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Effect of Supplemental Irrigation on Wheat Performance Grown in Semi-Arid Environment

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ABSTRACT

This study was carried out to determine the effects of different supplemental irrigation (SI) treatments on yield, yield components, and some drought-related traits in eight wheat varieties grown in the semi-arid environment of Jordan. Two SI treatments were used in addition to the control (i.e. rainfed treatment with 262.8mm accumulated rains): partially SI treatment (PSI=262.8mm rains+220mm irrigation at anthesis stage) and continuous SI treatment (CSI= 262.8mm rains + 377.5mm at 2-3 weeks intervals during different stages of wheat growth). Seven durum wheat varieties; namely Sham1, Omqais, Acsad65, Bani Suef6, Bani Suef4, Horani Nawawi, and Dairalla6 in addition to one bread wheat variety (Ammon) were included in this study. Yield and yield components were significantly increased and the time required to anthesis and maturity were delayed by SI. PSI treatment significantly increased grain yield by 50.2%, while CSI increased yield by 121% as compared to the control treatment. Considerable variations among varieties were observed under different irrigation treatments. Sham1 (2266.7 kg ha^{-1}), Omqais (2253.3 kg ha^{-1}), and Acsad65 (1963.3 kg ha^{-1}) gave the highest grain yield under control treatment with low drought susceptibility indices, implying their low grain yield losses under control as compared with SI treatments with high genetic potentials for drought tolerance. The top-yielding varieties under CSI were Acsad65 (4716.7 kg ha^{-1}), Dairalla6 (4586.7 kg ha^{-1}), Bani Suef6 (4460 kg ha^{-1}), and Omqais (4360 kg ha^{-1}). Under PSI, Sham1 (3303 kg ha^{-1}) followed by Dairalla6 (3193.3 kg ha^{-1}), Horani Nawawi (3130 kg ha^{-1}), and Bani Suef6 (3026.7 kg ha^{-1}) gave the highest grain yield. All yield components (number of kernels per spike, number of tillers, and grain size) significantly contributed to increasing grain yield under SI. In conclusion, SI under rainfed conditions improves yield-attributing traits, which led to a substantial increase in grain yield. It would be possible to increase GY by more than 3 and 4 tonnes ha^{-1} with PSI and CSI, respectively.

Keywords: Drought, Grain yield, Supplemental Irrigation, Wheat

INTRODUCTION

Wheat is considered one of the most important cultivated cereal crops and a main staple food for more than one-third of the world population and is considered a pillar of global food security (Statistics, FAO 2010-2020). The average world per capita consumption of wheat is around 67.7 kg per year. The consumption per capita is about 97.4 kg in developed countries and 60.4 kg in developing countries (Statistics, FAO 2010-2020).

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West Asia and North Africa (WANA) region, including Jordan, is characterized by a Mediterranean climate with long, hot, dry summers and cool short rainfall periods usually extended from November to April (Abdel-Ghani et al., 2015). Wheat production in semi-arid areas of WANA is unpredictable due to their dependence on rainfalls and due to uneven distribution of rains over and within cropping seasons. Wheat cropping areas in WANA are suffering from fluctuated drought with low yields ranging from 0.63- 1.38 ton ha-1, which is extremely lower than the world average (3.09 ton ha-1) (Statistics, FAO 2010-2020). In addition to drought, other abiotic stresses such as high temperature, nutrients deficiency, soil alkalinity, and late unpredicted spring frost that occurs during anthesis can also lead to significant yield losses (González Guzmán et al., 2022; Verslues et al., 2006).

Two terms could be used to describe yield: yield potential (YP) and potential yield (PY) (Evans et al., 1999). YP is the attainable yield when the crop is grown under favorable conditions with no limitations in yield inputs such as water, nutrients, and effective control of pests. However, PY is the grain yield of the crop when one or more of the yield inputs are limited especially the lack of precipitation under dry land farming. Therefore, continuous improvement of the crop growing conditions is an important issue to improve yield under dry farming conditions to reach YP.

Drought is a shortage of water available to the crop when transpiration is more than the amount of absorbed water (Botha et al., 2006; Silva et al., 2013). It is considered a major abiotic stress in semi-arid areas especially when drought occurs during critical stages of crop growth. Drought is a complex trait that is controlled by a combination of traits (also called drought-related traits) with a polygenic inheritance (Abdel-Ghani et al., 2015; Kumar et al., 2020). Selection for drought-tolerant varieties (Ahmed et al., 2019; Semcheddine et al., 2014) and improving the crop growth conditions are two ways used to attain YP. Supplemental irrigation (SI) is one major agricultural practice to reach YP. SI is mainly applied to provide crops with a portion of water when rainfall is limited for normal crop growth (Oweis, 1997; Shang et al., 2020; Wang, 2017). SI is used to improve and stabilize crop yield by supplying the crop with water by SI when rainfall is limited to provide sufficient moisture for normal plant growth (Oweis, 1997; Shang et al., 2020; Wang, 2017). Under limited rainfed conditions, irrigation scheduling is used to allocate irrigation water rationally during the critical growth stages to increase crop yield, and farm profit (Montazar et al., 2011). Therefore, selecting high-yielding varieties and using suitable agricultural practices in wheat production are considered major for wheat growers in Jordan to enhance grain yield under dry farming. The objectives of this study were to evaluate the effect of SI on yield and yield-attributing traits of eight wheat varieties grown under semi-arid conditions in Jordan.

MATERIALS and METHODS

Plant materials

Seven durum wheat (Triticum turgidum subsp. durum) varieties (Sham1, Omqais, Acsad65, Bani Suef6, Bani Suef4, Horani Nawawi, and Dairalla6) and one bread wheat (Triticum aestivum) variety (Ammon), were included in this study. Bani Suef4 and Bani Suef6 were introduced from Egypt. Other varieties are commonly used varieties by Jordanian farmers and they are obtained from National Center for Agricultural Research (NCAR), Jordan.

Experimental site and irrigation treatments

A field experiment was carried out during the long-term 2015/2016 cropping season the in western ret gion of Al-Karak district, Jordan with a semi-arid environment (i.e., 300-350 mm long-term annual precipia tation) and short cold rainy winter season usually extended from November to March. The texture is clay loam. The pH was 7.8 and the electrical conductivity (EC) was 2.2 ds m-1. The organic matter, nitrogen (N), phosphorus, (P) and potassium (K) contents were 1.21%,, 0.1%, 2.8ppm and 266 ppm, respectively. Detailed procedures for chemical analyses used in this study were reported by Subba Rao and Sammi Reddy (2013).

Two SI treatments were used in this study using a drip irrigation system to ensure even distribution of water in experimental plots in addition to the control treatment (i.e. rainfed or without SI). The accumulative number of rains received from the time of seeding (December 9, 2015) until the end of the cropping season was 262.8mm. Separated showers of rain were received in October and November with a total amount of 48.4mm. The SI treatments were as follows: (i) continuous supplementary irrigation (CSI) treatment where the plots were irrigated with 377.5mm of fresh water at 2-3 weeks intervals during the growing stages with accumulating amount of rains and SI for each plot of 640.3mm (262.8mm rains + 377.5mm SI) and (ii) partially supplementary irrigation (PSI) treatment where plots were irrigated at anthesis with 220mm freshwater with accumulative fresh water amount received by each plot of 482.8mm (262.8mm rains + 220mm SI). Irrigation schedules for CSI and PSI are shown in Table 1.

Experimental Design

Randomized Complete Block Design (RCBD) with split-plot arrangements was used. Water treatments (Control, PSI, and CSI) were laid as main plots, and varieties were nested within irrigation treatments as sub-plots. The number of replicates was three. Each plot nested in the main plots was considered an experimental unit. The main and subplots were randomly distributed. Plots were 2m long and 1.5m wide and consisted of six rows placed 25cm apart.

Soil preparation and agricultural practices

The soil was plowed twice using a chisel plow followed by disking and leveling. Furrows were opened for planting by duck foot plow. Planting was manually performed at 2-3cm depth. The varieties were sown at a rate of 300 seed m^{-2}. Germination tests were performed to determine the actual seeding rates for each variety. The seeds were treated with Canvel fungicide to control different types of kernel smuts. Spring worms appeared in February in some plots which were controlled by Cyren 50% insecticide. Slight infection with black aphid appeared especially on the Ammon variety which was controlled by the "C. More" insecticide. Weeds were controlled before sowing by Acigateherbicide at a rate of 50 L ha^{-1} after weeds growing in November, any visible broad leaf weeds and grasses that appeared after seeding were hand weeded.

Assessment of yield, yield components, and, other agronomic traits

At maturity (i.e. when 95% of the peduncles turned yellow), the four inner rows were harvested to determine the main traits including biological yield (BY, kg ha^{-1}), grain yield (GY, kg ha^{-1}), and straw yield (SY, kg ha^{-1}). The harvest index (HI, %) was calculated as a ratio between GY and BY. Yield components and other yield attributing traits were recorded: number of kernels per spike (NKS), number of spikes m_$^{-2}$ (NSM), thousand kernels weight (TKW, g), number of spikelets per spike (NSS), number of florets per spikelet (NFS) and awn and spike lengths (cm, AL, and SL, respectively). Other growth-related traits were also recorded including plant height (PH, cm), peduncle length (PL, cm), and flag leaf blade area (FLA, cm^2). PH was recorded from the soil surface to the tip of the main spikes excluding awns at maturity, as the average of 10 randomly selected plants per plot. Two types of measurements were recorded for PL. The first measurement of PL was recorded by measuring the distance from the last node to the base of the spike (PL1), while the second measurement was recorded by measuring the distance from the flag leaf ligule to the base of the spike (PL2). FLA was estimated two weeks after heading from 10 randomly selected flag leaves per plot using the following formula: length× width× 0.75 (Gardner *et al*., 1985). Phenological traits were also recorded including days to heading (DH), days to maturity (DM), and grain filling period (GFP). DH and DM were recorded in days from the planting date until 50% of awns appeared from the flag leaf collar and until 95% of peduncles turn yellow, respectively. GFP was estimated by calculating the period from DH to DM. Chlorophyll content was measured from ten leaves using a chlorophyll meter SPAD-502 (Minolta Camera Co., Osaka, Japan). Assessments of chlorophyll content were performed at the beginning of the heading stage.

Drought susceptibly index and water productivity

Drought susceptibly index (DSI) based on grain yield and biological yield was calculated using the following formula:

$$DSI = \frac{1 - Y_D / Y_P}{1 - X_D / X_P}$$

where, Y_D= mean yield of a specific variety under stress (i.e. control); Y_P = mean yield of a specific variety no stress (i.e. SI); X_D = mean of all varieties used in the experiment under stress condition; X_P = mean of all varieties under no stress (Fischer *et al*., 1978).

Water productivity (WP) was determined as the ratio of dry matter (kg) of crop yield (either BY or GY) per unit area to the total quantity of water received per unit area (m^3) (Molden *et al., 2010)*.

Statistical analyses

Analyses of variance were performed using the following mathematical model: $y_{jki} = \mu + G_j + T_i + B_{k(i)} + GT_{ji} + \varepsilon_{jki}$, where y_{jki} represents the individual observation of the jki^{th} experimental unit, μ is the grand mean for a trait under consideration, G_j is the effect of j^{th} genotype, T_i is the effect of i^{th} irrigation treatment, $B_{k(l)}$ is the effect of k^{th} block nested in i^{th} irrigation treatment (error a), GT_{ji} is the interactive effect of the i^{th} irrigation treatment with j^{th} genotype, and ε_{jki} (error b) is the residual.

Table 1: Supplemental irrigation schedules for continuous and partially supplemental irrigation (CSI and PSI, respectively) at different growth stages based on Feekes scale.

Growth Stage	Amount SI received (mm) CSI*	Date of Irrigation	Amount of SI received (mm) PSI**	Date of irrigation
0.0. Germination	55	25/12/2016		
1. Seedling development	***	***		
Tillering				
2. Beginning of tillering (main shoot and 1 tiller)	27.5	18/2/2016		
3. Tillers formed (main shoot and 6 tiller or more)	27.5	25/2/2016		
Jointing (Stem elongation)				
4. Leaf sheaths lengthen	***	***		
5. Leaf sheaths strongly erect	27.5	11/3/2016		
6. First node visible	27.5	13/3/2016		
7. Second node visible	27.5	18/3/2016		
8. Flag leaf visible	20.0	19/3/2016		
9. Ligule of flag leaf visible	***	***		
Booting				
10. Head just swollen from the flag leaf sheath	27.5	2/4/2016		
Heading				
10.1 First awns and first spikelet of the head visible	27.5	12/4/2016		
10.2 ¼ of complete heading	***	***		
10.3 ½ of complete heading	27.5	15/4/2016		
10.4 ¾ of complete heading	***	***		

10.5 Complete emergence of the head	***	***		
Anthesis				
10.51. Beginning of anthesis	***	***	82.5	22/4/2016
10.52. Flowering occurred on the top of the spike	***	***	55.0	24/4/2016
10.53. Flowering occurred on the base of the spike	***	***	55.0	25/4/2016
			27.5	27/4/2016
10.54. Kernel was watery ripe	27.5	2/5/2016		
Grain filling				
11.0. Early milk	***	***		
11.1. Milky ripe	27.5	7/5/2016		
11.2. Mealy ripe (soft dough)	27.5	12/5/2016		
Ripening				
11.3 Kernel hard	***	***		
11.4 Harvest ready (grain drying)	***	***		
Total supplementary irrigation	**377.5**		**220.0**	
Rainfall	**262.8**		**262.8**	
Total water received	**640.3**		**482.8**	

*CSI, continuous supplemental irrigation treatment;

**PSI, partially supplemental irrigation treatment;

***no supplementary irrigation was applied

RESULTS

Effects of different irrigation treatments on Yield and agronomic traits

Results obtained for GY and plant biomass are summarized in Table 2. The average GY over varieties under PSI and CSI treatments were 2889.2 and 4253.3 kg ha^{-1}; which were 50.2% and 121% greater when compared to the control treatment, respectively**.** Average BY over varieties under PSI and CSI treatments were 6181.3 and 9727.9 kg ha^{-1}, which were 50.1% and 136.3% greater, when compared to the control treatment, respectively. Similarly, SY was increased by one-half (3292.1 kg ha^{-1}) and by one- and one-half times (5474.6 kg ha^{-1}) under PSI and CSI treatments, when compared to the control treatment, respectively. SI revealed no significant effect on HI under different irrigation treatments. The averages of HI averaged over-irrigation treatments were not significant, with average values of 47.4%, 47.2%, and 44.3 % under control, PSI, and CSI treatments, respectively **(Table 2).**

Results showed significant effects of irrigation treatments on yield components (Table 3**).** NKS and NSM were obviously increased especially under CSI. NKS and NSM increased by 20.9% and 36.0% and by 8.6% and 48.6% under PSI and CSI treatments when compared to the control treatment, respectively. However, NSS and NFS showed intermediate increases under SI by 5.4% and 15.5% and by 4.9% and 9.8% under PSI and CSI, respectively. SI significantly increased TKW by 13.0% (44.2g) and 9.0% (42.5g), respectively in PSI and CSI treatments, when compared with the control (39.0g) treatment.

Plant height (PH) increased by 13.4% and 30.3%, respectively under PSI and CSI treatments, in comparison to the control (data are not shown) treatment. The two PL measurements were significantly increased by 11.6% and 24.5% for PL1 and by 18.9% and 38.6%, respectively for PL2 under PSI and CSI treatments, when compared to the control treatment (data are not shown). PSI increased FLA to a lesser extent than CSI (data are not shown). Flag leaf length was increased by 5.3% and 23.5%, flag leaf width by 15.4% and 38.5% and FLA increased by 25.0% and 70%, respectively under PSI and CSI, when compared to the control treatment, .

No significant differences were observed between control and PSI treatments in DH, while CSI significantly delayed DH and DM by 7 and 3 days when compared to the control. GFP extended by 15.5 and 9.1 days under PSI and CSI, when compared to the control, respectively (data are not shown). Leaves chlorophyll content increased by 8.6% and 11.9% under PSI and CSI treatments, when compared to the control treatment, respectively **(Table 3).**

Table 2*:* Effects of irrigation treatments, wheat varieties and their interactions on yield traits.

Treatments	Grain yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest Index (%)
Irrigation (IR)				
Control	1924.2 c	4117.1 b	2192.9 b	47.4 a
PSI	2889.2 b	6181.3 b	3292.1 b	47.2 a
	(50.2)	(50.1)	(50.1)	(-0.42)
CSI	4253.3 a	9727.9 a	5474.6 a	44.3 a
	(121)	(136.3)	(149.7)	(-6.5)
LSD(0.05)	848.9	2385.6	1576.7	4.33
Variety (V)				
Sham1	3151.1 a	6654.4 abc	3503.3 bcd	48 abc
Omqais	3183.3 a	7198.9 ab	4015.6 ab	45.8 bc
Ammon	2920.0 ab	5927.8 c	3007.8 d	49.3 ab
Acsad65	3013.3 ab	6875.6 abc	3862.2 abc	46.5 abc
Bani Suef6	3105.6 a	6285.6 bc	3180 cd	49.5 a
Bani Suef4	2643.3 b	5932.2 c	3288.9 bcd	44.6 c
Horani Nawawi	2927.8 ab	7420.0 a	4492.2 a	40.4 d
Dairalla6	3233.3 a	7108.9 ab	3875.6 abc	46.3 abc
LSD(0.05)	404.0	973.9	770.3	3.85
IR×V	ns	**	*	ns

Means within columns for each treatment with the same letter are not significantly different from each other at P=0.05.
**Significant at P=0.01; * significant at P=0.05; ns, not significant.
Values in brackets indicate the percentage of increase over their corresponding controls.

Table 3: Effects of irrigation treatments, wheat varieties and their interactions on yield components and spikelet-related traits.

Treatments	Number of kernels spike^{-1}	Number of spike m^{-2}	1000- kernal weight (g)	Number of Spikelet spike^{-1}	Number of florets spikelet $^{-1}$	Leaves chlorophyll contents (mg g^{-1}fresh weight)
Irrigation (IR)						
Control	22.5 c	220.4 b	39.0 b	16.8 b	4.1 b	42.8 b
PSI	27.2 b	239.4 b	44.2 a	17.7 b	4.3 ab	46.5 a
	(20.9)	(8.6)	(13.3)	(5.4)	(4.9)	(8.6)
CSI	30.6 a	327.6 a	42.5 a	19.4 a	4.5 a	47.9 a
	(36)	(48.6)	(9.00)	(15.5)	(9.8)	(11.9)
LSD(0.05)	3.32	56.11	2.09	1.01	0.36	3.24

Variety (V)						
Sham1	28.4 a	276.1 ab	40.0 c	18.4 b	4.6 a	47.7 ab
Omqais	29.6 a	252 cd	42.2 bc	19.4 a	4.3 b	47.02 b
Ammon	30.5 a	265.3 abc	35.0 d	18.2 bc	4.6 A	44.5 c
Acsad65	24.1 c	280.4 a	42.8 b	16.8 d	4.4 b	47.6 ab
Bani Suef6	25.5 bc	271.3 abc	42.2 bc	16.9 d	4.2 b	49.7 a
Bani Suef4	24.5 c	253 bcd	41.1 bc	17.1 d	4.4 b	43.6 cd
Horani Nawawi	23.5 c	263.2 abc	45.6 a	17.4 cd	3.7 d	42.2 d
Dairalla6	27.8 ab	238.3 d	46.1 a	19.5 a	3.98 c	43.6 cd
LSD(0.05)	2.88	23.65	2.6	0.85	0.24	2.2
IR×V	ns	ns	ns	*	ns	*

Means within columns for each treatment with the same letter are not significantly different from each other at P=0.05.
**Significant at P=0.01; * significant at P=0.05; ns, not significant.
Values in brackets indicate the percentage of increase over their corresponding controls.

Yield potential and potential yield

Grain yield over wheat varieties ranged from 1543.3 to 2266.7, from 2360 to 3303.3, and from 3800 to 4716.7 kg ha^{-1} under control treatment, PSI, and CSI treatments, respectively **(Table 4)**. Among the eight varieties, Sham1 followed by Omqais, Acsad65, Ammon, Dairalla6 and Bani Suef6 showed the highest PY under control treatment with average GY of 2266.7, 2253.3, 1963.3, 1946.7, 1920 and 1830 kg ha^{-1}, respectively. All varieties displayed non-significant differences in GY under PSI, However, there was an observed variability in yield. Sham1 followed by Dairall 6, Horani Nawawi, Bani Suef6, and Omqais were from the top yielding varieties with YP of 3303.3, 3193.3, 3130, 3026.7 and 2936.7 kg ha^{-1}, respectively, while Bani Suef4 displayed the lowest YP (2586.7 kg ha^{-1}). Under CSI, the highest YP was recorded in Acsad65 followed by Dairalla6. It is worth to be mentioned that Dairalla6 was from the highest yielding varieties under PSI and CSI treatments with average GY of 3193.3, and 4586.7 kg ha^{-1}, respectively, but it showed a medium PY under control treatment (1920 kg ha^{-1}). On the other hand, Sham1 displayed the highest PY under control treatment and YP under PSI with an average GY of 2266.3 and 3303.3, respectively.

The percentages of increase in GY under PSI and CSI treatments were 20.2% in Acsad65 to 87.4% in Horani Nawawi and from 71.3% in Sham1 to 146.2% (Bani Suef4), when compared to the control treatment **(Table 4)**. The highest increases in GY under PSI were observed in Horani Nawawi (87.4%) followed by Bani Suef4, Dairalla6, and Bani Suef6 (range =65.4-67.6%), when compared to the controls, respectively. However, under CSI, the maximum increases compared to control were recorded in Bani Suef4 (146.2%), followed by Bani Suef6, Acsad65, Horani Nawawi, and Dair Alla 6 (range=138.5-143.7%).

Table 4: The percentages of increase in grain yield in the eight wheat varieties under partially supplemental irrigation (PSI) and continuous supplemental irrigation (CSI) treatments in comparison with their corresponding control treatments

Variety	Control	PSI	% of GY Increase under PSI	CSI	% of GY Increase under CSI
Sham1	2266.7 a	3303.3 a	45.7	3883.3 bc	71.3
Omqais	2253.3 a	2936.7 a	30.3	4360 abc	93.5
Ammon	1946.7 ab	2576.7 a	32.4	4236.7 abc	117.6
Acsad65	1963.3 ab	2360 a	20.2	4716.7 a	140.2
Bani Suef6	1830 ab	3026.7 a	65.4	4460 ab	143.7

Bani Suef4	1543.3 b	2586.7 a	67.6	3800 c	146.2
Horani Nawawi	1670 b	3130 a	87.4	3983.3 bc	117.4
Dairalla6	1920 ab	3193.3 a	66.3	4586.7 a	138.9

Means within the same letter within each treatment are not significantly different from each other at $P>0.05$.

Drought susceptibility index estimates

The drought susceptibility index (DSI) based on GY ranged from 0.51 to 1.41 and from 0.76 to 1.08 under PSI and CSI, respectively (Table 5). DSI estimates revealed that the most tolerant varieties under PSI and CSI treatments, respectively, were as follows: Acsad65 (0.51 and 1.06), Omqais (0.71 and 0.88), Ammon (0.74 and 0.98) and Sham1 (0.95 and 0.76). However, the least tolerant varieties were Horani Nawawi followed by Bani Suef4, Dairalla6, and Bani Suef6 with DSI estimates ranging from 1.19 to 1.41 and from 1.06 to 1.08 under PSI and CSI, respectively. Based on DSI means based on GY under PSI and CSI treatments, varieties could be ordered according to their drought tolerance as follows: Acsad65 (0.79), Omqais (0.80), Sham1 and Ammon (0.86), Bani Suef6 (1.13), Dairalla6 (1.14), Bani Suef4 (1.15) and Horani Nawawi (1.24).

DSI values based on BY under PSI and CSI treatments ranged from 0.18 to 1.55 and from 0.77 to 1.14, respectively. DSI under PSI and CSI revealed that Omqais (DSI= 0.18 and 0.77) was the most tolerant variety followed by Acsad65 under PSI (DSI= 0.54) but not under CSI (DSI=1.14). Depending on the mean DSI values based on BY under both PSI and CSI treatments, varieties could be ordered according to their tolerance as follows: Omqais (0.48), Acsad65 (0.84), Ammon (0.88), Sham1 (0.94), Bani Suef4 and 6 (1.09 and 1.1), Dairalla6 (1.18) and Horanni (1.33).

Water productivity

Water productivity (WP) was calculated based on GY and BY for each variety under different irrigation treatments (**Table 6**). The highest WP based on GY was recorded in the control treatment (0.73) followed by CSI treatment (0.67 kg dry matter m^{-3}) and PSI treatment (0.60 kg dry matter m^{-3}). WP based on GY ranged over varieties from 0.59 to 0.86, from 0.49 to 0.68, and from 0.59 to 0.74 kg dry matter m^{-3} under control, PSI, and CSI treatments, respectively. The highest-yielding varieties showed high WP and vice versa. Sham1 and Omqais (0.86 kg dry matter m^{-3}) followed by Acsad65 (0.75 kg dry matter m^{-3}), Ammon (0.74 kg dry matter m^{-3}) and Dairalla6 (0.73 kg dry matter m^{-3}) displayed the highest WP under control treatment. Under PSI, there was an observed variability in WP. Sham1 (0.68 kg dry matter m^{-3}) followed by Dairalla6 (0.66 kg dry matter m^{-3}), Horani Nawawi (0.65 kg dry matter m^{-3}), Bani Suef6 (0.63 kg dry matter m^{-3}) were from the top yielding varieties with high WP values, while Acsad65 displayed the lowest value (0.49 kg dry matter m^{-3}) with low yield. Under CSI, the highest yielding varieties displayed high WP included Acsad65 (0.74 kg dry matter m^{-3}) followed by Dairalla6 (0.72 kg dry matter m^{-3}), Bani Suef6 (0.69 kg dry matter m^{-3}) and Omqais (0.68 kg dry matter m^{-3}), while Bani Suef4 (0.59 kg dry matter m^{-3}) was with the lowest WP value.

Based on BY, the highest WP was recorded in the control treatment (1.57 kg dry matter m^{-3}) followed by CSI (1.52 kg dry matter m^{-3}) and PSI (1.30 kg dry matter m^{-3}). WP ranged over varieties ranging from 1.34 to 2.12, from 1.01 to 1.61, and from 1.32 to 1.84 kg dry matter m^{-3} under control, PSI, and CSI treatments, respectively. The highest WP varieties under control treatment coincided with high BY and vice versa. Omqais (2.12 kg dry matter m^{-3}) followed by Sham1 (1.72 kg dry matter m^{-3}) were from the top-yielding varieties with high WP under control treatment, while other varieties displayed WP values ranging from 1.39 to 1.52 kg dry matter m^{-3}. Under PSI, there was an observed variability in WP. Horani Nawawi (1.61 kg dry matter m^{-3}) followed by Dairalla6 (1.60 kg dry matter m^{-3}) and Sham1 (1.44 kg dry matter m^{-3}) were from the top-yielding varieties with high WP values, while Acsad65 displayed the lowest WP value (1.01 kg dry matter m^{-3}) with low BY. Under CSI, the highest varieties for WP were obtained in Acsad65 (1.84 kg dry matter m^{-3}) followed by Horani Nawawi (1.67 kg dry matter m^{-3}), Dairalla6 (1.64 kg dry matter m^{-3}) and Omqais (1.58 kg dry matter m^{-3}), while Sham1 (1.32 kg dry matter m^{-3}), Ammon (1.33 kg dry matter m^{-3}) and Bani Suef4 (1.35kg dry matter m^{-3}) gave the lowest WP values.

Table 5: Drought Susceptibility Index (DSI) under partially supplementary (PSI) and continuous supplementary irrigation (CSI) for the eight wheat varieties based on grain yield and biological yield

Variety	DSI based grain yield			DSI based on biological yield		
	Under PSI	**Under CSI**	**Mean**	**Under PSI**	**Under CSI**	**Mean based of DSI based on BY**
Sham1	0.95	0.76	0.86	1.06	0.81	0.94
Omqais	0.71	0.88	0.80	0.18	0.77	0.48
Ammon	0.74	0.98	0.86	0.82	0.93	0.88
Acsad65	0.51	1.06	0.79	0.54	1.14	0.84
Bani Suef6	1.19	1.07	1.13	1.17	1.03	1.10
Bani Suef4	1.22	1.08	1.15	1.15	1.02	1.09
Horani Nawawi	1.41	1.06	1.20	1.55	1.11	1.30
Dairalla6	1.21	1.06	1.14	1.29	1.07	1.18
Mean	0.99	0.99		0.97	0.99	

Table 6: Water productivity (kg dry matter m^{-3}; kg DM m^{-3}) under control, partially supplementary (PSI) and continuous supplementary irrigation (CSI) treatments for the eight wheat varieties based on grain yield (GY) and biological yield (BY)

Varieties	WP based on GY (kg DM m^{-3})				WP based on BY (kg DM m^{-3})			
	Control	PSI	CSI	Mean	Control	PSI	CSI	Mean
Sham1	0.86	0.68	0.61	0.72	1.72	1.44	1.32	1.49
Omqais	0.86	0.61	0.68	0.72	2.12	1.23	1.58	1.64
Ammon	0.74	0.53	0.66	0.64	1.49	1.11	1.33	1.31
Acsad65	0.75	0.49	0.74	0.66	1.52	1.01	1.84	1.46
Bani Suef6	0.70	0.63	0.70	0.68	1.39	1.24	1.42	1.35
Bani Suef4	0.59	0.54	0.59	0.57	1.34	1.17	1.35	1.29
Horani Nawawi	0.64	0.65	0.62	0.64	1.45	1.61	1.67	1.58
Dairalla6	0.73	0.66	0.72	0.70	1.50	1.60	1.64	1.52
Mean (WP)	0.73	0.60	0.67	0.67	1.57	1.30	1.52	1.46

Interactive effects of varieties and water irrigation treatments on wheat traits

Grain yield (GY) did not show significant IR×V interaction. High significant IR×V interactions (P=0.01) were recorded on BY, while SY displayed a significant interactive effect at P=0.05. The highest BY and SY under different irrigation treatments are shown in Figures 1 and 2. The highest values for BY and SY under control treatments were observed in Omqais (values = 5580 and 3326.7 kg ha^{-1}, respectively) followed by Sham1 (4520 and 2253.3 kg ha^{-1}, respectively). The top-yielding varieties for BY and SY under PSI were Horani Nawawi (7786.7 and 4656.7 kg ha^{-1}, respectively) followed by Dairalla65 (7703.3 and 4010 kg ha^{-1}, respectively) and Sham1 (6963.3 and 3660 kg ha^{-1}, respectively). Under CSI, the top-yielding varieties for BY and SY were

Acsad65 (11780 and 7063.3 kg ha^{-1}, respectively) followed by Horani Nawawi (10663.3 and 6680 kg ha^{-1}, respectively), Dairalla6 (10476.7 and 5890 kg ha^{-1}, respectively) and Omqais (10086.7 and 5726.7 kg ha^{-1}, respectively).

No significant effects of IR×V interaction were observed on NKS, NSM, TKW, NFS, AL, and SL. IR×V interaction was significant on NSS (data not shown). Under control treatment; Dairalla6 (18.33) followed by Omqais (18.2), Ammon (18.07) and Sham1 (17.8) displayed the highest NSS (Figure 3). As a general trend, it is worth mentioning that the increase in the NSS induced by SI in all tested varieties. For example, NSS in Dairalla6 and Omqais increased from 19.4 to 20.73 and from 19.0 to 21.0 under PSI and CSI, when compared to their corresponding controls, respectively.

The interactive effects of IR×V on PH and PL1 were highly significant (P=0.01) and significant (P=0.05) for PL_2 **(data not shown)**. Horani Nawawi was the tallest variety followed by Omqais when exposed to different irrigation treatments, also the two varieties had the longest peduncles. However, the bread wheat variety (Ammon) had the shortest PH and PL.

All phenological traits exhibited highly significant IR×V interactions (P=0.01) (data not shown). Results revealed a non-significant effect of PSI on DH, even though DH was delayed by 2-17 days when compared to the control treatment. Varieties with earliest heading under control treatment were: Ammon (99.3 days) followed by Sham1 (103 days), Omqais, and Acsad65 (104.7 and 106.7 days, respectively), combined with high PY, early maturity, and relatively long GFP (34 and 33 days, respectively). Exposing varieties to CSI delayed heading and maturity in all tested varieties except Acsad65 and Dairalla6 which showed no or slight responses. Varieties under different irrigation treatments reached maturity within 127.3– 162.3 days with GFP ranging from 28- 45 days. The longest GFP under CSI was observed in Acsad65 (45 days), followed by Dairalla6 (43 days) and Bani Suf 6 (42 days) with high YP.

Leaves' chlorophyll content revealed a significant IR×V interaction (P=0.05, Figure 4). The highest chlorophyll content was observed in Bani Suef6 under all irrigation treatments. Drought as represented by the control treatment reduced the chlorophyll contents of all varieties when compared to their corresponding SI treatments. As a general trend, results also showed that varieties exhibited higher chlorophyll contents under CSI compared with PSI.

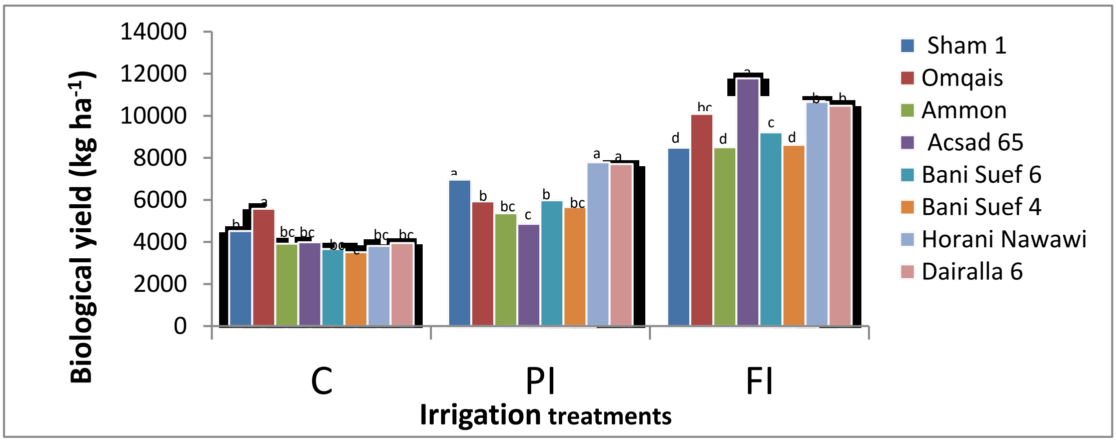

Figure 1: Interactive effect of irrigation treatments and varieties on biological yield. C, control (i.e., rainfed treatment); PSI, partially supplemental irrigation treatment; CSI, continuous supplemental irrigation treatment. Means for each treatment with the same letter are not significantly different at P=0.05.

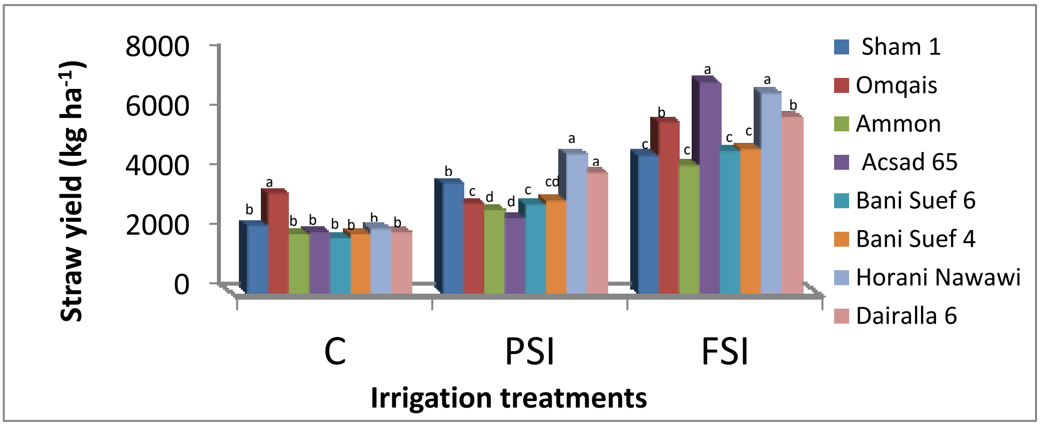

Figure 2: Interactive effect of irrigation treatments and varieties on straw yield. C, control (i.e., rainfed treatment); PSI, partially supplemental irrigation treatment; CSI, continuous supplemental irrigation treatment. Means for each treatment with the same letter are not significantly different at P=0.05.

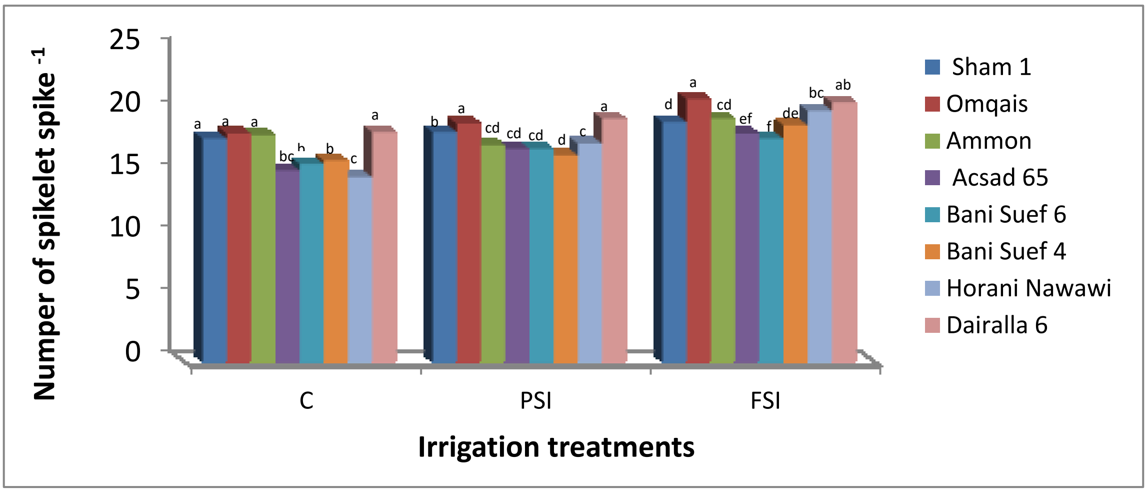

Figure 3: Interactive effect of irrigation treatments and varieties on number of spikelets spike^{-1}. C, control (i.e. rainfed treatment); PSI, partially supplemental irrigation treatment; CSI, continuous supplemental irrigation treatment. Means for each treatment with the same letter are not significantly different at P=0.05.

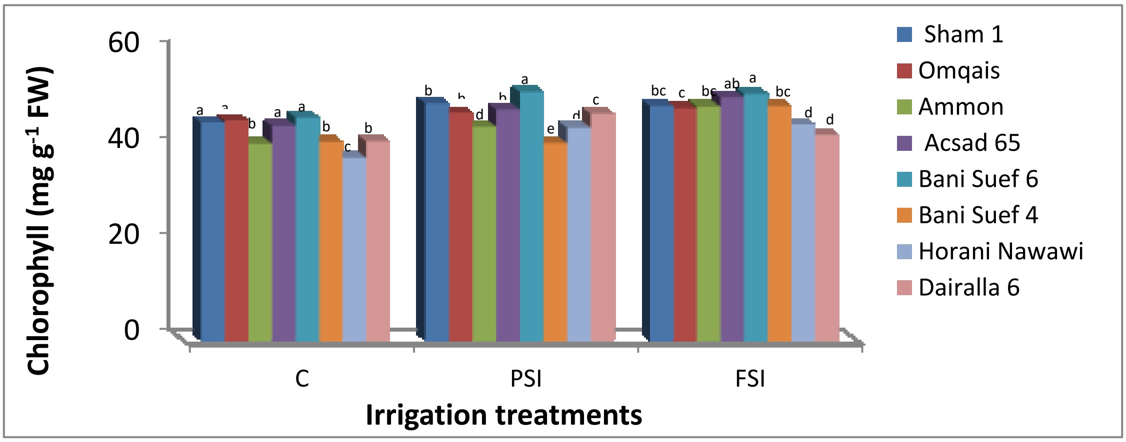

Figure 4: Interactive effect of irrigation treatments and varieties on leaves chlorophyll contents (mg g^{-1}fresh weight). C, control (i.e. rainfed treatment); PSI, partially supplemental irrigation treatment; CSI, continuous supplemental irrigation treatment. Means for each treatment with the same letter are not significantly different at P=0.05.

DISCUSSION

Effect of supplemental irrigation on yield and agronomictraits

Wide ranges of variation were observed in GY among the eight wheat varieties under different irrigation treatments. GY ranged from 1543.3 to 2266.7 kg ha^{-1}, from 2360 to 3303.3 kg ha^{-1} and from 3800 to 4716.7 kg ha^{-1} under control, PSI and CSI treatments, respectively. Under control treatment, the highest GY was observed in Sham1 (2266.7 kg ha^{-1}) followed by Omqais and Acsad65 (2253.3 and 1963.3 kg ha $^{-1}$, respectively). GY should be taken into consideration as a main direct selection trait for drought tolerance improvement for yield increasing under target environments (Abdel-Ghani, 2008). The top yielding varieties under PSI were Sham1 (3303.3 kg ha^{-1}) followed by Dairalla, Horani Nawawi and Bani Suef6 (3193.3, 3130 and 3026.7 kg ha^{-1}, respectively). Under CSI, Acsad65 gave the highest GY (4716.7 kg ha^{-1}) followed by Dairalla, Bani Suef6 and Omqais (4586.7, 4460 and 4360 kg ha^{-1}, respectively). High GY of these varieties under SI is attributed to enhanced growth as represented by high BY, SY, yield attributing traits (i.e. NKS, NSM, NSS, NFS, AL and SL), long GFP and high leaves chlorophyll content.

Results showed that highest BY, GY and SY of wheat varieties were obtained under CSI treatment. The average GY under CSI was almost doubled as compared with control treatment, whereas the average GY, BY and SY under PSI was one half greater than that of the control treatment. BY and SY exceeded the control treatment by one and one half under CSI, respectively. This indicates that drought is a main limiting factor affecting growth and plant biomass under semi-arid conditions (Abdel-Ghani, 2013; Al-Rjoub *et al.*, 2006). Under limited water conditions, irrigation scheduling is used to allocate irrigation water rationally during different wheat growing stages in order to maximize GY and WP (Montazar *et a*l., 2011). Similarly, many authors (Erekul *et al.*, 2012; Semcheddine *et al*., 2014; Shang *et al*., 2020) showed the importance of SI to increase yield under water limiting environments. Yield increase under PSI emphasizes the importance of SI during anthesis. SI with a small amount of water during critical stages under rain-fed crops led to a substantial increase in yield (Wani *et al*., 2009). SI at anthesis increases the photosynthesis rate, and gives plants extra time to translocate carbohydrate reserves to increase grain size and consequently leads to an increase in GY (Passioura, 1976). SI at anthesis and grain filling can enhance photosynthetic efficiency of the upper leaves in wheat, especially flag leaf and adequate SI can translocate more carbohydrate to grains (Fan *et al.*, 2005). Moreover, SI at anthesis stage survives the pollen and preventing pollen abortion that increases the number of fertilized florets in the spike (Briggs *et al., 1999)*. Water shortage at anthesis and grain filling stage will severely retard wheat growth and leads to substantial losses in yield (Abbasi *et al*., 2003).

NKS and NSM are very sensitive to drought (Giunta *et al*., 1993). In this study, NSM increased from 8.6% to 48.6% under PSI and CSI when compared with the control treatment, respectively. This led to an increase in the number of fertile tillers promoted by wet soil. It is obvious that there was a slight increase in tillers under PSI treatments, because insufficient water availability before anthesis suppressed tillers formation development. The results of this study showed that NKS was increased by 20.9% and 36% under PSI and CSI when compared to the control treatment, respectively. The reduction in NSS and consequently NKS led to GY reduction (Frank *et al*., 1987). Efficient pollination and fertilization under SI and thus high NKS is a main reason for high GY (Ashraf, 1998). However, TKW was decreased under CSI by 9.0% but increased by 13.3% under PSI when compared with the control treatment. The lighter kernel weight under CSI is due to the distribution of photosynthetic assimilates to a larger number of kernels on the same plant that resulted from tillers formation enhancement that increased the number of kernels per plant. Giunta *et a*l. (1993) reported that NKS and NSM were very sensitive to drought while grain weight remains relatively stable due to high remobilization of stored pre-anthesis assimilates. SI at critical stages (i.e. anthesis) can minimize yield losses by improving photosynthetic activity and water use efficiency (Oweis, 1997; Zhang *et al*., 1999). Wheat should not be exposed to water stress 10 days before anthesis through the late milk stage to minimize GY losses and to enhance yield (Miller, 1999). Slafer *et al.* (1994) showed that the low kernel weight associated with increased NSM and not only due to a lower amount of assimilates per kernel but it is the result of an increased NKS with a lower weight potential coming from more distal florets. According to Freeze *et al*. (1990), yield components have interdependent actions on GY and are able to compensate each other in order to stabilize yield under different conditions. Iqbal *et al*. (2012) found that SI at anthesis increased TKW compared to the control treatment, because of high carbohydrate translocation to wheat kernels resulted from growth enhancement. Adequate water at or after anthesis period improves grain size and leads to GY increases (Zhang *et al*., 1999). SI had pronounced significant effect on FLA and consequently on GY (Kilic *et al*., 2010).

Under PSI and CSI treatments, FLA increased by 25 to 70%, respectively. The great reduction in FLA by water stress might be reflected a reduction in photosynthesis rate and amount of assimilates available for grain development because most of assimilates for grain growth are found to be derived from flag leaf and its sheath (Joshi *et al*., 1982; Slafer *et al*., 1994). Flag leaf contributes with about 30 to 50% of the canopy photo-assimilate during grain filling (Lupton *et al*., 1966), which proves the importance FLA area in GY improvement.

CSI treatment significantly delayed heading by 7 days when compared with the control, while maturity delayed by 3 and 15 days under PSI and CSI, respectively. Water stress accelerates heading to escape drought stress that occurs at end of growing season (Hu et al., 2005; Xue *et al., 2004)*. Samarah (2005) showed that post anthesis water stress shortened GFP and consequently reduced GY regardless of the water stress severity level. In this study, long GFP was important for high GY under different SI treatments. Annicchiarico and Pecetti (1995) who concluded that earliness and extended GFP are among important indirect selection traits associated with high grain.

Irrigation significantly increased leaves chlorophyll content. This might indicates more efficient light and photosynthetic efficiency (Araus *et al*., 1997). Under PSI and CSI, total leaves chlorophyll content increased by 8.6

% and 11.9 %, when compared with the control treatment, respectively. High chlorophyll content indicates high degree of photosynthetic activity, and consequently higher carbohydrate assimilates available to increase yield (Farquhar *et al*., 1989).

Water productivity

Averages of WP estimates were higher under control treatment (0.73 kg dry matter m^{-3}) than average values obtained under PSI (0.60 kg dry matter m^{-3}) and CSI (0.67 kg dry matter m^{-3}). CSI after sowing enhanced early seedling emergence and a better seedling stand establishment, which in consequence might be reflected on yield. The higher WP under control treatment is attributed to low evapotranspiration of available soil moisture received by accumulative rains during cold months (December to March), whereas at the beginning of spring (April) water deficiency starts, plants grow faster and evapotranspiration increases. In this case, rainfed crops rely on little stored soil moisture after anthesis that reduces yield but increases WP. The reduction in WP under SI is mainly attributed to high water losses during hot months (from April to May) when high temperature accentuates evapotranspiration (Wani *et al*., 2009).

Drought susceptibility based on grain yield and biological yield

Many selection indices based on the mathematical relations between the stress and non-stress conditions have been suggested for determining the drought tolerance of crop varieties. The most popular index is DSI (Parchin *et al*., 2013). The stability of GY estimated by DSI derived from differences in yield losses between stress and non-stress treatments. Genotypes with low DSI values are presumed to be drought tolerant because they exhibited minimum yield losses under water stress as compared with non-stress condition (Ali *et a*l., 2012). Based on GY, Acsad65, Omqais, Sham1 and Ammon could be more stable for GY than other tested varieties, and hence they could be declared as tolerant varieties, while, Bani Suef6, Dairalla, Bani Suef4 and Horani Nawawi could be considered as drought susceptible varieties. Variation in DSI among tested varieties indicates their genetic variability in response to drought, and also indicates DSI estimates is a practical scope for selection for more stable varieties under drought (Bruckner and Frohberg, 1987). However, DSI does not necessarily a measure of differences in PY and YP among varieties (Clarke *et al*., 1984). Therefore, varieties with low DSI do not necessarily have high YP under SI.

Interactive effect of irrigation and wheat varieties on yield and other agronomic traits

Sham1, Omqais and Acsad65 can be considered as drought tolerant varieties. Sham1 out-yielded (2266.7 kg ha^{-1}) other wheat varieties under control treatment. In addition to that Sham1 displayed some desirable drought related traits including the highest values for NFS (4.6) and NKS (27.7), long awns (17.5 cm), high NSS (17.8), high NSM (233.7), high leaves chlorophyll content (45.2 mg g^{-1} FW), BY (4520 kg ha^{-1}), SY (2253.3 kg ha^{-1}) and earliness (103 days) with long GFP (34 days), even though Sham1 showed low TKW (35g). Omqais gave the highest BY (5580 kg ha^{-1}), SY (3326.7 kg ha^{-1}) and longest spikes (6.6 cm) under control treatment. Omqais was tall (70.6 cm) with long peduncles and it displayed high NSS (18.2), NKS (24.2), NSM (222.9), TKW (41.7 g) and leaves chlorophyll content (45.6 mg g^{-1} FW). Omqais was early in heading and maturity with extended GFP (33 days). High GY in Acsad65 under control treatment may be due to its high NSM (241.3), high leaves chlorophyll content (44.5 mg g^{-1} FW) and earliness with extended GFP (33 days). Selection for high NFS, NKS, NSS and NSM are considered as indirect selection traits to improve yield under drought (Slafer et al., 1994). Light kernels are negatively associated with high NSM and not only due to a lower amount of assimilates per kernel that resulted from high NKS. According to Freeze and Bacon (1990), yield components have interdependent action and are able to compensate each other in order to stabilize yield under different conditions. Varieties with high PY (grain and straw) under drought considered as a direct selection criterion under drought (Yani *et al*., 2012). The indirect selection strategy under drought should take into consideration earliness, long GFP, low DSI values, high NKS and high spike weight to increase yield (Kilic and Tacettin., 2010). Long awns are associated with high yield under drought. Removing of wheat awns causes a reduction in grain yield by 15.9%, kernel number per plant by 11.3 % and kernel weight by 5.2%, indicating the importance of awns under rainfed conditions (Duwayri, 1984). Evans and Rawson (1970) reported that AL was positively associated with GY in dry areas but not under irrigation. Heading of wheat was accelerated under drought condition as a strategy to escape from drought (Edwards *et al*., 1976; Xue *et al.*, 2004) and to adapt to terminal drought conditions that occurs the end of growing season (R. A. Richards, 2006; Samarah, 2005; Shakhatreh *et a*l., 2001).. This is in agreement with Annicchiarico and Pecetti (1995), who reported that long GFP may considered as one of the most important trait to increase GY under dry conditions. In Mediterranean region, most rainfalls occur in autumn and winter and water shortage starts in spring. This exposes wheat crop to late water stress during anthesis and GFP causes significant yield losses and substantial reductions in yield contributing traits (Blum *et al., 1990)*. It is worth to mention that drought tolerant wheat varieties with high chlorophyll content are more stable in yield under drought (Keyvan, 2010; Waines, 1994). Chlorophyll content in flag leaf might retain more photosynthate in the leaves, stems, which keeps photosynthetic activity for longer time (Inoue *et al*., 2004; R. Richards, 2000). Rapid leaf senescence may be indicate fast reserve mobilization to the grain under stress (Fokar *et al*., 1998).

Under PSI, Sham1 outyielded other varieties (3303.3 kg ha^{-1}) followed by Dairalla6 (3193.3 kg ha^{-1}). As compared to other varieties, results showed that Sham1 had the highest NSM (255.2), the longest awns (16.9 cm), it is also earlier in heading and maturity with longest GFP (35 days). In addition, Sham1 displayed high NKS (28.9), NSS (18.3), NFS (4.4), leaves chlorophyll content (49.3 mg g^{-1} FW) and BY (6963 kg ha^{-1}). TKW in Sham1 was substantially improved under PSI (45 g). Dairalla6 also displayed high yield under PSI, this is mainly attributed to the highest NSS (19.4) and long spikes (8.7 cm), large FLA (25.8 mg g^{-1} FW), heavy kernels (TKW=46.7 g) and high BY and SY (7787 and 4656.7 kg ha^{-1}). It had also high NKS (29.9) and long GFP (35 days). Horani Nawawi was from the highest yielding varieties under PSI (3130 kg ha^{-1}). High GY was coincided with high plant biomass in terms of BY and SY (7203 and 4010 kg ha^{-1}), tallness (98.5 cm), long peduncles, heavy kernels (TKW=46.7 g), large FLA (25.cm^2), high NSM (253), late heading and long GFP (35 days). Adequate water at or after anthesis period improves kernel size and consequently led to an increase in YP. Since fertility of florets depends on water availability at anthesis (Briggs et al., 1999; Zhang *et al.*, 1999), high NKS were observed under PSI. Even though, Sham1 was superior under control and PSI treatments, it showed the least increase in GY under CSI (71.3%) as compared with other varieties (range = 93.5% to 146.2%).

The highest GY under CSI was observed in Acsad65, which attributed to high NSM (356.2), BY (11780 kg ha^{-1}) and SY (7063.3 kg ha^{-1}). In addition, it displayed high NFS (4.8), high chlorophyll content (50.5 mg g^{-1} FW), early heading and maturity with long GFP (45 days). Dairalla6 ranked the second in GY (4586.7 kg ha^{-1}) under CSI, it showed high TKW (50 g), high NSS (20.7), large FLA (34.7 cm^2), relatively high BY (10476.7 kg ha^{-1}) and long GFP (43 days). Bani Suef6 was also from the top yielding varieties under CSI. High GY was attributed to high leaves chlorophyll content (51.2 mg g^{-1}), high NSM (351.5) and long GFP (42 days). Early irrigation without waiting for the onset of seasonal rain can elongate the growing season and consequently led to higher GY (Wani *et al.*, 2009).

CONCLUSIONS

Grain yield was increased by one half and doubled when PSI and CSI treatments were applied as compared with GY obtained under rain-dependent environment. High GY under SI was associated with higher NKS, NSS, NSM and TKW. The floret fertility represented in this study by NSM and NKS are greatly dependent on soil moisture availability before and during anthesis. GFP was elongated by SI, which might give the wheat an extra time to translocate more carbohydrates to kernels and improve yield. CSI is a successful agricultural practice that determines the crop growth and thus the length of the growing season without waiting for the onset of seasonal rain. WP was reduced with SI due to high evaporation during the hot months (April to May). GY could be increased beyond 3 and 4 tones ha^{-1} with PSI and CSI, respectively. This study is considered a pilot study carried out at a small scale which is needed for the future large-scale projects in Jordan. In consequence, both GY and crop biomass will be highly dependent on the amount and distribution of rainfall and on irrigation scheduling during the cropping season under semi-arid environments.

Conflict of interest

The author declares that there are no conflicts of interest.

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تأثير الري التكميلي على أداء القمح المزروع في البيئة شبه الجافة

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ملخص

أجريت هذه الدراسة لتحديد تأثير معاملات الري التكميلي المختلفة على الغلة ومكوناتها، وبعض الصفات المرتبطة بالجفاف في ثمانية أصناف من القمح المزروعة في بيئة شبه الجافة في الأردن. تم أستخدام معاملتي ري تكميلي بالإضافة إلى الشاهد (الزراعة بالاعتماد على الأمطار والمقدرة ب 262.8 ملم من الأمطار المتراكمة خلال الموسم): معاملة الري التكميلي الجزئي (PSI) والمكونة من (262.8 ملم من الأمطار+ 220 ملم من الري خلال مرحلة الأزهار) ومعاملة الري المستمر (CSI) والمكونة من (262.8 ملم من الأمطار + 377.5 ملم تم أضافتها كل 2-3 أسابيع خلال مراحل نمو القمح المختلفة). تم استخدام سبعة أصناف من القمح الصلب (شام 1، أم قيس، أكساد 65، بني سويف 6، بني سويف 4، حوراني نووي، ديرعلا6)، بالإضافة إلى صنف واحد من قمح الخبز (عمون). كان هناك زيادة معنوية في مكونات الغلة وبشكل كبير وتأخر في الوقت اللازم للتسبيل والنضج تحت الري التكميلي. أدت معاملة الري التكميلي الجزئي إلى زيادة معنوية في الغلة من الحبوب بنسبة 50.2٪، بينما أدت معاملة الري المستمر إلى زيادة الغلة بنسبة 121٪، مقارنة بالشاهد. لوحظ أن هناك اختلافات كبيرة بين الأصناف تحت معاملات الري المختلفة. أظهرت الأصناف شام 1 (2266.7 كغم هكتار$^{-1}$)، أم قيس (2253.3 كغم هكتار$^{-1}$)، أكساد 65 (1963.3 كجم هكتار$^{-1}$) أعلى غلة للحبوب في معاملة الشاهد مع مؤشرات حساسية منخفضة للجفاف، مما يدل على مستوى منخفض في النقص في الغلة في معاملة الشاهد مقارنة بمعاملات الري التكميلي والقدرة الوراثية العالية لتحمل الجفاف في هذه الأصناف. أعطت الأصناف أكساد 65 (4716.7 كغم هكتار$^{-1}$) ودير علا 6 (4586.7 كغم هكتار$^{-1}$) وبني سويف 6 (4460 كغم هكتار$^{-1}$) وأم قيس (4460 كغم هكتار$^{-1}$) أعلى غلة باستخدام الري المستمر، كما أعطى الصنف شام1 (3303 كجم هكتار$^{-1}$) أعلى غلة باستخدام الري الجزئي. ساهمت جميع مكونات المحصول (عدد الحبات في السنبلة وعدد الأشطاء وحجم الحبوب) معنوياً في زيادة الغلة تحت الري التكميلي. في الختام، أدى الري التكميلي الى تحسين مكونات المحصول، مما أدى إلى زيادة كبيرة في الغلة، من الممكن زيادة الغلة لأكثر من 3000 و4000 كغم هكتار$^{-1}$ باستخدام الري التكميلي الجزئي والري التكميلي المستمر، على التوالي.

الكلمات الدالة: الجفاف، الغلة، الري التكميلي، القمح.

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