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Effect of Irrigation Scheduling on some Agronomic and Physiological Traits of some Wheat Cultivars

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ABSTRACT

Field experiments were conducted at Shandaweel Agric. Res. Station, Sohag, Egypt, during the two growing seasons 2018/2019 and 2019/2020 to study the effect of six irrigation regimes, i.e. I1 (irrigation at tillering and elongation stage), I2 (irrigation at tillering and flowering stage), I3 (irrigation at tillering, elongation and flowering stage), I4 (irrigation at tillering, booting and grain filling stage), I5 (irrigation at tillering, elongation, booting and flowering stage) and I6 (irrigation at tillering, elongation, booting, flowering and grain filling stage) on some agronomic and physiological traits of four wheat cultivars, i.e.Shandaweel1, Sids 14, Sohag 4 and Sohag 5. Results showed that decreasing number of irrigations and amount of applied water at different growth stages significantly decreased all studied traits. The highest reduction was recorded under I1 (1432 m^{-3} ha^{-1}) for all studied traits, except days to heading and number of spikes m^{-2}. Meanwhile, the lowest reduction was observed under I5 (3088 m^{-3} ha^{-1}) for all studied traits as compared to I6 (3965 m^{-3} ha^{-1} of applied water). Irrigation at both booting and flowering are essential to reduce loss in grain yield. Moreover, Sids 14 exhibited lower yield reduction under different irrigation regimes, while sohag 4 and Sohag 5 exhibited the highest yield reduction. Therefore, Sids 14 proved to be drought tolerant cultivar, while Sohag 4 and Sohag 5 were drought sensitive. Planting Sids 14 cultivar with irrigation at tillering, booting, grain filling stages (I4) are useful to save about (36.97%) of applied water without significant decrease in grain yield.

Keywords: Wheat cultivars, irrigation regimes, growth stages, grain yield, RWC%, MSI%.

INTRODUCTION

Wheat is considered one of the most important strategic cereal crops not only in Egypt but also all over the world and it is a staple human food. The cultivated area of wheat all over the world in 2018 was 214.29 million hectare produced 734.05 million metric ton with an average productivity of 3.43 ton ha^{-1}, while the cultivated area in Egypt was 1.32 million hectare produced 8.8 million metric ton with an average productivity of 6.69 ton ha^{-1} (FAO, 2018). In Egypt wheat production is far below to meet the local consumption of the growing population of the country which resulted in increasing wheat imports. Increasing production could be achieved by increasing the productivity per unit area and expanding cultivated area.

Irrigation water is a limiting factor for crop production in Egypt. Water scarcity in Egypt has crossed the threshold value of 1000 m^3/capita/year. Considering the population predictions for 2025, Egypt will be down to absolute scarcity level of 500 m^3/capita/year, (FAO, 2016). This will further exaggerate the problems associated with water allocation for agriculture. Considering this situation, the challenge in Egypt is how to produce more food with less water resources. So, reducing the amount of water utilized for irrigation will help to solve this problem and will maximize the benefits from the available irrigation water. Irrigation scheduling is one of the most important approaches for water saving in irrigated agriculture. Water management at growth stages can help to manage water resources to meet crop requirement (Du *et al*., 2010). Tillering, elongation, booting, and grain formation were identified as moisture sensitive stages in wheat (Ali *et al*., 2007). Under scarcity of water, four irrigations scheduled at crown root initiation, tillering, flowering and milky stages saved two irrigations without significant yield loses (Ahmad and Kumar, 2015).The highest values of growth characters were obtained with five irrigations at crown root initiation, tillering, jointing, flowering and milking stages (Banker *et al*., 2008).Water stress through withholding irrigation at the ear emergence and grain filling phases reduced grain yield and its components as will as relative water content (Zarein *et al.*, 2014). Decreasing number of irrigations decreased days to heading, days to maturity, plant height, number of spikes m^{-2}, number of grains $spike^{-1}$ and 1000-kernel weight, grain yield, biological yield, and straw yield (El-Hag, 2017 and Seleiman and Abdel-Aal, 2018). According to many researchers, membrane stability index and relative water content are good physiological indices of drought tolerance and can be used for improving drought tolerance in wheat (Almeselmani *et al*., 2011).Water stress applied at different growth stages of wheat plant decreased leaf relative water content and membrane stability index (Akram, 2011, Mahmoud, 2015 and Abd El-hady *et al*., 2018).

The objectives of this study were: (i) to determine the effect of different irrigation regimes on agronomic and physiological traits of four wheat cultivars, (ii) identify cultivars with high yield potential under water stress

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conditions and (iii) determine the best and economical water regime that increase water use efficiency.

MATERIALS AND METHODS

Experimental site

Field experiments were conducted during the 2018/2019 and 2019/2020 seasons at the experimental farm of Shandaweel Agricultural Research Station, Sohag Governorate, Egypt with the longitude of 31°42´E and the latitude of 26°33´N, and height of 61 m above the sea level. The average annual rainfall and temperature are 1mm and 23.5°C. Soil samples from the experimental soil in both seasons were collected from 0-30 depth for physical and chemical analysis by stander methods of analysis (Table 1).

Table1. Mechanical and chemical properties of the experimental soil during both seasons.

Seasons	Sand %	Silt %	Clay %	Soil Texture	EC (ds m^{-1})	pH	Available (ppm)		
							N	P	K
2019	23.20	38.60	38.20	Clay loam	0.6	7.4	54	18	310
2020	21.50	39.90	38.50	Clay loam	0.8	7.7	50	16	290

Experimental materials

The experimental materials comprised of four Egyptian wheat cultivars with wide range of morphological and agronomical traits; Shandaweel 1, Sids 14 (bread wheat) and Sohag 4 and Sohag 5(durum wheat).The pedigree and selection history of these cultivars are presented in Table 2.

Table 2. Name, pedigree and selection history of the four wheat cultivars.

No	Name	Pedigree and selection history
1	Shandaweel 1	SITE//MO/4/NAC/TH.AC//3*PVN/3/MIRLO/BUC CM SS93B00S675S-72Y-010M-010Y-010M–3Y–0M–0THY–0SH
2	Sids 14	Bow"s"/Vee"s"// Bow"s"/TSI/3/BaniSewef 1 SD293-1SD-2SD-4SD-0SD
3	Sohag 4	AJAIA16//HORA/JRO/3/GAN/4/ZAR/5/SUOK7/6/STOT//ALTRA84/ALD CDSS99B00778S-0TOPY-0M-0Y-129Y-0M-0Y-1B-0SH
4	Sohag 5	TRN//21563/AA/3/BD2080/4/BD2339/5/RASCO37//TARRO2//RASCON3/6/AK/GULL//GREEN CDSS00B00364T-0T0PB -0B- 2Y-0M-0Y-1B-0Y-0SH.

All cultivars were grown under six irrigation regimes; I1: irrigation at tillering and stem elongation stage; I2: irrigation at tillering and flowering stage; I3: irrigation at tillering, stem elongation and flowering stage; I4: irrigation at tillering, booting and grain filling stage; I5: irrigation at tillering, stem elongation, booting and flowering stage, and I6: tillering, stem elongation, booting, flowering and grain filing stage. Water was supplied from a pump outlet to the plots by using plastic pipes, and a water meter was used to measure the amount of applied water. Irrigation scheduling at different stages of wheat and the amount of applied irrigation water are presented in Table 3. To avoid the effect of lateral movement of flooding water each treatment was isolated by ditches.

Each irrigation treatment was considered as a separate randomized complete block experiment with three replications and cultivars were distributed randomly within each replicate. The experiments were planted on November 25 in the both seasons. The plot size was 8.4 m^2 (12 rows, 20 cm apart × 3.5 m long). Phosphorus fertilizer was applied in the form of mono superphosphate (15.5%) at the rate of 35.71 kg P_2O_5 ha^{-1} during the land preparation. The recommended dose of nitrogen fertilizer (178.57 kg ha^{-1} in the form of Urea, 46.5% N) was applied two times; before planting irrigation (40%) and at tillering stage before the first irrigation (60%).The field was kept free from insects and pests using pesticides as needed. Weeds were controlled by recommended herbicides.

Table 3. Irrigation scheduling at different growth stages and amount of applied irrigation water.

Irrigation treatments	Growth stage					Applied irrigation water m^3ha^{-1}		
	Tillering	Elongation	Booting	Flowering	Grain filling	18/19	19/20	Mean
I1	+	+	-	-	-	1395	1468	1432
I2	+	-	-	+	-	1614	1718	1666
I3	+	+	-	+	-	2273	2420	2347
I4	+	-	+	-	+	2399	2599	2499
I5	+	+	+	+	+	2989	3187	3088
I6	+	+	+	+	+	3848	4082	3965

+ = irrigated & - = not irrigated

Measurements

Agronomic traits: number of days to heading (DH), number of days to maturity (DM), plant height (PHT), number of spikes m^{-2} (SM^{-2}), number of kernels $spike^{-1}$ (KS^{-1}), 1000- kernel weight (TKW) in g, grain yield ha^{-1} (GY) in tons and biological yield ha^{-1} (BY) in tons

Physiological traits: leaf relative water content (RWC) % and membrane stability index (MSI) were measured at the mid-grain filling stage in both seasons.

Relative water content% (RWC%): was determined by undertaken 30 discs (1.5 cm^2) of flag leaf, the discs were immediately weighed to obtain their fresh weight (FW), then the discs were floated on distillated water in a refrigerator (at 4°C in darkness) for 24 hr, after that the turgid leaf discs were rapidly blotted dry and weighted to obtain the turgid weight (TW). Leaf discs were then dried in an oven and weighted until a constant weight to obtain dry weight (DW). Leaf RWC was calculated by the following formula given by Pask *et al.* (2012)

RWC% = [FW – DW] / [TW – DW] × 100

Membrane stability index (MSI): was determined by recording the electrical conductivity of flag leaf leakages in double distilled water at 40 ºC and 100 ºC according to Sairam *et al*. (1997). Leaf samples (0.1 g) were cut into discs of uniform size and taken in test tubes containing 10 ml of double distilled water in two sets. One set was kept at 40 ºC for 30 minutes and another set at 100 ºC in boiling water bath for 10 minutes and their respective electric conductivities C1 and C2 were measured by Conductivity meter.

Membrane stability index = 1- [(C1/C2)] x 100

Statistical analysis

Separate analysis of variance in each of the two seasons as well as combined analysis of variance for each irrigation treatment were applied on plot mean base. Also, combined analysis of variance over irrigation treatments in both seasons and over all seasons and irrigation treatments was carried out after testing the homogeneity of errors using Barttlet (1937) according to Gomez and Gomez (1984).The least significant difference (LSD) test at 5% level of significance was used to compare means according to Waller and Duncan (1969).

RESULTS AND DISCUSSIONS

Number of days to heading

Irrigation regimes effect

Data in Table 4 show that number of days to heading was significantly affected by irrigation treatments in both seasons and their combined. The earliest heading was recorded by I2 (97.25, 95.42 and 96.33 day), while full irrigation I6 recorded the highest number of days to heading (101.58, 100.75 and 101.17 day) in the first, second seasons and their mean, respectively. Based on combined data, I1, I2, I3 and I4 treatments recorded the significant reduction of days to heading by 2.14, 4.78, 1.94 and 4.29 %., respectively, compared to full irrigation regime (I6). It is clear that withholding irrigation at elongation and/or booting stage led to significant reduction in days to heading, but skipping irrigation at elongation stage recorded the highest reduction. Water stress increased senescence by accelerating chlorophyll degradation, leading to a decrease in leaf area and photosynthesis then decrease the vegetative growth phase. Mekkei and El Haggan (2014) reported that skipping irrigation at elongation and initiation of booting stage decreased days to heading. Also, Menshawy *et al.* (2006) and El-Hag (2017) reported that decreasing number of irrigation caused early heading.

Differences between cultivars

Results in Table 4 show significant differences between cultivars for number of days to heading under each of irrigation regime and over irrigation regimes in both seasons and their combined analysis. The shortest period of days to heading was recorded by Sohag 5 (96.67, 93.67, 96.83, 98.00 and 98.50 day) under I1, I2, I4, I5 and I6, respectively, and Sohag 4 (95.67 day) under I3, while, the longest period recorded by Sids 14 cultivar (103.00, 100.83, 104.00, 102.00, 104.83 and 105.00 day) under I1, I2, I3, I4, I5 and I6, respectively, as an average of the two seasons. Based on combined data over all, Sohag 5 had the lowest value of number of days to heading (96.61 day) and it was statistically at par with Sohag 4 cultivar 97.36 day, while Sids 14 had the highest value (103.28 day). The significant variation among the studied cultivars might reflects their different genetic backgrounds and environmental condition. Menshawy *et al.* (2006) and El-Hag (2017) showed significant differences between wheat cultivars for days to heading under different irrigation treatments.

Interaction effect

The effect of the interaction between irrigation regimes and cultivars for number of days to heading was insignificant in both seasons. Moreover, combined analysis over all showed insignificant differences between seasons × irrigation regimes, seasons × cultivars, irrigation regimes × cultivars and seasons × irrigation regimes× cultivars interactions (Table 4).

Number of days to maturity

Irrigation regimes effect

Data illustrated in Table 4 indicated that the irrigation schedules had a significant effect on number of days to maturity in both seasons and their combined. The lowest values of number of days to maturity were obtained under I1 (138.25, 136.58 and 137.42 day), while the highest values were recorded under I6 (146.67, 145.42 and 146.04 day) in the first and second seasons and their combined, respectively. Significant reduction in days to maturity over both seasons by 5.90, 5.16, 3.59 and 2.42 % were obtained under I1, I2, I3 and I4, respectively, compared to I6. It is clear that decreasing number of irrigations led to significant reduction in days to maturity.

This may be due to water stress retards photosynthesis and translocation of photosynthates and affects plant development which shortening days to maturity. Moreover, water stress imposed at post flowering reduced the grain-filling period hence decreased days to maturity. These results are in line with those obtained by Menshawy *et al.* (2006), Mekkei and El Haggan (2014) and El-Hag (2017) who reported that skipping irrigation at elongation, booting and flowering stage decreased number of days to maturity.

Differences between cultivars

Results presented in Table 4 show that, number of days to maturity of the four wheat cultivars in both seasons and their mean differed significantly under each of irrigation schedule. Also, significant differences between cultivars were found across irrigation regimes in both seasons and their combined. As an average of both seasons, the lowest values of days to maturity (135.00, 135.83, 137.50, 138.50, 140.83 and 142.00 day) were recorded in Sohag 4 under I1, I2, I3, I4, I5 and I6, respectively. Meanwhile, the highest values (141.83, 143.67, 146.00, 147.50, 150.17 and 151.33 day) were obtained by Sids 14 under the abovementioned treatments, respectively. It was evident from combined analysis that, Sohag 4 was the earliest cultivar for number of days to maturity (138.28 day) and it was statistically at par with Sohag 5 (139.11 day), while Sids 14 was the latest cultivar (146.75 day). The differences between cultivars for days to maturity are often due to genetic makeup as well as the interaction between genetic makeup and environmental conditions. Morsy and Abd El-Hameed (2012) and El-Hag (2017) found significant differences between wheat cultivars for days to maturity under different irrigation regimes.

Table 4. Means of number of days to heading and days to maturity of four wheat cultivars as affected by irrigations regimes in the two seasons and their combined analysis.

	Traits	Days to heading			F test S	S × C LSD 0.05	Days to maturity			F test S	S × C LSD 0.05
	Seasons / Cultivars	2018/2019	2019/2020	Mean			2018/2019	2019/2020	Mean		
Irrigations regimes I1	Shandaweel 1	99.00	98.00	98.50		Ns	138.33	136.33	137.33		Ns
	Sids 14	104.00	102.00	103.00			143.00	140.67	141.83		
	Sohag 4	98.00	97.67	97.83			135.67	134.33	135.00		
	Sohag 5	97.00	96.33	96.67			136.00	135.00	135.50		
	Mean	99.50	98.50	99.00	Ns		138.25	136.58	137.42	**	
	LSD 0.05	4.75	3.81	2.70			4.57	4.38	3.03		
I2	Shandaweel 1	96.97	95.00	95.83		Ns	139.33	137.67	138.50		Ns
	Sids 14	102.33	99.33	100.83			145.33	142.00	143.67		
	Sohag 4	95.67	94.33	95.00			136.33	135.33	135.83		
	Sohag 5	94.33	93.00	93.67			136.00	136.00	136.00		
	Mean	97.25	95.42	96.33	**		139.25	137.75	138.50	Ns	
	LSD 0.05	3.84	4.21	2.53			5.68	4.57	3.23		
I3	Shandaweel 1	98.67	98.00	98.33		Ns	142.33	141.33	141.83		Ns
	Sids 14	104.33	103.67	104.00			147.00	145.00	146.00		
	Sohag 4	98.33	97.00	97.67			138.33	136.67	137.50		
	Sohag 5	97.67	96.00	96.83			138.33	137.33	137.83		
	Mean	99.75	98.67	99.21	Ns		141.50	140.08	140.79	Ns	
	LSD 0.05	4.77	4.43	2.89			5.74	5.70	3.59		
I4	Shandaweel 1	96.33	96.00	96.17		Ns	145.67	141.67	143.67		Ns
	Sids 14	103.00	101.00	102.00			148.67	146.33	147.50		
	Sohag 4	96.33	95.00	95.67			139.00	138.00	138.50		
	Sohag 5	96.67	95.33	96.00			140.33	140.33	140.33		
	Mean	98.08	96.83	96.83	Ns		143.42	141.58	142.50	Ns	
	LSD 0.05	3.94	3.95	2.48			6.52	5.34	3.74		
I5	Shandaweel 1	102.00	101.00	101.50		Ns	147.33	144.33	145.83		Ns
	Sids 14	105.67	104.00	104.83			151.33	149.00	150.17		
	Sohag 4	99.33	98.67	99.00			141.00	140.67	140.83		
	Sohag 5	99.00	97.00	98.00			142.33	141.33	141.83		
	Mean	101.50	100.17	100.83	Ns		145.50	143.83	144.67	Ns	
	LSD 0.05	4.67	4.35	2.83			5.97	5.84	3.70		
I6	Shandaweel 1	102.67	101.67	102.17		Ns	148.67	146.67	147.67		Ns
	Sids 14	105.33	104.67	105.00			152.33	150.33	151.33		
	Sohag 4	99.00	99.00	99.00			142.00	142.00	142.00		
	Sohag 5	99.33	97.67	98.50			143.67	142.67	143.17		
	Mean	101.58	100.75	101.17	Ns		146.67	145.42	146.04	Ns	
	LSD 0.05	4.25	4.65	2.79			5.98	5.02	3.46		
	General Mean	99.61	98.39	99.00			142.43	140.88	141.88		
Combined analysis S × C	Shandaweel 1	99.22	98.28	98.75			143.61	141.33	142.47		
	Sids 14	104.11	102.44	103.28			147.94	145.56	146.75		
	Sohag 4	97.78	96.94	97.36			138.72	137.83	138.28		
	Sohag 5	97.33	95.89	96.61			139.44	138.78	139.11		

	2018/2019		2019/2020		combined		2018/2019		2019/2020		combined	
Effect	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05
S					**	1.00					**	1.28
I	1.34	**	**	1.82	**	1.30	**	1.87	**	1.71	**	1.67
C	1.49	**	**	1.44	**	1.01	**	1.99	**	1.75	**	1.30
S × I					NS	--					NS	--
S × C					NS	--					NS	--
I × C	NS	--	NS	--	NS	--	NS	--	NS	--	NS	--
S × I × C					NS	--					NS	--

Ns, * and ** means not significant, significant at 0.05 and 0.01 probability, respectively

Interaction effect

The effect of the interaction between irrigation regimes and cultivars of days to maturity was insignificant in both seasons. Moreover, combined over all showed insignificant differences between seasons × irrigation regimes, seasons × cultivars, irrigation regimes × cultivars and seasons × irrigation regimes× cultivars interactions (Table 4).

Plant height

Irrigation regimes effect

The results in Table 5 revealed that plant height was significantly affected by irrigation regimes in both seasons and their combined. The highest values of plant height (116.08, 111.25 and 113.67 cm) were recorded under I6, while the lowest values (104.42, 97.58 and 101.00 cm) were recorded under I1in the first and second seasons and their combined, respectively. Based on combined data, decreasing number of irrigation and applied water decreased plant height by 11.15, 9.27, 7.51, 5.72 and 2.75% for I1, I2, I3, I4 and I5, respectively compared to the full irrigation regime (I6). It is clear that, irrigation wheat at tillering and elongation (I1) gave the highest significant reduction in plant height than those of other irrigation treatments and it was statistically similar with irrigation at tillering and flowering stage (I2).

However, skipping irrigation at grain filling (I5) gave an insignificant reduction in plant height compared to the full irrigation treatment (I6). Sarwar *et al.* (2010), Mekkei and El Haggan (2014), Teama *et al.* (2016) and El-Hag (2017) indicated that skipping irrigation at different growth stage decreased plant height. The reduction in plant height in response to drought stress may be due to the relative reduction of inflammation and water loss of the protoplasm, which contributes to the reduction of turgor pressure and cell division and the decreasing of size and number of cells (Mehraban *et al.,* 2019). Depressed water potential suppresses cell division, organ growth, net photosynthesis, protein synthesis and alters hormonal balance of major plant tissues (Moharram and Habib, 2011).

Differences between cultivars

Significant differences between cultivars for plant height were obtained in both seasons and their combined under each of irrigation regime (Table 5). Moreover, highly significant differences between cultivars over irrigation regimes for plant height were recorded in each of the two seasons and their combined. As an average of both seasons, Sids 14 was the tallest cultivar (115.33, 118.33, 120.00, 121.83, 123.83 and 126.17 cm) under I1, I2, I3, I4, I5 and I6, respectively while, Sohag 5 was the shortest one (92.50, 94.83, 97.17, 99.17, 102.33 and 105.67 cm) for plant height under I1, I2, I3, I4, I5 and I6, respectively.

Based on combined over all, Sids 14 was the tallest cultivar (120.92 cm) followed by Shandaweel 1 (107.47 cm) and Sohag 4 (100.08 cm), while Sohag 5 was the shortest one (98.61 cm) which it was at par with Sohag 4. Significant variations between wheat cultivars as affected by different irrigation regimes were reported by Menshawy *et al.* (2006) and El-Hag (2017).

Interaction effect

The effect of the interaction between irrigation regimes and cultivars on plant height was insignificant in both seasons. Moreover, combined over all showed insignificant differences between seasons × irrigation regimes, seasons × cultivars, irrigation regimes × cultivars and seasons × irrigation regimes× cultivars interactions (Table 5).

Number of spikes m^{-2}

Irrigation regimes effect

Variations in number of spikes m^{-2} due to decrease in number of irrigations and applied water were highly significant in both seasons and their combined (Table 5).

Application of five irrigations (I6) resulted in the highest number of spikes m^{-2} (438.83, 370.42 and 404.63) while, application of two irrigations at tillering and flowering stage (I2) recorded the lowest ones (407.08, 337.50 and 372.29) in the first and second seasons and their combined, respectively. Water deficit conditions during the different growth stages caused a significant reduction in number of spikes m^{-2} by (7.36, 7.99, 5.62, 3.93 and 1.89%) in I1, I2, I3, I4 and I5, respectively compared to I6. It is clear that the highest negative effect of decreasing irrigations number was observed when irrigation was applied at tillering and flowering stage (I2) and it was statistically at par with I1 when irrigation applied at tillering and elongation stages, whereas skipping irrigation at grain filling stage (I5) exhibited the lowest reduction for number of spikes m^{-2} in comparison to the I6.

Moreover, skipping irrigation at elongation and flowering stages (I4) exhibited lower reduction for number of spikes m^{-2} compared to skipping irrigation at booting and grain filling (I3). Tillers are initiated in the first growth stage, but the fertile tillers is controlled by the availability of nutrients, moisture and weather conditions during the whole growing period from emergence through tillering and stem elongation up to the stages of spike development and this was clear from our results which indicated the number of spikes m^{-2} is gradually increased with increasing irrigations number. Similar results were found by Akram (2011), El-Hag (2017) and Thapa *et al.* (2019).

Differences between cultivars

The results given in Table 5 showed insignificant differences between the four wheat cultivars for number of spikes m^{-2} under I1, I2 and I3, while there were significant differences for number of spikes m^{-2} between wheat cultivars under I4, I5 and I6 treatments in both seasons and their combined. Moreover, highly significant differences for number of spikes m^{-2} were recorded between cultivars in each season and their combined.

As an average of the two growing seasons, the highest values of number of spikes m^{-2} were recorded by Shandaweel 1 (378.17 and 376.50) under I1 and I2 and Sohag 5 (387.67, 397.33, 409.17 and 415.83) under I3, I4, I5 and I6, respectively. Meanwhile, the lowest values of number of spikes m^{-2} were obtained by Sids 14 (370.50, 368.33, 378.17, 380.17, 385.83 and 391.67) under I1, I2, I3, I4, I5 and I6, respectively. It was evident from combined data that, Sohag 5 recorded the highest number of spikes m^{-2} (392.64) followed by Sohag 4 (387.33), Shandaweel 1 (385.42) and Sids 14 (380.83). These results reported that Sohag 4 and Sohag 5 were the most cultivars affected by decreasing irrigation numbers of applied water for number of spikes m^{-2}. The differences between cultivars are mainly due to the interaction between their genetic makeup during growth stages and to the environmental factors prevailing during their development. Significant variations between wheat cultivars as affected by different irrigation regimes for number of spikes m^{-2} were reported by Sarwar *et al.* (2010), Teama *et al.* (2016) and El-Hag (2017).

Interaction effect

Significant effect of the interaction between cultivars and irrigation regimes for number of spikes m^{-2}were found in the first season and combined analysis, while insignificant differences were found between seasons × irrigation regimes, seasons × cultivars and seasons × irrigation regimes× cultivars (Table 5). The highest number of spikes m^{-2} (451.67 and 415.83) obtained by Sohag 5 cultivar under I6 in the first season and combined over all.

Table 5. Means of plant height and number of spikes m^{-2} of four wheat cultivars as affected by irrigations regimes in the two seasons and their combined analysis.

	Traits	Plant height			F test S	S × C LSD 0.05	Number of spikes m^{-2}			F test S	S × C LSD 0.05
	Seasons / Cultivars	2018/2019	2019/2020	Mean			2018/2019	2019/2020	Mean		
Irrigations regimes I1	Shandaweel 1	105.67	97.00	101.33			413.00	343.33	378.17		
	Sids 14	120.67	110.00	115.33		NS	411.33	341.67	376.50		NS
	Sohag 4	95.67	94.00	94.83			406.00	335.00	370.50		
	Sohag 5	95.67	89.33	92.50			410.00	338.33	374.17		
	Mean	104.42	97.58	101.00	**		410.08	339.58	374.83	**	
	LSD 0.05	13.01	9.77	7.22			Ns	Ns	Ns		
I2	Shandaweel 1	104.00	102.67	103.33			411.33	341.67	376.50		
	Sids 14	122.33	114.33	118.33		NS	407.00	338.33	372.67		NS
	Sohag 4	97.33	94.67	96.00			403.33	333.33	368.33		
	Sohag 5	95.67	94.00	94.83			406.67	336.67	371.67		
	Mean	104.83	101.42	103.13	Ns		407.08	337.50	372.29		
	LSD 0.05	13.17	10.44	7.45			Ns	Ns	Ns		
I3	Shandaweel 1	106.67	104.67	105.67			415.33	346.67	381.00		
	Sids 14	124.00	116.00	120.00		NS	413.00	343.33	378.17		NS
	Sohag 4	100.00	95.33	97.67			419.67	341.67	380.67		
	Sohag 5	99.33	95.00	97.17			425.33	350.00	387.67		
	Mean	107.50	102.75	105.13	**		418.33	345.42	381.88	**	
	LSD 0.05	12.62	10.61	7.31			Ns	Ns	Ns		
I4	Shandaweel 1	108.67	106.00	107.33			417.33	351.67	384.50		
	Sids 14	125.33	118.33	121.83		NS	415.33	345.00	380.17		NS
	Sohag 4	103.67	97.00	100.33			432.33	353.33	392.83		
	Sohag 5	102.67	95.67	99.17			434.67	360.00	397.33		
	Mean	110.08	104.25	107.17	*		424.92	352.50	388.71	**	
	LSD 0.05	11.58	11.18	7.14			15.76	9.58	8.18		
I5	Shandaweel 1	113.33	110.67	112.00			425.33	357.33	391.33		
	Sids 14	128.33	119.33	123.83		NS	418.33	353.33	385.83		NS
	Sohag 4	105.67	102.33	104.00			438.33	365.00	401.67		
	Sohag 5	104.00	100.67	102.33			443.33	375.00	409.17		
	Mean	112.83	108.25	110.54	*		431.33	362.67	397.00	**	
	LSD 0.05	12.15	8.94	6.69			18.14	14.96	10.42		
I6	Shandaweel 1	116.67	113.67	115.17			433.67	368.33	401.00		
	Sids 14	130.00	122.33	126.17		NS	421.67	361.67	391.67		NS
	Sohag 4	109.67	105.67	107.67			448.33	371.67	410.00		
	Sohag 5	108.00	103.33	105.67			451.67	380.00	415.83		
	Mean	116.08	111.25	113.67	*		438.83	370.42	404.63	**	
	LSD 0.05	10.73	9.334	6.31			21.54	11.97	10.93		
	General Mean	109.29	104.25	106.77			421.76	351.35	386.56		
S × C	Shandaweel 1	109.17	105.78	107.47			419.33	351.50	385.42		
	Sids 14	125.11	116.72	120.92			414.44	347.22	380.83		
	Sohag 4	102.00	98.17	100.08			424.67	350.00	387.33		
	Sohag 5	100.89	96.33	98.61			428.61	356.67	392.64		

Combined analysis	Plant height 2018/2019		2019/2020		combined		Number of spikes 2018/2019		2019/2020		combined	
Effect	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05
S					**	2.60					**	3.45
I	**	2.85	**	2.31	**	3.38	**	3.95	**	6.40	**	4.49
C	**	4.15	**	3.41	**	2.63	**	5.57	**	4.47	**	3.50
S × I					NS	--					NS	--
S × C					NS	--					NS	--
I × C	NS	--	NS	--	NS	--	*	13.65	NS	--	**	8.58
S × I × C					NS	--					NS	--

Ns, * and ** means not significant, significant at 0.05 and 0.01 probability, respectively

Number of kernels spike^{-1}

Irrigation regimes effect

The number of kernels spike^{-1} was significantly ($P \leq 0.01$) influenced by irrigation regimes in both seasons and their combined (Table 6) The highest values of number of kernels spike^{-1} (58.78, 52.22 and 55.50) were observed at I6, while the lowest values (51.03, 46.63 and 48.92) were recorded at I1 in the first and second seasons and their combined, respectively. Regarding the combined data, significant reduction in number of kernels spike^{-1} by (11.86, 10.18, 3.71 and 5.96%) was obtained under I1, I2, I3 and I4, respectively, compared to the full irrigation regime (I6). It is clear that, irrigation wheat only at tillering and elongation stage (I1) gave the highest significant reduction in number of kernels spike^{-1} and it was statistically similar with irrigation wheat at tillering and flowering stage (I2). However, skipping irrigation at grain filling stage (I5) gave insignificant reduction in number of kernels spike^{-1} compared to I6 treatment. This results indicated that introducing water stress at critical growth stages resulted in a serious reduction in number of kernels and irrigation should be implemented at during the booting stage through flowering to increase the number of kernels spike^{-1}. Dusek and Musick (1992) recommended adequate irrigation during the boot stage through flowering as one of the strategies to increase the seed number per square meter, and then grain yield. Decreasing in number of kernels spike^{-1} was found by omitting irrigation at stem elongation and flowering stage (Akram, 2011) as well as flowering stage (Gameh *et al.*, 2017).Water deficit at stem elongation stage causes a reduction in number of kernels due to its negative effect on floret formation and fertility and this reduction might be linked to reduction in plant growth that resulted in reduction in the capacity of source and sink size in drought-stressed plants compared to full-irrigation plants (Mehraban *et al.*, 2019). Skipping irrigation at different growth stages decreased number of kernels spike^{-1} (Morsy and Abd El-Hameed, 2012).

Differences between cultivars

Significant differences between cultivars for number of kernels spike^{-1} were obtained in both seasons and their combined under each of irrigation regime (Table 6). Moreover, highly significant differences between cultivars over irrigation regimes for number of kernels spike^{-1} were recorded in both seasons and their combined.

As a an average of both seasons, Sids 14 recorded the highest number of kernels spike^{-1} (51.80 and 52.58) under I1 and I2 and Shandaweel 1 (56.85, 55.14, 58.50 and 59.47) under I3, I4, I5 and I6, respectively. Meanwhile, the lowest values of number of kernels spike^{-1} (46.50, 47.21, 50.89, 49.64, 52.41 and 52.28) were observed by Sohag 4 under I1, I2, I3, I4, I5 and I6, respectively. Based on combined over all, Shandaweel 1had the highest number of kernels spike^{-1} (55.36) followed by Sids 14 (54.36), while Sohag 4 had the lowest number of kernels spike^{-1} (49.82) and it was at par with Sohag 5 (50.46). The differences between wheat cultivars are mainly due to the interaction between their genetic makeup during growth periods and to the environmental factors prevailing during their development. These results are in agreement with that observed by Menshawy *et al.* (2006), Sarwar *et al.* (2010), Akram (2011) and El-Hag (2017).

Table 6. Means of number of kernels spike^{-1} and 1000-kernel weight of four wheat cultivars as affected by irrigations regimes of the two seasons and their combined analysis.

	Traits	Number of kernels spike^{-1}			F test S	S × C LSD 0.05	1000-kernel weight			F test S	S × C LSD 0.05
	Seasons Cultivars	2018/ 2019	2019/ 2020	Mean			2018/ 2019	2019/ 2020	Mean		
Irrigations regimes I1	Shandaweel 1	53.20	47.74	50.47		NS	46.43	44.33	45.38		NS
	Sids 14	55.20	48.41	51.80			51.27	47.67	49.47		
	Sohag 4	48.53	44.46	46.50			48.50	45.03	46.77		
	Sohag 5	47.20	45.92	46.56			49.57	45.33	47.45		
	Mean	51.03	46.63	48.92	**		48.94	45.59	47.27	**	
	LSD 0.05	4.15	2.81	2.22			3.10	2.27	1.71		
I2	Shandaweel 1	54.53	48.91	51.72		NS	46.67	44.67	45.67		NS
	Sids 14	55.87	49.29	52.58			51.53	48.00	49.77		
	Sohag 4	49.53	44.89	47.21			49.07	45.25	47.16		
	Sohag 5	48.87	46.90	47.88			50.20	46.67	48.43		
	Mean	52.20	47.50	49.85	**		49.37	46.15	47.76	*	
	LSD 0.05	3.86	3.09	2.19			3.23	2.35	1.77		
I3	Shandaweel 1	60.87	52.84	56.85		NS	48.00	47.33	47.67		NS
	Sids 14	57.20	51.90	54.55			52.67	48.53	50.60		
	Sohag 4	54.20	47.57	50.89			55.00	51.33	53.17		
	Sohag 5	54.87	48.11	51.49			52.40	47.00	49.70		
	Mean	56.78	50.11	53.44	**		52.02	48.55	50.28	*	
	LSD 0.05	4.56	3.64	2.78			3.44	2.99	2.40		
I4	Shandaweel 1	58.53	51.75	55.14		NS	48.83	46.67	47.75		NS
	Sids 14	56.87	50.57	53.72			53.00	49.00	51.00		
	Sohag 4	52.53	46.74	49.64			56.33	51.67	54.00		
	Sohag 5	53.20	47.31	50.25			53.93	48.00	50.97		
	Mean	55.28	49.09	52.19	**		53.03	48.83	50.93	*	
	LSD 0.05	4.70	4.17	2.59			4.44	3.09	2.02		
I5	Shandaweel 1	62.53	54.47	58.50		NS	49.87	48.00	48.93		NS
	Sids 14	59.87	53.49	56.68			53.50	50.33	51.92		
	Sohag 4	55.20	49.61	52.41			57.33	53.67	55.50		
	Sohag 5	56.20	50.07	53.13			54.93	51.00	52.97		
	Mean	58.45	51.91	55.18	**		53.91	50.75	52.33	Ns	
	LSD 0.05	3.53	3.79	2.30			3.39	3.67	2.21		
I6	Shandaweel 1	63.53	55.41	59.47		NS	51.33	49.00	50.17		NS
	Sids 14	60.20	53.47	56.84			53.67	51.67	52.67		
	Sohag 4	54.87	49.69	52.28			58.80	55.33	57.07		
	Sohag 5	56.53	50.29	53.41			56.20	52.00	54.10		
	Mean	58.78	52.22	55.50	**		55.00	52.00	53.50	Ns	
	LSD 0.05	4.13	4.20	2.61			4.77	3.98	2.76		
	General Mean	55.42	49.58	52.50			52.04	48.65	50.34		
S × C	Shandaweel 1	58.87	51.85	55.36			48.52	46.67	47.59		
	Sids 14	57.53	51.19	54.36			52.61	49.20	50.90		
	Sohag 4	52.48	47.16	49.82			54.17	50.38	52.28		
	Sohag 5	52.81	48.10	50.46			52.87	48.33	50.60		

Combined analysis		2018/2019		2019/2020		combined		2018/2019		2019/2020		combined	
	Effect	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05
	S					**	0.91					**	0.80
	I	**	1.85	**	2.21	**	1.18	**	1.80	**	2.39	**	1.05
	C	***	1.41	**	1.24	**	0.92	**	1.28	**	1.06	**	0.81
	S × I					NS	--					NS	--
	S × C					NS	--					*	1.15
	I × C	NS	--	NS	--	NS	--	NS	--	*	2.59	**	2.00
	S × I × C					NS	--					NS	--

Ns, * and ** means not significant, significant at 0.05 and 0.01 probability, respectively

Interaction effect

The effect of interaction between irrigation treatments and wheat cultivars for number of kernels spike^{-1} was insignificant in both seasons. Furthermore, combined analysis over all (Table 6) showed insignificant differences between seasons × irrigation regimes, seasons × cultivars, irrigation regimes × cultivars and seasons × irrigation regimes× cultivars interaction effects.

1000- kernel weight

Irrigation regimes effect

Results of 1000- kernel weight during the two growing seasons and their combined, was highly significantly affected by the different irrigation regimes (Table 6). I6 resulted in the highest 1000- kernel weight (55.00, 52.00, 53.50 g) followed by I5, I4, I3 and I2, while the lowest 1000- kernel weight was observed under I1 (48.94, 45.59 and 47.27) in the first and second seasons and their combined, respectively. Concerning the combined data, there were significant reduction in 1000- kernel weight by (11.64, 10.73, 6.02, 4.80 and 2.19%) under I1, I2, I3, I4 and I5, respectively, compared to the I6. It is clear that, irrigation wheat at tillering and elongation (I1) gave the highest significant reduction in 1000- kernel weight compared to I6 treatment and it was statistically similar with irrigation wheat at tillering and flowering stage (I2). On the other hand, significant reduction in 1000- kernel weight was found under I3 (skipping irrigation at booting and grain filling stage) and I4 (skipping irrigation at elongation and flowering stage) compared to I6, but they were par with each other. Moreover, skipping irrigation at grain filling (I5) exhibited the lowest significant reduction compared to I6. It would be reasonable to conclude that 1000- kernel weight is severely reduced if irrigation is not applied at booting and grain filling stage. The expected reason for reduction in grain weight under water stress conditions might be due to drought influencing the emergent florets and lessening the weight of the carpel at pollination. Also, the moisture stress at grain filling may be hinders the translocation of photosynthates from leaves to ear and thus affected the seed size. These results are in accordance with those obtained by El-Hag (2017) and Seleiman and Abdel-Aal (2018). Moayedi *et al*. (2010) reported that the most susceptible growth and developmental stage with regard to 1000-kernel weight is from flowering to grain filling stage. Grain weight per spike significantly improved with addition of irrigation during grain filling (Khokhar *et al*., 2010). Reduction in grain weight resulted from water stress at elongation, booting and flowering stages (Akram, 2011 and Gameh *et al*., 2017).

Differences between cultivars

Results of 1000-kernel weight presented in Table 6 showed significant differences among cultivars in both seasons and their combined under each of irrigation regime and highly significant differences between cultivars over irrigation regimes in both seasons and their combined. As a an average of the two growing seasons, the greatest values of 1000-kernel weight were observed with Sids 14 (49.47 and 49.77 g) under the I1 and I2 and with Sohag 4 (53.17, 54.00, 55.50 and 57.07 g) under I3, I4, I5 and I6, respectively. Meanwhile, Shandaweel 1 had the lowest values of 1000-kernel weight (45.38, 45.67, 47.67, 47.75, 48.93 and 50.17 g) under I1, I2, I3, I4, I5 and I6, respectively.

Concerning combined data over all, Sohag 4 recorded the highest value of 1000- kernel weight (52.28 g) followed by Sids 14 (50.90) and Sohag 5 (50.60 g), while Shandaweel 1 had the lowest value of 1000- kernel weight (47.59 g). The differences in 1000-kernel weight among the evaluated four cultivars might be attributed to the genetic variations. Menshawy *et al*. (2006), Morsy and Abd El-Hameed (2012), Teama *et al*. (2016) and El-Hag (2017) found significant differences of 1000-kernel weight between wheat cultivars in their response to water stress under different irrigation treatments.

Interaction effect

The effect of the interaction between irrigation treatments and wheat cultivars for1000-kernel weight was significant in the second season (Table 6).

Regarding combined analysis over all, results showed significant and highly significant differences between seasons × cultivars and irrigation regimes × cultivars interactions, while they showed insignificant differences between seasons × irrigation regimes and seasons × irrigation regimes× cultivars interactions. Sohag4 gave the highest value of 1000-kernel weight (55.33 and 57.07 g) under I6 treatment, while Shandaweel 1 gave the lowest value (44.33 and 45.38 g) under I1 irrigation regime in the second season and combined over all, respectively.

Grain yield (t ha^{-1})

Irrigation regimes effect

The results in Table 7 and Fig. 1 indicated that different irrigation regimes during growth stages had highly significant effect on grain yield in both seasons and their combined. The highest grain yield (9.08, 7.26 and 8.17 t ha^{-1}) was produced under the full irrigation treatment (I6), while the lowest grain yield (7.03, 5.43, 6.23 t ha^{-1}) was recorded under the I1 in the first, second seasons and their combined, respectively. There were insignificant differences of grain yield between I1 and I2 in the first, second seasons and their combined, between I3 and I4, and between I5 and I6 in the second season. Regarding the combined data, grain yield generally was decreased as number of irrigations decreased. Significant reductions in grain yield by (3.79, 13.59, 17.26, 22.03 and 23.75%) were detected when applied water was reduced from 3965 m^3 (I6) to 3088 (I5), 2499 (I4), 2347 (I3), 1666 (I2) and 1432 m^3 ha^{-1} (I1), respectively (Table 3 and Fig 1). These results indicated that any subsequent irrigation when skipped at any critical growth stage of wheat resulted in significant reduction in yield as compared to full irrigation treatment. Low grain yield under lower water regimes was mainly due to the obvious reduction in the yield components such as spikes number, kernels number and 1000-kernel weight during the critical growth stages.

The combined stress at booting, flowering and grain filling stage (I1) caused significant reduction in grain yield compared to that at elongation, booting and grain filling stage (I2). Also, the combined stress at booting and grain filling stages (I3) caused significant reduction in grain yield compared to that at elongation and flowering stages (I4). It would be reasonable to conclude that grain yield is severely reduced if irrigation is not applied at booting and flowering. Drought at the pre-flowering stage can have greater yield reductions than in post-flowering stages, because it affects yield potential at the sink level via decreasing the number of spikes m^{-2} as well as the number of kernels $spike^{-1}$. Mojtaba *et al*. (2013), Mekkei and El Haggan (2014), Bashir *et al*. (2017) and Si *et al*. (2020) reported that decreasing number of irrigations and amount of water decreased grain yield at the different growth stages. For attaining maximum yield, moisture stress should be avoided at the time of booting and flowering stage (Ali and Sirelkhatim, 2010). El-Hag (2017) demonstrated that irrigation should be implemented at both of the elongation and booting stages. Withholding irrigation either at milky or booting decreased wheat grain yield (Yazal *et al*., 1994)

Differences between cultivars

Data in Table 7 clearly indicate the significant differences among wheat cultivars respecting grain yield ha^{-1} in both seasons and their combined under each of the irrigation treatments. Furthermore, significant and highly significant differences between cultivars over irrigation regimes were found in the first, second seasons and their combined. As an average of the two growing seasons, the highest grain yield (8.55, 8.29 t ha^{-1}) was obtained by Sohag 5 under I6 and I5 and by Sids 14 (7.45, 7.20, 6.73 and 6.60 t ha^{-1}) under I4, I3, I2 and I1, respectively. In contrast, the lowest grain yield was recorded by Sohag 4 (5.97, 6.07, 6.42 and 6.80 t ha^{-1}) under I1, I2, I3 and I4, respectively, Shandaweel 1 (7.56 t ha^{-1}) under I5 and Sids 14 (7.74 t ha^{-1}) under I6 treatment. Regarding combined data, Sids 14 had the highest grain yield (77.22 t ha^{-1}) and it was statistically at par with Sohag 5 (7.18 t ha^{-1}), while Sohag 4 had the lowest grain yield (6.94 t ha^{-1}) and it was statistically at par with Shandaweel 1 (6.95 t ha^{-1}). The differences between wheat cultivars are mainly due to the interaction between their genetic makeup during growth periods and to the prevailing environmental factors during their development. These results are in agreement with that observed by Morsy and Abd El-Hameed (2012), Teama *et al*. (2016), El-Hag (2017) and Seleiman and Abdel-Aal (2018).

Interaction effect

The effect of the interaction between irrigation treatments and wheat cultivars for grain yield ha^{-1} was significant in both seasons. Moreover, results of combined analysis over all (Table 7) showed significant and highly significant differences between seasons × cultivars and irrigation regimes × cultivars interactions, while there were insignificant differences between seasons × irrigation regimes and seasons × irrigation regimes× cultivars interactions. Sohag 5 recorded the highest grain yield (9.48, 7.62 and 8.55 t ha^{-1}) under I6 in the first, second seasons and their combined, respectively. In contrast, Sohag 4 gave the lowest grain yield (6.73, 5.21, 5.97 t ha^{-1}) under I1 irrigation regime in the first, second seasons and their combined, respectively.

It is worthily to mention that, Sids 14 was the highest cultivar over all seasons and irrigation treatments (7.22 t ha^{-1}) and gave the least reduction in grain yield from I6 to I1 as compared to other cultivars (Table 7). Furthermore, it gave insignificant reduction in grain yield under I5 (four irrigation, 3088 m^3 ha^{-1}) and I4 (three irrigation, 2499 m^3 ha^{-1}) compared to I6 (five irrigations, 3965 m^3 ha^{-1}). Moreover, it gave insignificant reduction in grain yield between I3 (three irrigation, 2347 m^3 ha^{-1}) and I4 (three irrigation, 2499 m^3 ha^{-1}) and between I1(two irrigation , 1432 m^3 ha^{-1}) and I2 (two irrigation, 1666 m^3 ha^{-1}). Accordingly, Sids 14 cultivar can be labeled "drought-tolerant genotype".

In contrast, Sohag 4 and Sohag 5 cultivars recorded the highest (8.37 and 8.55t ha^{-1}) and lowest (5.97 and 6.10 t ha^{-1}) grain yield and at par with each other. These results proved that Sids 14 is a drought tolerant cultivar, while Sohag 4 and Sohag 5 are drought sensitive cultivars. Therefore, planting Sids 14 under three irrigations (tillering, booting, and grain filling stage) was more effective to save about 36.97% of water applied with insignificant reduction in grain yield as compared with full irrigation treatment (I6).

On the other hand, applying five irrigations (I6) at all critical stages produced higher grain yield and net returns with the other three cultivars.

Biological yield (t ha^{-1})

Irrigation regimes effect

Irrigation regimes significantly affected biological yield ha^{-1}in both seasons and their combined (Table 7). The highest biological yield values (23.72, 19.78 and 21.75 t ha^{-1}) were obtained under I6 treatment while, the lowest biological yield values (16.85, 13.53 and 15.19 t ha^{-1}) were recorded under I1 treatment in the first and second seasons and their combined, respectively. As compared with full irrigation treatment (I6) water deficit during the different growth and development stages caused a significant reduction in biological yield $ha^{-1}$by (30.16, 29.56, 16.46, 13.56 and 3.68%) in I1, I2, I3, I4 and I5, respectively. It is clear that the highest negative effect of decreasing number of irrigations and water amount was observed when irrigation was applied at tillering and elongation stage (I1), whereas the lowest reduction of biological yield was noted when irrigation was applied at tillering, elongation, booting, flowering and grain filling stage (I6). Moreover, skipping irrigation at grain filling stage (I5) exhibited less reduction for biological yield ha^{-1}as compared to I6. The reduction in biological yield due to decreasing number of irrigations and amount of irrigation water was related to the reduction in yield, its components and plant height. These results were in a good line with those obtained by Akram (2011), Teama *et al*. (2016), Soomro *et al*. (2016) and Seleiman and Abdel-Aal (2018) who found that exposing wheat plants to water stress by decreasing number of irrigations and water applied caused a reduction in biological yield ha^{-1}. Mekkei and El Haggan (2014) found that the greatest reduction in biological yield was recorded when skipping irrigation at flowering stage.

Table 7. Means of grain yield $t ha^{-1}$ and biological yield $t ha^{-1}$ of four wheat cultivars as affected by irrigations regimes in the two seasons and their combined analysis.

	Traits	Grain yield ha^{-1}			F test S	S × C LSD 0.05	Biological yield ha^{-1}			F test S	S × C LSD 0.05
	Seasons / Cultivars	2018/ 2019	2019/ 2020	Mean			2018/ 2019	2019/ 2020	Mean		
Irrigations regimes: I1	Shandaweel 1	7.07	5.39	6.23		NS	18.61	12.98	15.79		NS
	Sids 14	7.46	5.74	6.60			19.51	14.95	17.23		
	Sohag 4	6.73	5.21	5.97			14.88	13.33	14.11		
	Sohag 5	6.85	5.36	6.10			14.40	12.86	13.63		
	Mean	7.03	5.43	6.23	**		16.85	13.53	15.19	*	
	LSD 0.05	0.50	0.35	0.27			2.71	1.47	1.37		
I2	Shandaweel 1	7.25	5.49	6.37		NS	18.09	14.17	16.13		NS
	Sids 14	7.60	5.85	6.73			19.18	15.60	17.39		
	Sohag 4	6.77	5.36	6.07			15.11	12.38	13.75		
	Sohag 5	7.21	5.40	6.31			16.05	12.02	14.04		
	Mean	7.21	5.52	6.37	**		17.11	13.54	15.32	**	
	LSD 0.05	0.53	0.34	0.28			2.47	1.79	1.35		
I3	Shandaweel 1	7.74	5.74	6.74		NS	20.47	16.31	18.39		NS
	Sids 14	8.12	6.29	7.20			23.56	18.21	20.89		
	Sohag 4	7.20	5.64	6.42			18.80	15.00	16.90		
	Sohag 5	7.63	5.72	6.68			18.35	14.64	16.50		
	Mean	7.67	5.85	6.76	**		20.30	16.04	18.17	**	
	LSD 0.05	0.57	0.47	0.32			2.57	2.19	1.81		
I4	Shandaweel 1	7.80	5.84	6.82		NS	21.09	16.55	18.82		NS
	Sids 14	8.55	6.36	7.45			23.72	19.64	21.68		
	Sohag 4	7.56	6.05	6.80			18.92	16.07	17.50		
	Sohag 5	8.05	6.27	7.16			18.57	15.83	17.20		
	Mean	7.99	6.13	7.06	**		20.57	17.02	18.80	*	
	LSD 0.05	0.65	0.37	0.33			3.43	2.47	1.58		
I5	Shandaweel 1	8.29	6.83	7.56		NS	23.09	18.29	20.69		NS
	Sids 14	8.58	6.55	7.57			25.82	20.60	23.21		
	Sohag 4	8.73	7.31	8.02			21.42	18.81	20.11		
	Sohag 5	9.17	7.40	8.29			21.78	17.83	19.81		
	Mean	8.69	7.02	7.86	**		23.03	18.88	20.95	*	
	LSD 0.05	0.57	0.60	0.37			3.00	1.89	1.57		
I6	Shandaweel 1	8.89	7.13	8.01		NS	24.75	19.26	22.01		NS
	Sids 14	8.69	6.79	7.74			25.19	21.73	23.46		
	Sohag 4	9.24	7.50	8.37			22.27	19.48	20.87		
	Sohag 5	9.48	7.62	8.55			22.65	18.66	20.65		
	Mean	9.08	7.26	8.17	**		23.72	19.78	21.75	**	
	LSD 0.05	0.55	0.59	0.36			2.31	1.99	1.35		
	General Mean	7.94	6.20	7.07			20.26	16.47	18.36		
S × C	Shandaweel 1	7.84	6.07	6.95			21.02	16.26	18.64		
	Sids 14	8.17	6.26	7.22			22.83	18.45	20.64		
	Sohag 4	7.70	6.18	6.94			18.57	15.85	17.21		
	Sohag 5	8.07	6.30	7.18			18.63	15.31	16.97		

Combined analysis	2018/2019		2019/2020		combined		2018/2019		2019/2020		combined	
Effect	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05
S					**	0.12					**	0.56
I	**	0.26	**	0.30	**	0.16	**	2.05	**	1.02	**	0.73
C	**	0.19	*	0.16	**	0.12	**	0.94	**	0.68	**	0.57
S × I					NS	--					NS	--
S × C					*	0.17					**	0.80
I × C		0.47	**	0.39**	**	0.30	NS	--	NS	--	NS	--
S × I × C					NS	--					NS	--

Ns, * and ** means not significant, significant at 0.05 and 0.01 probability, respectively

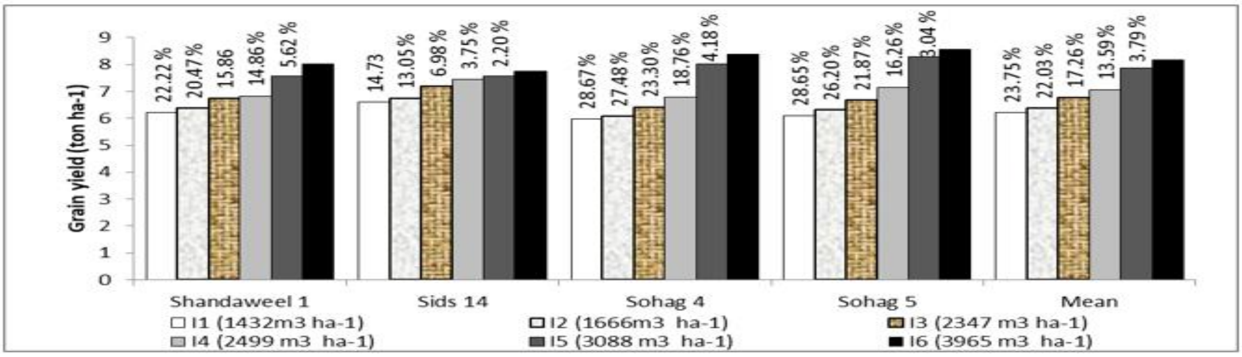

Figure 1. Means and reduction of grain yield $t ha^{-1}$ for four wheat cultivars as affected by different irrigation regimes and amount of applied water

Differences between cultivars

The results in Table 7 indicated significant differences among wheat cultivars respecting biological yield ha^{-1} in both seasons and their combined under each of irrigation treatment. Furthermore, highly significant differences between cultivars across the six irrigation regimes were found in both seasons and their combined. As an average of the two growing seasons, the highest biological yield was recorded with Sids 14 (17.23, 17.39, 20.89, 21.68, 23.21 and 23.46 t ha^{-1}) under I1, I2, I3, I4, I5 and I6, respectively. Meanwhile, the lowest biological yield was recorded by Sohag 5 (13.63, 16.50, 17.20, 19.81and 20.65 t ha^{-1}) under I1, I3, I4, I5 and I6 treatments, respectively and by Sohag4 (13.75 t ha^{-1}) under I2. Based on combined data, Sids 14 had the highest biological yield (20.64 t ha^{-1}) followed by Shandaweel 1 (18.64 t ha^{-1}), Sohag 4 (17.21), while the lowest biological yield recorded by Sohag 5 (16.97 t ha^{-1}) and it was statistically at par with Sohag 4. These results reported that Sohag 4 and Sohag 5 were the most cultivars affected by decreasing number of irrigations andapplied water in biological yield ha^{-1}. The differences between cultivars are mainly due to the interaction between their genetic makeup during growth stages and to the environmental factors prevailing during their development. Significant variations between wheat cultivars in biological yield as affected by number of irrigations and amount of applied water were reported by Moayedi *et al.* (2010), Ahmad and Kumar (2015),Teama *et al.* (2016) and Seleiman and Abdel-Aal (2018).

Interaction effect

Insignificant interaction effect between cultivars and irrigation regimes for biological yield ha^{-1} was found in both seasons. Also, combined analysis over all showed insignificant differences for seasons × irrigation regimes, irrigation regimes× cultivars and seasons × irrigation regimes× cultivars interactions, but showed significant differences for seasons × cultivars interaction (Table 7).

Leaf relative water content (RWC%)

Irrigation regimes effect

During the two growing seasons and their combined, leaf relative water content RWC was highly significantly affected by the different irrigation regimes (Table 8). I6 resulted in the highest RWC (87.30, 86.95, 87.12 %), while the minimum RWC (75.02, 73.81 and 74.41%) was observed under I1 in the first, second seasons and their mean, respectively. However, skipping irrigation at various growth stages decreased relative water content RWC in both seasons and their combined. Regarding to the combined data, the greatest reduction in RWC was noticed under I1(14.59 %) when irrigation was skipped at booting, flowering and grain filling stage followed by I2 (10.93%), I3 (6.78%) and I4 (6.01%), while the lowest reduction in RWC (3.51%) was found under I5 when irrigation was escaped at grain filling stage compared to the I6. Rahman *et al.* (2007) reported that plants grown under water stress conditions decrease the intracellular water by increasing of osmotic compounds to absorb water from the soil powerfully. Therefore, decreasing soil moisture or increasing water stress reduces leaf relative water content. Water stress is generally characterized by decrease in relative water content, resulting in wilting, stomatal closure and reduced growth (Lawlor and Cornic, 2002).

These results are in line with the finding of Akram (2011), Zareian *et al.* (2014), Mahmoud (2015) and Abd El-hady *et al.* (2018).

Differences between cultivars

Results of relative water content (RWC) presented in Table 8 showed significant differences between cultivars in both seasons and their combined under each irrigation regime except under I5 in the second season. Moreover, highly significant differences were detected among cultivars over irrigation regimes in both seasons and their combined. As an average of the two growing seasons, the greatest values of relative water content (RWC) were observed by Sohag 4 (88.65%) under the I6 and by Sids 14 (85.56, 85.09, 84.09, 82.08 and 79.76%) under I5, I4, I3, I2 and I1, respectively. Meanwhile, the lowest values of RWC were recorded by Sohag 5 (70.91, 79.89 and 83.03%) under I1, I4 and I5, respectively, Sohag 4 (74.59 and 79.41%) under I2 and I3, and Shandaweel 1 (85.07%) under I6 treatment. Concerning combined data over all, Sids 14 recorded the highest value of RWC (83.85%) followed by Shandaweel 1 (81.02%), Sohag 4 (79.81%) and Sohag 5 (79.51%). Sdis 14 exhibited the highest mean value of relative water content under stressful irrigation treatments, while Sohag 4 and Sohag 5 cultivars were statistically low and at par with each other. These results proved that Sids 14 was drought tolerant cultivar, while Sohag 4 and Sohag 5 were drought sensitive cultivars. This deviation in RWC between cultivars may be due to differences in their ability to absorb more water from the soil and/or control water loss through the stomata. It may also be due to differences in their ability to accumulate and adjust somatically to maintain tissue turgor, hence physiological activities. These results are in harmony with those obtained by Akram (2011), Zareian *et al.* (2014), Mahmoud (2015) and Abd El-hady *et al.* (2018).

Interaction effect

The effect of the interaction between irrigation treatments and wheat cultivars for relative water content (RWC) was highly significant in both seasons. Moreover, results of combined analysis over all (Table 8) showed highly significant differences between irrigation regimes × cultivars interaction, while it showed insignificant differences between seasons × irrigation regimes, seasons × cultivars and seasons × irrigation regimes× cultivars interactions. Sohag 4 recorded the highest values of relative water content (88.57, 88.73 and 88.65%) under I6, while Sohag 5 gave the lowest RWC (71.72, 70.10, 70.91%) under I1 in the first, second seasons and their mean, respectively.

Membrane stability index (MSI)

Irrigation regimes effect

Results of membrane stability index (MSI) presented in Table 8 showed highly significant differences between the irrigation regimes during the two growing seasons and their combined. The highest values of MSI (84.33, 79.66 and 82.00%) were observed under I6, while the lowest values (72.94, 66.08 and 69.51%) were recorded under I1 in the first, second seasons and their combined, respectively. However, skipping irrigation at various growth stages decreased membrane stability index (MSI) in both seasons and their combined. Based on combined data, the maximum reduction in MSI was observed under

I1 (15.23 %) when irrigation was skipped at booting, flowering and grain filling stages followed by I2 (13.28%), I3 (9.30%) and I4 (8.89%), while the lowest reduction in MSI (4.66%) was found under I5 when irrigation was skipped at grain filling stage compared to I6. Similar results were found by Abd El-hady *et al.* (2018) who reported that membrane stability index (MSI) decreased significantly under water stress at different growth stages of wheat. It is well known that water stress causes accumulation of reactive oxygen species which result in membrane damage. Water stress leads to increased electrolyte leakage in plant leaves. Therefore, increasing duration and severity of stress led to decreased membrane stability index of wheat plants (Sairam and Saxena, 2000 and Sibet and Birol, 2007).Water stress caused water loss from plant tissues which seriously impair both membrane structure and function (Buchanan *et al*., 2000).

Table 8. Means of relative water content RWC% and membrane stability index MSI% of four wheat cultivars as affected by irrigations regimes in the two seasons and their combined analysis.

		Traits	Relative water content			F test S	S × C LSD 0.05	Membrane stability index			F test S	S × C LSD 0.05
		Seasons / Cultivars	2018/ 2019	2019/ 2020	Mean			2018/ 2019	2019/ 2020	Mean		
Irrigations regimes	I1	Shandaweel 1	75.53	75.45	75.49		NS	72.45	65.75	69.10		NS
		Sids 14	80.72	78.80	79.76			77.25	69.79	73.52		
		Sohag 4	72.11	70.89	71.50			70.81	63.58	67.20		
		Sohag 5	71.72	70.10	70.91			71.23	65.19	68.21		
		Mean	75.02	73.81	74.41	**		72.94	66.08	69.51	**	
		LSD 0.05	4.51	4.45	2.81			3.22	2.82	1.90		
	I2	Shandaweel 1	78.48	78.40	78.44		NS	74.79	67.73	71.26		NS
		Sids 14	82.72	81.45	82.08			77.55	70.23	73.89		
		Sohag 4	75.12	74.07	74.59			71.63	66.42	69.03		
		Sohag 5	75.82	74.75	75.28			73.81	66.70	70.26		
		Mean	78.03	77.17	77.60	Ns		74.45	67.77	71.11	**	
		LSD 0.05	3.78	3.76	2.36			3.56	2.75	1.99		
	I3	Shandaweel 1	81.62	81.63	81.63		NS	77.33	68.78	73.05		NS
		Sids 14	84.75	83.42	84.09			78.89	72.93	75.91		
		Sohag 4	79.98	78.83	79.41			75.64	72.10	73.87		
		Sohag 5	81.18	78.23	79.71			76.57	72.75	74.66		
		Mean	81.88	80.53	81.21	Ns		77.11	71.64	74.37	**	
		LSD 0.05	3.10	4.18	2.11			1.88	2.98	1.62		
	I4	Shandaweel 1	82.08	81.75	81.92		NS	77.79	69.06	73.43		NS
		Sids 14	85.62	84.56	85.09			78.73	73.90	76.32		
		Sohag 4	81.52	79.76	80.64			75.95	72.97	74.46		
		Sohag 5	81.28	78.50	79.89			76.86	72.45	74.66		
		Mean	82.63	81.14	81.88	Ns		77.33	72.10	74.71	**	
		LSD 0.05	3.16	3.55	2.31			2.11	3.22	1.65		
	I5	Shandaweel 1	83.58	83.61	83.60		NS	79.26	72.33	75.79		NS
		Sids 14	86.72	84.40	85.56			80.53	75.67	78.10		
		Sohag 4	84.89	83.23	84.06			82.73	77.40	80.07		
		Sohag 5	84.05	82.00	83.03			81.03	76.48	78.76		
		Mean	84.81	83.31	84.06	Ns		80.89	75.47	78.18	**	
		LSD 0.05	2.17	Ns	1.59			2.25	3.32	1.78		
	I6	Shandaweel 1	85.00	85.13	85.07		NS	82.98	76.97	79.98		NS
		Sids 14	87.23	85.85	86.54			83.85	77.77	80.81		
		Sohag 4	88.57	88.73	88.65			86.25	81.67	83.96		
		Sohag 5	88.38	88.08	88.23			84.23	82.24	83.24		
		Mean	87.30	86.95	87.12	Ns		84.33	79.66	82.00	*	
		LSD 0.05	2.54	2.65	1.63			2.15	4.07	2.04		
		General Mean	81.61	80.49	81.05			77.84	72.12	74.98		
S × C		Shandaweel 1	81.05	81.00	81.02			77.43	70.10	73.77		
		Sids 14	84.63	83.08	83.85			79.47	73.38	76.42		
		Sohag 4	80.37	79.25	79.81			77.17	72.36	74.76		
		Sohag 5	80.41	78.61	79.51			77.29	72.64	74.96		

Combined analysis	2018/2019		2019/2020		combined		2018/2019		2019/2020		combined	
Effect	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05	F test	LSD 0.05
S					**	0.80					**	0.68
I	**	1.40	**	1.92	**	1.05	**	1.22	**	1.52	**	0.88
C	**	1.12	**	1.23	**	0.82	**	0.88	**	1.09	**	0.69
S × I					NS	--					NS	--
S × C					NS	--					**	0.97
I × C	**	2.74	**	3.02	**	2.00	**	2.16	**	2.68	**	1.69
S × I × C					NS	--					NS	--

Ns, * and ** means not significant, significant at 0.05 and 0.01 probability, respectively

Differences between cultivars

Our results of Membrane stability index (MSI) indicated significant differences among cultivars in both seasons and their combined under each of irrigation regime (Table 8). Moreover, highly significant differences were detected between cultivars over irrigation treatments in both seasons and their combined. As an average of both seasons, the highest values of MSI were recorded by Sohag 4 (83.96 and 80.07%) under I6 and I5 and by Sids 14 (76.32, 75.91, 73.89 and 73.52%) under I4, I3, I2 and I1, respectively. Meanwhile, the lowest values of MSI were recorded by Sohag 4 (67.20, and 69.03%) under I1 and I2 treatments and by Shandaweel 1 (73.05, 73.43, 75.79 and 79.98%) under I3, I4, I5 and I6 treatments, respectively.

Concerning combined data over all, Sids 14 recorded the highest value of membrane stability index (76.42%) followed by Sohag 5 (74.96%) and Sohag 4 (74.76%) and Shandaweel 1 (73.77%). Insignificant difference was recorded between Sohag 4 and Sohag 5 for MSI. Higher membrane stability index of Sids 14 reflects the existence of stress tolerance mechanism in this cultivar and this result indicating that Sids 14 cultivar was more tolerant to drought than other cultivars. The differences between cultivars in membrane stability index are mainly due to the interaction between their genetic makeup and the environmental factors. Significant differences were found between wheat cultivars in their response to water stress under different irrigation treatments for membrane stability index (MSI) (Almeselmani *et al.*, 2011 and Abd El-hady *et al.*, 2018).

Interaction effect

The effect of the interaction between irrigation treatments and wheat cultivars for membrane stability index (MSI) was highly significant in both seasons. Moreover, results of combined analysis over all (Table 8) showed highly significant differences between seasons × cultivars and irrigation regimes × cultivars interaction, while it showed insignificant differences between seasons × irrigation regimes, and seasons × irrigation regimes× cultivars interactions. The highest values of MSI were recorded by Sohag 4 (86.25 and 83.96%) in the first season and combined over seasons, and Sohag 5 (82.24%) in the second season under the I6 irrigation regime, while Sohag 4 gave the lowest MSI (70.81, 63.58, 67.20%) under I1 irrigation regime in the first, second seasons and their combined, respectively.

CONCLUSION

Based on results of both seasons, skipping irrigation at different growth stages caused significant reduction in most studied traits. Maximum grain yield was achieved under five irrigations (I6) at tillering, elongation, booting, flowering and grain filling stages with 3965 m^3ha^{-1} of water applied, while minimum grain yield was recorded under tow irrigations (I1) at tillering and elongation stages with 1432 m^3 ha^{-1} of water applied. Irrigation at both booting and flowering are essential to reduce loss in grain yield. Moreover, Sids 14 proved to be drought tolerant cultivar, while Sohag 4 and Sohag 5 were drought sensitive. In case of water shortage, planting Sids 14 cultivar with irrigation at tillering, booting, grain filling stages (I4) are most profitable to save about (36.97%) of applied water without significant decrease in grain yield.

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تأثير جدولة الري على بعض الصفات المحصولية والفسيولوجية لبعض أصناف القمح

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تم إجراء تجارب حقلية في محطة البحوث الزراعية بشندويل، سوهاج، مصر، خلال موسمي الزراعة 2019/2018 و 2020/2019 لدراسة تأثير ستة أنظمة ري وهى:نظام الري الأول (الري في مرحلة التفريع والاستطالة)، نظام الري الثاني (الري في مرحلة التفريع والتزهير)، نظام الري الثالث (الري في مرحلة التفريع، الاستطالة والتزهير)، نظام الري الرابع (الري في مرحلة التفريع، الحبلان وامتلاء الحبوب)، نظام الري الخامس (الري في مرحلة التفريع، الاستطالة، الحبلان والتزهير) ونظام الري السادس (الري في مرحلة التفريع، الاستطالة، الحبلان، التزهير وامتلاء الحبوب) على بعض الصفات المحصولية والفسيولوجية لأربعة أصناف من القمح وهي شندويل 1، سدس 14، سوهاج 4 وسوهاج 5. أظهرت النتائج أن نقص عدد الريات وكمية المياه المضافة في مراحل النمو المختلفة تحت أنظمة الري المختلفة أدى إلى نقص معنوي في جميع الصفات المدروسة. كان أعلى نقص تحت نظام الري الأول (1432 م3 ماء مضاف للهكتار) لجميع الصفات المدروسة ، باستثناء عدد الأيام حتى طرد السنابل 50% وعدد السنابل/ م2. بينما كان أدنى نقص تحت نظام الري الخامس (3088 م3 ماء مضاف للهكتار) لجميع الصفات المدروسة مقارنة بنظام الري السادس (3965 م3 ماء مضاف للهكتار). الري في كل من مرحلة الحبلان والتزهير ضروري لتقليل الخسارة في محصول الحبوب. علاوة على ذلك، أظهر الصنف سدس 14 اقل نقص في محصول الحبوب تحت أنظمة الري المختلفة، بينما أظهرت الأصناف سوهاج 4 وسوهاج 5 أعلى نقص في محصول الحبوب. لذلك فيعتبر الصنف سدس 14متحمل للجفاف، في حين أن الصنفين سوهاج 4 وسوهاج 5 حساسان للجفاف. زراعة الصنف سدس 14 مع الري في مرحلة التفريع، الحبلان وامتلاء الحبوب (نظام الري الرابع) هي أكثر المعاملات توفيرا لكمية المياه المستخدمة بنسبة (36.97٪) دون حدوث نقص معنوي في محصول الحبوب.