Menoufia J. Soil Sci., Vol. 2 December (2017): 331 - 350

IMPROVE WATER PRODUCTIVITY OF WHEAT IN SHALLOW WATER TABLE AREA IN THE NORTH NILE DELTA, EGYPT

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Received: Oct. 12 , 2017 Accepted: Nov. 2 , 2017

ABSTRACT: *Two field experiments were established in 2014/2015 and 2015/2016 winter seasons at Sakha Agriculture Research Station (31° 07′ N latitude, 30° 05′ E longitude), North Nile Delta, Egypt. Objective of the investigation is to improve productivity of water and wheat yield in shallow water table area. Irrigation scheduling treatments were assigned in the main plot, fertilizer levels were allocated in the sub-plots. While microorganisms treatments were allocated in sub sub-plots. Irrigation scheduling was done at 50%±5 (I_1), irrigation at 70% ±5 (I_2) and irrigation at 90%±5 (I_3) of available soil moisture depletion (ASMD). Treatments of nitrogen fertilizer were 75% (F_1) and 100% (F_2) of the recommended nitrogen fertilizer. The plant growth promoting rhizobacteria treatments (PGPR) were cyanobacteria (Cy), Rhizobium (R) and consortium cyanobacteria and Rhizobium (Cy +R) as well as the control treatment without inoculation (C).*

Results revealed that there are no significant differences in grain yield, harvest index, number of spikes m^{-2} and weight of 1000 grains between I_1 and I_2. Grain yield under I_3 decreased by 11% and 8% compared to I_1 and I_2 respectively over both growing seasons. The values of wheat consumptive use and irrigation water applied has the descending order $I_1 > I_2 > I_3$ over both growing seasons. The seasonal water consumptive use was 30.22, 26.25, and 22.81 cm for I_1, I_2 and I_3 respectively. Irrigation water applied was 39.02cm, distributed on five irrigations, 32.43 cm, distributed on four irrigations, and 27.36 cm distributed on three irrigations including seedling irrigation for I_1, I_2 and I_3 respectively. Total seasonal water requirement was 50.0, 47.38 and 45.75 cm for I_1, I_2 and I_3 respectively over both seasons. Mean percentage of groundwater contribution has the descending order $I_3 > I_2 > I_1$ to be 46%, 26.9% and 10.2% for I_3, I_2 and I_1 respectively over both seasons.

So, when water becomes a limiting factor for wheat productivity in such area, farmers can apply I_3 with F_1 and Cy +R because it increased productivity of irrigation water (PIW) and water productivity (WP) by 37% and 79% respectively, as well as saved nitrogen fertilizer and irrigation water by 25% and 30% respectively compared to I_1 with F_2 and C.

Key words: *Wheat, Scheduling irrigation, Groundwater contribution, Water productivity, Plant growth promoting rhizobacteria (PGPR)*

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important crops, worldwide it providing over 20% of the consumed calories by the world's population(Braun *et al.,* 2010 and Safa and Samarasinghe, 2011). It is the most widely cultivated cereal globally with over 218 M ha in cultivation (FAOSTAT, 2013). It is considered the important cereal crop in the world as well as in Egypt. It was grown on more that 1.38 million hectares from 2013- 2014 (Agricultural Economics Research Institute, 2015). So, one of the most important Egypt's aims is increasing wheat production to face the gap between production and the great demand of the highly increasing human population. Because of the projected limitation of water resources by climate change scenarios, worldwide requires serious attention to search for new water supplies for agriculture (Nouri *et al.,* 2016). Also, water management in agricultural lands largely depends on quality and quantity of available water and soil resources (Jalali *et al.,* 2017).

Scheduling irrigation and groundwater contribution in shallow water table areas such as North Nile Delta, Egypt are one of the important strategic practices to save irrigation water and increase productivity of irrigation water, moreover enhancing wheat yield. Irrigation water applied in surface irrigation may be reduced under shallow water table conditions (Kruse *et al.,* 1986).The capillary contribution from a shallower groundwater table was generally higher than that from a deeper water table (Kang *et al.,* 2002). Maintained water table at 1.5 m depth contributed to 25% of the total crop water use of safflower and irrigation applied without water table was 46% higher than water applied in the presence of water table(Soppe and Ayars, 2003). Wheat received its full water requirements from groundwater when, water table was maintained at 0.5 m depth (Kahlown *et al.,* 2005). Many researchers reported that groundwater can contribute significantly to crop water needs under shallow water table, therefore it could be reduced applied irrigation and should consider this contribution when scheduling irrigation. This contribution may be range from 30 to 40% of total crop water use (Ayars *et al.,* 2006), about 18% of the transpired water (Babajimopoulos *et al.,* 2007), 40% of wheat water requirement from the groundwater (Gowing *et al.,* 2009). The seasonally averaged ratio of the groundwater contribution to crop-water use reached as high as 75% in case of water table about 1.0m depth and no irrigation (Luo and Sophocleous, 2010). At 1.5m groundwater table, the percentage of groundwater contribution to the ET attains 29% (Huo *et al.,* 2012). Capillary rise supplied 29% of the water use of wheat during ripening to harvest periods when the groundwater table was about 1.5 m depth (Karimov *et al.,* 2014). Water productivity of the wheat biomass increases when groundwater levels decrease and increase groundwater contribution thus, the amount of irrigation water is reduced (Gowing *et al.,* 2009; Huo *et al.,* 2012; Karimov *et al.,* 2014; Luo and Sophocleous, 2010; Sepaskhah *et al.,* 2003; Soppe and Ayars, 2003 and Yang *et al.,* 2007). So, The interval between irrigations can be increased when roots have been fully developed taking advantage of the presence of the groundwater (Babajimopoulos *et al.,* 2007). and at the same time reducing the problem of disposing of drainage effluent(Gowing *et al.*, 2009).

Besides water, nutrient is another key factor determining the growth and yield of crops (Li *et al.,* 2009). Nitrogen (N) is a vital element in nutrition of plants and strongly influences crop yield. Improving nitrogen-use efficiency (NUE) is an important challenge to decline input cost to farmers, and harmful effect of N losses while maintaining crop yields. The interaction of complementary activities of water and N are the main factors that affect crop and resource productivity (water, N) the efficiency of crop production (Pandey *et al.,* 2001 and Pradhan *et al.,* 2014). Water productivity of wheat increased up to the application of 120 kg N ha^{-1} in all irrigation regimes(Pradhan *et al.,* 2014). Plant growth promoting rhizobacteria (PGPR) can increase the ability of plants to tolerate the stress caused by drought and the same time can reduce the high nutrient requirements in crops production especially nitrogen fertilizer and costs of fertilization that disturb national economies and environmental soundness. Cyanobacterial inoculation as a source of nitrogen, organic matter, oxygen, solubilize phosphate, amino acids, vitamins, auxins, increase the fertilizer use efficiency and enhance plant growth of crop plants. N_2-fixing cyanobacteria conservation of the supply of nutrients, providing a stable community that can diminish an attack by antagonists/stress factors and associated with roots of rice and wheat for improved plant growth and soil productivity (Prasanna *et al.,* 2012). Synergistic effects of bacteria and cyanobacteria on wheat showed that the shoot weight, root weight, total biomass and panicle weight were higher compared to control (Nain *et al.,* 2010). Inoculation by *Rhizobuim* and phosphate solubilizing bacteria significantly increased root and shoot weight, plant height, spike length, grain yield, grain content of phosphorus, leaf protein and leaf sugar content of the wheat plant (Afzal and Asghari, 2008). Rhizobial inoculation was increased the wheat yield component at both recommended and 20% less of recommended doses NPK (Adnan *et al.,* 2014)**.** *Rhizobium leguminosarum* bv. trifolii was increased the shoot dry matter, grain yields and to avoid the deleterious effects of wheat (Hilali *et al.,* 2001)**.** Yanni *et al.,* (2016) reported that, the inoculation by *Rhizobium* significantly increased wheat grain yield compared to the mean of farmers' yields using the same varieties in adjacent fields.

The main objective of this work is to improve on-farm water management in high water table areas through ground water contribution to water needs of wheat, increasing water productivity, and rationalization of irrigation water use, nitrogen fertilizer and plant growth promoting rhizobacteria (PGPR).

MATERIALS AND METHODS

Experimental site

In winter seasons of 2014/2015 and 2015/2016, two field experiments were established at Sakha Agriculture Research Station (31° 07' N latitude, 30° 05' E longitude), Kafr El-Sheikh Governorate, North Nile Delta, Egypt. The Agro-meteorological data were taken from Sakha Station during the growing winter seasons of 2014/2015 and 2015/2016 as shown in Table (1).

Table (1): Monthly mean values of agro-meteorological data of Sakha Station in 2014 /2015 and 2015/2016 winter seasons.

Seasons	Months	Air temperature			Relative humidity			Wind speed	Pan evaporation	Rain
		Max. (°C)	Min. (°C)	Mean (°C)	Max. (%)	Min. (%)	Mean (%)	Mean (km d^{-1})	Mean (mm d^{-1})	(mm $month^{-1}$)
2014/2015	November	24.30	13.79	19.05	87.80	60.50	74.15	67.30	2.77	24.60
	December	22.27	9.72	16.00	88.60	63.50	76.05	46.03	1.72	5.70
	January	18.79	6.46	12.61	88.10	61.10	74.60	70.80	2.71	52.55
	February	19.01	7.69	13.35	86.80	62.70	74.75	72.91	2.90	38.80
	March	22.69	11.69	17.19	82.36	58.82	70.59	87.64	3.23	6.25
	April	25.64	13.70	19.67	78.30	48.50	63.40	95.70	6.07	23.90
	May	30.19	18.79	24.49	77.30	46.10	61.70	114.60	7.15	00.00
2015/ 2016	November	24.40	14.42	19.41	87.00	64.20	75.60	70.30	3.19	52.40
	December	19.70	8.36	14.03	88.60	67.20	77.90	57.20	2.50	25.00
	January	18.40	6.35	12.38	85.60	62.50	74.05	69.20	2.52	43.21
	February	22.58	9.35	15.97	85.00	53.10	69.05	58.80	2.51	00.00
	March	24.50	11.60	18.05	81.50	58.30	69.90	63.20	3.59	13.80
	April	30.03	18.62	24.33	81.60	41.80	61.70	87.10	5.94	00.00
	May	30.40	22.80	26.60	71.00	45.80	58.40	97.00	6.47	00.00

Soil properties of the experiments site were determined before cultivation process, soil chemical properties were determined according to Page *et al.,* (1982). Particle-size distribution was carried out using the pipette method according to Klute, (1986), soil field capacity, permanent wilting point were determined by using pressure membrane method at 0.33 and 15 Atm according to James, (1988)**.** Soil bulk density was determined according to Vomocil, (1957) and total porosity P% was computed using values of soil bulk density according to Black, (1965) as shown in Table (2).

Experimental design and treatments:

The experiment had designed as a split split-plot design with four replicates. The irrigation scheduling treatments were assigned in the main plot, fertilizer levels were allocated in the sub-plots, while the plant growth promoting rhizobacteria treatments (PGPR) were allocated in sub sub-plots. Irrigation scheduling treatments carried out at 50±5 (I_1), 70 ± 5% (I_2) and 90±5% (I_3) of available soil moisture depletion (ASMD). Treatments of nitrogen fertilizer were 75% (F_1) and 100% (F_2) of the recommended nitrogen fertilizer. The PGPR treatments were: cyanobacteria (Cy), *Rhizobium* (R) and consortium cyanobacteria and *Rhizobium* (Cy+R) as well as the control treatment (C) without inoculation.

Inoculant preparation:

Peat as carrier was neutralized from its original pH of 5.0–5.5 using 5 % (w/w) of $CaCO_3$ and then pasteurized at 80 °C for 4 h. *Rhizobium leguminosarum* bv. trifolii was grown in yeast- extract mannitol (YEM) liquid medium (Vincent, 1970) at 30 ºC for three days with shaking and enumeration adjust of *rhizobium* populations in culture at 10^6 - 10^7 colony - forming units (CFUs) / mL. *Rhizobium* culture was mixed with a sterilize peat carrier (*1 v / 2 w*). Just before sowing, inoculation was mixed by wheat seeds slightly moistened by an adhesive component (5% water solution of Arabic Gum). The proportion of the inoculum was equivalent to 720 g inoculum per 144 kg seeds (the seed quantity for cultivation of one hectare of field area). *Anabaena oryzae* and *Anabaena cylindrica* were grown in modified Watanabe medium (El- Nawawy *et al.,* 1958) for 10 days under controlled laboratory conditions of 30 ± 2 °C and continuous illumination of 5500–6500 Lux. Soil as the cyanobacteria carrier, 2.5 cm of soil is spread in try (0.5× 1.0 m) and covered with 5 cm tap water and supplied with phosphate (0.2g Na_2HPo_4 /L), molybdenum (0.2 mg MoO/L) and 1.0 g carbofuran. After the soil settles down and the water in the trays becomes clear, each tray was then inoculated with 100 ml cyanobacteria culture of *Anabaena oryzae* and *Anabaena cylindrica*. The trays were kept in the open air up to 15 days and collected to dry. When completely dry, each dry cyanobacteria culture was thoroughly mixed together at the ratio of 1:1 (*W/W*) to represents the dried cyanobacteria inocula. Cyanobacteria inoculation was carried out 10 days after wheat sowing at the rate of 15 kg dried cyanobacteria crusts ha^{-1}.

Wheat cv. Masr1 were sown in November 16th, 2014 in the first season and November 19th, 2015 in the second season, and harvested in May 1st, 2015 and in May 3rd 2016, respectively. Phosphate fertilizer was applied after plowing and before planting, as superphosphate (15.5% P_2O_5) at the rate of 250 $kgha^{-1}$and Potassium fertilizers was applied before planting at rate 115 kg ha^{-1} in the form potassium sulfate (48% K_2O). The other agricultural practices were applied as the recommendations of Agricultural Research Center.

Table (2): Some soil physical and chemical properties of the experimental site as mean values of the two growth seasons.

Soil depth (cm)	Field capacity (%)	Wilting point (%)	Bulk density (Mg m^{-3})	Total porosity (%)	Sand (%)	Silt (%)	Clay (%)	Texture class	EC_e (dS m^{-1})	pH
0-15	47.21	25.26	1.25	52.83	19.03	27.01	53.96	Clayey	2.08	8.18
15-30	39.09	21.69	1.34	49.43	19.58	26.25	54.17	Clayey	2.34	8.29
30-45	38.13	21.82	1.39	47.55	20.07	25.74	54.19	Clayey	2.61	8.37
45-60	38.66	20.70	1.31	50.57	19.74	26.31	53.95	Clayey	2.93	8.52
Mean	40.77	22.37	1.32	50.10	19.61	26.33	54.07	Clay	2.49	8.34

Irrigation Water Applied (IW)

Soil moisture content was gravimetrically determined in soil samples which were taken from consecutive depths of 15 cm to 60 cm. For irrigation timing, soil samples were taken periodically until it reaches the desired level of allowable moisture. The amount of water applied at each irrigation for each treatment was determined on the basis of raising the soil moisture content to its field capacity plus 10% as leaching requirements.

Irrigation water was pumped from the main canal near the experimental field into a settling basin with a baffle wall to maintain a constant head over the crest of a fixed rectangular weir. Irrigation water was calculated by using the equation as following:

$$Q = 1.84LH^{1.5}$$

Where,

Q = Rate of discharge, m^3/min., L = Length edge of weir, cm

H = Height column of water above edge of weir, cm

Irrigation water was controlled by a steel gate for each experiment plot as well as those fixed at the side of each feeder canal.

Seasonal applied water (AW), was calculated as described by Giriappa, (1983) as follows:

AW=IW+ER+S, where IW= irrigation water applied, ER= effective rain and S= amount of soil moisture contribution to consumptive use from the shallow ground water

Effective rainfall = incident rainfall x 0.7 (Novica, 1979).

Water consumptive use (CU):

Water consumptive use was determined as the soil moisture depletion (SMD) using the following equation (Israelsen and Hansen, 1962).

$$CU\ (SMD) = \sum_{i=1}^{n=4} Di \times Bd \times (\theta_2 - \theta_1) /100$$

Where: CU = Water consumptive use (cm), D = Soil depth layer =15 cm, Bd = Soil bulk density, (Mg m^{-3}) for this depth, θ_1 = Soil moisture % before irrigation, θ_2 = Soil moisture %, 48 hours after irrigation and n = Number of soil layers.

Crop evapotranspiration (ETc), was calculated using the following equation:

$$ET_c = ET_o \times k_c$$

Where, ET_o refers to reference evapotranspiration and Kc refers to crop co-efficient values which quoted from (Doorenbos *et al.,* 1979). Reference evapotranspiration in the present study was calculated by two methods: Penman Montith (Allen *et al.,* 1998) which calculated using FAO CROP WAT 8.0 software (Smith, 1992), and pan evaporation method using class A pan (Doorenbos and Pruitt, 1977).

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

The productivity of irrigation water (Ali *et al.,* 2007) and water productivity (Paredes *et al.,* 2017) of the grain yield as kg m^{-3} were calculated as follow:

Productivity of irrigation water (kg m^{-3}) =

$$\frac{\text{Grain yield kg ha}^{-1}}{\text{Irrigation water applied (IW) in m}^{3}\text{ha}^{-1}}$$

Water productivity (kg m^{-3}) =

$$\frac{\text{Grain yield kg ha}^{-1}}{\text{Total water applied (AW) in m}^{3}\text{ha}^{-1}}$$

Where, AW includes rainfall, irrigation water applied and ground water contribution (Paredes *et al.,* 2017).

Fluctuation of groundwater table

In order to establish the diagram of groundwater table fluctuation during the growing seasons, nine observation wells were installed along different treatment. Perforated plastic tube with each observation well was two inches in diameter and two meter long. Daily reading of groundwater table was recorded by the aid of metallic sounder that fixed in a sealed tape to measure the water table depth**.**

Contribution of the groundwater table to crop water used (GWC %)

The contribution of groundwater table as a percentage of the consumptive use was calculated as follows:

$GWC\% = (ETc - SMD)/ETc \times 100$

Where ETc refers to Crop evapotranspiration and SMD refers to soil moisture depletion.

The collected data

Data collected were number of spikes/m^2, weight of 1000 grains weight, grain yield, straw yield and biomass yield at maturity. Data on number of tillers/ hill, weight of 1000 grain were taken on ten randomly selected guarded hills from the center of plots.

Harvest index (HI) = Biomass yield in kg ha^{-1}/Grain yield in kg ha^{-1}

The statistical analysis

Statistical analysis of variance (ANOVA) was performed using MSTAT-C software. The data for the two years were combined. Treatment means were compared using Duncan's multiple range test which was statistically significant when $P \leq 0.05$ according (Duncan, 1955)**.**

RESULTS AND DISCUSSION

Wheat yield and yield components

Data in Table (3) show that there were no significant differences in grain yield, harvest index number of spikes m^{-2} and weight of 1000 grains between irrigation treatments I_1 and I_2, however there are significant differences on straw yield and biomass yield between irrigation treatments I_1 and I_2 over both growing seasons. In compression with irrigation treatments of I_1 and I_2, irrigation treatment of I_3 gave less values in yields of grain, straw, biomass, harvest index, number of spikes m^{-2} and weight of 1000 grains. Grain yield resulted from irrigation treatment of I_3 decreased by 11% and 8% compared with I_1 and I_2 respectively over both growing seasons due to lower yield component such as number of spikes and 1000-grain weight (Table 3). These decrease in yield and its attributes may be due to negative impact of lower water supply (Hammad and Ali, 2014; Namich, 2007 and Osborne *et al.,* 2002). Water deficit could limit leaf expansion and elongation through inhibiting cell expansion (Namich, 2007). Also, drought reduce turgor pressure in cell, thus inhibiting enlargement and cell splitting causing slow plant growth and reduction of dry mass accumulation (Delfine *et al.,* 2002).

It is obvious from the same table that the highest values of grain yield, straw yield, biomass yield, harvest index, number of spikes m^{-2} and weight of 1000 grains were obtained with F_2 compared to F_1 and these parameters gave the highest values with the inoculation by the consortium (cyanobacteria and *Rhizobium*) compared to cyanobacteria, *Rhizobium* both alone and control. This is a results of the synergistic effects of the nitrogen fixing cyanobacteria which a source of nitrogen, organic matter, oxygen to the rhizosphere, solubilize phosphate, amino acids, vitamins, auxins, increase the fertilizer use efficiency and enhance plant growth of crop plants (Prasanna *et al.,* 2012). And *Rhizobium* capability to survive and improving seedling growth under drought of wheat (Hussain *et al.,* 2014). The interaction between irrigation × PGPR, nitrogen levels × PGPR and irrigation × nitrogen levels × PGPR had a highly significant effect on wheat yield and its attributes, while no significant differences of grain yield, straw yield, biomass yield, harvest index, number of spikes m^{-2} and weight of 1000 grains for irrigation × nitrogen levels × PGPR × years interaction.

Table (3): Mean values of wheat yield and yield component as influenced by irrigation treatments, nitrogen levels and PGPR treatments in combined analysis of 2014/ 2015 and 2015/2016 seasons.

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biomass yield (t ha^{-1})	Harvest index	No. of spikes m^{-2}	Weight of 1000 grains(g)
Irrigation						
I_1	8.075^{a}	10.770^{a}	18.844^{a}	0.43^{a}	589^{a}	37.58^{a}
I_2	7.817^{a}	10.189^{b}	18.006^{b}	0.43^{a}	559^{ab}	36.84^{a}
I_3	7.187^{b}	10.235^{b}	17.423^{c}	0.41^{b}	529^{b}	35.78^{b}
Fertilizer						
F_1	7.272^{b}	10.012^{b}	17.284^{b}	0.42^{a}	547^{b}	35.71^{b}
F_2	8.114^{a}	10.783^{a}	18.898^{a}	0.43^{a}	571^{a}	37.75^{a}
PGPR						
C	6.173^{c}	10.050^{b}	16.223^{c}	0.39^{c}	464^{d}	32.60^{b}
R	7.643^{b}	10.640a	18.283^{b}	0.42^{b}	563^{c}	38.11^{a}
Cy	8.045^{b}	10.259^{ab}	18.304^{b}	0.44^{ab}	581^{b}	37.74^{a}
Cy +R	8.911^{a}	10.642^{a}	19.553^{a}	0.46^{a}	629^{a}	38.47^{a}
I × F	**	**	**	**	**	ns
I × PGPR	**	**	**	**	**	**
F × PGPR	*	**	**	**	*	**
I × F × PGPR	**	**	**	**	**	**
I × F × PGPR ×year	ns	ns	ns	ns	ns	ns

Means designed by the same letter at each cell are not significantly different at the 5% Level according to Duncan's multiple range test
n.s: Indicate not significant**.**

The highest values of grain yield, straw yield, biomass yield and number of spikes m^{-2} and weight of 1000 grains were obtained under $I_1 \times F_2$ interaction, while the lowest values of grain yield, harvest index, number of spikes m^{-2} and weight of 1000 grains were obtained under $I_3 \times F_1$ interaction. The lowest values of straw yield and biomass yield were obtained under $I_1 \times F_1$ interaction over both growing seasons, this may be due to the nutrients uptake increase with decreasing the soil moisture depletion (Nwachukwu and Ikeadigh, 2012 and Rizk and Sherif, 2014) as shown in Table (4). The interaction between scheduling irrigation and plant growth promoting rhizobacteria had a significant effect on wheat yield and its components. As shown in Table 4, the highest values of weight of 1000 grains, straw yield (t ha^{-1}), biomass yield (t ha^{-1}) and No. of spikes m^{-2} resulted from irrigation at I_1 with Cy+R, while the highest values of grain yield and harvest index were obtained under I_2 with Cy+R in over both growing seasons. PGPR induced physical and chemical changes in plants that resulted in enhancement tolerance to abiotic stress. It had proved its significance in plant growth promotion through enhanced nutrient acquisition, phytohormone production, and biological control (Nakkeeran *et al.,* 2005)**.** More recent studies reported that the effects of PGPR on different plants through their increase the ability to tolerate the several abiotic stress factors, including drought (Dimkpa *et al.,* 2009 and Yang *et al.,* 2009). Wheat plants inoculated by PGPR are able to feel drier soil more quickly and produce non- hydraulic root-sourced signals earlier, total leaf areas larger, photosynthetic products accumulated, higher shoot dry weight and water use efficiency than non-inoculated under water stress condition(Zhu *et al.,* 2014).

The lowest values of wheat yield and its attributes were obtained under $I_3 \times C$. In general application of a consortium of cyanobacteria and *Rhizobium* give positive effects in yield and its attributes with different irrigation treatments in both two growing seasons.

The interaction between fertilizer levels and PGPR treatments showed that the highest values of grain yield, biomass yield, harvest index, number of spikes m^{-2} and weight of 1000 grains were obtained under $F_2 \times$ Cy+R interaction, while the lowest values of the same wheat yield and its attributes resulted from $F_1 \times C$ interaction over both growing seasons as shown in Table (5). Mussa *et al.,* (2003) found that, the wheat plants inoculation with cyanobacteria enhanced the nitrogen use efficiency.

The highest values of grain yield, number of spikes m^{-2} and weight of 1000 grains were obtained under $I_1 \times F_2 \times$ Cy+R and $I_2 \times F_2 \times$ Cy+R without any significant differences between them over both two growing seasons. Whereas the highest values of the harvest index were obtained under $I_2 \times F_2 \times$ Cy+R interaction over the both growing seasons. However, the lowest values of grain yield, harvest index and weight of 1000 grain resulted from $I_3 \times F_1 \times C$ interaction over both two growing seasons. The highest values of straw yield, biomass yield and number of spikes m^{-2} were obtained under $I_1 \times F_2 \times$ Cy+R interaction, while the lowest values of straw yield and biomass yield resulted from $I_1 \times F_1 \times C$ interaction over both growing seasons as shown in Table (6). Cyanobacteria are the best models for planning strategies to manage agricultural water stress in an eco-friendly manner, and use of N_2- cyanobacteria as biofertilizer or a plant growth regulator consider improver in arid soils (Apte, 2001)**.**

The highest values of grain yield resulted from $I_1 \times F_2 \times$ Cy to be 10.357 t ha^{-1} followed by $I_1 \times F_2 \times$ Cy+R which produced 9.818 t ha^{-1} and $I_2 \times F_1 \times$ Cy+R which produced 9.249 t ha^{-1} and $I_3 \times F_1 \times$ Cy+R which produced 8.820 t ha^{-1}. Keeping on the economic productivity under water shortage requires applying $I_2 \times F_1 \times$ Cy+R or $I_3 \times F_1 \times$ Cy+R. This depends mainly on the level of water shortage required for the economic yield. In other words, under the conditions of irrigation water shortage for wheat productivity, farmer should apply $I_2 \times F_1 \times$ Cy+R which produced 9.249 t ha^{-1} or $I_3 \times F_1 \times$Cy+R which produced 8.820 t ha^{-1}.

Table (4): The interaction between irrigation treatments × fertilizer levels and irrigation treatments × PGPR on wheat yield and its components in combined analysis over both growing seasons.

Irrigation	Fertilizer		PGPR			
	F_1	F_2	C	R	Cy	Cy+R
Grain yield (t ha^{-1})						
I_1	7.307^{d}	8.842^{a}	6.607^{g}	8.032^{de}	9.229^{ab}	8.431^{bcd}
I_2	7.717^{bc}	7.918^{b}	6.298^{gh}	8.087^{cde}	7.478^{ef}	9.407^{a}
I_3	6.792^{e}	7.583^{cd}	5.615^{h}	6.811^{fg}	7.429^{ef}	8.896^{abc}
Straw yield (t ha^{-1})						
I_1	8.865^{d}	12.674^{a}	9.673^{d}	10.604^{bc}	10.706^{bc}	12.097^{a}
I_2	10.641^{b}	9.736c	9.934^{cd}	10.299^{bcd}	10.401^{bcd}	10.121^{cd}
I_3	10.530^{b}	9.941^{bc}	10.544^{bc}	11.017^{b}	9.669^{d}	9.711^{d}
Biomass yield (t ha^{-1})						
I_1	16.172^{d}	21.517^{a}	16.279^{f}	18.636^{c}	19.935^{ab}	20.528^{a}
I_2	18.358^{b}	17.654^{c}	16.232^{f}	18.386^{cd}	17.879^{cde}	19.528^{b}
I_3	17.322^{c}	17.524^{c}	16.158^{f}	17.829^{de}	17.098^{e}	18.607^{cd}
Harvest index						
I_1	0.45^{ab}	0.41^{de}	0.42^{de}	0.44^{bcd}	0.46^{abc}	0.41^{de}
I_2	0.42^{cd}	0.45^{ab}	0.39^{ef}	0.44^{bcd}	0.41^{de}	0.48^{ab}
I_3	0.39^{e}	0.43^{bc}	0.35^{f}	0.38^{ef}	0.44^{bcd}	0.48^{ab}
No. of Spikes m^{-2}						
I_1	559^{bc}	619^{a}	513^{e}	579^{c}	608^{b}	657^{a}
I_2	548^{bc}	548^{bc}	440^{f}	569^{c}	571^{c}	656^{a}
I_3	513^{d}	546^{c}	438^{f}	542^{d}	564^{cd}	573^{c}
Weight of 1000 grains						
I_1	36.88^{a}	38.27^{a}	31.10^{g}	40.32^{ab}	37.35^{cde}	41.55^{a}
I_2	36.97^{a}	36.72^{a}	34.45^{f}	38.53^{bcd}	38.94^{bc}	35.47^{ef}
I_3	33.30^{b}	38.26^{a}	32.25^{g}	35.50^{ef}	36.94^{de}	38.42^{bcd}

Means designed by the same letter at each cell are not significantly different at the 5% Level according to Duncan's multiple range test

Table (5): The interaction between plant growth promoting rhizobacteria (PGPR) and fertilizer on wheat yield and its components in combined analysis of 1 st and 2nd seasons.

PGPR	Fertilizer		Fertilizer		Fertilizer	
	F_1	F_2	F_1	F_2	F_1	F_2
	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		Biomass yield (t ha^{-1})	
C	5.625^{e}	6.721^{d}	10.137^{bcd}	9.963^{cde}	15.762^{e}	16.684^{d}
R	7.645^{c}	7.641^{c}	9.333^{e}	11.946^{a}	16.979^{cd}	19.587^{ab}
Cy	7.446^{c}	8.645^{b}	9.886^{de}	10.632^{bc}	17.331^{c}	19.277^{b}
Cy+R	8.371^{b}	9.452^{a}	10.693^{b}	10.593^{bc}	19.064^{b}	20.044^{a}
	Harvest index		No. of Spikes m^{-2}		Weight of 1000 grains(g)	
C	0.37^{e}	0.41^{cd}	445^{f}	483^{e}	31.74^{e}	33.46^{d}
R	0.45^{ab}	0.39^{de}	549^{d}	578^{c}	38.01^{b}	38.23^{b}
Cy	0.43^{bc}	0.45^{ab}	581^{c}	581^{c}	37.16^{bc}	38.32^{b}
Cy+R	0.44^{bc}	0.47^{a}	616^{b}	641^{a}	35.95^{c}	41.02^{a}

Means designed by the same letter at each cell are not significantly different at the 5% Level according to Duncan's multiple range test.

Wheat water consumptive use and applied irrigation water

Data in Table (7) indicate that, the peak values of wheat water consumptive use were in March during the flowering stage. There are visible differences of the values of wheat water consumptive use between irrigation treatments and fertilizer levels. A slight increase was observed in water consumptive use in favour of treatment of F_2 compared to F_1 treatment. This increment may be attributed to nitrogen fertilizer which increased photosynthetic activity and promote the growth of the plants (Pradhan *et al.,* 2014), but there are no obvious differences in the values of water consumptive use between PGPR treatments as a mean of the two growing seasons. Also, there are no clear differences in the values of irrigation water applied between nitrogen levels and PGPR treatments.

The values of wheat consumptive use and irrigation water applied has the descending order $I_1 > I_2 > I_3$ over both growing seasons, this may be due to increase the number of irrigations during growing season (Eldardiry *et al.,* 2010 and Khan *et al.,* 2007), obtained results agree with data presented by (FAO, 2010 and Rizk and Sherif, 2014), they concluded that total cumulative evapotranspiration increased with more applied irrigation and increasing available soil moisture compared with less irrigation. The amount of irrigation water applied over both growing seasons was 39.02, 32.43 and 27.36 cm for irrigated wheat plants at 50%±5 (I_1), irrigation at 70% ±5 (I_2) and irrigation at 90%±5 of ASMD respectively. Amount of irrigation water at 50%±5 of ASMD was the highest and distributed on five irrigations involving the seeding irrigation while amount of irrigation at 90%±5 of ASMD was the least value, and distributed on three irrigations including seeding irrigation. Amount of irrigation water at 70%±5 ASMD was between 50%±5 and 90%±5 of ASMD and distributed on four irrigations having seeding irrigation. Also, irrigation water applied decreased by 17% and 30 % under I_2 and I_3 respectively compared to I_1 as a mean of the two growing seasons, this may be due to deficit irrigation which reduce irrigation water application(Karrou *et al.,* 2012) as shown in Table (7).

Table (6): Effect of the interaction among irrigation treatments, nitrogen levels and PGPR on wheat yield and its components over both seasons.

Treatments			Parameters					
			Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biomass yield ($t\ ha^{-1}$)	Harvest index	No. of Spikes m^{-2}	Weight of 1000 grains (g)
I_1	F_1	C	6.182^{ij}	7.098^{l}	13.280^{k}	0.47^{abcde}	490^{kl}	30.42^{hi}
		R	7.900^{defg}	7.808^{kl}	15.708^{ij}	0.50^{ab}	540^{hij}	40.32^{ab}
		Cy	8.102^{cdef}	9.391^{hij}	17.493^{gh}	0.46^{bcde}	570^{fgh}	35.55^{def}
		Cy+R	7.044^{fghij}	11.163^{defg}	18.207^{defg}	0.39^{hij}	637^{bc}	41.24^{a}
	F_2	C	7.031^{fghij}	12.247^{abcd}	19.278^{d}	0.36^{ij}	536^{ij}	31.77^{ghi}
		R	8.163^{cdef}	13.399^{a}	21.563^{bc}	0.38^{hij}	617^{cd}	40.32^{ab}
		Cy	10.357^{a}	12.020^{bcde}	22.377^{ab}	0.46^{bcde}	645^{abc}	39.15^{abc}
		Cy+R	9.818^{ab}	13.030^{ab}	22.848^{a}	0.43^{defgh}	676^{a}	41.86^{a}
I_2	F_1	C	5.861^{jk}	10.609^{fg}	16.470^{hi}	0.36^{j}	420^{o}	35.63^{def}
		R	8.808^{bcde}	9.042^{ij}	17.850^{fg}	0.49^{abc}	594^{def}	40.71^{ab}
		Cy	6.948^{fghij}	11.387^{def}	18.336^{defg}	0.38^{hij}	602^{de}	41.27^{a}
		Cy+R	9.249^{abc}	11.528^{def}	20.777^{c}	0.45^{bcdefg}	666^{ab}	30.27^{hi}
	F_2	C	6.734^{ghij}	9.259^{ij}	15.994^{i}	0.42^{efghi}	460^{lm}	33.28^{fg}
		R	7.365^{fghi}	11.556^{cdef}	18.921^{def}	0.39^{ghij}	544^{ghi}	36.34^{de}
		Cy	8.007^{cdefg}	9.414^{hij}	17.422^{gh}	0.45^{bcdef}	540^{hij}	36.60^{cde}
		Cy+R	9.565^{ab}	8.713^{jk}	18.278^{defg}	0.52^{a}	646^{abc}	40.66^{ab}
I_3	F_1	C	4.832^{k}	12.704^{abc}	17.536^{gh}	0.27k	424^{no}	29.17^{i}
		R	6.228^{ij}	11.150^{defg}	17.379^{gh}	0.36^{j}	512^{jk}	33.00^{fgh}
		Cy	7.287^{fghi}	8.878^{ijk}	16.165^{i}	0.45^{bcdef}	570^{fgh}	34.67^{ef}
		Cy+R	8.820^{bcde}	9.387^{hij}	18.207^{defg}	0.48^{abcd}	544^{ghi}	36.33^{de}
	F_2	C	6.397^{hij}	8.383^{jk}	14.780^{j}	0.43^{cdefgh}	452^{mn}	35.33^{def}
		R	7.394^{fghi}	10.884^{efg}	18.278^{defg}	0.40^{fghi}j	572^{efg}	38.00^{bcd}
		Cy	7.570^{efgh}	10.460^{fgh}	18.031^{efg}	0.42^{efghi}	558^{ghi}	39.21^{abc}
		Cy+R	8.972^{bcd}	10.035^{ghi}	19.007^{de}	0.47^{abcde}	602^{de}	40.49^{ab}

Means designed by the same letter at each cell are not significantly different at the 5% Level according to Duncan's multiple range test

Table (7): Monthly, seasonal water consumptive use (CU) and seasonal irrigation water applied (IW) of wheat as a means of the two growing seasons

Treatments			Monthly CU (cm)							Seasonal CU (cm)	IW (cm)
			Nov.	Dec.	Jan.	Feb.	March	April	May		
I_1	F_1	C	1.41	4.30	4.03	5.93	8.92	5.19	0.36	30.14	39.02
		R	1.41	4.30	4.03	5.93	8.93	5.19	0.36	30.15	39.02
		Cy	1.41	4.30	4.03	5.93	8.93	5.19	0.36	30.15	39.02
		Cy +R	1.41	4.30	4.04	5.94	8.94	5.19	0.36	30.18	39.02
	F_2	C	1.41	4.30	4.06	5.96	8.96	5.21	0.36	30.26	39.02
		R	1.41	4.30	4.06	5.97	8.96	5.22	0.36	30.28	39.02
		Cy	1.41	4.30	4.06	5.97	8.97	5.22	0.36	30.29	39.02
		Cy +R	1.41	4.30	4.07	5.98	8.98	5.23	0.36	30.33	39.02
Mean			1.41	4.30	4.05	5.95	8.95	5.20	0.36	30.22	39.02
I_2	F_1	C	1.41	4.30	3.31	3.64	7.77	5.39	0.37	26.19	32.43
		R	1.41	4.30	3.31	3.64	7.78	5.39	0.37	26.20	32.43
		Cy	1.41	4.30	3.31	3.64	7.78	5.39	0.37	26.20	32.43
		Cy +R	1.41	4.30	3.32	3.64	7.79	5.40	0.37	26.23	32.43
	F_2	C	1.41	4.30	3.33	3.66	7.80	5.41	0.37	26.28	32.43
		R	1.41	4.30	3.33	3.66	7.80	5.41	0.37	26.28	32.43
		Cy	1.41	4.30	3.33	3.66	7.81	5.41	0.37	26.29	32.43
		Cy +R	1.41	4.30	3.34	3.67	7.82	5.42	0.37	26.33	32.43
Mean			1.41	4.30	3.32	3.65	7.80	5.40	0.37	26.25	32.43
I_3	F_1	C	1.41	4.30	2.54	2.28	6.78	5.10	0.35	22.76	27.36
		R	1.41	4.30	2.54	2.28	6.79	5.10	0.35	22.77	27.36
		Cy	1.41	4.30	2.54	2.28	6.79	5.10	0.35	22.77	27.36
		Cy +R	1.41	4.30	2.55	2.28	6.80	5.10	0.35	22.79	27.36
	F_2	C	1.41	4.30	2.55	2.32	6.81	5.10	0.35	22.84	27.36
		R	1.41	4.30	2.55	2.33	6.81	5.10	0.35	22.85	27.36
		Cy	1.41	4.30	2.55	2.33	6.81	5.10	0.35	22.85	27.36
		Cy +R	1.41	4.30	2.56	2.33	6.81	5.11	0.35	22.87	27.36
Mean			1.41	4.30	2.55	2.30	6.80	5.10	0.35	22.81	27.36
Overall means of CU			I_1 = 30.22			I_2 = 26.25		I_3 = 22.81			
			F_1 = 26.38					F_2 = 26.48			

Contribution of groundwater

In the studied area, water table depth fluctuation ranged from 35 cm to 55 cm on all growing season. At late season, when irrigation stopped, groundwater, moved down up to a depth of 80-85cm as mean of the two growing seasons. There are a slight difference in water table depth fluctuation between different irrigation treatments as a mean of the two growing season as shown in Fig (1). So the percentage of groundwater contribution to wheat water consumptive use in this experiment is very important especially when applying deficit irrigation such as I_3 irrigation treatment.

The percentage of groundwater contribution using ET_c values obtained by the class A pan method is higher than that at Penman Montieth. Irrigation treatment of I_3 gave the highest percentage of groundwater contribution to be 50.4% and 41.6% using class A pan and Penman Montieth methods respectively, as a mean of the two growing seasons. Irrigation treatment of I_1 resulted in the lowest percentage of groundwater contribution to be 13.5% and 6.9% using class A pan and Penman Montieth methods respectively, this consider groundwater contribution to crop water use may be due to the contribution of shallow water table which increase capillary supplied and groundwater contribution to crop water use varied from 18% to 40% (Ayars *et al.,* 2006; Babajimopoulos *et al.,* 2007; Gowing *et al.,* 2009; Huo *et al.,* 2012; Karimov *et al.,* 2014 and Soppe and Ayars, 2003). The mean percentage of groundwater contribution has the descending order $I_3 > I_2 > I_1$, it is about 46%, 26.9% and 10.2% for I_3, I_2 and I_1 respectively as a mean of the two growing seasons. This result agree with (Babajimopoulos *et al.,* 2007 and Sepaskhah *et al.,* 2003) who reported that under shallow water table, the interval between irrigation could be increase. The seasonally averaged ratio of the groundwater contribution to crop-water use varied with the seasonal water input and depth of water table, the ratio reached about 75% in case of water table depth about 1m with no irrigation. This ratio decreased to 3% in case of water table depth more than 3.0 m and three irrigation applications as shown in Fig (2).

Data in Fig. (3) illustrate that the highest total seasonal water input was associated with I_1 which was 5000 m^3ha^{-1} that divided to three components, 78% for irrigation, 15.8% for effective rain and 6.2% for groundwater contribution. While the lowest seasonal water applied was associated with I_3 to be 4575 m^3ha^{-1}, which divided to 59.8% for irrigation, 17.3% for effective rain and 22.9% for groundwater contribution. The total seasonal water applied decreased by 5.2 % and 8.5% with the irrigation treatments of I_2 and I_3 compared to I_1 respectively as mean of the two growing seasons. These result are harmony with those obtained by (Babajimopoulos *et al.,* 2007; Gowing *et al.,* 2009; Huo *et al.,* 2012; Karimov *et al.,* 2014; Kruse *et al.,* 1986; Soppe and Ayars, 2003 and Yang *et al.,* 2007) who mentioned that the significant contribution of groundwater to meet part of crop water requirement and should take it in consideration when scheduling irrigation, thus could reduce applied irrigation to achieve water saving.

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

Data in Table (8) show that there are a significant difference in PIW and WP between irrigation treatments, nitrogen levels and PGPR treatments, the highest values of PIW and WP resulted from F_2 and R+Cy compared to F_1 and with other PGPR treatments as mean of the two growing seasons, this may be due to the higher grain yield compared to the other treatments. The highest values of PIW resulted from I_3 while the lowest values of PIW resulted from I_1. This results agree with (Bandyopadhyay and Mallick, 2003) who found that productivity of irrigation water increased when irrigation intervals increased. The highest values of WP were observed with I_1 and I_2 without any significant differences between them while the lowest values resulted from I_3. This may be due to the higher grain yield of I_1 and I_2 compared to I_3. As for the interaction among irrigation, N-fertlizer and PGPR treatments, the highest values of PIW and WP were obtained under $I_2 \times F_2 \times$ R+Cy, $I_3 \times F_2 \times$ R+Cy, and $I_3 \times F_1 \times$ R+Cy interactions without any significant differences between them, while the lowest values were obtained under $I_3 \times F_1 \times$ C as a mean of the two growing season. It could be due to that *Rhizobium* can increase the photosynthetic rate, transpiration velocity, stomatal conductance and flag leaf area of the plant therefore it is increasing water utilization efficiency (Chi *et al.,* 2005) in addition to the role of cyanobacteria, which accumulated higher levels of indoleacetic acid and gibberellin phytohormones (Jaiswal *et al.,* 2008). Plant-growth-promoting rhizobacteria was increased chlorophyll content, the root and shoot biomass, height of plants, yield and the wheat plants could withstand water stress more efficiently, enhanced antioxidant responses and increased accumulation of antioxidants such as carotenoids and ascorbate (Chakraborty *et al.,* 2013).

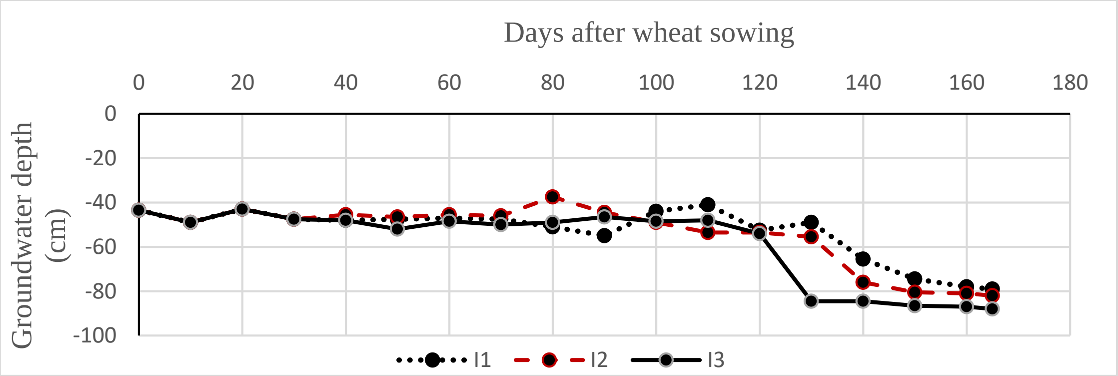

Fig (1): **Fluctuation of groundwater table during growth period as a mean of the two growing season.**

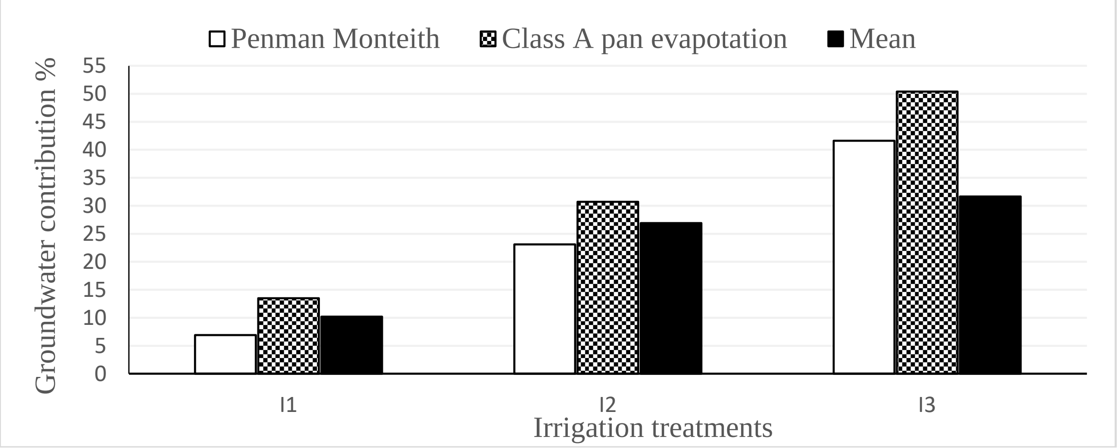

Fig (2): **Groundwater contribution to wheat consumptive use using Penman Monteith and class A pan evaporation method as mean of the two growing seasons.**

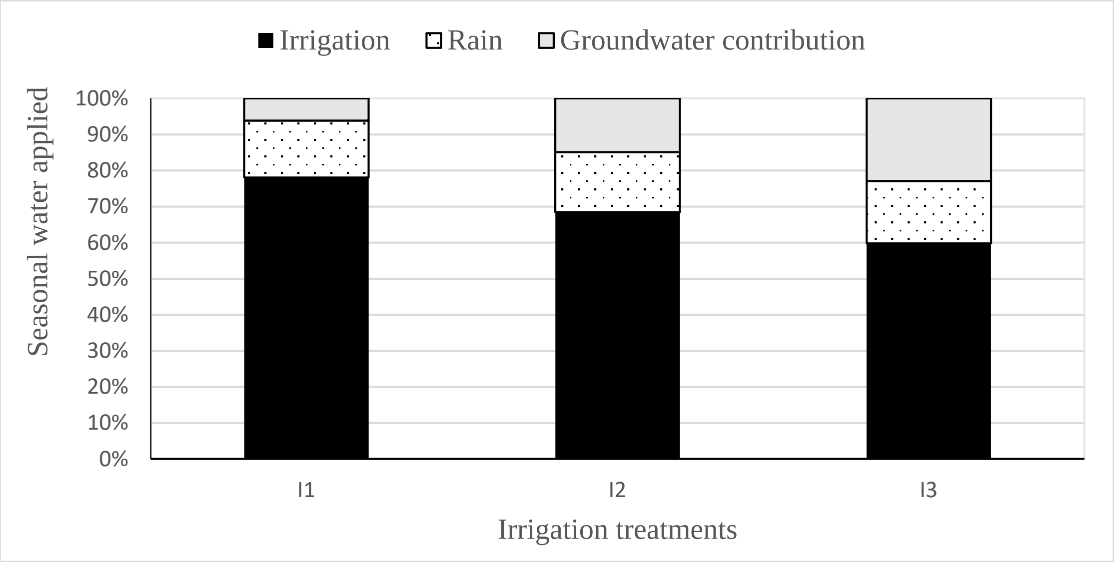

Fig (3): Average of total seasonal water applied over both seasons.

Table (8): Influence of irrigation scheduling, nitrogen levels and PGPR on productivity of irrigation water and water productivity of wheat over both seasons.

Irrigation	WP								Over all means
	F_1				F_2				
	C	R	Cy	R +Cy	C	R	Cy	R + Cy	
I_1	1.23 ^{gh}	1.58^{cdef}	1.62 ^{cde}	1.41^{defg}	1.4^{efg}	1.63 ^{bcd}	2.07^{a}	1.96^{a}	1.61 ^{ab}
I_2	1.23 ^{gh}	1.85 ^{ab}	1.46^{cdef}	1.95^{a}	1.42^{defg}	1.55^{cdef}	1.69^{bc}	2.01^{a}	1.65 ^{a}
I_3	1.05^{h}	1.36 ^{fg}	1.59 ^{cde}	1.92^{a}	1.39 ^{efg}	1.61 ^{cde}	1.65^{bc}	1.96^{a}	1.57 ^{b}
Over all means	F_1 = 1.52 ^{b}				F_2 = 1.70 ^{a}				
	C = 1.29 ^{c}		R = 1.60 ^{b}		Cy = 1.68 ^{b}		R + Cy = 1.87 ^{a}		
	PIW								
I_1	1.58 ^{k}	2.02 ^{ij}	2.08 ^{hij}	1.81 ^{jk}	1.8 ^{jk}	2.09 ^{hij}	2.65 ^{bcdef}	2.52^{cdefg}	2.07 ^{c}
I_2	1.81 ^{jk}	2.72 ^{bcd}	2.14 ^{ghij}	2.85 ^{bc}	2.08 ^{hij}	2.27^{fghi}	2.47^{cdefgh}	2.95 ^{ab}	2.41 ^{b}
I_3	1.77 ^{jk}	2.28^{efghi}	2.66^{bcde}	3.22 ^{a}	2.34^{defghi}	2.70^{bcd}	2.77 ^{bc}	3.28^{a}	2.63 ^{a}
Over all means	F_1 = 2.45 ^{b}				F_2 = 2.49 ^{a}				
	C = 1.9 ^{c}		R = 2.38^{b}		Cy = 2.46 ^{b}		R + Cy = 2.77 ^{a}		

Means designed by the same letter at each cell are not significantly different at the 5% Level according to Duncan's multiple range test

Productivity of irrigation water and water productivity are good relation between irrigation water applied and grain yield because they increase when grain yield increase and/or water applied decrease (Ali *et al.,* 2007; Ghane *et al.,* 2009 and Zwart and Bastiaanssen, 2004).

CONCLUSION

In the studied area of North Nile Delta, Egypt where lack of irrigation water and shallow water table, farmers should add irrigation water at the time of actual need of the crop with just enough water to wet the effective root zone soil via applying irrigation scheduling at 90±5% with the addition of 75% of the recommended nitrogen fertilizer and inoculation with a consortium N_2 – fixing cyanobacteria and Rhizobium (Cy+R) because it increased WP and PIW by 37% and 79% respectively, as well as saved nitrogen fertilizer and irrigation water by 25% and 30% respectively compared to I_1 with F_2 and C. As well as enhancing use of groundwater contribution under water scarcity areas.

REFERENCES

Adnan, M., Z. Shah, A. Khan, G.A. Khan, A. Ali, N.A. Khan, N. Saleem, S. Nawaz, S. Akbar and S. Samreen (2014). Integrated effects of rhizobial inoculum and inorganic fertilizers on wheat yield and yield components. Am. J. Plant Sci. 5: 2066-2073.

Afzal, A. and B. Asghari (2008). Rhizobium and phosphate solubilizing bacteria improve the yield and phosphorus uptake in wheat (Triticum aestivum). Int J Agric Biol 10: 85–88.

Agricultural Economics Research Institute, (2015). National agricultural income estimates (Ministry of Agriculture and Land Reclamation).

Ali, M.H., M.R. Hoque, A.A. Hassan and A. Khair (2007). Effects of deficit irrigation on yield, water productivity, and economic returns of wheat. Agric. Water Manag. 92: 151–161.

Allen, R.G.; L.S. Pereira; D. Raes and M. Smith (1998). Crop evapotranspiration-Guidelines for computing crop water requirements. Irrig. Drain. Pap. 56 FAO, Rome 300, D05109.

Apte, S.K. (2001). Coping with salinity/water stress: cyanobacteria show the way. Proceedings-Indian Natl. Sci. Acad. part B 67: 285–309.

Ayars, J.E., E.W. Christen and J.W. Hornbuckle (2006). Controlled drainage for improved water management in arid regions irrigated agriculture. Agric. Water Manag. 86: 128–139.

Ayars, J.E., P. Shouse and S.M. Lesch (2009). In situ use of groundwater by alfalfa. Agric. Water Manag. 96: 1579–1586.

Babajimopoulos, C., A. Panoras, H. Georgoussis and G. Arampatzis (2007). Contribution to irrigation from shallow water table under field conditions. Agric. Water Manag. 92: 205–210.

Bandyopadhyay, P.K. and S. Mallick (2003). Actual evapotranspiration and crop coefficients of wheat (Triticum aestivum) under varying moisture levels of humid tropical canal command area. Agric. Water Manag. 59:33–47.

Black, C.A. (1965). Methods of Soil Analysis: 2 Parts. American Society of Agronomy.

Braun, H.J., G. Atlin and T. Payne (2010). Multi-location testing as a tool to identify plant response to global climate change. Clim. Chang. Crop Prod. 1: 115–138.

Chakraborty, U., B.N. Chakraborty, A.P. Chakraborty and P.L. Dey (2013). Water stress amelioration and plant growth promotion in wheat plants by osmotic stress tolerant bacteria. World J. Microbiol. Biotechnol. 29:789–803.

Chi, F., S.H. Shen, H.P. Cheng, Y.X. Jing, Y.G. Yanni and F.B. Dazzo (2005). Ascending migration of endophytic rhizobia, from roots to leaves, inside rice plants and assessment of benefits to rice growth physiology. Appl. Environ.

Microbiol. 71: 7271–7278.

Delfine, S., R. Tognetti, F. Loreto and A. Alvino (2002). Physiological and growth responses to water stress in field-grown bell pepper (Capsicum annuum L.). J. Hortic. Sci. Biotechnol. 77: 697–704.

Dimkpa, C., T. Weinand and F. Asch (2009). Plant–rhizobacteria interactions alleviate abiotic stress conditions. Plant Cell Env. 32:1682–1694.

Doorenbos, J., A.H. Kassam, C.L.M. Bentvelsen and V. Bronchied (1979). Yield response to water. Irrig. Drain. Pap. No. 33 Rome, Italy.

Doorenbos, J. and W.O. Pruitt (1977). Guidelines for predicting crop water requirements FAO. Irrig. Drainage, Pap. 24, FAO, Rome, Italy

Duncan, D.B. (1955). Multiple range and multiple F tests. Biometrics 11, 1–42.

El- Nawawy, A.S., M. Lotfi and M. Fahmy (1958). Studies on the ability of some blue- green algae to fix atmospheric nitrogen and their effect on growth and yield of paddy. Agric. Res. Rev., Min. Agric., Cairo 36: 308–320.

Eldardiry, E.I., M. Abd El-Hady and S.M. El-Ashry (2010). Effect of water regime and Potassium application on water relations and nutrient uptake of wheat plant. Int. J. Acad. Res., 2: 75–82.

FAO, (2010). Food Outlook Report, http://www.fao.org/docrep/./ak349e00.pdf (accessed 20.01.11).

FAOSTAT, (2013). Production domain. In: Crops. FAO, Rome (accessed 20.12.13).

Giriappa, S. (1983). Water use Efficiency in Agriculture. Oxford & IBH Publishing co. pvt. ltd.

Gowing, J.W., D.A. Rose and H. Ghamarnia (2009). The effect of salinity on water productivity of wheat under deficit irrigation above shallow groundwater. Agric. Water Manag. 96: 517–524.

Hammad, S.A.R. and O.A.M. Ali (2014). Physiological and biochemical studies on drought tolerance of wheat plants by application of amino acids and yeast extract. Ann. Agric. Sci. 59: 133–145.

Hilali, A., D. Prevost, W.J. Broughton and H. Antoun (2001). Effects of inoculation with Rhizobium leguminosarum biovar trifolii on wheat cultivated in clover crop rotation agricultural soil in Morocco. Can. J. Microbiol. 47:590–593.

Huo, Z., S. Feng, G. Huang, Y. Zheng, Y. Wang and P. Guo (2012). Effect of groundwater level depth and irrigation amount on water fluxes at the groundwater table and water use of wheat. Irrig. Drain. 61: 348–356.

Hussain, M.B., Z.A. Zahir, H.N. Asghar and M. Asghar (2014). Can catalase and exopolysaccharides producing rhizobia ameliorate drought stress in wheat. Int J. Agric. Biol. 16:3–13.

Israelsen, O.W. and V.E. Hansen (1962). Irrigation Principles and Practices 3rd Edit. John Willey and Sons. Inc., New York.

Jaiswal, P., R. Prasanna, S. Nayak, A. Sood and M.R. Suseela (2008). Characterization of rhizo-cyanobacteria and their associations with wheat seedlings. Egypt J. Biol., 10: 20–27.

Jalali, V., S. Asadi and M. Homaee (2017). Evaluating performance of macroscopic water uptake models at productive growth stages of durum wheat under saline conditions. Agric. Water Manag. 180: 13–21.

James, L.G. (1988). Principles of Farm Irrigation System Design. John Wil-ley&Sons (ed.), New Yourk, pp.543.

Kahlown, M.A. and M. Ashraf (2005). Effect of shallow groundwater table on crop water requirements and crop yields. Agric. Water Manag. 76: 24–35.

Kang, S., L. Zhang, Y. Liang and X. Hu (2002). Effects of limited irrigation on yield and water use efficiency of winter wheat in the Loess Plateau of China. Agri Cult. Water Manag. 55: 203–216.

Karimov, K.A., J. Sim, M.A. Hanjra, M. Avliyakulov and I. Forkutsa (2014). Effects of the shallow water table on water use of winter wheat and ecosystem health : Implications for unlocking the potential of groundwater in the Fergana Valley (Central Asia). Agric. Water Manag. 131: 57–69.

Karrou, M., T. Oweis, R. Abou, E. Enein and M. Sherif (2012). Yield and water productivity of maize and wheat under deficit and raised bed irrigation practices in Egypt. African J. Agric. Res. 7:1755–1760.

Khan, M.J., T. Sarwar, A. Shahzadi and A. Malik (2007). Effect of different irrigation schedules on water use and yield of wheat. Sarhad J. Agric. 23: 1061–1066.

Klute, A. (1986). Methods of Soil Analysis, part 1: Physical and Miner-alogical Methods (2nd) Ed Ameri-can Soci. of Agronomy, Madison, Wisconsin, USA.

Kruse, E.G., R.E. Yoder, D.L. Cuevas and D.F. Champion (1986). Alfalfa water use from high, saline water tables. Am. Soc. Agric. Eng. Microfich. Collect.

Li, S.-X., Z.H. Wang, S.S. Malhi, S.Q. Li, Y.J. Gao and X.H. Tian (2009). Nutrient and water management effects on crop production, and nutrient and water use efficiency in dryland areas of China. Adv. Agron. 102: 223–265.

Luo, Y. and M. Sophocleous (2010). Seasonal groundwater contribution to crop-water use assessed with lysimeter observations and model simulations. J. Hydrol. 389: 325–335.

Mussa, S.A., M.H. Mona and F.M. Ghaza (2003). Effect of cyanobacteria-wheat association on wheat growth and yield components. Egypt. J. Biotechnol. 14: 164–174.

Nain, L., A. Rana, M. Joshi, S.D. Jadhav, D. Kumar, Y.S. Shivay, S. Paul and R. Prasanna (2010). Evaluation of synergistic effects of bacterial and cyanobacterial strains as biofertilizers for wheat. Plant Soil, 331:217–230.

Nakkeeran, S., W.G.D. Fernando and Z.A. Siddiqui (2005). Plant growth promoting rhizobacteria formulations and its scope in commercialization for the management of pests and diseases, in: Biocontrol and Biofertilization. Springer, pp. 257–296.

Namich, A.A.M. (2007). Response of cotton cultivar Giza 80 to application of glycine betaine under drought conditions. Minufiya J. Agric. Res. 32: 1637–1651.

Nouri, M., M. Homaee, M. Bannayan and G. Hoogenboom (2016). Towards modeling soil texture-specific sensitivity of wheat yield and water balance to climatic changes. Agric. Water Manag. 177: 248–263.

Novica, V. (1979). Irrigation of agriculture crops. Fac. Agric. Press, Novi Sad, Yugoslavia.

Nwachukwu, O.I. and M.C. Ikeadigh (2012). Water use efficiency and nutrient uptake of maize as affected by organic and inorganic fertilizer. PAT 8:199–208.

Osborne, S.L., J.S. Schepers, D.D. Francis and M.R. Schlemmer (2002). Use of spectral radiance to estimate in season biomass and grain yield in nitrogen and water stressed corn. Crop Sci. 42: 165–171.

Page, A.L., R.H. Miller and D.R. Keeney (1982). Methods of Soil Analysis - Chemical and Microbiological Properties. Madison, Wisconsin.

Pandey, R.K., J.W. Maranville and A. Admou (2001). Tropical wheat response to irrigation and nitrogen in a Sahelian environment. I. Grain yield, yield components and water use efficiency. Eur. J. Agron. 15: 93–105.

Paredes, P., G.C. Rodrigues, M. R. Cameira, M.O. Torres and L.S. Pereira (2017). Assessing yield, water productivity and farm economic returns of maltbarley as influenced by the sowing dates and supplemental irrigation. Agric. water manag. 179:132-143.

Pradhan, S., U.K. Chopra, K.K. Bandyopadhayay, R. Singh, A.K. Jain and I. Chand (2014). Effect of deficit irrigation and nitrogen levels on water productivity and nitrogen use efficiency of wheat (Triticum aestivum) in a semi-arid environment. Indian J. Agric. Sci. 84(7):887-891.

Prasanna, R., P. Jaiswal, J. Shrikrishna, M.

Joshi, L. Nain, A. Rana and Y.S. Shivay (2012). Evaluating the potential of rhizo-cyanobacteria as inoculants forrice and wheat. J. Agric. Technol. 8: 157–171.

Rizk, A.H. and M.M. Sherif (2014). Effect of soil moisture depletion on the yield of wheat under sprinkler irrigation at Toshka area, Egypt. Middle East J. Agric. Res. 3: 981–987.

Safa, M. and S. Samarasinghe (2011). Determination and modelling of energy consumption in wheat production using neural networks:A case study in Canterbury province, New Zealand. Energy 36: 5140–5147.

Sepaskhah, A.R., A. Kanooni and M.M. Ghasemi (2003). Estimating water table contributions to corn and sorghum water use. Agric. Water Manag. 58: 67–79.

Smith, M. (1992). CROPWAT: A computer program for irrigation planning and management”, FAO. Irrig. Drain. Pap. No. 46, Rome, Italy.

Soppe, R.W.O. and J.E. Ayars (2003). Characterizing ground water use by safflower using weighing lysimeters. Agric. water Manag. 60: 59–71.

Vincent, J.M. (1970). A manual for the practical study of the root-nodule bacteria. A Man. Pract. study root-nodule Bact.

Vomocil, J.A. (1957). Measurement of soil bulk density and penetrability: A review of methods. Adv. Agron. 9: 159–175.

Yang, J., J.W. Kloepper and C. Ryu (2009). Rhizosphere bacteria help plants tolerate abiotic stress. Trends Plant Sci 14: 1–4.

Yang, J., S. Wan, W. Deng and G. Zhang (2007). Water fluxes at a fluctuating water table and groundwater contributions to wheat water use in the lower Yellow River flood plain , China. Hydrol. Process. 724: 717–724.

Yanni, Y.G., F.B. Dazzo, A. Squartini, M. Zanardo, M.L. Zidan and A.E.Y. Elsadany (2016). Assessment of the natural endophytic association between Rhizobium and wheat and its ability to increase wheat production in the Nile delta. Plant Soil 407: 367–383.

Zhu, Y., Z. Wang, J. Wang, Z. Wang and J. Zhou (2014). Plant growth-promoting rhizobacteria improve shoot morphology and photosynthesis in dryland spring wheat. . WIT Trans. Built Environ. 145: 343–350.

Zwart, S.J. and W.G.M. Bastiaanssen (2004). Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agric. water Manag. 69: 115–133.

تحسين انتاجية مياه الرى لمحصول القمح بمنطقة ذات مستوى ماء أرضي مرتفع بشمال دلتا النيل - مصر

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الملخص العربى

اجريت تجربتان حقليتان بمحطة البحوث الزراعية بسخا- شمال دلتا النيل خلال الموسمين الزراعيين 2014 /2015 و 2015 /2016 وذلك بهدف تحسين انتاجية المياه ومحصول القمح بهذه المنطقة ذات مستوى الماء الأرضي القريب من سطح التربة. وكان تصميم التجربة قطع منشقة مرتين حيث وضعت معاملات جدولة الرى فى القطع الرئيسية وهى الرى عند استنفاذ 50 ±5 % و70 ±5 % و 90±5 % من الماء الميسربالتربة (I_1) و(I_2) و(I_3) بالترتيب. ووضعت مستويات التسميد النيتروجينى فى القطع تحت الرئيسية وهى التسميد بمعدل 100 % و75 % من المعدل الموصى به باستخدام السماد النيتروجيني (يوريا 46.5 %) (F_1) و (F_2), فى حين وضعت معاملات التلقيح بالميكروبات فى القطع تحت التحت رئيسية وهى السيانوبكتيريا المثبتة لازوت الهواء الجوي (Cy) والريزوبيا (R) المفرزة لمواد النمو والخليط بينهما (Cy + R) بالاضافة الى الكنترول بدون تلقيح ميكروبى (C) وكانت أهم النتائج المتحصل عليها كما يلى:

1- عدم وجود فروق معنوية في محصول الحبوب ودليل الحصاد وعدد السنابل / م^2 ووزن 1000 حبة بين المعاملات I_1 و I_2 . ولقد انخفض محصول الحبوب تحت المعاملة I_3 بنسبة 11% و 8% مقارنة مع I_1 و I_2 على التوالي خلال موسمى الزراعة.

2- أخذت قيم الاستهلاك المائى للقمح وكمية مياه الرى المضافة الترتيب التنازلى التالى $I_1 > I_2 > I_3$ خلال موسمى الزراعة وكانت قيم الاستهلاك المائى الموسمى 30.22 و26.25 و 22.81 سم لمعاملات جدولة الرىI_1 و I_2 و I_3 على الترتيب وكانت قيم مياه الرى المضافة 39.02 سم موزعة على 5 ريات و 32.43 سم موزعة على 4 ريات و 27.30 سم موزعة على 3 ريات تشمل رية الزراعة للمعاملاتI_1 و I_2 و I_3 على الترتيب.

3- وكانت قيم الاحتياجات المائية الكلية خلال الموسم 50.00 و 47.38 و 45.75 سم لمعاملات I_1 و I_2 و I_3 على الترتيب خلال موسمى الزراعة.

4- واخذت متوسط قيم مساهمة الماء الارضى فى الاستهلاك المائى الترتيب التنازلى التالى $I_3 > I_2 > I_1$ حيث كانت القيم 46.0 % و26.9 و 10.2 لمعاملات I_3 و I_2 و I_1 على الترتيب خلال موسمى الزراعة.

لذلك عندما يصبح الماء العامل المحدد لانتاجية القمح فى مثل هذه المنطقة فان المزارعين يمكنهم تطبيق معاملة جدولة الرى I_3 مع معاملة التسميد F_2 مع اضافة (Cy +R) لأن تطبيق هذة المعاملة يزيد انتاجية المياة وانتاجية مياة الرى بمقدار 37 % و79 % على الترتيب وايضا يوفر التسميد النيتروجينى ومياة الرى المضافة بمقدار 25 % و30 % على الترتيب مقارنة بمعاملة جدولة الرى I_1 مع معاملة التسميد النتروجينى F_2 مع عدم التلقيح بالميكروبات.