Response of wheat cultivars to water deficit in North Nile Delta

Abstract

A field experiment was carried out during at two wheat growing seasons of 2020/21 and 2021/22 on Sakha Agricultural Research farm, middle north of Nile Delta to find out the impact of water deficit on five bread wheat cultivars; Misr 2, Sakha 95, Misr 3, Giza 171 and Shandaweel 1, with three treatments irrigation were; A-irrigating with 60% water needs (WN), B-irrigating with 80%of WN and C-irrigating with 100% of WN. The obtained results showed that irrigating with 100% of WN recorded the highest values of heading, and maturity days, biological, grain and straw yield and yield components. Sakha 95 has the highest grain yield, Sakha 95 and Giza 171 had the highest values of 1000 grain weight and number of grains/spike, while Misr 2 and Giza 171 has the highest values of biological yield. Irrigating wheat with 80% of WN has so many advantages; high yield as the full irrigation and saving water. Crop-water function of PIW and WP increased with water deficit.

Key words: wheat cultivars, water deficit, PIW and WP.

Introduction

Wheat (*Triticum aestivum* L.) ranks among the most significant cereal food crops worldwide. In Egypt, wheat production does not meet national demand, leading the government to strive to decrease the import percentage to below 50% of total consumption (FAO, 2021). Wheat production is shaped by several factors, such as climatic conditions, irrigation practices, and soil fertility. In Egypt, agriculture is heavily dependent on irrigation from the Nile River, with the sector consuming over 84% of the country's available water resources (El-Beltagy and Abo-Hadeed, 2008). The availability of water is a critical constraint for field crop production, and sustainable agriculture seeks to maximize grain yields while minimizing irrigation water use. Grain yield is influenced by both the severity of water deficit and the growth stage during which it occurs (Salter and Good, 1967). Research indicates that optimizing wheat yield and water use efficiency (WUE) requires carefully timed irrigation at specific growth stages. Xue *et al.*, (2003) recommended three irrigation applications during the jointing, booting, and anthesis stages, totaling 300 mm. Zhang *et al.*, (2004) suggested applying irrigation at jointing, booting, and post-heading stages, while Zhang *et al.*, (2007) proposed two applications during the tillering and heading stages. The physiological and genetic factors contributing to high WUE can differ significantly among crop varieties (Monclus *et al.*, 2009).

Globally, agriculture consumes about 70% of water resources, creating pressure to meet the increasing food demand amid limited water availability. Egypt presents unique challenges due to its arid environment and reliance on the Nile River as the sole fresh water source. Rapid population growth and climate change exacerbate water scarcity, reducing per capita water availability below the water poverty line of 1000 m^3. Consequently, deficit irrigation, which involves applying less water than the crop's total evapotranspiration requirement, has emerged as a critical strategy (English and Nuss, 1982). In Egypt, irrigated agriculture consumes approximately 85% of the national freshwater supply (El-Badawy, 2014). Ouda *et al.,* (2021) stated that in many dry areas of the world, deficit irrigation has become a precise approach to agricultural production. This strategy offers a viable solution to enhance water efficiency and sustain agricultural productivity in water-scarce regions.

Therefore, the primary aim of this study was to examine how various wheat cultivars respond to deficit irrigation.

- To assess the effect of deficit irrigation on wheat yield and its components.

- To evaluate the role of deficit irrigation in crop-water relation, specifically its impact on Irrigation water productivity (IWP) and water productivity (WP).
- To analyze the impact of deficit irrigation on both irrigation water use and crop-water consumption

Materials and methods

A field experiment was carried out during the two wheat growing seasons of 2020/21 and 2021/22 at Sakha Agricultural Research Station, middle north of Nile Delta. The site is located at 31^0. 07^- latitude, $30^0.57^-$ longitude and 6 meters above mean sea level as altitude.

Climatological elements were collected from the agro-meteorological station at the site and recorded in Table (1).

<u>Soil properties:</u>

The soil in the experimental field is characterized as clayey, as detailed in Table 2, which includes information on particle size distribution and soil-water constants. Bulk density (Db) and particle size distribution across different soil layers were measured following the procedures outlined by Klute (1986). The field capacity (FC) and wilting point (WP), which are key soil-water constants, were determined using the method described by James (1988). The chemical properties of the soil, including cations and anions, were analyzed according to Jackson's methodology (1973) and are summarized in Table (3).

Table (1): Climatic elements at Sakha: temperature (T. ^OC), relative humidity (RH%), Wind speed (μ_2, m sec^{-1}), Pan evaporation (EP, mm day^{-1}) and rain fall (Rf, mm day^{-1}).

Month	1st season 2020/21	2nd season 2021/22

	T. °C	R.H. %	μ2, mm sec-1	EP mm day-1	Rf mm day-1	T. °C	RH, %	μ2, mm sec-1	EP mm day-1	Rf mm day-1
Nov.	21.5	71.7	0.54	2.3	12.4	22.7	73.1	0.75	3.9	12.7
Dec.	18.5	72.5	0.53	2.4	19	16.2	74	0.72	4	20.7
Jan	17.3	73.1	0.46	2.5	14.1	13.8	75.4	0.72	3.9	50.4
Feb.	16.6	72.6	0.68	3.6	-	15.1	70.7	0.96	3.5	25.3
Mar	18.5	65	0.9	4	5.4	15.1	69.1	1.14	3.8	5.3
Apr	23.5	60	1.1	6.3	-	23.6	60.3	1.33	5.5	-
May	28	58.3	1.13	8.9	-	25.9	60.6	1.45	6.5	-
Mean	20.6	67.6	0.76	4.3	50.9	18.9	69	1.01	4.4	114.3

Table (2): Particle size distribution and soil-water constants of the Sakha studied experiments site.

Soil depth cm	Particle size distribution				Soil-water constants:			
	Sand %	Silt %	Clay %	Texture	F.C. %	W.P.	A.W.%	Db., Mg m^{-3}
0-15	17.9	28.7	50.4	Clay	44.3	24.1	20.2	1.1
15-30	20.4	28.4	49.3	Clay	39.6	21.5	18.1	1.2
30-45	26.8	20.6	48.6	Clay	36.7	19.9	16.8	1.3
45-60	24.6	25	42.8	clay	34.2	18.6	15.6	1.3
Mean	22.4	25.7	47.8	clay	38.7	21	17.7	1.2

Where: F.C.,%= soil field capacity, W.P.,%=wilting point,
A.W.,%= available soil water, and Db., Mg m^{-3}=Soil bulk density.

Table (3): Some chemical properties of the experimental site.

Soil depth cm	Soluble ions, mmole*							
	Cautions				Anions			
	Ca++	Mg++	Na+	K+	Co3-	Hco3-	Cl-	So4-
0-15	4.2	2.1	7.9	0.1	0	2.8	7.6	3.9
15-30	8.6	3.9	8.5	0.2	0	2.9	8.8	9.5
30-45	7.7	4.8	9.1	0.2	0	2.4	6.7	12.7
45-60	10.4	5.2	11	0.2	0	2.3	6	18.8
Mean	7.7	4	9.1	0.2	0	2.6	7.3	11.2

mmole charge

Cultural practices:

All agricultural procedures were done according the recommendation of the Agricultural Research Center (ARC), except for the irrigation treatments. For this investigation, five wheat cultivars were selected; Misr 2, Sakha 95, Misr 3, Giza 171 and Shandaweel 1. The irrigation treatments were; A- irrigation with 60% crop water need (CWN), B- irrigation with 80% CWN and the control treatment C which irrigate with 100% CWN. The name and pedigree of the studied cultivars are in Table (4).

Table(4): Name and pedigree of five bread wheat cultivars.

Name	Pedigree and selection history
Misr 2	SKAUZ/BAV92 CMSS96M03611S-1M-0105Y-010M-010SY-8M-OY-OS
Sakha 95	PASTOR // SITE / MO /3/ CHEN / AEGILOPS SQUARROSA (TAUS) // BCN /4/ WBLL1 (CMSA01Y00158S-040P0Y-040M-030ZTM-040SY-26M-0Y-0SY-0S)
Misr 3	Rohf 07*2/Kiriti CGSS 05 B00123T-099T0PY-099M-099NJ-6WGY-0B-0BGY-0GZ
Giza 171	SAKHA 93/GEMMEIZA 9 Gz 2003-101-1Gz-4Gz-1Gz-2Gz-OGz
Shandaweel 1	SITE/MO/4/NAC/THAC//3*PVN/3/MIRLO/BUC CMSS93B00567S-72Y-010M-010Y-010M-3Y-0M-0HTY-0SH

The soil preparation followed according to the recommendations of the Wheat Research Department, utilizing precision leveling with a laser device. Three experiments separate were conducted, one experiment for every one treatments of irrigations and combined analysis were performed for all the three treatments irrigation.

A flow meter was used to measure the irrigation water for each treatment, as outlined by Michael (1978). Each plot consisted of six rows with 20 cm apart, covering an area of 1.2 x 3.5 m (4.2 m^2) in a randomized completely block design (RCBD)with three replications. The irrigation amounts for each treatment (100%, 80%, and 60% of crop water need) were calculated based on the proposed irrigation schedule.

Sowing dates for both growing seasons were in the last week of November while the harvesting dates were in the first week of May.

Data collections

Agronomic traits:

-No. of days from sowing to heading.

-No. of days from sowing to maturity.

-Grain filling period.

-Grain filling rate (kg/fed./day) from heading to maturity.

-Plant height (cm).

-No. of spikes/m^2

-1000grain weight (g).

-No. of grains/spike.

-Biological yield (ton $fed.^{-1}$)

-Grain yield (ton $fed.^{-1}$)

-Straw yield (ton $fed.^{-1}$)

-Harvest index (%).

Susceptibility index (SI)

Yield potential (optimum planting) (YP) and stressed yield (late planting) (YS), the following quantitative criteria of tolerance to late planting were calculated:

1- Tolerance index (TOL) and mean productivity (MP) (Rosielle and Hambling, 1981)**:** TOL = YP-YS and MP= (YP+YS)/2

2- Stress Susceptibility index (SSI) (Fischer and Maurer, 1978**):**

SSI= (1 - YS/YP)/SI and SI= (1 -ÝS/ÝP)

Where, SI=stress intensity and ÝS and ÝP = mean of all genotypes in the stress and no stress conditions, respectively.

3- Geometric Mean Productivity (GMP**)** (Kristin *et al.*, 1997; Fernandez (1992): GMP=$\sqrt[2]{(yp)(ys)}$

4- Stress Tolerance index (STI) (Fernandez, 1992):

STI= (YP/ÝP) (YS/ÝS) (ÝS/ÝP) = (YP) (YS)/$(ÝP)^2$

5- Yield reduction ratio (Yr) (Golestani and Assad, 1998): Yr= 1 - (Ys/Yp)

6- Relative performance (RP) **(**Abo- Elwafa and Bakheit, 1999):

P= (YS/YP)/R and R= (ÝS/ÝP)

7- Superiority or relative yield (RY) was calculated as the yield of a specific genotype under moisture stress, divided by that of the highest yielding genotype under moisture stress conditions (Lin and Binns, 1988).

Water parameters

- Irrigation water (IW).
- Consumptive use (CU).

Crop-Water function

- Productivity of irrigation water (PIW).
- Water productivity **(WP).**

Irrigation water

Applied irrigation water (AIW) was controlled and measured by contracted rectangular. Irrigation water was calculated as described by Michael (1978)**:**

Q = LH……………………………1

Where:

Q = water discharge, m^3sec^{-1}

L = width of the weir crest (cm)

H = head over the crest (cm)

Consumptive use

Consumptive use (CU) of the wheat growing crop were determined based on soil moisture depletion in the effective root zone or so-called the actual consumed water of the growing crop as described by Hansen *et. al.,* (1979):

$CU = S_2$-$S_1/100/D_b$*dA…………………2

Where:

CU = consumed water, m^3

S_2= soil moisture percentage (48hrs.) following irrigation

S_1= soil moisture percentage before irrigation and at harvest

D_b = bulk density, M gm^{-3}

d =effective root zone of 60 cm

A = irrigated area (m^2)

Crop-water function:

Productivity of irrigation water

Productivity of irrigation water (PIW) reflects the capability of applied irrigation water in producing the marketable yield as described by Bos (1981)**:**

PIW = Y/IW……………………….3

Where:

PIW = productivity of irrigation water, kg m^{-3} applied irrigation water

Y = marketable yield (kg)

IW = applied irrigation water m^3

Water productivity

Water productivity (WP) reflects the capability of consumed water by the growing crop in producing the marketable yield as stated by Bos (1981)**:**

WP = Y/CU……………………………4

Where:

WP = water productivity, kg m^3consumed water.

Y = marketable yield (kg)

CU = consumed water m^3

Statistical analysis:

All data collected from the irrigation treatments were subjected to a combined analysis of variance (ANOVA) for the randomized complete block design of each experiment, as described by Gomez and Gomez (1984). The data processing was carried out using the MSTAT-C program (MSTAT Development Team, 1990). The means of the cultivars and irrigation treatments were compared using the Least Significant Difference (LSD) test.

Results and discussion

Effect of irrigation treatments: -

Data in Table (5) showed that the variation due to Irrigation treatments recorded highly significant effects on Number of days from sowing to heading, significant effect for Number of days from sowing to maturity, grain filling period and highly significant regarding grain filling rate in both growing seasons. Irrigation treatment Ir.3 (control treatment i.e., without deficit irrigation) caused late heading (107.1, 103.7 days) and maturity (151.1 and 146.7 days) in both seasons, respectively. On the other hand, deficit irrigations treatments decreased days to heading due to decreasing the vegetative growth.

Table (5): Means of number of days to heading, number of days to maturity, grain filling period and grain filling rate as affected by irrigation treatments, wheat cultivars and their interaction in 2020/21 and 2021/22 seasons.

Treatment	Number of days to heading		Number of days to maturity		Grain filling period		Grain filling rate kg/fed./day	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Irrigation treatments(A)								
Ir.1	102.2	98.9	149.3	145.7	47.1	46.8	53.5	52.3
Ir.2	104.7	101.6	149.9	146.5	45.2	44.9	61.8	60.4
Ir.3	107.1	103.7	151.1	146.7	43.9	43.0	69.7	69.1
F test	**	**	*	*	*	*	**	**
LSD $_{0.05}$	0.54	0.52	1.03	1.0	3.03	1.9	5.3	6.2
wheat cultivars (B)								
Misr 2	105.6	101.7	153.6	149.4	47.9	47.8	51.8	50.4
Sakha 95	104.2	101.2	149.8	145.7	45.6	44.4	67.2	66.9
Misr 3	104.1	100.7	149.0	147.1	44.9	46.4	61.6	57.7
Giza 171	104.8	101.7	148.9	144.2	44.1	42.6	65.8	66.2
Shandaweel1	104.8	101.8	149.3	145.0	44.6	43.2	61.7	61.0
F test	NS	NS	**	**	*	**	**	**
LSD $_{0.05}$	-	-	4.1	2.4	2.6	3.5	16.2	5.3
Interaction A*B	NS	NS	NS	**	NS	**	*	**

*,**and NS indicated significant at P<0.05, P<0.01 and not significant, respectively.

Ir.1 treatment were unfavorable for suitable ecological situation such as soil moisture and nutrient conditions compared with irrigation treatment Ir.3

extends the vegetative growth period, thereby increasing the number of days from sowing to physiological maturity and harvest readiness. Regarding the grain filling period, Ir.3 treatment was recorded the lowest period (43.9 and 43.0 days) in both seasons, respectively also recorded the highest grain filling rate (69.7 and 69.1 kg/fed./day) due to increase grain yield/fed., while decrease grain filling period.

Data presented in Table (6) show that irrigation treatments had a highly significant impact on plant height during the second season. Ir.3 treatment recorded the highest plant height (102.5 cm), while there was insignificant effect on number of spikes/m^2 in both seasons. On the other hand, the effects of irrigation treatments were significant on 1000 grain weight in both seasons and number of grains/spikes in the second season. Ir.1 treatment recorded the highest 1000 grain weight with (42.1 and 40.1g) in both seasons, respectively. Meanwhile, Ir.3 treatment recorded the highest number of grains/spikes with (64.1) in the second season. Additionally, the 1000 grain weight increased as the number of grains/spikes decreased.

The data presented in Table (7) illustrate the impact of different irrigation treatments on biological yield, grain yield, straw yield, and harvest index percentage. The analysis of variance revealed that the variation among irrigation treatments was significant and highly significant for biological yield in both the first and second seasons. Additionally, there was a highly significant effect on grain yield and straw yield across both seasons. The Ir.3 treatment yielded the highest values for these traits, recording (8.166, 7.181, 3.187, 2.971, 4.979, and 4.210 tons per fed.), respectively. The highest values were due the favorable conditions of soil moisture and available nutrients which in the Ir.3 treatment (control). Comparing to Ir.3 treatment, the reduction percentages due to deficit irrigation treatments Ir.1 and Ir.2 in both seasons for biological yield, grain yield and straw yield were; (16.1, 9.4, 15.8, 11.2, 13.8 and 17.6%) respectively. Adequate water supply helps maintain soil moisture close to field capacity in the root zone, reducing water stress on plants, particularly during the reproductive stage. This optimal moisture enhances ion uptake and the translocation of photosynthetic products from leaves to the grain, positively affecting grain yield and its attributes. These results are consistent with the findings of Salter and Good (1967) and Shaaban (2006). Xue *et al.,* (2003) suggested that maximizing wheat yield and water use efficiency (WUE) requires three irrigation applications: at jointing, booting, and anthesis, totaling 300 mm. Zhang *et al.,* (2004) recommended applying irrigation three times during the jointing stage. Zhang *et al.,* (2007) found that two irrigation applications one at tillering and another at heading are effective. The physiological and genetic factors contributing to high water use efficiency (WUE) very significantly among crop varieties (Monclus *et al.,* 2009). Recent cultivars have demonstrated notably higher grain yield and WUE compared to older varieties (Song *et al.,* 2009; Fang *et al.,* 2011; Yang *et al.,* 2013), whereas older cultivars showed lower yield and reduced responsiveness to irrigation (Rizza *et al.,* 2012). Zhang *et al.,* (2010a) reported a 20% variation in yield and WUE among 16 winter wheat cultivars released between 1998 and 2002, with higher yields generally associated with higher water use efficiency (WUE). Keyvan and Kobraee (2013) demonstrated that as drought stress increased, grain yield, biological yield, harvest index, and water use efficiency (WUE) decreased, while evapotranspiration efficiency (ETE) increased. Meng *et al.,* (2015) found that supplemental irrigation (SI) enhanced both yield and water use efficiency (WUE) for the wheat cultivar ‘Jimai 22’, with the W1 treatment at 75% field capacity being the most effective. Omar *et al.*, (2014) reported that various irrigation frequencies influenced days to heading, days to maturity, plant height, number of spikes per square meter, grain yield, straw yield, harvest index, number of grains per spike and 1000-grain weight. They observed that increasing the number of irrigation events generally improved these traits, whereas fewer irrigation events led to decreased values.

VARIETAL DIFFERENCE:

Data presented in Tables (5 and 6) reveal significant and highly significant differences in all traits investigated, except for the number of days to heading in both seasons and the number of grains per spike in the first season. Misr 2 exhibited the longest number of days to maturity (153.6 and 149.4 days) and the longest grain filling period (47.9 and 47.8 days). Sakha 95 recorded the highest grain filling rate (67.2 and 66.9 kg/day/fed.) in both seasons.

Data in Table (6) reveal varietal differences in plant height, number of spikes per square meter, 1000-grain weight, and number of grains per spike. Misr 2 achieved the highest values for plant height and number of tillers per square meter, recording (111.1, 106.9cm, 374.6 and 335.1) across both seasons. Giza 171 had the highest values for 1000-grain weight and number of grains per spike in the second season, with (44.4, 41.6g and 66.5), respectively.

Table (7) highlights varietal differences in biological yield, grain yield, straw yield, and harvest index. Misr 2 and Giza 171 had the highest biological yield in both seasons, with (7.948 and 6.946 tons per fed.and43.6%). Sakha 95 recorded the highest grain yield in both seasons, with (3.221 and 2.811 tons per fed.). Misr 2 achieved the highest straw yield in the first and second seasons, with (5.272 and 4.635 tons per fed.). Sakha 95 also had the highest harvest index in both seasons, with (44.9% and 43.6%).

Table (6): Means of plant height, number of spikes/m^2, 1000 grain weight and number of grain/spike as affected by irrigation treatments, wheat cultivars and their interaction in 2020/21 and 2021/22 seasons.

Treatment	Plant height (cm)		Number of spikes/m^2		1000 grain weight (g)		Number of grains/spike	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Irrigation treatments(A)								
Ir.1	103.7	98	282.5	284.4	42.1	40.1	52.4	61.2
Ir.2	105.7	101.1	291.9	286.2	39.5	39.1	55.2	62.5
Ir.3	108.6	102.5	304.5	307.1	37.8	38.3	56.2	64.1
F test	NS	**	NS	NS	*	*	NS	*
LSD 0.05	-	1.3	-	-	0.8	0.9	-	1.9
Wheat cultivars(B)								
Misr 2	111.1	106.9	374.6	335.1	34.6	36.7	52.4	58.7
Sakha 95	103.9	99.3	268.6	275.8	42.1	41.4	56.6	66.3
Misr 3	103.9	96.6	284	264	39	39.2	58.1	62.8
Giza 171	106.8	101.7	260.9	314.9	44.4	41.6	54.8	66.5
Shandaweel 1	104.2	98.1	276.8	272.2	38	36.8	51	58.8
F test	**	**	**	*	**	**	NS	**
LSD 0.05	4.1	1.3	50.4	40.5	4.5	2		3.5
Interaction A*B	NS	**	*	NS	NS	**	**	NS

*,**and NS indicated significant at P<0.05, P<0.01 and not significant, respectively

Table (7): Means of biological yield (ton/fed.), grain yield (ton/fed.), straw yield (ton/fed.) and harvest index %affected by irrigation treatments, wheat cultivars and their interaction in 2020/21 and 2021/22 seasons.

Treatment	Biological yield (ton/fed.)		Grain yield (ton/fed.)		Straw yield (ton/fed.)		Harvest index (%)	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Irrigation treatments (A)								
Ir.1	6.851	6.113	2.79	2.369	4.061	3.744	40.7	38.6
Ir.2	7.6	6.64	2.965	2.568	4.635	4.072	39.2	38.7
Ir.3	8.166	7.181	3.187	2.971	4.979	4.21	39.2	41.4
F test	**	**	**	**	**	**	**	NS
LSD 0.05	0.521	0.487	0.206	0.368	0.302	0.125	1.4	-
Wheat cultivars (B)								
Misr 2	7.948	6.913	2.676	2.279	5.272	4.635	33.7	32.9
Sakha 95	7.453	6.806	3.221	2.811	4.232	3.995b	43.3	41.3
Misr 3	7.469	6.479	2.909	2.543	4.56	3.936	39.1	39.2
Giza 171	7.491	6.946	3.264	2.672	4.227	4.274	43.6	38.5
Shandaweel 1	7.334	6.125	2.834	2.525	4.5	3.6	38.6	41.2
F test	**	**	**	**	**	**	**	**
LSD 0.05	0.357	0.31	0.115	0.16	0.26	0.29	0.28	2.5

Interaction A*B	**	**	NS	**	**	**	**	NS

*,**and NS indicated significant at P<0.05, P<0.01 and not significant, respectively.

The differences between cultivars are primarily attributed to the interaction between their genetic characteristics and the environmental conditions during their growth periods. Moayedi *et al.,* (2010), Sharshar (2010), El-Hag Walaa (2011), Ngwako & Mashiqa (2013), Qamar *et al.,* (2013), Singh & Singh (2013), Omar *et al.,* (2014), El-Hag Dalia (2016), Kandil *et al.,* (2016) and El-Hag Dalia *et al.,* (2021) all reported that traits such as days to heading and maturity, plant height, number of spikes per square meter, number of grains per spike, 1000-grain weight, grain yield, straw yield, and harvest index are significantly influenced by the wheat cultivars.

Effect of deficit water on grain yield: -

The highest yield potential (YP) under optimal irrigation over the two seasons was achieved by Giza 171 and Shandaweel 1 cultivars, which recorded 3.323 and 3.333 tons per fed., respectively. For yield under water deficit (YS), the Giza 171 cultivar excelled with 2.743 tons per fed., Shandaweel 1 also had the highest tolerance index (TOL) of 0.85. The highest mean productivity (MP) was observed in Giza 171, with a value of 3.03. The Shandaweel 1 cultivar had a stress susceptibility index (SSI) of 0.700, indicating greater tolerance to water deficit compared to Misr 2, which had an SSI of 1.285 and was more susceptible to water deficit. Giza 171 produced the highest geometric mean productivity (GMP) at (3.012), compared to Misr 2(2.470). Giza 171 also had the highest stress tolerance index (STI) at 0.939. In contrast, Misr 2 had the highest yield ratio (Yr) of 0.140 and the highest relative performance (RP) of

1.048. Under water deficit conditions, Giza 171 and Sakha 95 cultivars yielded the highest, as detailed in Table (8).

Table (8): Estimate of susceptibility index as affected by water stress over mean of the two seasons.

Trait	YP	YS	TOL	MP	SSI	GMP	STI	YR	RP	RY
Misr 2	2.6675	2.295	0.37	2.48	1.285	2.470	0.630	0.140	1.048	0.93
Sakha 95	3.2135	2.6625	0.55	2.94	1.046	2.920	0.881	0.171	1.010	1.07
Misr 3	3.044	2.607	0.44	2.83	1.250	2.816	0.817	0.144	1.044	1.05
Giza 171	3.3235	2.743	0.58	3.03	1.027	3.012	0.939	0.175	1.006	1.11
Shandaweel 1	3.333	2.4785	0.85	2.91	0.700	2.874	0.851	0.256	0.906	1.00

The Interaction: -

The interaction between water treatments and wheat cultivars on crop yield and yield components was significant and highly significant, as shown in Tables (9, 10, 11 and 12). Generally, Misr 2 had the highest number of spikes per square meter under all three irrigation treatments, with no significant difference from Sakha 95 under the Ir3 treatment in the first season. For 1000-grain weight, Sakha 95 recorded the highest value of (43.0 g) under the Ir.1 treatment, while Giza 171 had the highest value of (42.0g) under the Ir.3 treatment. Misr 3 in the first season and Sakha 95 in the second season produced the highest number of grains per spike, as detailed in Table (10).

Misr 2, Shandaweel 1 and Misr3 were recorded the highest biological yield under Ir.3 treatment. Giza 171 was the superior cultivar for grain yield without significant values compared with Sakha 95 and Misr 3 under Ir.3 treatment Table (11). Table (12) indicates that Misr 2 and Misr 3 achieved the highest straw yield under the Ir.3 treatment in the first season. Conversely, Giza 171 recorded the highest harvest index under the Ir.1 treatment in the first season.

Table(9): Mean of number of spikes/m^2 and 1000 grain weight as affected by interaction between irrigation treatments and wheat cultivars in 2020/21 and 2021/22 seasons.

Trait	Number of spikes/m^2 2020/21			1000 grain weight 2021/22		
Treatment	**Ir.1**	**Ir.2**	**Ir.3**	**Ir.1**	**Ir.2**	**Ir.3**
Misr 2	375.3	373.7	374.7	38	35.7	36.3
Sakha 95	241.3	239	325.3	43	41	40.3
Misr 3	277.3	319.3	255.3	40.3	40	37.3
Giza 171	255.3	245.0	282.3	41.3	41.3	42
Shandaweel 1	263.0	282.3	285.0	37.7	37.3	35.3
F test	*			**		
LSD 0.05	55.12			1.5		

*,** indicated significant at P<0.05, P<0.01, respectively.

Table (10): Mean of Number of grain/spike as affected by interaction between irrigation treatments and wheat cultivars in 2020/21 and 2021/22 seasons.

Trait	Number of grain/spike 2020/21			Number of grain/spike 2021/22		
Treatment	**Ir.1**	**Ir.2**	**Ir.3**	**Ir.1**	**Ir.2**	**Ir.3**
Misr 2	48.7	50	58.7	60.8	57.1	58.1
Sakha 95	51.1	57.9	60.7	64.5	65.6	68.8
Misr 3	56.5	53.9	64	64.5	64	59.7
Giza 171	52.5	52.4	59.3	66.1	66.1	67.2
Shandaweel 1	53	61.7	58.3	60.3	59.7	56.5
F test	**			**		
LSD 0.05	3.75			2.43		

*,** indicated significant at P<0.05, P<0.01, respectively.

Table (11): Mean of biological yield and grain yield as affected by interaction between irrigation treatments and wheat cultivars in 2020/21 and 2021/22 seasons.

Trait	Biological yield (ton/fed.) 2020/21			Grain yield (ton/fed.) 2021/22		
Treatment	**Ir.1**	**Ir.2**	**Ir.3**	**Ir.1**	**Ir.2**	**Ir.3**
Misr 2	7.183	7.133	8.5	2.04	2.267	2.528
Sakha 95	6.96	7.333	8.267	2.388	3.034	3.01
Misr 3	6.633	7.73	8.44	2.371	2.301	2.958
Giza 171	6.803	7.643	7.94	2.423	2.397	3.197
Shandaweel 1	6.677	7.683	8.5	2.4	2.458	2.716
F test	**			**		
LSD 0.05	0.25			0.251		

*,** indicated significant at P<0.05, P<0.01, respectively.

Table (12): Mean of straw yield and harvest index as affected by interaction between irrigation treatments and wheat cultivars in 2020/21 and 2021/22 seasons.

Trait	Straw yield (ton/fed.) 2020/21			Harvest index (%) 2021/22		
Treatment	**Ir.1**	**Ir.2**	**Ir.3**	**Ir.1**	**Ir.2**	**Ir.3**
Misr 2	4.633	5.49	5.693	35.5	32.76	33.1
Sakha 95	4.023	3.823	4.85	42.16	46.4	41.33
Misr 3	3.79	4.58	5.31	42.86	37.5	37.06
Giza 171	3.74	4.45	4.49	45.03	42.43	43.46
Shandaweel 1	4.12	4.83	4.55	38.3	36.8	40.8
F test	**			**		
LSD 0.05	0.315			2.93		

*,** indicated significant at $P<0.05$, $P<0.01$, respectively.

Water parameters:

Irrigation water (IW)

Table (13) presents the seasonal values of applied irrigation water (IW) for the two growing seasons, measured in cubic meters per fed. (m^3/fed.) and centimeters (cm), along with their averages. The data clearly show that the irrigation treatment directly affects the amount of applied irrigation water. This observation is likely due to the varying availability of soil moisture in the effective root zone. The average values of (IW), arranged in ascending order, are 28.1 cm for Ir.1, 34.3 cm for Ir.2, and 40.5 cm for Ir.3. Therefore, treatment Ir.3 of full irrigation which deals as the control treatment has the highest value of (IW) that leads to the abundant of soil moisture. Comparing deficit irrigation treatments of Ir.1 and Ir.2 with the full irrigation treatment Ir.3, the reduction in (IW) are 30.6 and 15.3% for Ir.1 and Ir.2, respectively. The average seasonal values of IW are presented in Figure (1).

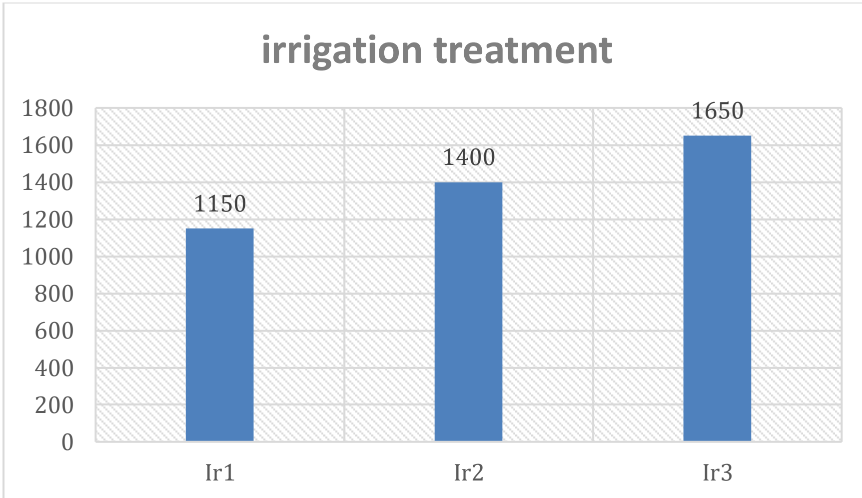

Fig 1: Average seasonal irrigation water (IW, cm) as affected with different irrigation treatments

These findings align with the results reported by Abdrabbo *et al.*, (2013). revealed that a drop yield of 8% was resulted from water saving of 20% in clay soil. Also, Karrou *et al.*, (2012) stated that a 15% of wheat yield loss was occurred when only a 78% of full irrigation was applied.

Table (13): Seasonal irrigation water (IW, $m^3 fed.^{-1}$, cm) for wheat as affected with Irrigation treatment in 2020/21 and 2021/22 seasons.

Treatment	2020/21 season		2021/22 season		Average	
	M^3 fed^{-1}	Cm	M^3 fed^{-1}	cm	M^3 fed^{-1}	Cm
Ir.1	1150	27.4	1210	28.8	1180	28.1
Ir.2	1400	33.3	1480	35.2	1440	34.3
Ir.3	1650	39.3	1750	41.7	1700	40.5

A=irrigation with 60% water need (CWN), B=80% (CWN), C= 100%%(CWN) control

Consumptive use (CU)

Seasonal values of wheat consumptive use for different irrigation treatments, measured in centimeters (cm) and its rate in millimeters per day (mm/day), are presented in Table (14). The data from the two growing seasons reveal that the average values of wheat consumptive use can be arranged in ascending order as follows: (22.0, 28.9 and 35.1 cm) for treatments Ir.1, Ir.2 and Ir.3, respectively. Generally, values of (CU) took have the same trend of (IW) due to the fact that the source of (CU) is the (IW). Furthermore, seasonal rate of (CU) of the deficit treatments Ir.1 and Ir.2 are (1.4- and 1.8-mm day^{-1}), respectively compared with (2.2 mm day^{-1}) for non-deficit i.e., full irrigation treatment Ir.3.

The obtained results are in line with those of Mona El-Mansoury *et al.*, (2019), who found similar trends when irrigating wheat with FC-10%. gave a contribution of 30.52% from groundwater to crop water needs.

Table (14): Seasonal consumptive use for wheat (Cμ, cm) and its rate (mm day^{-1}) as affected with irrigation treatment in the two seasons of study.

Treatment	2020/21 season		2021/22 season		Average	
	Seasonal, (cm)	Rate, mm day^{-1}	Seasonal, (cm)	Rate, mm day^{-1}	Seasonal, (cm)	Rate, mm day^{-1}
A	22.1	1.4	21.9	1.4	22	1.4
B	29.3	1.5	28.4	1.8	28.9	1.8
C	35.2	2.2	34.9	2.2	35.1	2.2

Ir.1=irrigation with 60% water need (CWN), Ir.2=80% (CWN), Ir.3= 100%%(CWN) control

Crop-water function:

Productivity of irrigation water (PIW) and water productivity (WP).

Values for both parameters of the crop-water function productivity of irrigation water (PIW) and water productivity (WP) are presented in Table (14). The findings indicate that deficit irrigation positively impacts both parameters. Meaningfully, by increasing the treatment of deficit irrigation, values of (PIW and WP) increased. This finding could be attributed to (IW and CU) for the deficit treatments are the dominator in calculating both parameters less than that of full non-deficit irrigation. This result is cleared as fulgurated in Figure (2). Herewith, taking into consideration that determination of both (PIW and WP) must evaluate from the two sides of crop yield and water either applied irrigation or (CU) by the growing crop. In other words, the irrigation treatment with the high value of (PIW and/or WP) can't be executed unless crop yield evaluated. Meaningfully, both parameters must be taking crop yield and water in consideration.

These results are in a good agreement with those obtained by Bekele and Tilahun (2007) who stated that to increase (WP), deficit irrigation could be successfully practiced.

Table (15): Productivity of irrigation water (PIW, Kg m^{-3} water applied) and water productivity (WP, Kg m^{-3} consumed water) for wheat as affected with irrigation treatments.

Treatment	Grain yield (Kg fed^{-1})	Irrigation water (m^3 $fed.^{-1}$)	Consumptive use (m^3 $fed.^{-1}$)	PIW (Kg m^{-3})	WP (Kg m^{-3})
Ir.1	2579.5	1180	924	2.2	2.8
Ir.2	2766.5	1440	1213.8	1.9	2.3
Ir.3	3079	1700	1474.2	1.8	2.1

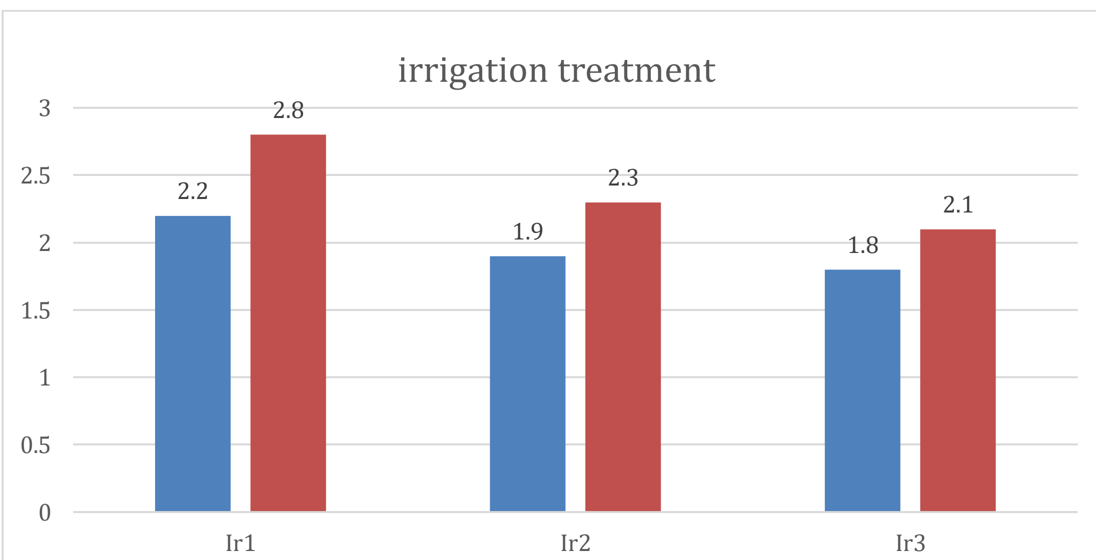

Figure 2: Productivity of irrigation water (PIW, Kg m^{-3} water applied) and water productivity (Wp, Kg m^{-3} consumed water) for wheat as affected with irrigation treatment.

Conclusion

Suitable wheat cultivars to be grown in middle North of Nile Delta are Sakha 95, Giza 171 and Misr 2. Irrigation level of 80% crop water needs is very attractive; it gives almost the same yield of the non-deficit irrigation. Both elements of PIW and WP should be evaluated as crop yield and unit of water. Saving water should be directed to irrigate new lands. Therefore, deficit irrigation is an effective way for farm irrigation management.

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