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Effect of Nitrogen and Potassium Fertilizers on Wheat Productivity under Different Soil Moisture Contents

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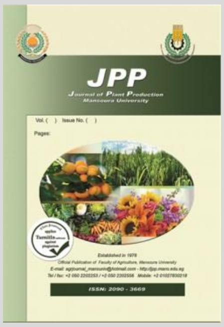

ABSTRACT

Wheat cv. Sakh 93 was planted on a clay soil at Agricultural Research Station Farm, Kafrelsheikh, in 2014/2015 and 2015/2016 seasons to investigate the influence of irrigation regime (irrigation at 40, 55, and 70% depletion of available soil moisture, DASM), nitrogen rates (50,70 and 90 kg N/fed.) and potassium rates (0,12 and 24 kg K_2O/fed.) on productivity and certain water relations. The reduction in DASM from 70% to 40% at irrigation and increasing either nitrogen or potassium rates resulted in significant increases in spike number m^{-2}, grain number/ spike, 1000-grain weight, grain yield, water Applied (WA), water Consumptive Use (WCU), productivity of Water Applied (PWA), productivity of Water Consumptive Use (PWCU), stored Water (SW). Irrigation at 55% DASM with 70 kg N and 24 kg K_2O/fed^{-1} recorded the best values of PWA for grain (1.12 and 1.09 kg grain m^3 AW). Raising the nitrogen rate from 50 to 90 kg N fed^{-1} significantly raised water applied efficiency (WAE %) in both seasons. Irrigation at 70% DASM with 90 kg N and 0 kg K_2O fed^{-1} produced the highest values of WAE (86.43 and 86.98 %), while irrigation at 40% DASM with 50 kg N and 24 kg K_2O/fed produced the lowest values (71.77 and 71.60 %) in both seasons. In conclusion, irrigation at 55% DASM with application of 70 kg N and 12 or 24 kg K_2O fed^{-1} was the best treatment, which resulted in high grain yield with fewer amounts of applied irrigation water and consumptive use.

Keywords: Wheat productivity, nitrogen fertilization, potassium fertilization, soil moisture, Water Relations

INTRODUCTION

Water availably is the first prerequisite for a good yield. Water is the most important determinant of crop production in Egypt and in many parts of the world due to water shortages. In the following decades, the worldwide challenge will be to increase agricultural productivity while using less water. This can be partially achieved by increasing crop water use efficiency (Tari, 2016). Wheat production was increased by optimization of supplemental irrigation (Gharib and Meleha, 2016). Withholding irrigation water at different growth stages of wheat plant and irrigation based on measurements of soil moisture in several soil layers were studied by many previous researchers (Yi *et al.*, 2013).(Gharib and Meleha, 2016) observed no significant differences between full irrigation based on the soil water content at soil layer 0-60cm (W_1) and 0-40 cm (W_2) in spikes number m^{-2}, kernels number $spike^{-1}$, 1000-kernel weight, straw yield and grain yield. They added that seasonal water applied amounted 2517 and 2025 m^3 fed^{-1} and water consumptive use values were 1584 and 1480 m^3 fed^{-1} over the two seasons for W_1 and W_2, respectively. Sun *et al* (2006) and Zhang *et al* (2006) revealed that reducing water application by 50 mm from wheat's water requirement had no effect on grain output and boosted water productivity. Karim *et al.* (1997) discovered that irrigation at % available soil water depletion (ASMD) resulted in the maximum yield (4.71 t/ha) with 120 kg N application, but irrigation at % ASMD resulted in a sufficient yield (4.13 t/ha) with the highest WUE (196.5 kg /ha cm).

Fertilization is a significant and dynamic component of crop growth technology, with the greatest impact on the creation of the economic component of grain wheat yield (Ivanova *et al.*, 2007). Nitrogen and potassium are major elements influencing wheat yield and quality. If there is insufficient nitrogen fertilizer, wheat output and quality would suffer; on the other hand, excessive nitrogen application will result in decreased nitrogen usage efficiency in wheat and increased environmental contamination (Dogan and Bilgili, 2010; Liu and Shi, 2013). A sufficient nitrogen supply enhances the protein content of vegetative organs as well as storage tissues and produces protein from carbs (Tari, 2016). The ideal nitrogen fertilizer levels for wheat vary greatly in quantity, ranging from 70 to 120 kg N fed-1 depending on environmental conditions (Mosaad and Fouda ,2016).

Potassium is a necessary nutrient and the most abundant cation in plants. K is required enzyme activation, protein synthesis, photosynthesis, osmoregulation, stomatal movement, energy transfer, phloem transport, cation-anion balance, and stress tolerance (Ngwako and Mashiqa 2013). According for to (Rahimi, 2012), potassium improves crop tolerance to water stress through a well-developed root system, as well as promotes optimum water uptake and improves water usage efficiency. Li *et al.* (2015) concluded that application of potassium improve leaf water potential, osmotic potential, turgor potential , spike length, number of grain per spike and grain yields under water stress. Gharib and Meleha (2016) discovered that applying K fertiliser reduced the detrimental impacts of not watering on yield and its

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components. They also stated that the application of K fertiliser had no influence on seasonal irrigation water or consumptive usage, but it boosted water productivity by boosting grain output.

The objectives of this work were to investigate the influence of irrigation regime, as well as nitrogen and potassium fertilizer rates, on wheat production and water relationship.

MATERIALS AND METHODS

Wheat cultivar Sakh 93 (*Triticum aestivum* L.) was grown on a clay soil at the farm of Agricultural Research Station, Kafr El-Sheikh Governorate (6 m altitude, 31° 07$^-$ latitude and 30° 52$^-$ longitude) in 2015 and 2016 seasons, to determine the effect of soil moisture depletion, nitrogen and potassium fertilization on grain and straw yields and some water relations. The preceding crop was maize in the two seasons. The soils of the experimental field were clay with some water table of 70-95 cm in both seasons. The soil bulk density, field capacity and wilting point were determined in the experimental sites as given in Table 1. Some chemical properties of the experimental soil in the two seasons are presented in Table 2.

The experimental field was fertilized with 15.5 kg P_2O_5/feddan in the form of calcium superphosphate (15.5 % P_2O_5) during soil preparation. Irrigation treatments were started after the first irrigation (sowing irrigation). Three irrigation regimes were used at 40, 55 and 70 % depletion of available soil moisture (DASM) at 0-60 cm soil depth. The actual irrigation requirement was estimated by drying soil samples for 24 hours at 110 C^0 and expressing the percentage of moisture as an oven dry weight basis. Soil samples were collected at each 15 cm soil depth up to 60 cm before and after each irrigation to calculate wheat's water consumptive use (WCU). Potassium fertilizer was applied with the rates of 0, 12 and 24 kg K_2O/feddan in the form of potassium sulphate (48 % K2O) at the second irrigation. Nitrogen fertilizer was given with the rates of 50, 70 and 90 kg N/feddan in the form of urea (46.5 % N) in two doses, 20% at sowing and 80% at the first irrigation (onset tillering stage).

Table 1. Field capacity, wilting point and bulk density for the experimental field in 2014/15 and 2015/16season

Soil depth (cm)	Field capacity %		Wilting point %		Bulk density (g/cm^3)	
	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16
0-15	42.04	43.64	22.42	23.68	1.19	1.13
15-30	41.88	41.45	20.85	21.55	1.23	1.21
30-45	38.91	38.98	19.72	21.22	1.29	1.21
45-60	37.57	36.19	19.48	19.76	1.31	1.28
Mean	40.10	40.06	20.62	21.55	1.26	1.21

Table 2. Chemical analysis of the experimental soil (0-30 cm depth) in 2014/15 and 2015/16season

Season	pH (1:2.5)	EC (ds/m)	Organic matter (%)	Available N (ppm)	Available P (ppm)	Available K (ppm)
2014/15	8.20	2.05	1.21	17.75	10.65	158.50
2015/16	8.13	2.90	1.55	19.25	12.45	204.00

The experimental design was split-split-plot with three replicates. The irrigation regimes were allocated to the main plots, the nitrogen rate to the sub-plots, and the potassium rate to the sub-sub plots. The sub-sub plot size was 20 m^2 (4 X 5 m). To avoid the influence of lateral movement of irrigation water, the major plots were separated by 1.5 m wide levees. Wheat seed was drilled by hand in rows 20 cm a part at the rate of 50 kg seed feddan^{-1} on 15 and 18 November in 2014 and 2015 seasons, respectively. Each sub-sub plot included 20 rows. The standard cultural practices for cultivating wheat were followed exactly as recommended. Table 3 displays the weather data from Sakha Station over the two growing seasons.

Table 3. Mean monthly of temperature, relative humidity, wind speed and pan evaporation as well as rainfall quantity in 2014/2015 and 2015/2016 seasons.

Month	Temperature (^{o}C)		Relative humidity (%)		Wind speed (km/day)		Pan evaporation (mm/month)		Rainfall (mm/month)	
	2015/16	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16	2014/15
Nov	19.05	19.41	74.15	75.6	67.3	70.3	277	319	24.6	52.40
Dec	15.99	14.03	76.05	77.9	46.03	57.9	172	250	5.70	25.00
Jan	12.63	12.38	74.6	74.05	70.8	69.2	271	252	52.55	43.21
Feb	13.35	15.97	74.75	69.05	72.91	58.8	290	252	38.80	-
Mar	17.19	18.05	70.59	69.90	87.64	63.2	323	359	6.25	13.2
Apr	18.17	24.33	63.4	61.70	95.7	87.1	607	594	23.90	-
May	24.49	26.6	61.7	58.40	114.6	97	715	647	-	-

At harvest, number of spikes m^{-2} was counted. Ten spikes were collected randomly to estimate number of grains / spike, and 1000-grain weight. The central area of 8 m^2 (2 X 4 m) were harvested and threshed to calculate grain and straw yield. The weight of grain yield was adjusted to 14.5% moisture content.

Water relations:

A rectangular sharp crested weir was used to measure the amount of irrigation water. Soil samples were collected at 15 cm depths up to 60 cm before and after irrigation to determine the water consumptive use (WCU) of the wheat plant according to Israelsen and Hansen (1962) equation as follows:

$$\mathbf{WCU} = \frac{\theta_2 - \theta_1}{100} \times \mathbf{B.d} \times \mathbf{D} \times \mathbf{4200}$$

Where:

WCU = Amount of water consumptive use (m^3/feddan).
θ_2 = Soil moisture content % after irrigation.
θ_1 = Soil moisture content % before the next irrigation.
B.d = Bulk density (g/cm^3).
D = Depth of soil layer (m).

Water consumptive use (WCU) was computed from sowing to harvest. Water productivity was calculated as the ratio of grain and straw yields with amount of applied irrigation water (PAW) and water consumptive use (PWCU) according to Michael (1978)as follows:

$$\mathbf{PWA} = \frac{\text{Yield (kg/ feddan)}}{\text{Applied water } (m^3/\text{feddan})}$$

$$\mathbf{PWCU} = \frac{\text{Yield (kg/ feddan)}}{\text{water consumpitive use } (m^3/\text{feddan})}$$

According to Gomez & Gomez (1984), the collected data were analyzed using analysis of variance Duncan's Multiple Range Test was used to compare treatment means (Duncan, 1955). All statistical analyses were carried out using the analysis of variance technique and the "MSTATC" computer software package.

RESULTS AND DISCUSSION

A. Yield attributes:

Spikes number m^{-2}, grains number spike^{-1} and 1000-grain weight as affected by irrigation regime, nitrogen rate and potassium rate in 2015 and 2016 seasons are presented in Table 4. Irrigation regime had significant effect on spikes number m^{-2}, grains number spike^{-1} and 1000-grain weight in both seasons. Irrigation at 40 and 55% depletion of available soil moisture DASM resulted in significant increase in spikes number m^{-2}, grains number spike^{-1} and 1000-grain weight compared with irrigation at 70% DASM. There were no significant differences in these traits between irrigation at 40 and 55% DASM in both seasons. Water stress (irrigation at 70% DASM) accelerated tiller death which causes reduction in number of survival active tillers (spikes number m^{-2}). Certainly the sufficient soil moisture content induced vegetative growth (cell division and elongation) and thus the expansion of leaves, which resulted in great photosynthetic available for dry matter accumulation and in turn increased spike number and grain number per spike. In this regard, Mekkei and El Haggan (2014) concluded that applying five irrigations at various wheat growth phases resulted in a larger number of spikes m^{-2}, whereas omitting irrigation at stem elongation, booting, or anthesis stage resulted in a lower number of spikes m^{-2}. These findings are consistent with those of Attia and Barsoum (2013), Rizk and Sherif (2014), Shirazi *et al*. (2014), and Gharib and Meleha (2016).

Table 4.Grain yield attributes, straw yield and harvest index as affected by irrigation regime, nitrogen and potassium rate in 2014/15 and 2015/16 season

Factor	Spikes(No/m^2)		Grains (No/spike)		1000-g (g)		Straw yield(t/fed)		Harvest index	
	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16
Depletion % (D)										
40	340 a	355 a	61.2 a	62.1 a	52.65 a	50.16 a	4.683 a	4.146 a	0.389	0.421
55	334 a	340 a	60.4 a	58.9 a	50.59 b	49.19ab	4.550 a	3.698 ab	0.383	0.417
70	311 b	299 b	55.3 b	54.8 b	45.00 c	48.38 b	3.171 b	3.124 b	0.389	0.404
F test	**	**	**	**	*	*	**	*	Ns	Ns
kg N/fed. (N)										
50	307c	309b	55.7 b	54.4 b	44.70c	48.38c	3.723 b	3.044 b	0.389	0.418
70	331b	332ab	59.0a	58.4ab	53.35a	50.22a	4.206 ab	3.730 a	0.388	0.417
90	346a	353a	62.2a	63.0a	50.18 b	49.13 b	4.475 a	4.195 a	0.385	0.408
F test	**	*	**	**	*	*	**	*	Ns	Ns
kg K_2O/fed. (K)										
0	306c	295c	55.1c	55.3c	46.01c	48.15c	4.022	3.535	0.383	0.41
12	332b	334b	59.1 b	58.2 b	50.05 b	49.38 b	4.138	3.691	0.387	0.416
24	345a	365a	62.7a	62.3a	52.17a	50.21a	4.244	3.743	0.391	0.416
F test	**	**	**	**	*	*	Ns	Ns	Ns	Ns
Interaction										
D x N	**	**	**	**	**	**	**	**	Ns	Ns
D x K	**	**	**	**	**	NS	**	**	Ns	Ns
N x K	**	**	**	**	**	**	**	**	Ns	Ns
D x N x K	**	**	**	**	**	**	**	**	Ns	Ns

***, ** and Ns indicate p < 0.05, < 0.01 and not significant, respectively. Means of each factor followed by the same letter are not significantly different at 5 % level, according to Duncan s multiple range test.**

In all seasons, increasing the nitrogen rate from 50 to 90 kg N ha^{-1} steadily increased the number of spikes m^{-2} and the amount of grains spike^{-1}. In the two seasons, the rates of 70 and 90 kg N fed^{-1} were statistically equal in the two features described. Nitrogen's effect may be linked mostly to its role in the stimulation of numerous physiological processes such as cell division and cell elongation, which resulted in more photosynthetic area, which boosted photosynthetic production and, as a result, spike and grain numbers. In all seasons, the application of 70 kg N fed^{-1} enhanced 1000-grain weight much more than the low rate of 50 kg N and the high rate of 90 kg N fed^{-1}. The reduction in 1000-grain weight at high N rate may be due to increase nitrogen content in plant, which may be resulted in a shortage of carbohydrate supplied per grain and in turne it is directly caused by an excessive number of grains produced by high N fertilization. The promoting effects of nitrogen on spikes number m^{-2} and grains number spike^{-1}was reported by El-Sayed and Hammad (2007), El-Samahy (2009), Ali (2013) and Javaid *et al*. (2014). El-Samahy (2009) added that increasing nitrogen fertilizer decreased 1000 kernel-weight.

Each increase in potassium fertilizer raised spikes number /m^2, grains number/ spike, and 1000-grain weight significantly during the two seasons. K application increased enzymatic activities, which likely resulted in higher nutrient mobilization in soil and plant, as well as photosynthetic translocation in plant, resulting in more spikes m^{-2}, grains spike^{-1}, and 1000-grain weight. These findings are corroborated by prior studies by El-Ashry and El-Kholy (2005), as well as Gharib and Meleha (2016).

All interactions had significant effect on spikes number m^{-2}, grains number spike^{-1} and 1000-grain weight in both seasons and except the interaction irrigation and potassium for 1000-grain weight in the second season (Table 4).

B. Straw and grain yields and harvest index:

Means of straw yield, grain yield and harvest index as affected by irrigation regime, nitrogen and potassium rate in 2015 and 2016 seasons are given in Tables 4 and 5.

Irrigation regime had significant effect on straw and grain yields in the two seasons. However, harvest index was not affected by irrigation regime in both seasons. Straw and grain yields per feddan were significantly increased by increasing soil moisture in root zone by irrigation at 40% DASM compared with irrigation at 70% DASM. Wheat plots irrigated at 40 or 55 % DASM produced nearly identical straw and grain yields. Soil moisture abundance increased grain yield by increasing the number of spikes m^{-2}, grains $spike^{-1}$, and grain weight. The increase in straw yield could be attributed to an increase in the number of tillers per unit area. Adequate water during or after anthesis not only helped the wheat plant to improve photosynthetic rate, but also provided extra time for the carbohydrates in grains to translocate, resulting in larger grain size and, eventually, increased grain output (Mirbahar *et al*., 2009). These findings are consistent with those obtained by Rizk and sherif (2014), Shirazi *et al* (2014) and Gharib and Meleha (2016).

There was a substantial difference in grain and straw yields obtained among nitrogen rates in both seasons. Raising the nitrogen rate from 50 to 90 kg N/ fed. resulted in a considerable improvement in grain and straw yields. In the two seasons, grain and straw yields were statistically equivalent at rates of 70 and 90 kg N/ fed. Thus, the increased nitrogen rate (90 kg N /fed) improved grain yield by increasing the number of spikes m^{-2} and grains $spike^{-1}$, and the medium nitrogen rate (70 kg N /fed) increased grain yield by increasing the previous two traits as well as the 1000-grain weight. These findings corroborate those of El-Sayed and Hammad (2007), Hafez (2007), EL-Samahy (2009),Zeidan *et al.* (2009), Abedi *et al.* (2011), El-Hag (2011) and EL-Hag (2012).

Table 5. Grain yield as affected by interaction of irrigation regime, nitrogen and potassium rate in 2014/15 and 2015/16 season

D %	Kg $K_2O fed^{-1}$	2014/2015 season Kg N fed^{-1}			Mean	2015/2016 season Kg N fed^{-1}			Mean
		50	70	90		50	70	90	
			D x N-mean		**D-mean**		**D x N-mean**		**D-mean**
40		2.292 b	3.085 a	3.220 a	2.865 a	2.359 b	3.119 a	3.176 a	2.885 a
55		2.108 b	3.031 a	3.193 a	2.777 a	2.194 b	3.086 a	3.130 a	2.803 ab
70		1.828 b	2.028 b	2.257 b	2.038 b	1.982 b	2.360 b	2.395 b	2.246 b
			N x K-mean		K-mean		N x K-mean		K-mean
	0	1.978 c	2.548 abc	2.789 ab	2.438 b	2.087 b	2.735 a	2.757 a	2.527 b
	12	2.068 c	2.727 ab	2.932 a	2.576 ab	2.181 b	2.874 a	2.929 a	2.661 ab
	24	2.182 bc	2.869 a	2.949 a	2.667 a	2.267 b	2.956 a	3.015 a	2.746 a
			D x N x K-mean		DxK-mean		D x N x K-mean		DxK-mean
40	0	2.127 ef	2.963 a-d	3.138 ab	2.743 a	2.219 ef	3.029 a-d	3.070 a-d	2.773 ab
	12	2.271 c-f	3.074 abc	3.268 a	2.871 a	2.368 ef	3.139 ab	3.206 ab	2.904 a
	24	2.477 a-f	3.218 a	3.253 a	2.983 a	2.488 def	3.190 ab	3.252 a	2.977 a
55	0	2.023 f	2.869 a-e	3.115 ab	2.669 ab	2.106 ef	2.996 a-d	3.002 a-d	2.701 ab
	12	2.106 ef	3.059 abc	3.225 a	2.797 a	2.193 ef	3.099 abc	3.182 ab	2.824 a
	24	2.196 def	3.165 ab	3.239 a	2.867 a	2.284 ef	3.161 ab	3.205 ab	2.884 a
70	0	1.783 f	1.813 f	2.113 ef	1.903 c	1.937 f	2.181 ef	2.200 ef	2.106 c
	12	1.827 f	2.047 ef	2.303 c-f	2.059 c	1.981 ef	2.384 ef	2.398 ef	2.254 c
	24	1.873 f	2.223 def	2.356 b-f	2.151 bc	2.028 ef	2.516 c-f	2.586 b-e	2.377 bc
N-mean		2.076 b	2.715 a	2.890 a		2.178 b	2.855 a	2.900 a	

Means of each factor followed by the same letter are not significantly different at 5 % level, according to Duncan s multiple range test.

Potassium fertilizer significantly affected grain yield in both seasons and harvest index in the first season, only. Application of 24 kg KO_2 $feddan^{-1}$ significantly increased the mentioned traits compared the control treatment without potassium. There was no significant deference in these respects between rates of 24 and kg KO_2 $feddan^{-1}$. Application of potassium fertilizer increased grain yield through increased spikes number m^{-2}, grains number $spike^{-1}$ and 1000-grain weight. The increase in harvest index is due to increase in grain yield as reported by Gharib and Meleha (2016).

All the first and second order of interactions exerted a significant effect on straw yield and grain yield in the two seasons (Table 4). None of the interaction had a significant effect on harvest index in the two seasons. Data in Table 5 show that irrigation at 40 or 55% DASM along with addition of 70 or 90 kg N fed^{-1}, being insignificant, outyielded the other combination among irrigation regime and nitrogen rate in grain yield in both seasons. The interaction between irrigation regime and potassium rate had a significant effect on grain yield (Table 5). No significant difference in grain yield among the three potassium rates with irrigation at 40 or 55% DASM. The mention interactions resulted in significant increase in grain yield compared with irrigation at 70% DASM without potassium or 12 kg k_2O fed^{-1}. The interaction of the medium irrigation regime without potassium did not differ than the low irrigation regime with 24 kg k_2O fed^{-1} in grain yield. This indicated that application of potassium improved grain yield at water stress. Data also indicated that grain yield was more affected by irrigation regime than potassium fertilizer. El-Ashry and El-Kholy (2005) found that spraying wheat plants with K before submitting them to drought treatment reduces the detrimental effects of drought on growth and, as a result, enhances yield per plant. Zareian *et al.* (2014) concluded that maximum grain yield values could be obtained from wheat cultivar WS-82-9 when irrigated normally and sprayed with 3.0 percent K2O. These conclusions are backed by earlier research findings. Aown et al (2012) and Gharib and Meleha (2016).

Grain yield was significantly affected by the interaction of nitrogen rate x potassium rate in both seasons (Table 5). The addition of 70 or 90 kg N fed-1 potassium fertilizer had no influence on grain output. In grain yield, the aforementioned interactions outperformed 50 kg N fed^{-1} without potassium and 12 kg k2O fed^{-1}. In both seasons, the second-order interaction had a considerable impact on grain yield (Table 5). In both seasons, the relative ranking of the interaction between irrigation regime, nitrogen rate, and potassium rate for grain output was inconclusive. (Table 5). The relative ranking of the interaction among irrigation regime, nitrogen rate and potassium rate for grain yield was inconsistent in both seasons. Irrigation at 40 or 55% DASM along with addition of 70 or 90 kg N fed^{-1} at any potassium rate were among those treatments having high grain yield, being insignificant, in both seasons. The interaction of low irrigation regime x low nitrogen rat x without potassium was recorded the lowest grain yield in the two seasons.

C. Water measurements:

1. Seasonal water

Seasonal of applied irrigation water (AW), water consumptive use (WCU) and stored water (SW) from sowing to harvest as affected by irrigation regimes, nitrogen and potassium rate in 2015 and 2016 seasons are presented in Table 6. AW, WCU and SW were gradually decreased by increasing soil moisture depletion from 40% to 70% DASM before irrigation in both seasons. Such increase in seasonal irrigation water (AW) by decreasing soil moisture depletion at irrigation may be attributed to increase in available moisture in root zone, which resulted in considerable increase in leaf area, in turn resulted in a greater transpiration and water requirement.

Meleha (2016) reported that the seasonal values of water applied can be descended in order irrigation to reach the field capacity in soil depths 0-60 cm >0-40 cm > 0-20 cm.Jazy et al (2012) reported that wheat may be irrigated after 90 mm cumulative pan evaporation not only may save about 22% in irrigation water with no significant loss in yield under condition similar to this experiment.

The increase of actual water consumptive use at full irrigation treatment (W1, 5I-D60) can be attributed to the increase in evaporation at high available moisture; more supplying plants with sufficient moisture led to an increase in green cover and hence increase transpiration. Rizk and sherif (2014) reported that consumptive use was increased with increasing available soil moisture. Shirazi et al (2014) found that water consumed by wheat genotypes throughout the growing season was about 293 mm / m^2 under control conditions. Tari (2016) reported that the seasonal water-consumptive use of experimental treatments varied between 206 and 571 mm. These results agree with those of Meleha (2016).

Each increment of nitrogen fertilizer increased AW, WCU and SW in the two seasons. Such effect of nitrogen could be attributed mainly to its role in the stimulation of various physiological processes including cell division and cell elongation of internodes resulting in more tillers formation, leaf numbers and leaf area, which resulted in more evapotranspiration (WCU) and in turn increased water requirement (AW). Jacobet al (2014) reported that Applying sufficient N fertilizer pre plant is most beneficial to WUE.

Application of potassium fertilizer resulted in slight increase in AW, WCU and SW in compared with control (without k) in the two seasons. These results are supported by the previous findings of Gharib and Meleha (2016).

Table 6. Water Applied (WA), Productivity of Water Applied (PWA), Water Consumptive Use (WCU), Productivity of Water Consumptive Use (PWCU), Stored Water (SW) And Water Application Efficiency (WAE) as affected by irrigation regime, nitrogen rate and potassium rate in 2014/15 and 2015/16season

Factor	WA (m^3/fed)	PWA (kg grain/m^3)	PWA (kg straw/m^3)	WCU (m3/fed)	PWCU (kg grain/m^3)	PWCU (kg straw/m^3)	SW (m^3/fed)	WAE (%)
				2014/2015 season				
Depletion % (D)								
40	3190	0.90	1.47	1973	1.45	2.37	2440	76.45
55	2824	0.98	1.61	1694	1.64	2.68	2215	78.39
70	2476	0.82	1.28	1375	1.48	2.30	2062	83.24
kg N/fed. (N)								
50	2767	0.75	1.34	1647	1.27	2.26	2085	75.73
70	2831	0.95	1.47	1678	1.61	2.49	2241	79.44
90	2892	0.99	1.54	1717	1.68	2.60	2391	82.90
kg K_2O/fed. (K)								
0	2817	0.86	1.42	1676	1.45	2.39	2234	79.55
12	2833	0.90	1.45	1681	1.53	2.45	2240	79.32
24	2840	0.93	1.49	1684	1.58	2.51	2243	79.20
				2015/2016 season				
Depletion % (D)								
40	3204	0.90	1.29	1979	1.46	2.09	2472.4	77.1
55	2884	0.97	1.28	1712	1.63	2.15	2266.9	78.51
70	2500	0.90	1.25	1383	1.62	2.25	2095.3	83.76
kg N/fed. (N)								
50	2784	0.79	1.09	1653	1.33	1.84	2097.7	75.74
70	2864	1.00	1.30	1698	1.69	2.19	2278.3	79.84
90	2941	0.98	1.43	1723	1.69	2.46	2458.4	83.78
kg K_2O/fed. (K)								
0	2852	0.88	1.23	1688	1.50	2.10	2273.3	79.92
12	2866	0.93	1.28	1692	1.58	2.19	2278.8	79.72
24	2871	0.96	1.30	1694	1.63	2.22	2282.4	79.72

Water Applied (WA), Productivity of Water Applied (PWA), Water Consumptive Use (WCU), Productivity of Water Consumptive Use (PWCU), Stored Water (SW) and Water Application Efficiency (WAE)

There were substantial differences in AW, WCU and SW among combination of irrigation regime and nitrogen fertilizer rate in both seasons (Tables 7 and 8). AW, WCU and SW were increased by decreasing water depletion before irrigation along with increasing nitrogen rate. At the same nitrogen rate, decreasing water depletion before irrigation led to markedly increase in AW, WCU and SW in the two seasons. Data showed that irrigation regime had more effect on the mentioned trait than nitrogen rate. The interaction of irrigation at 40% DASM and 90 kg N fed^{-1} recorded the highest values of AW (3241 and 3256 m^3 fed^{-1}), WCU (2011 and 2017 m^3 fed^{-1}) and SW (2618 and 2688 m^3 fed^{-1}), while irrigation at 70%

DASM with 50 kg N fed^{-1} recorded the lowest values of AW (2421 and 2433 m^3 fed^{-1}), WCU (1342 and 1350 m^3 fed^{-1}) and SW (1943 and 1961 m^3 fed^{-1}) in the two season.

The interaction between irrigation and K fertilizer distinctly influenced v,AW, WCU and SW in both seasons. Application of K fertilizer slightly increased the mentioned traits at the same irrigation regime in the two seasons. Data show that irrigation treatments were more effective on AW, WCU and SW than K fertilizer.

Data in Tables 7 and 8 shows that the interaction between N and K rates nitrogen rate more influenced on AW, WCU and SW than K rate. These traits were increased by increasing N rate at any K rate, while it was slightly increased by K fertilizer compared without K at any N rate.

Table 7. Water Applied (WA), Productivity of Water Applied (PWA), Water Consumptive Use (WCU), Productivity of Water Consumptive Use (PWCU), Stored Water (SW) And Water Application Efficiency (WAE) as affected by irrigation regime (depletion %, D) , nitrogen and potassium rates in 2014/2015 season.

D	N	K	WA (m^3/fed)	PWA (kg grain/m^3)	PWA (kg straw/m^3)	WCU (m3/fed)	PWCU (kg grain/m^3)	PWCU (kg straw/m^3)	SW (m^3/fed)	WAE (%)
1	1	1	3124	0.68	1.31	1933	1.10	2.12	2252	72.09
1	1	2	3142	0.72	1.31	1938	1.17	2.13	2258	71.88
1	1	3	3150	0.79	1.33	1941	1.28	2.16	2261	71.77
1	2	1	3176	0.93	1.49	1967	1.51	2.41	2440	76.82
1	2	2	3194	0.96	1.50	1972	1.56	2.43	2446	76.59
1	2	3	3202	1.00	1.59	1975	1.63	2.57	2449	76.48
1	3	1	3226	0.97	1.54	2006	1.56	2.47	2613	81.00
1	3	2	3244	1.01	1.55	2012	1.62	2.51	2620	80.76
1	3	3	3252	1.00	1.57	2015	1.61	2.54	2623	80.64
2	1	1	2728	0.74	1.45	1656	1.22	2.39	2052	75.23
2	1	2	2743	0.77	1.50	1661	1.27	2.48	2058	75.01
2	1	3	2750	0.80	1.52	1664	1.32	2.51	2060	74.90
2	2	1	2812	1.02	1.56	1686	1.70	2.61	2210	78.61
2	2	2	2828	1.08	1.66	1691	1.81	2.78	2216	78.38
2	2	3	2835	1.12	1.73	1694	1.87	2.90	2219	78.26
2	3	1	2892	1.08	1.66	1726	1.80	2.78	2369	81.89
2	3	2	2909	1.11	1.70	1731	1.86	2.85	2375	81.65
2	3	3	2916	1.11	1.70	1734	1.87	2.85	2378	81.53
3	1	1	2410	0.74	1.19	1339	1.33	2.14	1939	80.44
3	1	2	2424	0.75	1.21	1343	1.36	2.19	1944	80.20
3	1	3	2430	0.77	1.25	1345	1.39	2.25	1946	80.08
3	2	1	2465	0.74	1.19	1367	1.33	2.14	2057	83.47
3	2	2	2479	0.83	1.24	1372	1.49	2.25	2063	83.22
3	2	3	2485	0.89	1.29	1374	1.62	2.34	2065	83.10
3	3	1	2519	0.84	1.36	1407	1.50	2.44	2177	86.43
3	3	2	2533	0.91	1.38	1411	1.63	2.48	2183	86.17
3	3	3	2539	0.93	1.39	1413	1.67	2.51	2185	86.05

Water Applied (WA), Productivity of Water Applied (PWA), Water Consumptive Use (WCU), Productivity of Water Consumptive Use (PWCU), Stored Water (SW) and Water Application Efficiency (WAE)

The second order interaction among irrigation, N and K rate distinctly influenced AW, WCU and SW in both seasons (Tables 7 and 8). Decreasing soil moisture depletion before irrigation along with increasing N and K rate substantially increased AW, WCU and SW in both seasons. Abundance of available soil moisture (irrigation at 40% DASM) with 90 kg N and 24 kg K_2O fed^{-1} produced the highest values of AW (3252 and 3264 m^3 fed^{-1}), WCU (2015 and 2020 m^3 fed^{-1}) and SW (2623 and 2693 m^3 fed^{-1}). However, irrigation at 70% DASM with 50 kg N and without k fertilizer recorded the lowest values of AW (2410 and 2423 m^3 fed^{-1}), WCU (1339 and 1347 m^3 fed^{-1}) and SW (1939 and 1956 m^3 fed^{-1}) in the two seasons.

2. Water productivity:

Grain yield per unit of applied water (AW) and water consumptive use (WCU) in kg grain or straw m^{-3}water were used to determine water productivity. Data in Table 6 show that water productivity of grain and straw (kg m^{-3} water) for either AW or WCU was increased by increasing soil moisture depletion from 40 to 55% DASM at irrigation and then it decreased. This may be due to increase grain and straw yields.

In this connection, Rizk and Sherif (2014) found that the highest value of water use efficiency when irrigation water was applied at 40 % available soil moisture for grain. Guendouz et al (2016) found that water deficit increased water use efficiency. Tari (2016) reported that irrigation water-use efficiencies varied between 0.51 and 1.17 kg m^{-3}. These results agree with those of Meleha (2016) and Guendouz *et al* (2016).

The water productivity of grain and straw for AW and WCU was increased by increasing nitrogen rate from 50 to 90 kg N fed^{-1} and potassium rate from 0 to 24 kg k_2O fed^{-1} in both seasons. NK fertilizer increased water productivity through increasing grain and straw yields. In this connection, Gharib and Meleha (2016) found that the water productivity for AW and WCU was slightly increased by application of K fertilizer.

The interaction of irrigation regime and nitrogen rate influenced the water productivity of grain and straw for AW and WCU in both seasons (Tables 7 and 8). The relative ranking of the interaction between irrigation regime and nitrogen rate for water productivity was inconsistent in both seasons. At the same irrigation regime, application of 70 or 90 kg N fed^{-1} increased the water productivity of grain and straw for AW and WCU compared with 50 kg N fed^{-1}. Irrigation at 55% DASM along with addition of 70 or 90 kg N fed^{-1} were among those treatments having high water productivity of grain and straw for AW and WCU in the most cases. Application of 70 or 90 kg N fed^{-1} practically produced the same productivity of grain and straw for AW and WCU at any irrigation regime.

Table 8. Water Applied (WA), Productivity of Water Applied (PWA), Water Consumptive Use (WCU), Productivity of Water Consumptive Use (PWCU), Stored Water (SW) and Water Application Efficiency (WAE) as affected by irrigation regime (depletion %, D) , nitrogen and potassium rates in 2015/2016 season

D	N	K	WA (m^3/fed)	PWA (kg grain/m^3)	PWA (kg straw/m^3)	WCU (m3/fed)	PWCU (kg grain/m^3)	PWCU (kg straw/m^3)	SW (m^3/fed)	WAE (%)
1	1	1	3140	0.71	1.15	1938	1.15	1.86	2254.3	71.78
1	1	2	3156	0.75	1.23	1942	1.22	1.99	2259.8	71.60
1	1	3	3161	0.79	1.23	1945	1.28	1.99	2263.3	71.60
1	2	1	3193	0.95	1.31	1973	1.53	2.12	2464.7	77.19
1	2	2	3209	0.98	1.31	1978	1.59	2.13	2470.7	77.00
1	2	3	3214	0.99	1.33	1980	1.61	2.16	2474.6	77.00
1	3	1	3243	0.95	1.35	2014	1.52	2.17	2682.2	82.70
1	3	2	3259	0.98	1.36	2018	1.59	2.20	2688.8	82.49
1	3	3	3264	1.00	1.38	2020	1.61	2.23	2693	82.49
2	1	1	2755	0.76	0.95	1665	1.27	1.57	2068.9	75.09
2	1	2	2769	0.79	0.99	1668	1.31	1.64	2074	74.91
2	1	3	2773	0.82	1.01	1670	1.37	1.67	2077.3	74.91
2	2	1	2874	1.04	1.35	1735	1.73	2.23	2263.1	78.75
2	2	2	2888	1.07	1.43	1739	1.78	2.38	2268.7	78.55
2	2	3	2893	1.09	1.44	1741	1.82	2.40	2272.2	78.55
2	3	1	2990	1.00	1.41	1727	1.74	2.45	2453.9	82.07
2	3	2	3005	1.06	1.44	1731	1.84	2.51	2459.9	81.86
2	3	3	3010	1.06	1.45	1733	1.85	2.52	2463.8	81.86
3	1	1	2423	0.80	1.07	1347	1.44	1.92	1956.4	80.73
3	1	2	2435	0.81	1.08	1350	1.47	1.95	1961.2	80.53
3	1	3	2439	0.83	1.09	1352	1.50	1.97	1964.3	80.53
3	2	1	2492	0.88	1.11	1376	1.59	2.01	2092.5	83.98
3	2	2	2504	0.95	1.16	1379	1.73	2.11	2097.6	83.77
3	2	3	2508	1.00	1.21	1380	1.82	2.20	2100.9	83.77
3	3	1	2556	0.86	1.41	1418	1.55	2.53	2223.4	86.98
3	3	2	2569	0.93	1.53	1421	1.69	2.77	2228.8	86.77
3	3	3	2573	1.01	1.55	1423	1.82	2.81	2232.3	86.77

Water Applied (WA), Productivity of Water Applied (PWA), Water Consumptive Use (WCU), Productivity of Water Consumptive Use (PWCU), Stored Water (SW) and Water Application Efficiency (WAE)

The interaction between irrigation regime and potassium rate influenced the water productivity of grain and straw for AW and WCU in both seasons (Tables 7 and 8). Application of K fertilizer slightly increased the water productivity of grain and straw for AW and WCU at the same irrigation regime in the two seasons. Irrigation at 55% DASM with 24 kg K_2O fed^{-1} markedly increased the water productivity of grain and straw for AW in both seasons and WCU in the first season compared with irrigation at 70% DASM without K fertilizer. In the second season, the highest of water productivity of grain and straw for WCU was obtained from irrigation at 70% DASM with the rate of 24 kg K_2O fed^{-1}, while the lowest one was obtained from irrigation at 40% DASM without K fertilizer.

The interaction between nitrogen rate and potassium rate had a substantial effect on the water productivity of grain and straw for AW and WCU in both seasons (Tables 7 and 8). The mentioned traits were increased by increasing NK rate. Application of 90 or 70 Kg N along with 24 kg K_2O fed^{-1} resulted in pronounce increase in the water productivity of grain and straw for AW and WCU compared with 50 Kg N without K fertilizer.

The interaction of irrigation x N rate x K rate had a substantially effect on the water productivity of grain and straw for AW and WCU in both seasons. Irrigation at 55% DASM with 70 kg N and 24 kg K_2O fed^{-1} produced the highest water productivity values of grain for AW (1.12 and 1.09 kg grain m^3 AW), while irrigation at 40% DASM with 50 kg N and without K fertilizer (0.68 and 0.71 kg grain m^3 AW) in the two seasons. Irrigation at 55% DASM with 70 or 90 kg N and 12 or 24 kg K_2O fed^{-1} did not differ in the productivity of grain for AW than Irrigation at 55% DASM with 70 kg N and 24 kg K_2O fed^{-1} in both seasons. In the first season, Irrigation at 55% DASM with 70 kg N and 24 kg K_2O fed^{-1} produced the highest water productivity values of grain for WCU (1.73 kg grain m^3 WCU), while irrigation at 40% DASM with 50 kg N and without K fertilizer (1.19 kg grain m^3 WCU). Irrigation at 55% DASM with either combination of 70 or 90 kg N and 24 kg K_2O fed^{-1} or 70 or 90 kg N and 12 or 24 kg K_2O fed^{-1} practically produced the same productivity of grain for WCU Irrigation in the first seasons. The relative ranking of the interaction among irrigation regime, nitrogen rate and potassium rate for water productivity of straw for AW was inconsistent in both seasons. In the first season, Irrigation at 55% DASM with 70 kg N and 24 kg K_2O fed^{-1} produced the highest water productivity values of straw for AW (1.73 kg straw m^3 AW), while irrigation at 40% DASM with 50 kg N and without K fertilizer (1.19 kg straw m^3 AW). Irrigation at 55% DASM with either combination of 70 or 90 kg N and 24 kg K_2O fed^{-1} or 70 or 90 kg N and 12 or 24 kg K_2O fed^{-1} practically produced the same productivity of straw for AW in the first seasons. The water productivity of grain or straw for AW was increased at 70 or 90 kg N fed^{-1} with any potassium rate by increasing soil moisture depletion at irrigation from 40 to 55% DASM and then it decreased.

The water productivity of grain and straw for WCU as affected by the interaction of irrigation, nitrogen rate and potassium rate are presented in Tables 7 and 8 . Increasing soil moisture depletion at irrigation from 40 to 55% DASM at any combination of NK fertilizer markedly increased the water productivity of grain for WCU and then decreased it in both seasons. Irrigation at 55% DASM along with addition of 70 or 90 kg N fed^{-1} and 12 or 24 kg K_2O fed^{-1} were among those treatments having high water productivity of grain for WCU in the two seasons. The water productivity of grain for WCU (kg grain m^3 WCU) was ranged from 1.19 to 1.73 in the first season and from 1.15 to 1.85 the second season.

3. Water application efficiency %

The percentage of water application efficiency (WAE) was substantially increased by decreasing amount of applied water by irrigation at 70% DASM in both seasons (Table 6). This may be due to decreased WCU at 70% DASM.

Increasing nitrogen rate from 50 to 90 kg N fed^{-1} gradually increased WAE% in both seasons. Application of 90 kg N fed^{-1} recorded the highest values of WAE %, while Application of 50 kg N fed^{-1} recorded the lowest ones. This may be due to increased AW at the high N rate.

Application of potassium fertilizer had slightly effect on the percentage of WAE in the two seasons.

The interaction of irrigation regime and nitrogen rate influenced the percentage of WAE in both seasons (Tables 7 and 8). Data show that increasing soil moisture depletion at irrigation along with increasing nitrogen rate exerted a marked increase in WAE % in the two seasons. The highest values of WAE% were obtained from irrigation at 70% DASM with application of 90 kg N fed^{-1}, while the lowest ones were obtained from irrigation at 40% DASM with application of 50 kg N fed^{-1}.

The interaction between irrigation regime and potassium rate influenced the WAE % in both seasons (Tables 7 and 8). At the same irrigation regime, WAE % did not affect by application of K fertilizer in the two seasons. In the contrary, decreasing amount of AW by increasing soil moisture depletion from 40 to 70% at irrigation substantially increased WAE % at any K fertilizer rate. This indicated that irrigation regime more effective than potassium fertilizer on WAE %.

WAE% was pronouncedly influenced by the interaction between nitrogen rate and potassium rate in both seasons (Tables 7 and 8). Application of K fertilizer had inferior effect on WAE% at the same nitrogen rate in the two seasons. However, WAE% was increased by increasing nitrogen rate at any potassium rate in the two seasons.

The interaction among irrigation regime, nitrogen rate and potassium rate had a substantially effect on WAE% in both seasons (Tables 7 and 8). Potassium fertilizer had a slightly effect on WAE% at the same combination of irrigation regime and nitrogen rate in the two seasons. However, increasing of soil moisture depletion at irrigation with increasing nitrogen rate increased WAE% at the same potassium rate. Irrigation at 70% DASM with 90 kg N and 0 kg K_2O fed^{-1} produced the highest values of WAE (86.43 and 86.98 %), while irrigation at 40% DASM with 50 kg N and 24 kg K2O fed-1 produced the lowest values (71.77 and 71.60 %) in the two seasons.

It can be concluded that irrigation at 55% DASM with application of 70 kg N and 12 or 24 kg K_2O fed^{-1} was the best treatment, which resulted in high grain yield with less amount of applied irrigation water (1.12 and 1.09 kg grain m^3 AW), and water consumptive use (1.73 kg grain m^3 WCU) in Kafr Elshiekh Governorate.

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تاثير اسمدة النيتروجين و البوتاسيوم على انتاجبة القمح فى ظل اختلاف محتوى رطوبة التربة

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1 قسم المحاصيل ،كلية الزراعة ،جامعة كفر الشيخ

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تم زراعة صنف القمح سخا 93 في تربة طينيه بمزرعة محطة البحوث الزراعية بكفر الشيخ في عامى 2015/2014 و2016/2015 ، لدراسة تأثير ثلاث مستويات ري وثلاث معدلات للسماد نيتروجين وثلاث معدلات للسماد البوتاسي على النمو والمحصول ومكوناته والمحتوى الكيمياوي فى الحبوب والقش وبعض العلاقات المائية. تم استخدام مستويات الري عند استنفاذ 40 و 55 و 70% من الرطوبة الميسرة بالتربة على عمق 0-60 سم. وقد تم استخدام السماد النيتروجينى في صورة يوريا (46.5% نيتروجين) بمعدلات 50، 70 و 90 كجم ن/فدان. وقد تم استخدام السمادالبوتاسي في صورة سلفات البوتاسيوم (48% K_2O) بمعدلات 0, 12 و 24 كجم K_2O/ فدان.أدى الري عند استنفاذ 40 أو 55 ٪ من الرطوبة الميسرة بالتربة إلى زيادة معنوية في عدد السنابل/م^2، طول السنبلة ، عدد الحبوب فى السنبلة، وزن 1000- حبة ومحصول الحبوب والقش بالمقارنة بالري عند استنفاذ 70% من الرطوبة الارضية في كلا الموسمين. ولم تظهر فروق معنوية في مكونات المحصول السابقة بين الري عند استنفاذ 40 أو 55 ٪ من الرطوبة الميسرة بالتربة في الموسمين.أدت زيادة استنفاذ رطوبة التربة من 40 إلى 55٪ عند الرى مع اى توليفة من التسميد النيتروجيني والبوتاسى الى زيادة واضحه فى إنتاجية المياه من الحبوب لكل من كمية ماء الري والاستهلاك المائى ثم انخفضت عند استنفاذ 70٪ من الرطوبة الارضية عند الرى في كلا الموسمين. كان الري عند استنفاذ 55٪ من الرطوبة الارضية مع إضافة 70 أو 90 كجم نيتروجين /فدان و 12 أو 24 كجم K_2O/ فدان من بين هذه المعاملات أعطت إنتاجية عالية من المياه للحبوب في كلا الموسمين. سجل الري عند استنفاذ 70٪ من الرطوبة الارضية مع 90 كجم نيتروجين/فدان بدون سماد بوتاسى أعلى قيم لكفاءة مياة الرى (86.43 و 86.98٪) ، بينما الري عند استنفاذ 40٪ من الرطوبة الارضية مع 50 كجم نيتروجين /فدان و 24 كجم K_2O/فدان سجلت اقل القيم (71.77 و 71.60٪) في كلا الموسمين.ويستنتج من النتائج السابقة بانه يمكن رى القمح عند استنفاذ 55٪ من الرطوبة الارضية مع إضافة 70 كجم نيتروجين + 12 كجم K_2O/ فدان للحصول على اعلى إنتاجية محصول حبوب القمح في محافظة كفرالشيخ.