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DEFICIT IRRIGATION OF WHEAT UNDER SPRINKLER IRRIGATION IN THE NEWLY RECLAIMED SOILS OF EGYPT

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ABSTRACT

Two seasons field experiments were conducted at Sugar Beet region, West Nubaria on wheat (*Triticum aestivum* L.) cv. Sakha 8 under sprinkler irrigation system. The aim of this study was to investigate the effect of deficit irrigation and N fertilization rate on yield and yield components of wheat grown in the newly reclaimed soils that facing conditions of limited irrigation water in order to accomplish optimum production. Five regimes of irrigation were randomly assigned as main plots, and two N fertilization rates 143 and 214 kg ha^{-1} (60 and 90 kg/feddan) as sub-plots in a split plot design. The irrigation regimes were selected to impose water stress throughout the growing season, and stress at one of the growth stages of wheat (vegetative, flowering, and yield formation), in addition to full irrigation. Imposing the stress at a certain stage imply that only 50 % of the crop evapotranspiration (ET_c) was applied in irrigation.

Data showed that the five irrigation regimes resulted in grain yield of 2801, 4571, 4345, 3994, and 5390 kg ha^{-1}, respectively. These values were corresponding to actual evapotranspiration (ET_a) of 207.9, 312.6, 381.4, 336.6, and 449.5 mm, crop factor (k_c) of 0.449, 0.676, 0.825, 0.728, and 0.973, yield response factor (k_y) of 0.735, 0.378, 0.538, 0.595, and 0.176, and water use efficiency (WUE) of 13.60, 14.60, 11.44, 11.89, and 11.98 kg ha^{-1} per mm ET_a, respectively. The saving of irrigation water due to deficits at the vegetative, flowering, and yield formation stages were 26.8, 13.2, and 23.4% resulted in reduction of grain yield 15.2, 19.4, and 25.9%, respectively. Several water regimes of low water application gave grain yields, which were insignificantly different from the full irrigation treatment. Reducing the applied N fertilizer from 214 to 143 kg ha^{-1} (33.3 %) resulted in reduction of grain yield from 4504 to 3936 kg ha^{-1} (12.6 %), and had little effects on the other yield characteristics.

This study showed that the efficient use of limited amount of irrigation water available for wheat production was reached if applied to relieve stress during flowering (mid- late-February to mid- late-March) followed by yield formation (late-March to mid-April), and least during vegetative stage (mid-December to late-February). This can be coupled with the application of N fertilizer rate of 143 kg ha^{-1} which leads to optimum yield and environment sustainability.

INTRODUCTION

Water scarcity in the next decades is a real threat to food production in arid and semi-arid areas where water is the limiting factor in the expansion of cultivated land. Therefore, water management that maximize yield per unit of water consumed by plant are highly desired. In Egypt, limited water resources coupled with high population forced to a great competition for water supply that makes conservation and efficient use of water obligatory (Ibrahim, 1999; and Gaber, 2000). Moreover, the newly reclaimed soils facing numerous problems; amongst water shortage which is the most important factor for crop production. Subsequently, efficient and optimal scheduling of limited amounts of water for high yields of some selected low water consuming and high valuable crops is urgently needed.

Wheat is a major strategic food and feed grain crop successfully grown under limited water conditions, i.e. the newly reclaimed soils, therefore, its growth, and high productivity depend mainly on the proper water and fertilizer management. The various crop development stages posses different sensitivities to moisture stress where time, duration, and the degree of the stress all affect yield (Doorenbos and Kassam, 1986; English and Nakamura, 1989; and Ghahraman and Sepaskhah, 1997).

Deficit irrigation is a strategy which allows a crop to sustain some degree of water stress in growth stages of less sensitive to water or throughout the whole growing season in order to save irrigation water (Kirda, 1999; and Labhsetwar, 2003). The knowledge of the critical stage/s to water deficit is very important for judicious water management (Gad El-Rab *et al.*, 1988). The expectation is that any yield reduction will be insignificant compared with the benefits gained through diverting the saved water to irrigate other areas/crops. This strategy maximizing WUE, i.e. producing more with less irrigation water applied, and where properly practiced, may increase profits and crop quality. For example, the protein content and baking quality of wheat increase under deficit irrigation (Kirda, 1999). Deficit irrigation can be practical choice for growers, and they must have prior knowledge of crop yield responses to deficit irrigation. The relationships between crop growth, soil-water, and fertilization level are complicated and must be justified in order to develop better soil, water, and crop management (Huang *et al.*, 2003).

The objective of this study was to investigate the effect of imposed water stress through deficit irrigation in certain growth stages of wheat, and N fertilization rate aiming at the levels that optimizing the productivity and save water under limited supply of irrigation water of the newly reclaimed soils in Egypt.

MATERIALS AND METHODS

The field experiments were conducted at West Nubaria, Sugar Beet region, Village 3 of youth graduates (30°20'N , 30°40'E) during the successive seasons of 2000/2001 and 2001/2002. The soil of the experimental site is calcareous (*Typic Calcids*), non-saline, loamy sand with bulk density of 1.32-1.42 Mg m^{-3}. Wheat was drilled in soil at 0.2 m×0.2 m spacing on December 14, 2000 and November 29, 2001. The wheat variety was Sakha 8 (local) with about 160-165 days of growing season. Five levels of deficit irrigation were tested as main plots,and two N fertilization rates 143 and 214 kg ha^{-1}(60 and 90 kg/feddan), divided in two doses 3 and 8 weeks from planting, as sub-plots in a split plot design with three replications. The irrigation regimes include full watering (1111) and stress (0000) throughout the growing season, and stress at the vegetative including tillering and head development (0111), flowering (1011), and yield formation known as seed filling (1101) growth stages. The selected growth stages are most relatively sensitive to water stress (Zhang, 2003). The development of uniform water deficit at all growth stages (0000) was necessary for valid comparisons and rarely attempted in the field (Doorenbos and Kassam, 1986). The vegetative stage was the longest and extended to March 3 and February 20 in the first and second season, respectively. The irrigation system was hand-moved sprinkler system of 12 m×12 m spaces. Imposing the stress at a specified growth stage of wheat imply that only 50% of the ET_c was applied in irrigation. The potential evapotranspiration (ET_0) was calculated from weather data according to Penman-Monteith formula (Allen *et al.*, 1998) using the CROPWAT software, FAO, and related to ET_c through the k_c as:

$$ET_c = k_c \times ET_0$$

Catchments cans of 100 mm in diameter were placed at 0.5, 1, 2, 4 and 6 m distances from each of two successive sprinklers to estimate the average water applied. To prevent distortion of water application patterns, irrigation was applied every fourth day during periods of no or minimum wind movement.

The water-balance equation was used to estimate actual evapotranspiration in the root zone:

$$ET_a = I + P + \Delta S - R_u - D_r$$

where I is irrigation, P is precipitation, ΔS is soil water depletion (change in moisture content) in the root zone , R_u is runoff, and D_r is drainage below root zone. Irrigation was applied with assurance that R_u and D_r were minimal or zero. Gravimetric soil samples were collected every 15 cm-interval down to 75 cm depth before and after irrigation from the center of each plot at two replicates of each irrigation treatment to monitor the moisture regime. Soil samples were collected before planting and after harvesting to monitor salt balance with different water regimes.

The general recommended agricultural practices for commercial wheat production were followed. Harvesting was carried out on May 9 and May 2, respectively for the first and second seasons. The yield and yield characteristics were estimated from 0.5 m strip along the sprinklers line. The deficit irrigation stress index (DISI) and nitrogen stress index (NSI) were calculated as 100×[(highest value-parameter value)/highest value] for each deficit irrigation and fertilizer treatment, respectively.

RESULTS AND DISCUSSION

Yield and Yield Characteristics:

The averages of yield and yield components of wheat in the two growing seasons for the five irrigation regimes and the two N fertilizer rates are given in Table 1.

I) Gross Yield:

Irrigation regimes resulted in no significant differences in gross yields with the application of 143 kg N ha^{-1} in both seasons, but all were higher than 0000 regime in the second season. The application of 214 kg N ha^{-1} fertilization showed that the 0111 and 1011 were not significantly different, but higher than other regimes in the first season, and the 1111 was the highest regime and not differed from 0111 regime in the second season. The average of irrigation regimes data showed that 0111 and 1011 in the first season, 1111 and 0111 in the second season were the highest regimes in gross yield and not differed from each other. The DISI were in this order 0000>1101>1111>0111>1011 and 0000>1101>1011>0111>1111 in the first and second season, respectively. Reducing the amount of applied water by 1120 (26.7%) and 1240 (26.8%) m^3ha^{-1} (from 1111 to 0111 regime) resulted in 12.4% more and 7.8% less gross yield in the first and second season, respectively.

Table 1. Yield and yield components of wheat grown at Village 3, Sugar Beet Region, West Nubaria.

Season I								
Parameter	Applied N (kg ha^{-1})	Irrigation Regime[†]					Avg. N Tr't	NSI[#] (%)
		0000	0111	1011	1101	1111		
Gross Wt. (kg ha^{-1})	143	12450^{ab}	13833^{a}	13667^{a}	12667^{a}	12884^{a}	13100^{x}	9.45
	214	12583^{b}	16414^{a}	16883^{a}	12892^{b}	13568^{b}	14468^{y}	0
	Avg. Irrig. regime	12517^{b}	15124^{a}	15275^{a}	12780^{b}	13226^{b}	*	
	DISI (%)	18.06	0.99	0	16.34	13.41		
Grains Wt. (kg ha^{-1})	143	2655^{b}	3963^{a}	4118^{a}	3751^{ab}	4892^{a}	3876^{x}	10.98
	214	2966^{b}	4580^{a}	4764^{a}	4188^{ab}	5271^{a}	4354^{y}	0
	Avg. Irrig. regime	2811^{b}	4272^{a}	4441^{a}	3970^{ab}	5082^{a}	**	
	DISI (%)	44.69	15.94	12.60	21.88	0		
Straw Wt. (kg ha^{-1})	143	9795^{a}	9870^{a}	9549^{a}	8916^{a}	7992^{a}	9224^{x}	8.79
	214	9617^{b}	11834^{a}	12119^{a}	8704^{b}	8297^{b}	10114^{y}	0
	Avg. Irrig. regime	9706^{ab}	10852^{a}	10834^{a}	8810^{b}	8145^{b}	*	
	DISI (%)	10.56	0	0.17	18.82	24.94		
Plant Height (cm)	143	85.3^{b}	92.4^{a}	90.5^{a}	84.7^{b}	93.2^{a}	89.2^{x}	3.53
	214	85.1^{b}	97.1^{a}	96.4^{a}	86.8^{b}	97.0^{a}	92.5^{x}	0
	Avg. Irrig. regime	85.2^{b}	94.8^{a}	93.5^{a}	85.8^{b}	95.1^{a}	*	
	DISI (%)	10.41	0.37	1.74	9.83	0		
Avg. No. of Grains per Spike	143	35^{c}	39^{abc}	41^{ab}	36^{bc}	43^{a}	39^{x}	5.83
	214	38^{b}	41^{ab}	45^{a}	37^{b}	45^{a}	41^{x}	0
	Avg. Irrig. regime	37^{b}	40^{ab}	43^{a}	37^{b}	44^{a}	**	
	DISI (%)	17.05	9.09	2.27	17.05	0		
100-Kernels Wt. (g)	143	5.89^{b}	6.23^{ab}	6.14^{ab}	6.15^{ab}	6.37^{a}	6.16^{x}	6.90
	214	6.37^{a}	6.66^{a}	6.73^{a}	6.60^{a}	6.70^{a}	6.61^{y}	0
	Avg. Irrig. regime	6.13^{x}	6.45^{a}	6.44^{a}	6.38^{a}	6.54^{a}	*	
	DISI (%)	6.20	1.38	1.53	2.45	0		
Avg. Spike Length (cm)	143	9.6^{a}	9.8^{a}	9.8^{a}	9.5^{a}	10.1^{a}	9.8^{x}	1.41
	214	9.6^{b}	9.9^{ab}	10.1^{ab}	9.5^{b}	10.4^{a}	9.9^{x}	0
	Avg. Irrig. regime	9.6^{b}	9.9^{ab}	10.0^{ab}	9.5^{b}	10.3^{a}	*	
	DISI (%)	6.34	3.90	2.93	7.32	0		
No. of Spikes m^{-2}	143	333^{a}	367^{a}	366^{a}	349^{a}	389^{a}	361^{y}	7.34
	214	364^{a}	398^{a}	382^{a}	388^{a}	415^{a}	389^{x}	0
	Avg. Irrig. regime	349^{a}	383^{a}	374^{a}	369^{a}	402^{a}	NS	
	DISI (%)	13.31	4.85	6.97	8.33	0		

Table 1...con't

SEASON II								
Parameter	Applied N (kg ha^{-1})	Water Regime					Avg. N Tr't	NSI (%)
		0000	0111	1011	1101	1111		
Gross Wt. (kg ha^{-1})	143	10668^{c}	13500^{b}	14167^{a}	13033^{a}	14426^{a}	13159^{x}	4.27
	214	12016^{c}	14333^{ab}	13458^{b}	13167^{bc}	15757^{a}	13746^{x}	0
	Avg. Irrig. regime	11342^{c}	13917^{ab}	13813^{b}	13100^{bc}	15092^{a}	**	
	DISI (%)	24.85	7.79	8.47	13.20	0		
Grains Wt. (kg ha^{-1})	143	2435^{c}	4193^{ab}	4438^{ab}	3862^{b}	5049^{a}	3995^{x}	14.15
	214	3146^{d}	5547^{ab}	4058^{bc}	4174^{cd}	6344^{a}	4654^{y}	0
	Avg. Irrig. regime	2791^{c}	4870^{b}	4248^{b}	4018^{bc}	5697^{a}	**	
	DISI (%)	51.01	14.51	25.43	29.47	0		
Straw Wt. (kg ha^{-1})	143	8233^{a}	9307^{a}	9729^{a}	9171^{a}	9377^{a}	9163^{x}	0
	214	8870^{a}	8786^{a}	9400^{a}	8859^{a}	9413^{a}	9086^{x}	1.13
	Avg. Irrig. regime	8552^{a}	9047^{a}	9565^{a}	9015^{a}	9395^{a}	NS	
	DISI (%)	10.59	5.42	0	5.75	1.78		
Plant Height (cm)	143	78.5^{d}	88.6^{ab}	86.2^{bc}	85.1^{c}	89.6^{a}	85.6^{x}	4.08
	214	83.3^{c}	93.7^{a}	87.4^{b}	90.5^{ab}	91.3^{a}	89.2^{y}	0
	Avg. Irrig. regime	80.9^{c}	91.2^{a}	86.8^{b}	87.8^{b}	90.5^{ab}	**	
	DISI (%)	11.25	0	4.77	3.68	0.77		
Avg. No. of Grains per Spike	143	37^{b}	41^{ab}	44^{a}	41^{ab}	45^{a}	42^{y}	6.36
	214	42^{b}	45^{ab}	44^{ab}	41^{b}	48^{a}	44^{x}	0
	Avg. Irrig. regime	40^{b}	43^{ab}	44^{ab}	41^{b}	47^{a}	**	
	DISI (%)	15.05	7.53	5.38	11.83	0		
100-Kernels Wt. (g)	143	5.38^{c}	6.67^{b}	7.93^{a}	6.62^{b}	6.94^{b}	6.71^{x}	14.55
	214	6.92^{c}	7.41^{ab}	7.23^{ab}	7.12^{b}	7.88^{a}	7.31^{y}	0
	Avg. Irrig. regime	6.15^{c}	7.04^{ab}	7.58^{a}	6.87^{b}	7.41^{a}	*	
	DISI (%)	18.87	7.12	0	9.37	2.24		
Avg. Spike Length (cm)	143	8.5^{b}	9.9^{a}	10.1^{a}	9.8^{a}	10.2^{a}	9.7^{x}	8.48
	214	9.1^{c}	11.0^{a}	10.2^{b}	10.3^{b}	11.1^{a}	10.3^{y}	0
	Avg. Irrig. regime	8.8^{c}	10.5^{ab}	10.2^{ab}	10.1^{b}	10.7^{a}	**	
	DISI (%)	17.37	1.88	4.69	5.63	0		
No. of Spikes m^{-2}	143	367^{b}	429^{ab}	469^{ab}	403^{ab}	482^{a}	430^{x}	6.80
	214	392^{b}	486^{ab}	443^{ab}	408^{b}	524^{a}	451^{x}	0
	Avg. Irrig. regime	380^{c}	458^{ab}	456^{ab}	406^{bc}	503^{a}	*	
	DISI (%)	24.55	9.05	9.34	19.38	0		

[†] 0 ="Stress" water application equal to 50% of ET_c, and 1 ="Full Irrigation" water application equal to 100% of ET_c at the specified growth stage.

[‡] Values in the same rows for irrigation regimes or same column for fertilizer averages followed by same letter/s are not significantly different at the 0.05 level of probability.

[*] NS, *, ** interactions are not significant, significant at 0.05, and significant at 0.01 levels of probability, respectively.

[§] DISI=Deficit Irrigation Stress Index, and NSI= Nitrogen Stress Index.

Other options were the reduction of 560 (13.3%) m^3ha^{-1}(from 1011 to 0111 regimes) and 1080 (23.4%) m^3ha^{-1} (from 1111 to 1101 regime) resulted in 1% and 13.2% less gross yields in the first and second season respectively. Increasing the applied N fertilization (from 143 to 214 kg ha^{-1}) resulted in significant (9.5%) and non-significant (4.3%) increases in gross yield in the first and second season, respectively. The interactions of irrigation regime × N fertilization were significant and highly significant in the first and second season, respectively.

ii) Grain Yield:

Different irrigation regimes resulted in significantly higher grain yield than 0000 except 1101 regime with both applications of 143 and 214kg N ha^{-1} in the first growing season. In the second growing season, the highest 1111 regime was not significantly differed from 0111 and 1011 regimes with 143, and from 0111 with 214 kg N ha^{-1}, but higher than 0000 regime. Additionally, the 1011 was not significantly differed from 0111 and 1101, and all higher than 0000 regime with the application of 143 kg N ha^{-1}, and the pairs 0111 and 1011, 1101 and 1101, and 1011 and 0000 were not significantly different with 214 kg N ha^{-1}. The average of irrigation regimes data showed that 1111 was the highest in both seasons, but not significantly differed from 0111, 1011, and 1101 in the first, and differed from other irrigation regimes in the second season. The DISI were in this order 0000>1101>0111>1011>1111 and 0000>1101>1011>0111>1111 in the first and second growing season, respectively. Generally, decreasing the amount of irrigation water resulted in less grain yield of wheat. It is worth to note that seasonal stress resulted in 44.7% and 51.0% reduction in grain yield. Also, reducing the amount of applied water by 1120 (26.7%) and 1240 (26.8%) m^3ha^{-1} (from 1111 to 0111 regime) resulted in 15.9% and 14.5% reduction in grain yield in the first and second season, respectively. Other options were the reduction of 560 (13.3%) m^3ha^{-1} and 640 (13.9%) m^3ha^{-1} (from 1011 to 0111 regime) resulted in 3.3% less and 10.9% more grains yields in the first and second season respectively. Increasing the applied N fertilization (from 143 to 214 kg ha^{-1}) resulted in significant 11.0% and 14.2% increases in grain yield in the first and second season, respectively. The interactions of irrigation regime × N fertilization were highly significant in both seasons.

iii) Straw yield:

The straw yield showed non-significant responses to different irrigation regimes in both seasons, except 0111 and 1011 were higher than others with 214 kg N ha^{-1} fertilization in the first season. The DISI were in this order 1111>1101>0000>1011>0111 and 0000>1101>0111>1111>1011 in the first and second season, respectively. The reduction in applied water by 1120 (26.7%) and 1240 (26.8%) m^3ha^{-1} (from1111 to 0111 regime) resulted in 24.9% and 3.6% reduction in straw yield In the first and second season, respectively. Increasing the applied N fertilization (from 143 to 214 kg ha^{-1}) resulted in significant increase (8.8%) in the first season, while there was a non-significant change in the second season, respectively. The interactions of irrigation regime × N fertilization were significant and non-significant in the first and second season, respectively.

iv) Plant height:

Data of plant height showed non-significant differences between 1111, 0111, and 1011 and all higher than 1101 and 0000 irrigation regimes in the first season. The 1111 irrigation regime resulted in the highest plant height with non-significant differences from 0111 with 143 kg N ha^{-1}, and 0111 highest with no differences than 1111 and 1101 with 214 kg N ha^{-1} fertilization rate in the second season. No significant differences were observed between 0111 and 1011, 1011 and 1101 with 143 kg N ha^{-1}, and 1101 and 1011 with 214 kg N ha^{-1}, and all significantly higher than 0000 irrigation regime in the second season. Seasonal averages of water regimes showed that 0111 was the highest with no significant differences from 1111, no differences between 1111, 1101, and 1011, and all significantly higher than 0000 irrigation regime in the second season. The DISI were in this order 0000>1101>1011>0111>1111 and 0000>1011>1101>1111>0111 in the first and second growing season, respectively. Reducing the amount of applied water by 1120 (26.7%) and 1240 (26.8%) m^3ha^{-1} (from 1111 to 0111 regime) resulted in non-significant (0.4% and 0.8%) changes in plant height in the first and second season, respectively. Increasing the applied N fertilization (from 143 to 214 kg ha^{-1}) resulted in non-significant and significant (4.1%) increase in plant height in the first and second season, respectively. The interactions of irrigation regime × N fertilization were significant and highly significant in the first and second season, respectively.

v) Average number of grains per spike:

The 1111 regime resulted in the highest average no. of grains without significant differences than 0111 and 1011 regimes in the first season. Also, no significant differences were observed between 1011, 0111 and 1101, 0111, and 0000 with 143 kg N ha^{-1}, and 1101, 0111, and 0000 with 214 kg N ha^{-1} in the first season. In second season, the 1111 regime was significantly higher than 0000 regime with 143 kgN ha^{-1}, and 1101 and 0000 regimes with 214 kg N ha^{-1}, wile other regimes showed non-significant differences. The DISI were in this order 0000>1101>0111>1011>1111 for both growing seasons. Reducing the amount of applied water by 1120 (26.7%) and 1240 (26.8%) m^3ha^{-1} (from 1111 to 0111 regime) resulted in 9.1% and 7.5% reduction in the average number of grains in the first and second season, respectively. Different applied N rates did not significantly affect the average number of grains in both growing seasons. The interactions of irrigation regime × N fertilization were highly significant in both growing seasons.

vi) 100-Kernnels weight:

No significant differences in kernels weights were noticed between irrigation regimes except 1111 and 0000 with 143 kg N ha^{-1} rate in the first season. In the second season, the highest weights were observed with 1011, 1111 and 1011 with no significant between others, no significant than 0111 and 1011, and no significant than 1111 and 0111, while 0000 was the lowest than all with 143, 214 kg N ha^{-1}, and seasonal averages, respectively. The DISI were in this order 0000>1101>1011>0111>1111 and 0000>1101>0111>1111>1011 in the first and second season, respectively. Increasing the N rate from 143 to 214 kg ha^{-1} significantly not affected and increased kernels weight by 14.6% in the first and second season, respectively. The interactions of irrigation regime × N fertilization were significant in both seasons.

vii) Average spike length:

The irrigation regimes had no significant differences in spike lengths with the application of 143 kg N ha^{-1}, while 1111 regime showed highest lengths with no differences than 0111 and 1011 with 214 kg N ha^{-1} and for seasonal averages in the first season. The lowest spike length was noticed with 0000 irrigation regime, and no differences were noticed between the highest 1111 and other regimes, 0111, and 0111 and 1011 with 143 and 214 kg N ha^{-1}, and seasonal averages, respectively in the second season. The DISI were in this order 1101>0000>0111>1011>1111 and 0000>1101>1011>0111>1111 in the first and second season, respectively Increasing the N rate from 143 to 214 kg ha^{-1} significantly not affected and increased spike lengths by 8.5 % in the first and second season, respectively. The interactions of irrigation regime × N fertilization were significant and highly significant in the first and second season, respectively.

viii) Number of spikes per square meter:

No significant differences in number of spike were observed between irrigation regimes with different rates of N application, and for seasonal averages in the first season. In the second season, the 1111 regime resulted in the highest number of spikes with no significant differences than 0111 and 1011 with N rates and seasonal averages. The DISI were in this order 0000>1101>1011>0111>1111 for both growing seasons. Different applied N rates did not significantly affect the number of spikes in both growing seasons. The interactions of irrigation regime × N fertilization were not-significant and significant in the first and second season, respectively.

Salinity Profiles Observed with Irrigation Regimes:

The averages of salinity profiles measured pre-cultivation and after harvesting for different irrigation regimes are given in Fig.1. Different irrigation regimes resulted in different soil salinity profiles. The lower salinities were noticed at the surface layer, and increased with depth. The less the amount of water applied to soil (i.e. stress condition) the higher the salinity was observed as compared to full watering condition. The stress at early stage (i.e. vegetative) leads to less salinity at the root zone of wheat as compared to stresses at the other growth sages. The relation of salinity and applied water was found inversely linear for the top 25 cm of soil, and non-linear for the profile averages.

The best-fit of data resulted in the following relationships of soil electrical conductivity (EC) in dS m^{-1} and applied water (AW) in mm:

$$EC = 5.18 - 0.00714\,AW \qquad r = 0.817 \ldots \text{at 0 - 25 cm depth}$$

$$EC = 10.77 - 0.0441\,AW + 0.0000634\,AW^2 \qquad R^2 = 0.671 \ldots \text{at 25 - 50 cm depth}$$

$$EC = 10.32 - 0.0339\,AW + 0.0000488\,AW^2 \qquad R^2 = 0.547 \ldots \text{at 50 - 75 cm depth}$$

$$EC = 8.44 - 0.0263\,AW + 0.0000343\,AW^2 \qquad R^2 = 0.818 \ldots \text{Overall}$$

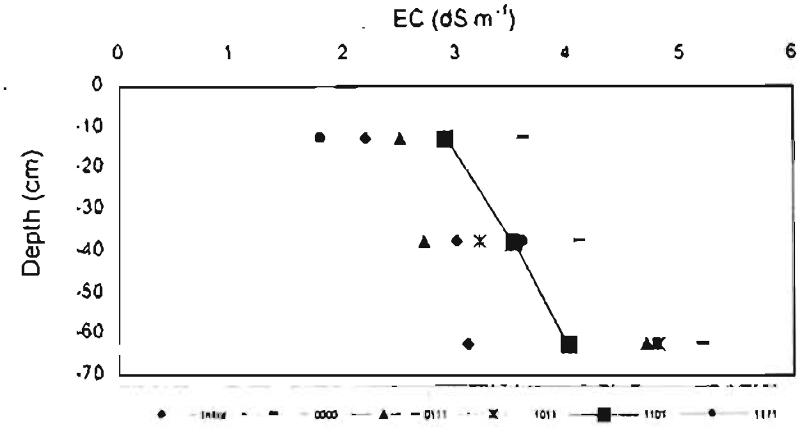

Fig. 1: Averages of soil electrical conductivities (dS m^{-1}) pre-cultivation (initial) and after harvesting with different irrigation regimes, at Sugarbeet region, West Nubaria (0000=stress throughout the growing season, 1111=full irrigation, 0111=stress at vegetative, 1011=stress at flowering, and 1101=stress at yield formation stage).

Actual Evapotranspiration and Applied Irrigation Water Relationships:

The ET_a was positively increased with increasing the amount of irrigation water. Factors affecting the ET_a values were irrigation regimes developed through deficit irrigation, N fertilizer rates, and growing seasons. The average ET_a values of 207.9, 312.6, 381.4, 336.6 and 449.5 mm were obtained with 0000, 0111, 1011, 1101, and 1111 irrigation regimes, respectively. The revealed variations in ET_a are due to water stress at various growth stages causing stomatal closure to certain levels. This considered as the primary cause for the decrease in transpiration and photosynthesis rates (Shimshi, 1982), and affecting yield and other characters. Seasonal averages of ET_a were 334.4 and 340.7 mm with 143 and 214 kg N ha^{-1}, and 318.3, 356.8, and 337.6 mm for wheat in the first, second, and overall seasons, respectively. Reported values of seasonal ET_a for wheat over several water treatments were 455-489 mm (Seif El-Yazal *et al.*, 1983) on cv. Giza 157, 209-349 mm (Gad El-Rab *et al.*, 1988) and 292.6-562.9 mm (Gaber, 2000) on cv. Sakha 8, and 292.5-392.1 mm (Ibrahim, 1999) on cv. Giza 163 under shallow water table The overall equation of ET_a (mm) and AW (mm) is quadratic as:

$$ET_a = -22.3 + 0.982AW - 1.954 \times 10^{-4} AW^2 \qquad R^2 = 0.985$$

Gross Yield and Applied Water Relationships:

The amount of water applied in different irrigation regimes significantly affected the gross yield with the two N fertilizer rates in the two growing seasons. High rates of N fertilization enhancing root and shoot growth and make more water available for crop use especially under mild stress (Huang *et al.*, 2003). Non-linear relationships between gross yield and the amount of irrigation water were observed in the two growing seasons. The best-fit of the responses data of gross yield (GSY) in kg ha^{-1} to AW in mm are as follow:

1) First season:

$$GSY = 6258 + 42.59AW - 0.0635AW^2 \quad R^2 = 0.434 \quad ...at\ N = 143\ kg\ ha^{-1}$$

$$GSY = -6391 + 129.9AW - 0.1937AW^2 \quad R^2 = 0.371 \quad ...at\ N = 214\ kg\ ha^{-1}$$

2) Second season:

$$GSY = 16.07(0.9975)^{AW}(AW)^{1.3} \quad R^2 = 0.973 \quad ...at\ N = 143\ kg\ ha^{-1}$$

$$GSY = 11720 - 4.295AW - 0.0266AW^2 \quad R^2 = 0.740 \quad ...at\ N = 214\ kg\ ha^{-1}$$

3) Averages of the two seasons:

$$GSY = 7351 + 24.91AW - 0.0224AW^2 \quad R^2 = 0.536 \quad ...at\ N = 143\ kg\ ha^{-1}$$

$$GSY = \frac{AW}{0.0000548AW + 0.00545} \quad R^2 = 0.296 \quad ...at\ N = 214\ kg\ ha^{-1}$$

$$GSY = 3212.45(AW)^{0.248} \quad R^2 = 0.402 \quad ...Overall$$

These functions provided different gross yield-water options for the region.

Grain Yield and Applied Water Relationships:

The amount of water applied in different irrigation regimes significantly affected the grain yield with the two N fertilizer rates in the two growing seasons. Several studies showed significant increase in the grain yield with the increase in water application rates (Gad El-Rab *et al.*, 1988; Al-Kaisi *et al.*, 1997; Ibrahim, 1999; and Gaber 2000). Positive trends were clearly noticed and the best-fit of the responses data of grain yield (GY) in kg ha^{-1} to AW in mm are given in Fig. 2.

1) First season:

$$GY = \frac{AW}{0.00003658AW + 0.07162} \quad R^2 = 0.973 \quad ...at\ N = 143\ kg\ ha^{-1}$$

$$GY = 9431.7\exp\left(\frac{-244.6}{AW}\right) \quad R^2 = 0.959 \quad ...at\ N = 214\ kg\ ha^{-1}$$

2) Second season:

$$GY = 10660\ \exp\left(\frac{-343.5}{AW}\right) \quad R^2 = 0.969 \quad ...at\ N = 143\ kg\ ha^{-1}$$

$$GY = 480 + 11.86AW \quad r = 0.803 \quad ...at\ N = 214\ kg\ ha^{-1}$$

3) Averages of the two seasons:

$$GY = -964.7 + 18.86\,AW - 0.01265\,AW^2 \quad R^2 = 0.933 \quad ...at\ N = 143\ kg\ ha^{-1}$$

$$GY = \frac{AW}{0.00003988\,AW + 0.06275} \quad R^2 = 0.798 \quad ...at\ N = 214\ kg\ ha^{-1}$$

$$GY = -225.0 + 15.65\,AW - 0.00739\,AW^2 \quad R^2 = 0.782 \quad ...Overall$$

The quadratic production function was also reported to describe the response of wheat grain yield at different locations of China, Syria, and USA (Zhang and Oweis, 1999; and Zhang, 2003). Generally, these non-linear response functions offer suitable yield-water options for the region.

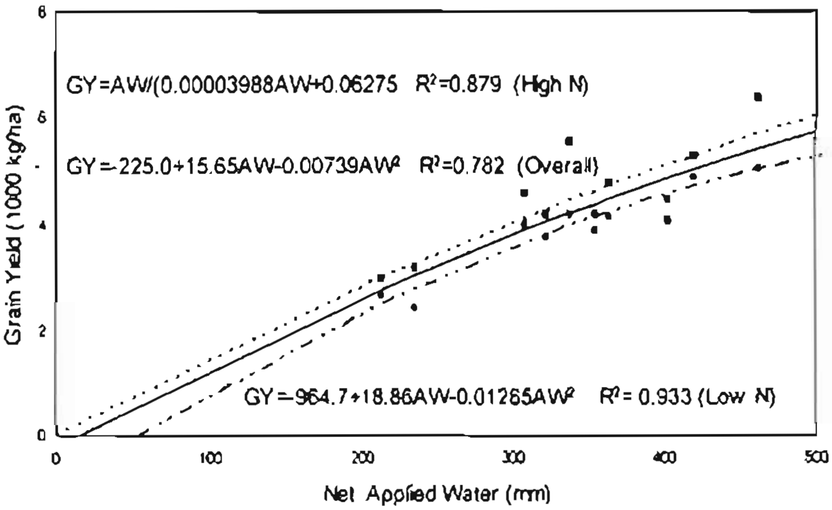

Fig. 2: **Wheat grain yield as related to net applied irrigation water with different N fertilizer rates (143kg/ha=low N and 214 kg/ha=high N), and the overall quadratic relation.**

Crop Factor:

The crop factor reflects all the crop characteristics, sowing date, rate of crop development, and length of growing season under certain climatic conditions. Stresses at different growth stages affected the obtained k_c values (estimated from ET_a and ET_0 data) that greatly lowered with the prolonged stress. Seasonal averages of wheat k_c values of 0.449, 0.676, 0.825, 0.728, and 0.973 were obtained with 0000, 0111, 1011, 1101, and 1111 irrigation regimes, respectively. Deviation from the k_c of normal watering (i.e. 1111 irrigation regime) may considered as stress factor for different growth stages. The average k_c values of 0.707, 0.753, and 0.730 were obtained in the first, second, and overall seasons, respectively. Increasing the applied N fertilizer from 143 to 214 kg ha^{-1} increased the k_c from 0.703 and 0.744 to 0.711 and 0.762 in the first and second seasons, respectively. Reported values of seasonal k_c for wheat were 0.87 (El-Sayed, 1982), 0.35-0.59 (Gad El-Rab *et* *al.*, 1988), and 0.78 under shallow water table (Amer *et al.*, 1989). For most crops, Doorenbos and Kassam (1986) reported k_c value between 0.8-0.9 for the total growing period. The relation of seasonal k_c and AW (mm) is exponential as:

$$k_c = 9.334 \times 10^{-4} AW^{1.141} \qquad R^2 = 0.999$$

Grain Yield Responses to Water:

The grain yield responses to water was determined through the yield response factor according to Doorenbos and Kassam (1986) which relates the relative yield decrease $[1-(GY/GY_m)]$ to relative evapotranspiration deficit $[1-(ET_a/ET_m)]$, as GY and GY_m are actual and maximum yield, ET_a and ET_m are actual and maximum evapotranspiration, respectively.

$$\left[1 - \frac{GY}{GY_m}\right] = k_y \left[1 - \frac{ET_a}{ET_m}\right]$$

The higher k_y value refers to a greater yield loss under the condition of limited water (Doorenbos and Kassam, 1986). The obtained values of k_y were lower than 1 (Fig. 3) and varies with different irrigation regimes, N fertilizer rates, and growing seasons. A response factor lower than unity indicates that the expected relative yield decrease for a given evapotranspiration deficit is proportionately less than the relative decrease in evapotranspiration. The k_y greatly reduced with increasing the applied water with different deficit regimes. The average k_y values of 0.735, 0.378, 0.538, 0.595, and 0.176 were obtained with 0000, 0111, 1011, 1101, and 1111 irrigation regimes, respectively. Different N fertilizer rates showed contrasted trends between the two growing seasons, but on the averages basis there were no changes. Seasonal averages of k_y were 0.422, 0.526, and 0.484 for wheat in the first, second and overall seasons, respectively. Kirda (1999) reported seasonal k_y values of 0.76 and 0.93 for wheat under sprinkler and basin irrigation, respectively. Only those crops and growth stages with a lower crop yield response factor (k_y<1.0) can generate significant savings in irrigation water through deficit irrigation (Kirda 1999) and well shown in the results of this study. The relation of seasonal k_y and AW (mm) is quadratic as:

$$k_y = 0.6594 + 1.454 \times 10^{-3} AW - 5.509 \times 10^{-6} AW^2 \qquad R^2 = 0.692$$

The k_y factor may apply for planning, design, and operation of irrigation projects allows quantification of water supply and water use in terms of crop yield and total production of the area.

Water Use Efficiency:

The WUE (kg grains ha^{-1} per mm ET_a) values were affected by irrigation regimes based on different water deficit at different growth stages, and N fertilization rates. The average WUE values of 13.60, 14.60, 11.44, 11.89, and 11.98 kg ha^{-1} mm^{-1} were found with 0000, 0111, 1011, 1101, and 1111 irrigation regimes, respectively. Seasonal stress or stress at early stage (i.e. vegetative) resulted in higher WUE. The lowest WUE was noticed with the stress at flowering or yield formation stages. Increasing the applied N fertilizer rate from 143 to 214 kg ha^{-1} increased the WUE from 11.92 to 13.48 kg ha^{-1} mm^{-1} due to the increase in grain yield. Seasonal average of WUE was 12.70 kg ha^{-1} mm^{-1} for wheat in the W. Nubaria region. Reported values of seasonal WUE for wheat were 7.6-14.8 (Singh *et al.*, 1980) in India, 9.8-11.9 (Seif El-Yazal *et al.*, 1983) on cv. Giza 157, 23.9-31.3 (Gad El-Rab *et al.*, 1988) and 10.5-14.0 (Gaber, 2000) on cv. Sakha 8, and 13.6-16.4 kg ha^{-1} per mm (Ibrahim, 1999) on cv. Giza 163 under shallow water table. Generally, the higher the applied irrigation water, the lower the WUE of the wheat. The linear relationship of WUE (kg ha^{-1}mm^{-1}) and AW (mm) is given as:

$$WUE = 16.175 - 0.0102\,AW \qquad r = 0.609$$

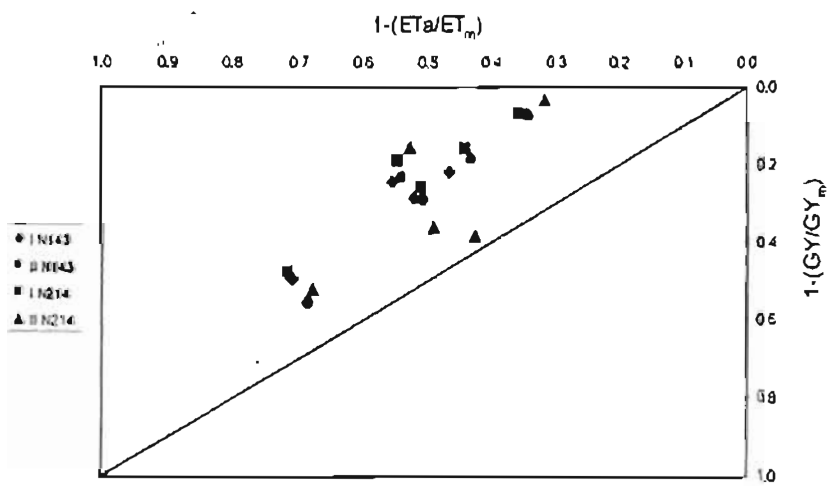

Fig. 3:The relations of growing season relative yield decrease and relative evapotranspiration deficit for wheat grown in West Nubaria region (I=first season, II=second season, N143=143 kg N/ha, and N214=214 kg N/ha)

CONCLUSION

This study showed that the averages of irrigation regimes 0000, 0111, 1011, 1101, and 1111 were 11930, 14521, 14544, 12920, and 14159 kg ha^{-1} for gross yield, 2801, 4571, 4345, 3994, and 5390 kg ha^{-1} for grain yield, and 9129, 9950, 10199, 8946, and 8769 kg ha^{-1} for straw yield, respectively. This corresponding to ET_a of 207.9, 312.6, 381.4, 336.6, and 449.5 mm, k_c of 0.449, 0.676, 0.825, 0.728, and 0.973, k_y of 0.735, 0.378, 0.538, 0.595, and 0.176, and WUE of 13.60, 14.60, 11.44, 11.89, and 11.98 kg ha^{-1} mm^{-1}, respectively. The region overall averages of all treatments were

13619, 4220, and 9399 kg ha^{-1} for gross, grain, and straw yields, respectively, corresponding to ET_a of 337.6 mm, k_c of 0.711, k_y of 0.484, and WUE of 12.70 kg ha^{-1} mm^{-1}. The yield and yield characteristics increased while the efficiency of water utilization decreased as the quantities of irrigation water increased. These results stood in great agreements with the reported data of wheat growth with different water application rates of Seif El-Yazal *et al.* (1983), Gad El-Rab *et al.* (1988), Amer *et al.* (1989), Al-Kaisi *et al.* (1997), Ibrahim (1999), Gaber (2000), and Moussa (2000).

The saving in irrigation water was 26.8% due to stress at the vegetative stage and resulted in reduction of 0.2% gross, 15.2% grain, and 2.4% straw yields, and minor effects on the other yield characteristics. The effects exhibited by the stress at the flowering stage were close to those of the stress at the vegetative stage, and the resulted saving in irrigation water was 13.2%. Saving 23.4% of irrigation water due to the stress at the yield formation stage leads to reduction of 11.0% gross, 25.9% grain, and 12.3% straw yields, and double reduction of the other characteristics as compared to the stress at vegetative stage. Imposing water stress throughout the whole season caused great loss in grain yield and other yield characteristics. English and Raja (1996) suggested that deficits between 15 and 59% would be economical. Therefore, if the amount of irrigation water available for wheat production is limited, it could be used more efficiently if applied to relieve stress during flowering (mid-late- February to mid- late- March) followed by yield formation (late-March to mid- April), and least during vegetative stage (mid-December to late-February).

Similar to that reported by Zhang and Oweis (1999) grain yield linearly increased with the increase in ET_a and better trend was observed with relative wheat yield vs. relative growing season ET (Fig. 4) because of avoiding variations in yield in different years and normalizing the relationship (Singh *et al.*, 1980). The fitted GY (kg ha^{-1}) with ET_a (mm), and the relative relation are given as:

$$GY = 954.5 + 9.674 ET_a \qquad r = 0.845$$

$$\frac{GY}{GY_m} = 0.175 + 1.136 \frac{ET_a}{ET_m} \qquad r = 0.871$$

The reduction in ET_a due to stresses at one growth stage between vegetative and yield formation were 15.1-30.5% resulted in 15.2-25.9% reduction in grain yield. Zhang (2003) reported that 40% reduction in ET during same period reduced yield by 15-20% in Syria.

Reducing the applied N fertilizer from 214 to 143 kg ha^{-1} (33.3 %) resulted in reduction from 14107 to 13130 kg ha^{-1} (6.9 %), 4504 to 3936 kg ha^{-1} (12.6 %), and 9603 to 9194 kg ha^{-1} (4.3 %) of gross, grain, and straw yields, respectively, and had minor effects on the other yield characteristics. Amer *et al.* (1989) suggested that the rate of 150 kg N ha^{-1} is optimum for high grain yield of wheat. Thus, N application of 143 kg ha^{-1} can be of environmental advantage. However, it is better matching N application with wheat needs under sprinkler irrigation (Eck, 1988).

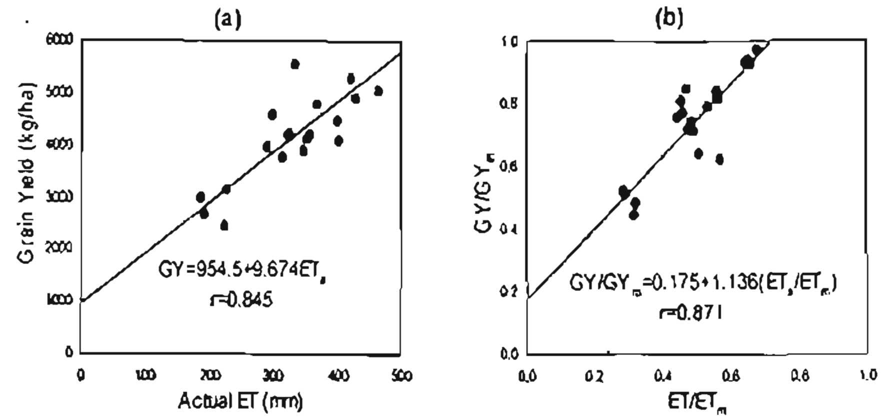

Fig. 4: The relations of (a) wheat grain yield vs. growing season actual evapotranspiration, and (b) relative wheat yield vs. relative growing season actual evapotranspiration.

Deficit irrigation is an efficient strategy for higher productivity of wheat with the same amount of water resources compared with full irrigation under water shortage conditions found in the newly reclaimed soils. Higher productivity of applied water is achieved at water supply level lower than that of maximum yield. The risk with deficit irrigation is low because the response curve of yield to water supply often has a wide plateau, and can be minimized through proper irrigation scheduling by avoiding water stress especially during the growth stages more sensitive to water stress. Thus, a considerable amount of water can be saved without a significant yield reduction compared with full irrigation.

This work may provide guidelines for practicing deficit irrigation with wheat in the newly reclaimed soils of Egypt for identifying likely growth stages for imposing reduced irrigation (or ET), and for assessing the economic feasibility and acceptability of deficit irrigation through the estimation of expected relative yield decreases.

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إنقاص رى القمح تحت نظام الرى بالرش فى الأراضى المستصلحة حديثا بمصر

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أجريت تجربة حقلية على محصول القمح تحت نظام الرى بالرش صنف سخا ٨ لمدة موسمين فى منطقة بنجر السكر – غرب النوبارية بهدف دراسة تأثير إنقاص الرى ومعدل التسميد النيتروجينى على المحصول والصفات المحصولية للقمح النامى فى الأراضى المستصلحة حديثا والتى تواجه ظروف نقص فى المياه المتوفرة للرى من أجل الوصول للإنتاجية المثلى.

تم تنفيذ الدراسة بالتعيين العشوائى لخمس معاملات للرى للقطع الرئيسية وبمعدلين للتسميد النيتروجينى ١٤٣، ٢١٤كجم/هكتار (٦٠ ، ٩٠ كجم/فدان) للقطع تحت الرئيسية فى نظام القطع المنشقة . أختيرت معاملات الرى لتحدث إجهادا مائيا طوال موسم النمو ، وإجهادا مائيا فى واحد من كل من أطوار نمو القمح الثلاثة وهى الخضرى ، والإزهار ، وتكوين المحصول ، بالإضافة للرى الكامل . ويتم إحداث الإجهاد المائى خلال طور معين للنمو بإضافة رى يساوى ٥٠٪ من البخر – نتح المحصولى.

أظهرت نتائج الدراسة أن معاملات الرى الخمس أدت إلى محصول حبوب ٢٨٠١ ، ٤٥٧١ ، ٤٣٤٥ ، ٣٩٩٤ ، ٥٣٩٠ كجم/هكتار ، على التوالى. هذه القيم تطابق قيم بخر – نتح فعلى ٢٠٧,٩ ، ٣١٢,٦ ، ٣٨١,٤ ، ٣٣٦,٦ ، ٤٤٩,٥ مم ، وقيم معامل محصول ٠,٤٤٩ ، ٠,٦٧٦ ، ٠,٨٢٥ ، ٠,٧٢٨ ، ٠,٩٧٣ ، وقيم معامل إستجابة المحصول ٠,٧٣٥ ، ٠,٣٧٨ ، ٠,٥٣٨ ، ٠,٥٩٥ ، ٠,١٧٦ ، وقيم كفاءة إستخدام المياه ١٣,٦٠ ، ١٤,٦٠ ، ١١,٤٤ ، ١١,٨٩ ، ١١,٩٨ كجم هكتار$^{-1}$ مم$^{-1}$ على التوالى.

أدى توفير المياه نتيجة للإجهاد المائى خلال أطوار النمو الخضرى ، الإزهار ، تكوين المحصول بمقدار ٢٦,٨ ، ١٣,٢ ، ٢٣,٤٪ إلى نقص فى محصول الحبوب بمقدار ١٥,٢ ، ١٩,٤ ، ٢٥,٩٪ ، على التوالى . أعطت العديد من معاملات الرى ذات الإضافات بمعدلات منخفضة محصول حبوب غير مختلف معنويا عن معاملات الرى الكاملة. أدى إنقاص معدل إضافة السماد النيتروجينى من ٢١٤ إلى ١٤٣ كجم/هكتار (٣٣,٣٪) إلى نقص فى محصول الحبوب من ٤٥٠٤ إلى ٣٩٣٦ كجم/هكتار (١٢,٦٪) وأحدث تأثيرات بسيطة فى الصفات المحصولية الأخرى.

هذه الدراسة أظهرت أن الاستخدام الكفء لكمية مياه الرى المحدودة والمتاحة لإنتاج القمح يتم لو أضيف الماء لتلافى الإجهاد المائى خلال طور الإزهار (من أواسط–أواخر شهر فبراير الى أواسط–أواخر شهر مارس) يليه طور تكوين الحبوب (أواخر شهر مارس إلى أواسط شهر أبريل) ، وأقليم الطور الخضرى (أواسط شهر ديسمبر إلى أواخر شهر فبراير). هذا مع إضافة سماد نيتروجينى بمعدل ١٤٣ كجم/هكتار مما يؤدى إلى محصول أمثل وبيئة مستدامة.