1.27, 4.66 to 3.48, and 6.57 to 4.75 on grain, straw and biological yield, respectively. Water use efficiency increased with increasing the deficit of irrigation (Akram *et al.*, 2014). The reduction of water consumption effect on grain, straw, biological yield and 1000 kernels weight (Abdelkhalak *et al.*, 2015). They detected significant differences among three wheat varieties. Misr 1 had the highest response of water factor (Ky) followed by Misr 2. While, water productivity (WP) decreased with increasing irrigation events and reached the maximum values at three irrigation treatments under North Nile Delta conditions. The use of deficit irrigation in drip-irrigated wheat under arid conditions in Egypt is an effective tool to maximize efficiency of water use (Eissa *et al.*, 2018). Mirbahar *et al*. (2009) and Akram (2011) indicated that water stress significantly reduced height, spike length, spikelet per spike, kernels per spike and 1000 kernels weight of all 25 wheat varieties. Abdelkhalak *et al*. (2015) showed that, the decreased irrigation treatment reduced grain, straw, biological yield and 1000 kernels weight. Ghalab *et al.* (2018) showed that, biological and grain yields, plant height, number of spikes m^{-2}, number of kernels $spike^{-1}$ and 1000 kernels weight were significantly affected by the irrigation and cultivar. Maximum biological and grain yields were obtained by irrigation with amount of water equals 100% of crop evapotranspiration in Nubaria region, Egypt. Many stress indices have been used to evaluate the cultivars for their tolerance to water stress. The stress susceptibility index (Fischer and Maurer 1978) may be useful to identify the drought tolerance of wheat genotypes (Farhat, 2015, Shehab-Eldeen and Farhat 2020 and Farhat *et al*., 2021). Genotype main effect and genotype environment interaction (GGE) biplot are the graphically method that allow visualization of the patterns in a dataset from different angles (Yan *et al*., 2007). GGE biplot analysis has been mainly used to analyze data from multi environment variety trials and other types of data that can be organized a two-ways table. Biplot analysis appeared as a valuable to use different types of biplot graphs and its application that can be useful in visualizing genotype comparison and selection. Thus, it can be utilized as a screening tool to identify the tolerant wheat cultivars under stress condition (Feltaous and Koubisy, 2020 and Mohammadi and Golkari, 2022).

The current research aimed to identify the high yielding and stable variety under deficit of water irrigation. To detect the appropriate Egyptian cultivars to reduced irrigations under calcareous soil conditions at El-Nubaria region, Egypt (longitude 29º 58’’ 01’ E, latitude 30º 52’’ 56’N).

2. MATERIAL AND METHODS

2.1. Site and plant material

A field experiments were held at Nubaria Agricultural Research Station, Agricultural Research Center, Egypt (longitude 29º 58’’ 01’ E, latitude 30º 52’’ 56’ N) over two successive seasons 2018/2019 and 2019/2020 to study the effect of different irrigation regimes on the productivity of four bread wheat cultivars which newly recorded in the Wheat Research Department. Pedigree of the four studied cultivars is present in Table (1).

2.2. Design and layout of the experiment

The experiment was conducted in a strip plot

Table (1): Name, pedigree and selection history of four studied bread wheat cultivars.

Name	Pedigree and selection history*
Giza171	SAKHA 93/GEMMEIZA 9 S.6-1GZ-4GZ-1GZ-2GZ-0S
Shandaweel1	SITE/MO/4/NAC/TH.AC//3*PVN/3/MIRLO/BUC CMSS93B00567S-72Y-010M-010Y-010M-3Y-0M-0HTY-0SH
Sids14	Bow"s"/Vee"s"//Bow's'/Tsi/3/BANI SUEF1 SD293-1SD-2SD-4SD-0SD
Sakha95	PASTOR // SITE / MO /3/ CHEN / AEGILOPS SQUARROSA (TAUS) // BCN /4/ WBLL1 CMA01Y00158S-040POY-040M-030ZTM-040SY-26M-0Y-0SY-0S.

* Source: Wheat Research Department, Corp Field Research Institute, ARC, Egypt.

design with three replications. The irrigation regimes (I1 = full irrigation 100%, I2 = irrigation with 60% of full irrigation and I3 = irrigation with 40% of full irrigation) were distributed in the horizontal strips. The four bread wheat cultivars (C1 = Giza 171, C2 = Shandaweel 1, C3 = Sids 14 and C4 = Sakha 95) were distributed in vertical strip. The experimental plot size was 5.6 m^2. Each plot consisted of eight rows with 3.5 meters long and 20 cm apart. Soil mechanical and chemical analysis of the experimental site were shown in Table (2). The sowing date was November 20th in both seasons, and the harvest date was 10th of May. The irrigation was stopped on 20th of April. All recommended agriculture practices were applied at the proper time from sowing to harvest.

2.3. Climatic data

The main agrometeorological data and the calculated reference evapotranspiration (ETo) values during the two growing seasons at the experimental site are presented in Table (3).

2.4. Cultural practices and studied parameters

To determine the best treatment, the following parameters were determined:

1. Days to heading (HD, days): Estimated as number of days from sowing date to the day in which the main spikes of 50% of plants were completely emerged in each plot.

2. Days to maturity (DM, days): Estimated as number of days from sowing date to the day in which the main spikes reached to the physiological maturity of 50% of plants in plot.

3. Plant height (PH, cm): Measured as the height in (cm) from soil surface to the top of the main spike excluding awns.

4. Number of spikes m^{-2} (NS): Determined as a number of spikes of fertile tillers per meter square at harvest time.

5. Number of kernels $spike^{-1}$ (NK/S): Estimated by counting number of kernels of random 10 spikes from each plot.

6. One thousand kernels weight (KW, g): Determined by weighting 1000 random kernels in grams per plot.

7. Grain yield (GY, t $faddan^{-1}$): At harvest, the two external rows were eliminated from each plot to avoid the boarder effect. The plants were then harvested, threshed and their grain yields were weighed and adjusted to $tons/faddan^{-1}$.

8. Biological yield (BY, t $faddan^{-1}$): At harvest, the two external rows were eliminated from each plot to avoid the boarder effect. Then the whole plants (grains + straw) were weighing for each plot.

9. Harvest index (HI, %): Calculated as the percentage of grain yield (economic yield) to the biological yield (grain and straw yields), by the following formula:

Table (2): Chemical, physical properties and available macronutrients in the soil at the experimental site.

Chemical properties		Soil depth (cm) 0-30	Soil depth (cm) 30-60	Chemical and physical properties		Soil depth (cm) 0-31	Soil depth (cm) 30-61
EC (dS/m)		2.13	1.98	$CaCO_3$ %		22.73	23.82
	pH	8.27	8.33	Organic Matter %		0.26	0.18
Soluble cations, meq/l	Ca^{++}	6.77	7.05	Particle size distribution	Sand %	83.13	81.45
	Mg^{++}	1.98	1.68		Silt %	10.44	11.97
	Na^{+}	10.13	8.79		Clay %	6.43	6.58
	K^{+}	2.42	2.28	Soil texture		Loamy sand	Loamy sand
Soluble anions, meq/lL	CO_3^{--}	-	-	Available macronutrients	N (ppm)	40.21	33.8
	HCO_3^{-}	4.11	3.81		P (ppm)	3.62	3.11
	Cl^{-}	11.82	10.32		K (ppm)	89.81	82.21
	SO_4^{--}	5.37	5.67				

Table (3): Agrometeorological data and reference evapotranspiration values at the experimental site.

Date	Tmin (°C)	Tmax (°C)	Humidity (%)	Wind Speed (m/s)	Sunshine (hr.)	ETo (mm)
			1st season, 2018/ 2019			
Oct. 2018	15.90	29.00	61.4	4.20	9.2	**5.17**
Nov.	12.50	24.50	63.1	3.50	9.1	**3.68**
Dec.	4.30	17.10	61.5	7.50	9.00	**2.95**
Jan. 2019	6.10	18.80	64.2	6.40	9.00	**3.55**
Feb.	6.10	18.8	65.21	3.63	9.20	**3.69**
Mar.	7.80	20.80	63.4	6.90	9.50	**4.53**
Apr.	8.80	24.60	56.4	6.90	10.00	**6.09**
May	10.40	31.40	46.1	6.80	10.94	**8.79**
Date			2nd season, 2019/ 2020			
Oct. 2019	16.30	29.90	62.5	6.20	9.20	**5.69**
Nov.	12.70	26.60	61.8	5.50	9.10	**4.79**
Dec.	9.60	20.30	67.7	7.00	9.00	**3.49**
Jan. 2020	7.90	17.10	70.8	6.90	9.00	**2.88**
Feb.	8.40	18.60	70.8	6.30	9.20	**3.25**
Mar.	8.90	21.40	66.1	7.10	9.50	**4.47**
Apr.	10.60	23.70	58.6	6.30	10.00	**5.25**
May	13.10	31.40	54.7	6.70	11.0	**7.11**

* Source: Agrometeorological at Nubaria Research Station, ARC, Egypt.

Harvest Index (HI, %) = $\left(\frac{Grain\ yield}{Biological\ yield}\right) X\ 100$

2.5. Stress susceptibility index (SSI)

Stress susceptibility index (SSI) was determined according to the Fischer and Maurer (1978), SSI was calculated by using the following equations:

$$SSI = \left(1 - \frac{Ys}{Yp}\right) / SI \qquad SI = \left(1 - \frac{MYs}{MYp}\right),$$

Where:

SI= Stress intensity

Yp= The mean values for the studied trait under non-stress conditions.

Ys= Trait mean value under stress conditions.

MY= Mean trait value of all genotypes under non-stress conditions.

Mys= Mean trait value of all genotypes under stress conditions.

2.6. Soil and plant water relations

2.6.1. Reference and crop evapotranspiration (ET_o, ETc)

The ET_o values for the two growing seasons were calculated by using the weather data from weather station established at Nubaria Research Station in Egypt using CROPWAT model (Smith, 1991) based on FAO, Penman- Monteith method. The equation is given as:

$$ETo = \frac{0.408\,\Delta\,(Rn - G) + \gamma\,[900/(T + 273)]\,U_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,U_2)}$$

Where:

Rn = net radiation (MJ m^{-2} d^{-1})

G = soil heat flux (MJ m^{-2} d^{-1})

Δ = slope of vapor pressure and temperature curve (kPa $°C^{-1}$)

γ = psychrometric constant (kPa $°C^{-1}$)

U_2 = wind speed at 2 m height (m s^{-1})

e_s-e_a = vapor pressure deficit (kPa)

T = mean daily air temperature at 2 m height (°C)

The crop evapotranspiration (ETc) values were calculated according to following equation:

$$ETc = ETo\ X\ Kc$$

Where:

ET_c = Crop evapotranspiration (mm/day).

ET_o = reference evapotranspiration (mm/day).

K_c = Crop coefficient. Wheat crop coefficient values were obtained from FAO no. 56 (Allen *et al*., 1998).

2.6.2. Amount of applied irrigation water (AIW)

The amount of applied irrigation water was measured by a flow meter and was calculated according to the following equation:

$$AIW = \frac{ETc}{Ea}$$

Where:

AIW = Applied irrigation water depth (mm).

E_a = Irrigation efficiency (70% for surface irrigation system under experimental conditions).

2.6.3. Productivity of irrigation water (PIW)

Productivity of irrigation water (PIW) was calculated according to Ali *et al*. (2007) using the following equation:

$$PIW = \frac{GY}{AIW}$$

Where:

PIW= productivity of irrigation water (kg grains/m^3),

AIW= Applied irrigation water (m^3/ha).

2.6.4. Yield response factor (Ky)

The relationship between relative evapotranspiration reduction ($1 - \frac{ETa}{ETm}$) and relative yield reduction ($1 - \frac{Ya}{Ym}$) was determined using the method given by Doorenbos and Kassam (1979). The equations are as follows.

$$\left(1 - \frac{Ya}{Ym}\right) = Ky\left(1 - \frac{ETa}{ETm}\right)$$

Ya is actual harvested yield, *Ym* is maximum harvested yield, *Ky* is yielding response factor, *ETa* is actual evapotranspiration, *ETm* is maximum evapotranspiration, *Yd* is relative yield reduction, and *ETd* is relative evapotranspiration reduction.

2.7. Statistical analysis

In the presence of homogeneity of experimental errors over the two seasons, a combined analysis was performed (Levene, 1960). The obtained data showed no homogeneity between experimental errors of the two seasons thus, the results of each season will be discussed separately. The statistical analyses were performed according to Gomez and Gomez (1984) using GenStat 18 (Payne *et al.,* 2017). Differences among treatment means were compared by using the least significant differences test (LSD) at 0.01 and 0.05 probability levels.

3. RESULTS AND DISCUSSION

3.1. Effect of irrigation treatments

The effect of irrigation regimes on studied traits during the two seasons are shown in Table (4). All studied traits were significantly affected by the irrigation treatments except harvest index. Results showed that full irrigation (100%) treatment produced the highest values of all studied traits, followed by irrigation regime 60% then irrigation with 40% of full irrigation. Similar results were obtained by Feltaous and Koubisy (2020). They declared a high reduction for most agronomic traits as a result of terminal water stress conditions. Mehraban *et al*. (2019) stated a considerable reduction in number of days to maturity under water stress conditions.

3.2. Effect of cultivars

The effect of cultivars on studied traits during the two seasons are presented in Table (5). Results showed that there is insignificant difference between all studied cultivars in their heading dates during the two seasons. Meanwhile, for maturity date Sakha 95 was the earliest while, Sids 14 was the latest cultivar in both seasons. Moreover, the shortest plants were produced from Giza 171 in the both seasons, while the tallest plants were produced from Sakha 95 and Sids 14 in the first and second seasons, respectively. Significant differences were detected between cultivars on their yield and its components, except number of spikes m^{-2}, number of kernels $spike^{-1}$, biological yield and harvest index in the first season. Data cleared that Sakha 95 had the highest No. of spikes and grain yield in both seasons. Moreover, it had the highest biological yield in the second season. Meanwhile, Shandaweel 1 had the highest No. of kernels $spike^{-1}$ in both seasons, and highest value of harvest index in the second season. Moreover, data showed the superiority of Giza 171 for kernels weight in both seasons. On the other hand, the least values were obtained by Sids 14 for No. of kernels $spike^{-1}$, grain yield and harvest index in both seasons. Moreover, it had the lowest value of 1000 kernels weight and biological yield in the first season.

3.3. Interaction between irrigation treatments and cultivars

Results of interaction between irrigation treatments and cultivars in the two seasons are presented in Table (6). It was noticed that Sakha 95 was the earliest heading and maturity under all irrigation treatments. In addition, the earliest plants were produced from Sakha 95 under 40% of full irrigation. On the other hand, the latest plants were produced from Giza 171 under full irrigation. Moreover, under 40 % of full irrigation the latest heading plants were produced from Sids 14 in the two seasons. Moreover, Sids 14 was the latest maturity cultivar under all irrigation treatments. Meanwhile, Sakha 95 was the earliest maturity cultivar under all irrigation treatments. In addition, the tallest plants under 40% from full irrigation were obtained from Sakha 95 and Shandaweel 1.

Table (4): Mean performance of the studied traits as affected by irrigation treatments for the studied bread wheat cultivars across 2018/2019 and 2019/2020 seasons.

Irrigation treatments	No. of days to heading (days)			No. of days to maturity (days)			Plant height (cm)		
	2018/19	**2019/20**	**Mean**	**2018/19**	**2019/20**	**Mean**	**2018/19**	**2019/20**	**Mean**
40%	91.00	92.75	91.808	140.70	145.20	142.90	91.38	92.92	92.10
60%	96.58	95.58	96.08	147.70	148.60	148.10	111.58	108.92	110.20
100%	97.92	97.00	97.46	152.90	152.00	152.50	116.08	118.00	117.00
Mean	95.17	95.11		147.08	148.58		106.50	106.61	
Irrigations $LSD_{5\%}$	1.09	1.85		3.99	3.19		7.82	2.52	
Irrigation treatments	**No. of spikes m^{-2}**			**No. of kernels $spike^{-1}$**			**1000-Kernels weight (g)**		
	2018/19	2019/20	Mean	2018/19	2019/20	Mean	2018/19	2019/20	Mean
40%	283.50	277.10	280.30	47.46	46.42	46.94	46.23	50.47	48.35
60%	289.70	300.00	294.80	48.04	51.00	49.52	48.23	53.08	50.66
100%	327.10	310.00	318.50	54.76	53.03	53.89	51.34	55.26	53.30
Mean	300.10	295.7		50.09	50.15		48.60	52.94	
Irrigations $LSD_{5\%}$	24.02	12.60		4.89	2.63		2.84	3.40	
Irrigation treatments	**Grain yield (t fad^{-1})**			**Biological yield (t fad^{-1})**			**Harvest index %**		
	2018/19	2019/20	Mean	2018/19	2019/20	Mean	2018/19	2019/20	Mean
40%	2.51	2.67	2.59	7.71	7.12	7.42	32.68	37.73	35.21
60%	2.75	3.09	2.92	8.43	8.36	8.39	32.71	37.11	34.91
100%	3.69	3.84	3.77	9.89	9.66	9.78	37.43	39.88	38.66
Mean	2.98	3.20		8.68	8.38		34.27	38.24	
Irrigations $LSD_{5\%}$	0.50	0.51		0.39	0.81		N.S.	N.S	

40%, 60% and 100% from total water requirements

Table (5): Mean performance of the studied traits as affected by cultivars for the studied bread wheat cultivars across 2018/2019 and 2019/2020 seasons.

Cultivars	No. of days to heading (days)			No. of days to maturity (days)			Plant height (cm)		
	2018/19	**2019/20**	**Mean**	**2018/19**	**2019/20**	**Mean**	**2018/19**	**2019/20**	**Mean**
Giza 171	96.33	96.22	96.28	147.90	147.30	147.60	99.11	101.67	100.39
Shandaweel 1	95.67	93.22	94.44	146.20	148.80	147.50	109.00	105.22	107.11
Sids 14	96.11	96.89	96.5	150.60	151.00	150.80	107.89	112.44	110.17
Sakha 95	92.56	94.11	93.33	143.70	147.20	145.40	110.00	107.11	108.56
Mean	95.17	95.11		147.08	148.58		106.50	106.61	
$LSD_{5\%}$	N. S	N. S		2.31	2.90		4.61	2.90	

Cultivars	No. of spikes m^{-2}			No. of kernels $spike^{-1}$			1000-Kernels weight (g)		
	2018/19	2019/20	Mean	2018/19	2019/20	Mean	2018/19	2019/20	Mean
Giza 171	287.00	268.30	277.70	48.97	49.13	49.05	54.99	57.70	56.34
Shandaweel 1	294.00	298.90	296.40	53.24	55.88	54.56	45.56	48.71	47.13
Sids 14	291.30	301.70	296.50	46.21	45.95	46.08	44.98	51.28	48.13
Sakha 95	328.00	313.90	320.90	51.94	49.64	50.79	48.89	54.06	51.47
Mean	300.10	295.7		50.09	50.15		48.60	52.94	
$LSD_{5\%}$	N.S.	19.28		N. S	1.97		3.04	2.38	

Cultivars	Grain yield (t fad^{-1})			Biological yield (t fad^{-1})			Harvest index %		
	2018/19	2019/20	Mean	2018/19	2019/20	Mean	2018/19	2019/20	Mean
Giza 171	3.09	3.12	3.11	9.15	8.28	8.72	33.43	37.60	35.52
Shandaweel 1	2.92	3.16	3.04	8.41	7.88	8.15	34.76	40.05	37.41
Sids 14	2.45	2.92	2.68	8.35	8.30	8.32	29.39	35.38	32.39
Sakha 95	3.49	3.62	3.55	8.80	9.05	8.93	39.51	39.92	39.71
Mean	2.98	3.20		8.68	8.38		34.27	38.24	
$LSD_{5\%}$	0.47	0.51		N.S.	0.75		N.S.	4.47	

Table (6): Means performance of the studied traits as affected by cultivars and irrigation treatments during the two growing seasons 2018/2019 and 2019/2023.

Irrigations treatments	Cultivars	No. days to heading (days)		No. days to maturity (days)		Plant height (cm)		No. spikes m^{-2}		No. kernels $spike^{-1}$		1000-Kernels weight (g)	
		2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20
40 %	**Giza 171**	91.0	93.0	140.3	144.0	88.00	87.33	91.0	93.0	140.3	144.0	88.00	87.33
	Shandaweel 1	91.3	92.3	139.7	145.0	94.00	92.67	91.3	92.3	139.7	145.0	94.00	92.67
	Sids 14	92.7	94.3	145.7	148.0	92.67	99.00	92.7	94.3	145.7	148.0	92.67	99.00
	Sakha 95	89.0	91.3	137.0	143.7	92.67	92.67	89.0	91.3	137.0	143.7	92.67	92.67
60 %	**Giza 171**	97.7	96.0	150.0	147.7	100.00	103.67	97.7	96.0	150.0	147.7	100.00	103.67
	Shandaweel 1	97.3	93.3	147.7	148.7	115.67	108.00	97.3	93.3	147.7	148.7	115.67	108.00
	Sids 14	97.3	98.0	149.3	150.0	115.00	114.00	97.3	98.0	149.3	150.0	115.00	114.00
	Sakha 95	94.0	95.0	143.7	148.0	115.67	110.00	94.0	95.0	143.7	148.0	115.67	110.00
100 %	**Giza 171**	100.3	99.7	153.3	150.3	109.33	114.00	100.3	99.7	153.3	150.3	109.33	114.00
	Shandaweel 1	98.3	94.0	151.3	152.7	117.33	115.00	98.3	94.0	151.3	152.7	117.33	115.00
	Sids 14	98.3	98.3	156.7	155.0	116.00	124.33	98.3	98.3	156.7	155.0	116.00	124.33
	Sakha 95	94.7	96.0	150.3	150.0	121.67	118.67	94.7	96.0	150.3	150.0	121.67	118.67
$LSD_{5\%}$	4.13	3.32	5.77	4.84	8.80	4.62		4.13	3.32	5.77	4.84	8.80	4.62

40%, 60% and 100% from total water requirements.

Table (6): Cont.

Irrigations treatments	Cultivars	Grain yield (t fad^{-1})		Biological yield (t fad^{-1})		Harvest Index %	
		2018/19	2019/20	2018/19	2019/20	2018/19	2019/20
40 %	**Giza 171**	2.39	2.46	8.07	7.04	29.54	35.12
	Shandaweel 1	2.42	2.63	7.71	6.79	31.31	39.00
	Sids 14	2.18	2.67	7.72	7.15	30.91	37.67
	Sakha 95	2.87	2.92	7.35	7.50	38.97	39.12
60 %	**Giza 171**	3.02	2.97	8.86	8.26	34.02	36.47
	Shandaweel 1	2.60	3.02	8.04	7.80	32.77	38.72
	Sids 14	2.24	2.76	8.15	8.28	26.33	33.19
	Sakha 95	3.26	3.6	8.65	9.08	37.71	40.07
100 %	**Giza 171**	3.87	3.92	10.52	9.55	36.74	41.21
	Shandaweel 1	3.73	3.82	9.48	9.06	40.21	42.43
	Sids 14	2.82	3.32	9.17	9.45	30.93	35.29
	Sakha 95	4.33	4.30	10.40	10.50	41.84	40.58
Irrigations x cultivar $LSD_{5\%}$		0.71	0.28	0.90	1.14	8.69	6.79

40%, 60% and 100% from total water requirements.

Moreover, in the first season Sids 14 and Shandaweel 1 and Sids 14 in the second one produced the highest plants under 60 % of full irrigation. Under 100% of full irrigation, the tallest plants were obtained from Shandaweel 1 and Sids 14 in the first and second season, respectively. In addition, Sakha 95 and Sids 14 had the highest no. of spikes m^{-2} under all conditions. In the same trend, Shandaweel 1 has the height number of kernels $spike^{-1}$ under all irrigation treatments. Moreover, the highest values of 1000 kernels weight were detected in Giza 171, while the least values were detected in Shandaweel 1. The obtained results showed the superiority of Sakha 95 in grain, biological yield and harvest index percentage. These results cleared that Sakha 95 was the best cultivar under all irrigation treatments. On the other hand, the worst cultivar was Sids 14 for grain yield, Sids 14 and Shandaweel 1 for biological yield, Giza 171 for harvest index % under all irrigation treatments. According to the previous studies, the genotypes behaved differently under irrigation treatments across different seasons (Farhat, 2015, Feltaous and Koubisy, 2020, Shehab-Eldeen and Farhat, 2020 and Farhat *et al.,* 2020).

3.4. Reduction %

Table (7) shows the minimum, maximum and average reduction values for all studied characters traits as a result to decrease the irrigation during the two seasons. This reduction ranged from 0.31 to 3.71, from, 1.81 to 9.30, and from 1.07 to 6.86% for heading date. The reduction rate in maturity date ranged from 1.33 to 4.72, from 4.19 to 8.85, and from 1.33 to 6.47%. The plant height the reduction rate ranged from 0.26 to 4.35, from 1.19, to 6.91 and from 0.28 to 3.58%. In case of number of $spikes/m^{2,}$ the reduction ranged from 3.48 to 13.12, from 6.81 to 19.73, and from 0.51 to 10.88%. The reduction in the number of kernels /sp. ranged from 1.57 to 11.77, from 8.5 to 18.56, and from 3.19 to 12.04%. The reduction in case of 1000 kw ranged from 1.48 to 8.79, from 6.75 to 13.61 and from 1.39 to 7.64%. The reduction rate in grain yield ranged from 15.58 to 30.29, from 19.58 to 38.24 and from 2.68 to 20.86%. Regarding the biological yield, the reduction ranged from 11.12 to 16.83, from 15.81 to 29.33 and from 4.10 to 17.40%. The reduction in harvest index ranged from 3.89 to 10.85, from 7.17 to 25.03, and from 3.08 to 15.91% for as a result to decreased irrigation from 100% to 60%, from 100% to 40%, and from 60% to 40% from full irrigation, respectively.

Decreased irrigation from 60 to 40% from full irrigation had the least effect on all studied characters traits. Grain yield was highly effect under different irrigation regimes and environments because of its sensitivity to different growing conditions as reflected by its high coefficient of variation (Shamuyarira *et al*., 2022). This high variability in grain yield among the genotypes and between the water regimes reflects the efforts dedicated drought in drought-prone environments due to climate change (Shavrukov *et al.*, 2017).

3.5. Stress susceptibility index (SSI)

Table (8) demonstrates stress susceptibility index (SSI) based on grain yield for the studied cultivars in the two seasons. In respect to reduced irrigation, it could be considered that cultivars with SSI values less than 1 are tolerant, higher than 1 are sensitive and equal or near to 1 are moderate tolerant or sensitive. Sids 14 revealed the lowest SSI and could be considered the most tolerant cultivar under these conditions. On the other hand, the highest SSI was obtained from Giza 171. Thus, it could be named as the most susceptible genotype under these conditions. Moreover, Sakha 95 and Shandaweel 1 are moderately tolerant. Similar results were obtained by Farhat (2015), Shehab-Eldeen and Farhat (2020), Feltaous and Koubisy (2020), and Farhat *et al*. (2021).

3.6. Genotype main effect plus genotype x environment interaction (GGE) biplot for grain yield

Nevertheless, water stress susceptibility index is not ideal to characterize genotypes with high yield performance and high stress tolerance under reduced irrigation (Thiry *et al*., 2016). GGE (genotype + genotype by environments interaction effect) biplot graph are commonly used to explain two-way data considering the first two principal components (PC1 and PC2).

This method was employed to explain relationship between evaluated genotypes and tested environments in the same graph to assess the adaptability or stability range (Yan and Kang, 2003). The GGE biplot method illustrates together the grain yield superiority and relative tolerant cultivars to reduced irrigation expressed with the most stability under the studied environments. In this method, an average

Table (7): Means and ranges of reduction% due to irrigations treatments for the studied traits in the two seasons.

Reduction %		Season	No. days to heading	No. days to maturity	Plant height (m)	No. spikes m^{-2}	No. kernels $spike^{-1}$	1000-Kernel weight	Grain yield	Biological yield	Harvest index
100%-60%	Min.	2018/19	0.74	2.15	0.96	8.38	6.99	4.11	20.57	11.12	7.14
		2019/20	0.31	1.33	0.26	3.48	1.57	1.48	15.58	12.38	3.89
	Max.	2018/19	2.62	4.72	4.35	13.12	11.77	7.49	30.29	16.83	10.85
		2019/20	3.71	3.23	0.92	9.65	4.92	8.79	24.23	13.91	5.23
	Mean	2018/19	1.35	3.41	2.86	11.40	9.92	6.01	24.38	14.73	8.60
		2019/20	1.45	2.23	0.59	5.36	3.80	3.99	19.41	13.33	4.61
100%-40%	Min.	2018/19	5.70	7.02	3.54	8.84	13.44	7.24	22.70	15.81	15.25
		2019/20	1.81	4.19	1.19	6.81	8.50	6.75	19.58	24.34	7.17
	Max.	2018/19	9.30	8.85	6.91	19.73	18.56	13.61	38.24	29.33	25.03
		2019/20	6.72	5.04	2.09	15.89	16.04	10.19	37.24	28.57	8.49
	Mean	2018/19	7.03	8.00	5.16	15.41	15.68	9.93	32.44	21.77	18.10
		2019/20	4.37	4.49	1.73	11.56	12.34	8.74	30.02	26.06	7.82
60%-40%	Min.	2018/19	4.73	2.41	0.91	0.51	3.19	1.39	2.68	4.10	6.87
		2019/20	1.07	1.33	0.28	2.86	3.76	1.54	3.26	12.95	3.08
	Max.	2018/19	6.86	6.47	3.58	8.23	10.69	6.62	20.86	15.03	15.91
		2019/20	3.89	2.91	1.75	10.88	12.04	7.64	19.56	17.40	3.60
	Mean	2018/19	5.77	4.74	2.37	4.57	6.36	4.18	10.61	8.33	10.43
		2019/20	2.97	2.31	1.14	6.55	8.88	4.87	13.23	14.69	3.37

Table (8): Water stress susceptibility index (SSI) based on grain yield for the studied cultivars in the two seasons.

Reduction %		Susceptible index for reduced irrigation	
		2018/19	2019/20
100%-60%	Giza 171	1.84	1.25
	Shandaweel 1	0.61	0.94
	Sids 14	0.24	0.24
	Sakha 95	1.06	1.42
100%-40%	Giza 171	1.15	1.22
	Shandaweel 1	1.06	1.02
	Sids 14	0.68	0.64
	Sakha 95	1.02	1.05
60%-40%	Giza 171	0.89	1.25
	Shandaweel 1	1.23	1.08
	Sids 14	0.84	0.87
	Sakha 95	1.00	0.80

environment is defined by the average PC1 and PC2 scores of all environments, represented by A line with single arrow passes through the biplot origin and the average environment (small circle) and is referred to as (average environment axis) or AEA. The arrow pointes to higher mean performance for the genotypes. The line perpendicular to AEA and passes through the biplot origin pointed to higher performance variability or less stability in both direction (grand mean) (Yang *et al*., 2009). A longer projection to the AEC ordinate regardless as the direction, represents a greater tendency of the GEI of a genotype, which means that it is more variable and less stable across environments or vice versa (Kaya *et al*., 2006).

Figure 1 visualizes the appropriate cultivars for the three irrigations treatemnts in the two seasons (6 Environments). Where E1 = 100% of full irrigation in 2018/19, E2 = 60% of full irrigation in 2018/19, E3 = 40% of full irrigation in 2018/19, E4 = 100% of full irrigation in 2019/20, E5 = 60% of full irrigation in 2019/20, E6 = 40% of full irrigation in 2019/20. The lines split the biplot into eight sectors and the six environments were grouped into two main sectors. The "which-won-where" pattern showed that Sakha 95 was the vertex cultivar under 40 % of full irrigation in the two seasons and 60 % in the second season. In addition, Giza 171 was won under 100 % of full irrigation in the two seasons and 60 % in the first season, and four cultivars Giza 171 (CV1), Shandaweel 1 (CV2), Sids 14 (CV3) and Sakha 95 (CV4).

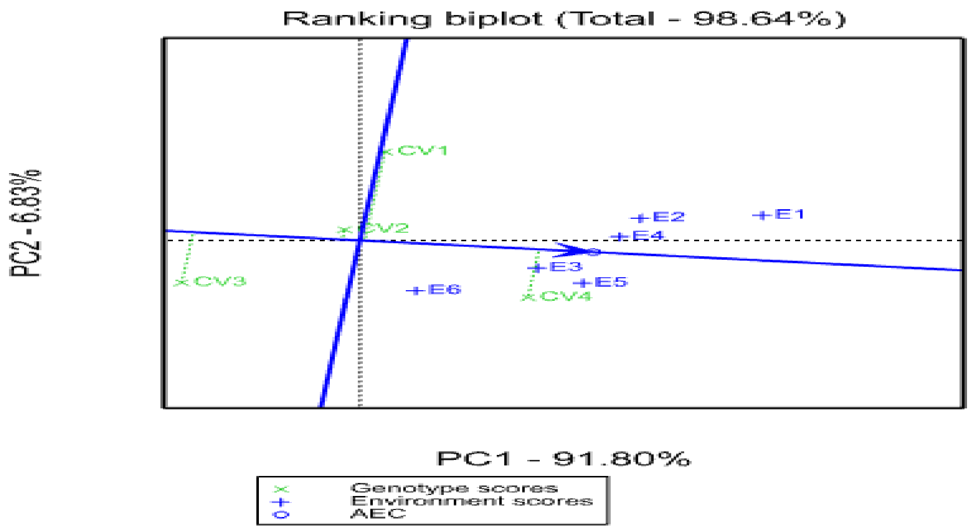

Fig. (1): Ranking the four cultivars based on their grain yields over the irrigation treatments in 2018/19 and 2019/20 seasons.

In general, Shandaweel 1 was the most stable regardless of its grain yield. Whatever, Sakha 95 was the most superior cultivar with moderlate tolerant to reduced irrigation. Conteraly, Sids 14 had reasonable stability and was the worst one for grain yield. Moreover, Giza 171 was the most unstable cultivar under these environments. GGE biplot provides an easyto-use method for analyzing yield stability and mega-environment investigations (Mohammadi and Golkari, 2022). Similar results were reported by Kendal (2019), Feltaous and Koubisy (2020) and Farhat *et al*. (2021).

3.7. Applied irrigation water, irrigation water productivity and yield response factors for wheat cultivars in two seasons

Results in Table (9) showed that the grain yields (GY) of the studied wheat cultivars were affected by the different amounts of applied irrigation water. The total applied water values were 990.4, 1485.7 and 2476.1 m^3/fed in the first season and were 943.0, 1414.6 and 2357.6 m^3/fed in the second season for the 40%, 60% and 100% irrigation treatments, respectively. The obtained results were in close agreement with those reported by Noreldin and Mahmoud (2017), who showed that the applied water for wheat crop were 2722 m^3/fed under full rrigation and 1633 m^3/fed under stress conditions.

From the obtained results, irrigation water productivity (IWP) values increased with increasing water stress for all wheat varieties. The highest IWP values were 2.90 and 3.10 kg/m^3 in both seasons, respectively by using water stress treatment 40% from full irrigation with Sakha 95. While, the lowest values were 1.14 and 1.41 kg/m^3 were obtained for Sids 14 with 100% irrigation treatment in the first and second season respectively. These results were in agreement with the results of Noreldin and Mahmoud (2017), who reported that water productivity for wheat crop of 1.03 kg/m^3 applied water under full irrigation and 1.22 kg/m^3 water under stress conditions.

The linear relations between the relative reduction in applied water and relative reduction in grain yield of the tested varieties are illustrated in Figures (2- 5). The obtained linear relations for the tested varieties were:

For Giza 171:

$$\boldsymbol{y = 0.613\, X, \quad r^2 = 0.99}$$

For Shandaweel 1:

$$\boldsymbol{y = 0.579\, X, \quad r^2 = 0.98}$$

For Sids 14:

$$\boldsymbol{y = 0.388\, X, \quad r^2 = 0.97}$$

For Sakha 95:

$$\boldsymbol{y = 0.535\, X, \quad r^2 = 0.98}$$

Where y is the relative reduction in grain yield, X is the relative reduction in applied irrigation water. The coefficient in each equation represents the yield response factor (Ky). The obtained Ky values, which are less than 1.0, indicate that all tested cultivars are tolerant to water stress. The high values of coefficient of determination (r^2 = 0.92 - 0.99) indicate that the developed equations well represent the studied relation. The obtained results were close to Ky

Table (9): Total applied water, irrigation water productivity, and yield response factors of the four cultivars.

Irrigation treatment	Cultivars	Grain yield (kg/fed)		AIW (m^3/fed)		IWP (kg/m^3)	
		2018/19	2019/20	2018/19	2019/20	2018/19	2019/20
40%	Giza 171	2390	2460	990.4	943.0	2.41	2.61
	Shandaweel 1	2420	2630	990.4	943.0	2.44	2.79
	Sids 14	2180	2670	990.4	943.0	2.20	2.83
	Sakha 95	2870	2920	990.4	943.0	2.90	3.10
60%	Giza 171	3020	2970	1485.7	1414.6	2.03	2.10
	Shandaweel 1	2600	3020	1485.7	1414.6	1.75	2.13
	Sids 14	2240	2760	1485.7	1414.6	1.51	1.95
	Sakha 95	3260	3630	1485.7	1414.6	2.19	2.57
100%	Giza 171	3870	3920	2476.1	2357.6	1.56	1.66
	Shandaweel 1	3730	3820	2476.1	2357.6	1.51	1.62
	Sids 14	2820	3320	2476.1	2357.6	1.14	1.41
	Sakha 95	4330	4300	2476.1	2357.6	1.75	1.82

IWP= Irrigation water productivity.

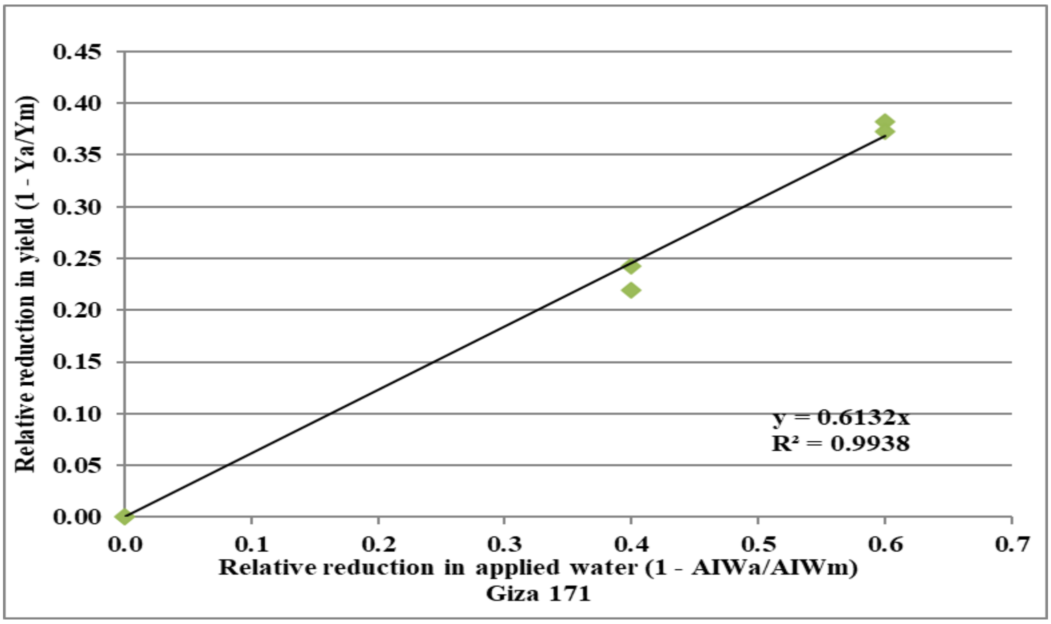

Fig. (2): Linear relation between relative reduction in applied water and relative reduction in grain yield of Giza 171 cultivar.

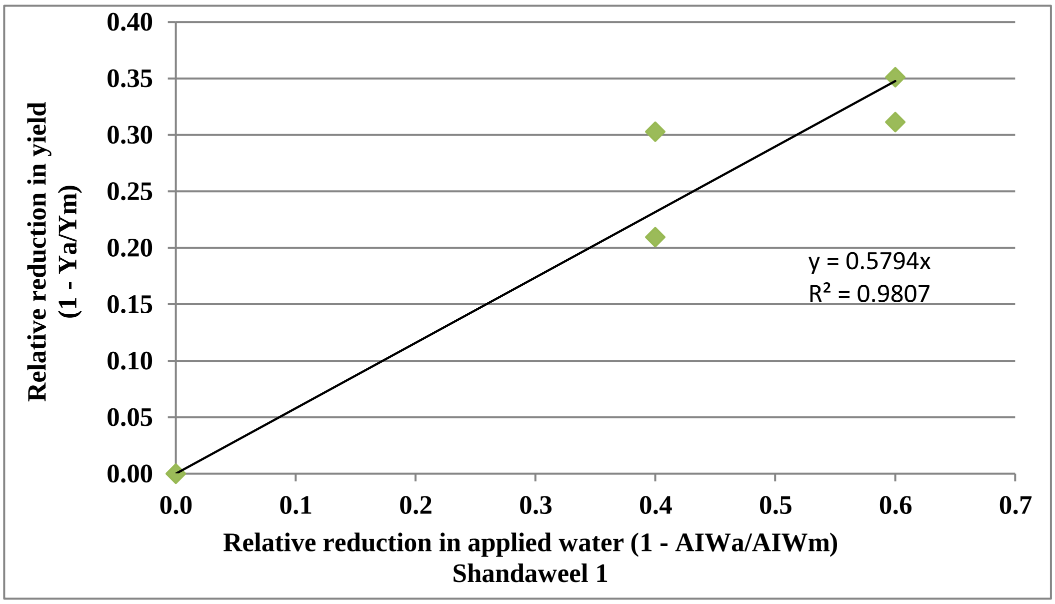

Fig. (3): Linear relation between relative reduction in applied water and relative reduction in grain yield of Shandaweel 1 cultivar.

values for wheat crop reported by Abdelkhalak *et al*. (2015) and García *et al.* (2020).

The tested cultivar can be arranged according to their tolerance to water stress as Sids 14 > Sakha 95 > Shandaweel 1 > Giza 171.

Conclusions

From the obtained results of this study, it could be concluded that:

- Sakha 95, the recent cultivar bred by Agricultural Research Center was suitable to be cultivated under reduced irrigation in the calcareous soil at EL-Nubaria region, since it produces the highest biological and grain yields with the irrigation water productivity values.
- Sids 14 could be used as a source of water stress tolerance in Egyptian wheat breeding program.

- GGE biplot analysis could be facilitates testing genotypes for high yielding and relatively tolerant to reduced irrigation at the same time.
- The early heading or maturity cultivars were the lowest affected on grain yield, as a result to reduce irrigation under calcareous soil.
- The calculated values of total applied water were 990.4, 1485.7 and 2476.1 m^3/fed in the first season and were 943.0, 1414.6 and 2357.6 m^3/fed in the second season.

The highest IWP values were 2.90 and 3.10 kg/m^3 of applied water in the first and second season, respectively for the 40% water stress treatment with Sakha 95 variety.

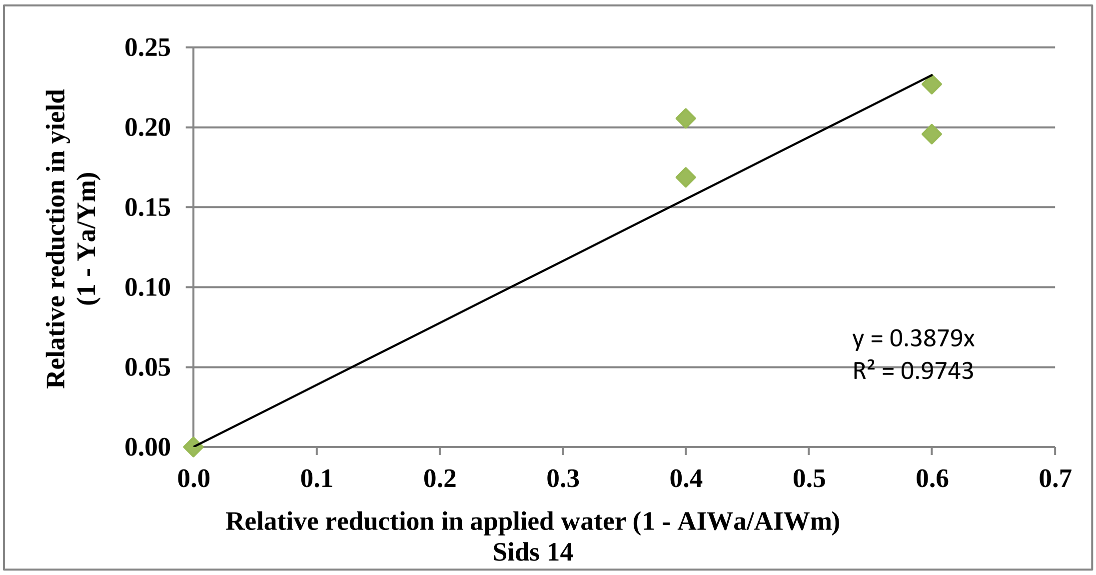

Fig. (4): Linear relation between relative reduction in applied water and relative reduction in grain yield of Sids 14 cultivar.

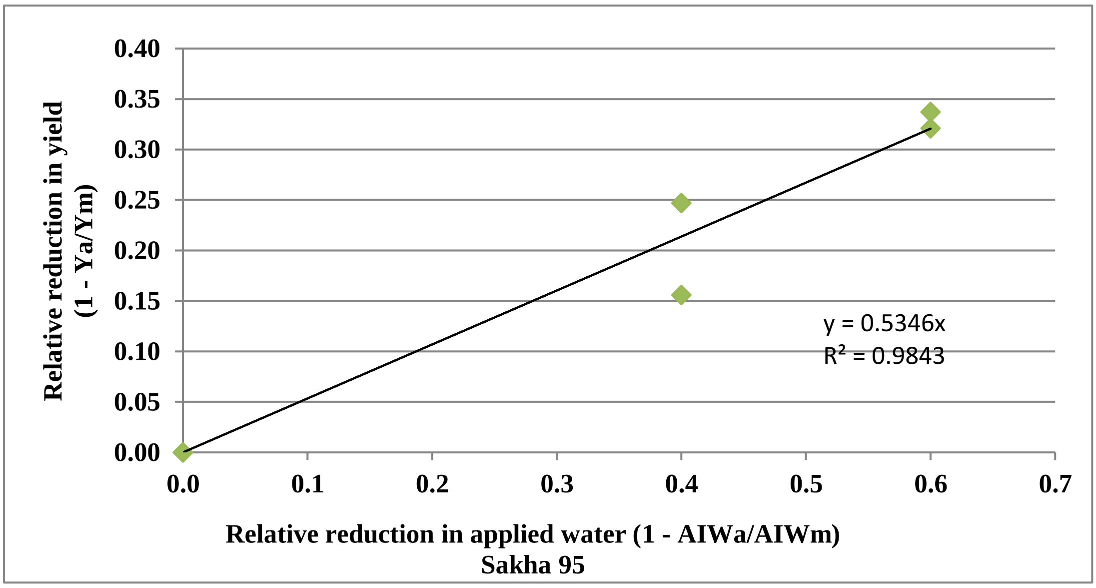

Fig. (5): Linear relation between relative reductions in applied water and relative reduction in grain yield of Sakha 95 cultivar.

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تأثير نقص مياه الري على إنتاجية أربعة أصناف قمح الخبز تحت ظروف الأراضي الجيرية بمصر

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[2] قسم بحوث المقننات المائية والري الحقلي، معهد بحوث الاراضي والمياه والبيئة، مركز البحوث الزراعية، 12619 - الجيزة- مصر.

ملخص

يعتبر نقص كميات مياه الري أحد أهم المشاكل التي تواجه إنتاج القمح خاصة في الأراضي الجيرية في مصر. أربعة أصناف من قمح الخبز (جيزة 171، شندويل 1، سدس 114 وسخا 95) تم دراستهم تحت المعاملة ب 100٪، 60٪ و 40٪ من كميات الري الكامل تحت ظروف التربة الجيرية في مصر. الثلاث معاملات مائية وزعت في شرائح أفقية ووزعت الأربع أصناف قمح الخبز في شرائح عمودية. أوضحت النتائج أن الري بالكمية الكاملة (100%) بالكمية المضافة 2476 م^3/فدان في الموسم الأول و2357 م^3/فدان في الموسم الثاني قد أنتجت أعلى إنتاج في كل الصفات، تلى ذلك الري ب 60% ثم الري ب 40 % من الري الكامل. أوضحت النتائج تفوق صنف سخا 95 من حيث الحبوب، المحصول البيولوجي ومؤشر الحصاد النسبي. بالإضافة فقد كانصنف سخا 95 أفضل صنف تحت جميع معاملات الري المدروسة. وعلى العكس من ذلك، فقد كان صنف سدس 14 أسوأ الأصناف من حيث الحبوب والمحصول البيولوجي. أظهر تحليل Biplot للنمط الجيني والتفاعل البيئي (GGE) أن صنف شندويل 1 كان أكثر أصناف ثباتا من حيث المحصول. بينما كان صنف سخا 95 أكثر الأصناف تفوقاً مع المقاومة المتوسطة لقلة الري. وعلى النقيض من ذلك، فقد كان صنف سدس 14 له ثبات معقول وأسوأ الأصناف من حيث محصول الحبوب. بالإضافة إلى ذلك فقد كان صنف جيزة 171 هو الصنف غير الثابت تحت هذه الظروف. لقد زادت قيم إنتاجية مياه الري مع زيادة العجز المائي لجميع أصناف القمح وكانت أعلى قيم إنتاجية لمياه الري المضافة هي 2.9 و 3.1 كجم حبوب/م^3 من الماء المضاف ، تحت ظروف نقص الري بنسبة 40٪ للصنف سخا 95 للموسمين الأول والثاني على التوالي. على الجانب الآخر، كان معامل استجابة المحصول لنقص المياه 0.76 و 0.62 مع المعاملة 100٪ في الموسمين الأول والثاني للصنف سدس 14 على التوالي. توصي الدراسة بزراعة صنف سخا 95 تحت ظروف نقص مياه الري في الأراضي الجيرية.

المجلة المصرية للعلوم الزراعية المجلد (74) العدد الأول (يناير 2023) : 19- 35 .

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