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Response of some wheat varieties to irrigation and nitrogen fertilization using ammonia gas in North Nile Delta region

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Abstract Strategies of regulated irrigation and fertilization are one of the most practical ways in saving irrigation water and N-fertilizer of farmland in arid and semi-arid regions. A field experiments were conducted in the two winter seasons of 2012/2013 and 2013/2014 on clay soil to investigate the effect of 3, 4 and 5 irrigation events and their interaction with two N-fertilization levels using ammonia gas; 75 and 90 kg N fed^{-1} which represent 100% and 120% of nitrogen recommended dose, respectively on wheat water consumptive use, grain yield, yield components and water productivity (WP) of three Egyptian wheat varieties; Misr-1, Misr-2 and Sakha-94 and compare the estimated wheat crop evapotranspiration (ET_c) values computed using Hargreaves, Penman–Monteith and Class A pan methods with the measured actual wheat evapotranspiration (ET_a) to evaluate the suitable method for estimating the reference evapotranspiration in North Nile Delta conditions.

The obtained results showed that the irrigation treatments (3 events) gave the lowest values for water consumptive use, grain, straw, biological yield and 1000-grain weight. Nitrogen fertilizer in ammonia up to 90 kg N fed^{-1} decreased all characters studied except grain yield which has no any significant differences between both N levels. Significant differences were detected among the three wheat varieties in all characters studied during both seasons and their interaction with the other treatments combined. Misr-1 cultivar was superior and gave the highest value of all studied characters and yield response to water factor (K_y) followed by Misr-2 while Sakha-94 showed the lowest values in all studied characters. Thus, Misr-1 cultivar proved to be more tolerant cultivar to drought followed by Misr-2 and Sakha-94. WP decreased with increasing irrigation events and nitrogen levels, and reached the maximum values at three irrigation treatments (3 events) and at 90 kg N fed^{-1}. So, irrigating the wheat 4 events during growing seasons and application of 75 kg N fed^{-1} in the form of ammonia gave the highest values of yield and yield components of Misr-1 wheat cultivar under North Nile Delta condition.

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Also, results showed that FAO Penman–Monteith is a suitable method for North Delta, Egypt, because of the least amount of error and least percentage deviation between ET_a and ET_c comparing with the other evaluated methods.

Introduction

Within the arid and semi-arid regions, water available is a major limitation for crop production. Wheat crop needs sufficient available water and N to achieve optimum yields, quality and adequate grain-protein content. In recent years, the water shortage has gradually increased in our country mainly due to the annual increasing irrigation and dry climate. Therefore, a better understanding of the water balance is essential for exploring water saving measures. One of the most important aspects of water balance is number of irrigation to the crop, which is a key factor to determine proper to improve water use efficiency in irrigated agriculture. In Egypt, its production does not meet the current demand. The Egyptian government is doing more efforts to reduce the imported percentage to less than 50% from the total consumption (Abdrabbo et al., 2010).

The key to raise crop yield, lies to a large extent, in the increase of usable water and raising the efficiency of water use (Li et al., 2001). Over the last decades, a number of studies have been conducted on the regulation of water and fertilizers in arid and semi-arid regions in an attempt to increase crop yield (De Juan et al., 1999 and Li et al., 2001). Ouda et al. (2010) reported that irrigation was rescheduled (1804.6 m^3-fed^{-1}) and number of irrigations for wheat was reduced to 5 irrigations instead of 6 irrigations. Sarwar et al. (2010) found that wheat crop supplied with five irrigations at crown root + tillering + booting + earing + milking recorded the highest grain yield (5696.8 kg ha^{-1}). Wajid et al. (2002) reported that wheat crop produced highest grain yield by applying irrigation at all definable growth stages. Because irrigation is an expensive input, farmer, agronomist, economist and engineer need to know the response of yield to irrigation.

There were many intelligent irrigation systems computing applied water and evapotranspiration (ET) that based on climatic conditions (McCready et al., 2009; Mendez-Barroso et al., 2008; Lozano and Mateos, 2008). Aggarwal et al. (1986) showed that water use efficiency (WUE) for wheat decreased with increasing ET. The use of frequent, but low water application volumes is superior to the more traditional scheduling of few applications of large irrigation volumes in terms of irrigation water use efficiency (IWUE) (Dukes et al., 2010; Locascio, 2005; Zotarelli et al., 2009). Jin et al. (1999) reported that excessive irrigation led to a decrease in crop WUE and that effective deficit irrigation may result in higher production and WUE. On the contrary, Olesen et al. (2000) showed that the effect of irrigation on wheat yield was almost solely due to increase transpiration, while WUE and harvest index remained unaffected.

Moussa and Abdel-Maksoud (2004) found that evapotranspiration (ET) value was increased as supplemental irrigation increased in wheat crop, since evapotranspiration ranged from 338 to 382 mm at one third of full supplemental irrigation and from 434 to 453 mm at full supplemental one. El-Far and Teama (1999) found that the highest number of spikes m^{-2}, 1000-grain weight and grain yield was obtained from irrigation every 31 days but the highest straw yield was obtained at irrigation every 21 days. Sharaan et al. (2000) reported that skipping irrigation either at heading or at drought-ripe stage decreased all studied traits except biological and straw yields fed^{-1}. Moreover, Normal irrigation produced the highest averages of different traits followed by those resulted from skipping one irrigation at drought ripe stage, meanwhile, the lowest values were obtained from skipping one irrigation at heading stage.

Both organic and inorganic sources of supplemental nitrogen are available to the farmers. Costs and form of the supplemental nitrogen dictate which of these sources should be used in a given situation. In addition, nitrogen fertilizer sources have considerable effect on both soil pH and solubility of cations. Shams El-Din et al. (1990) found that anhydrous ammonia, urea, ammonium sulfate and ammonium nitrate were equal as a source of nitrogen fertilization, and the effect of the interactions between N rates and sources on the yield and yield components was not significant. So, on the basis of previous and from an economical point of view, the use of anhydrous ammonia in fertilizing wheat crop was recommended under Egyptian conditions. Many researchers found that grain and straw yields of wheat plants were increased due to increasing nitrogen level while, Abd El-Hmeed and Omar (2006) concluded that, increasing N levels up to 105 kg N fed^{-1} significantly increased each of spike length, 1000-grain weight and grain yield. Mahmoud et al. (2006) recorded that grain and straw yields for wheat plants were increased due to increasing nitrogen level from 20 to 40, 60, 80 and 100 kg N fed^{-1}.

The determination of crop water requirements is the first step used in planning and design. The operation commonly involves of the reference crop evapotranspiration (ET_o) or evaluation of crop evapotranspiration (ET_c). Better estimates of crop evapotranspiration play important role to accurately determine the crop water requirements. Different methods can be used to determine crop evapotranspiration (ET_c), which is an essential element in crop water use (Attarod et al., 2005). The FAO Penman–Monteith method (Allen et al., 1998) is generally considered to be the best approach for estimating crop evapotranspiration. Crop coefficients are used to estimate evapotranspiration of crops multiplied by calculated potential or reference evapotranspiration (ET_o). An estimate of evapotranspiration forms the foundation for the planning and designing of all irrigation projects and efficient water usage, providing a basic tool for computing water balance and predicting water availability and requirement (Humphrey et al., 1994; Pereira et al., 1999). Crop water requirements are directly related to crop evapotranspiration (ET_c) and vary depends on crop grown and its different growth stages. Evapotranspiration involves a highly complex set of processes, which are influenced by many factors depend on the local conditions. These conditions range from precipitation and meteorology factors to soil moisture, plant water requirements and the physical nature of the land covered (Dunn and Mackay, 1995).

So, this study aimed to twofold. First, evaluate the impact of number of irrigations and its interaction with nitrogen fertilization on yield of some wheat cultivars and water use efficiency to develop a best management of wheat irrigation for obtaining high yield and WUE simultaneously in a semi-arid region. Compare the estimated wheat crop evapotranspiration (ET_c) values computed using different methods with the measured actual wheat evapotranspiration (ET_a) to evaluate the best method for estimating the reference evapotranspiration which is suitable at North Nile Delta conditions.

Materials and methods

The present study was conducted at Sakha Agricultural Research Station, Kafr El-Sheikh Governorate during the two successive winter seasons 2012/2013 and 2013/2014. The station is situated at 31°-07′N latitude, 30°-57′E longitude. It has an elevation of about 6 m above mean sea level. It represents the conditions and circumstances of the Northern part of the Middle Nile Delta region. Agro meteorological data of Sakha station, during the two seasons of study are presented in Table 1.

Soil particle size distribution and bulk density were determined as described by Klute (1986). Field capacity, permanent wilting point and available water characters were determined according to James (1988). Chemical characteristics of soil were determined as described by Jackson (1973) and all data are illustrated in Table 2.

Experimental layout and treatments

Wheat as a winter crop was sown on 13th and 10th, December in the first and second seasons, respectively, for the three studied wheat cultivars with dry broadcasting method. Crop was harvested on 14th and 10th May in the first and second seasons, respectively. The experimental design was a split split-plot involving three factors; main treatments (number of irrigations), submain treatments (two nitrogen fertilization levels injected by gaseous ammonia 82%) and sub-submain (wheat varieties) with three replicates as follows:

The main plots (number of irrigations (I)) are three irrigations, 4 irrigations and 5 irrigations per season and were as in Table 3.

The submain plots (nitrogen fertilization levels injected by gaseous ammonia) are:

N_1 = 100% of recommended dose of nitrogen = 75 kg N fed^{-1} and
N_2 = 120% of recommended dose of nitrogen = 90 kg N fed^{-1}.

The sub-submain plots (wheat varieties):

V_1 = Misr-1.
V_2 = Misr-2.
V_3 = Sakha-94.

1. Irrigation water (IW):

Irrigation water was controlled and measured by submerged rectangular weir upstream and water was distributed and maintained by spills inserted beneath the bank of each irrigated furrows set. Applied irrigation water quantity was determined according to Michael (1978) as follows:

$$Q = 1.84LH^{1.5} \quad (1)$$

where
Q = Water discharge, $m^3\,s^{-1}$,
L = width of weir,
H = the head above weir crest.

2. Water consumptive use, cm:

Water consumptive use was calculated as soil moisture depletion (SMD) according to Hansen et al. (1979).

$$\mathrm{CU} = \mathrm{SMD} = \sum_{i=1}^{i=N} \frac{\theta_2 - \theta_1}{100} * \mathrm{Dbi} * D_i \quad (2)$$

where
CU = Water consumptive use in the effective root zone (60 cm), cm,
θ_2 = Gravimetric soil moisture percentage 48 h after irrigation,
θ_1 = Gravimetric soil moisture percentage before the next irrigation,
Dbi = soil bulk density (Mg m^{-3}) for the given depth,
D_i = soil layer depth (15 cm),
i = number of soil layers each (15 cm) depth.

3. Yield and yield components:

- Plant height (cm),
- Biological yield (kg fed^{-1}),
- Grain yield (kg fed^{-1}),
- Straw yield (kg fed^{-1}),
- Number spike (m^{-2}),
- Spike length (cm), and
- 1000 grain weight (g).

4. Crop-water relations

4.1. Water productivity (WP)

Water productivity is generally defined as crop yield per cubic meter of water consumption. It was calculated according to (Ali et al., 2007)

$$\mathrm{WP} = \frac{\mathrm{GY}}{\mathrm{ET}} \quad (3)$$

where
WP = water productivity (kg m^{-3}),
GY = grain yield (kg fed^{-1}), and
ET = Total water consumption of the growing season ($m^3\,fed^{-1}$).

4.2. Productivity of irrigation water (PIW)

Productivity of irrigation water (PIW) was calculated according to (Ali et al., 2007).

$$\mathrm{PIW} = \frac{\mathrm{GY}}{\mathrm{IW}} \quad (4)$$

where
PIW = productivity of irrigation water (kg grains m^{-3}),

Table 1 Mean of some meteorological data for Kafr El-Sheikh Area during two growing seasons of wheat crop. *Source*: meteorological station at Sakha 31°-07N latitude, 30°-57E longitude, N. elevation 6 m.

Month	T (°C)			RH (%)			W_s (m/s)	Pan evap. (mm)	Rainfall (R) (mm/month)
	Max.	Min.	Mean	Max.	Min.	Mean			
2012/2013									
November	25.32	15.47	20.40	89.53	61.80	75.67	0.66	1.87	28.20
December	21.35	10.52	15.94	84.77	60.83	72.80	0.73	2.25	13.02
January	19.22	7.62	13.42	91.06	65.35	78.21	0.52	1.99	78.74
February	20.68	8.88	14.78	89.89	64.04	76.97	0.73	2.89	–
March	24.56	12.45	18.51	79.48	50.84	65.16	1.03	4.46	–
April	26.04	15.87	20.96	74.20	43.90	59.05	1.11	5.30	8.40
May	31.43	21.85	26.64	75.03	45.78	60.41	1.20	6.35	0.00
2013/2014									
November	25.39	15.14	20.27	87.00	64.43	75.72	0.80	2.28	–
December	19.64	8.51	14.06	92.07	67.61	79.84	0.61	4.15	81.9
January	20.34	7.55	13.95	93.69	70.55	80.55	0.54	1.60	20.7
February	20.64	8.19	14.42	91.90	67.15	79.53	0.79	2.52	16.5
March	22.94	11.71	17.33	86.10	56.80	71.45	0.96	3.14	26.2
April	27.50	15.53	21.52	81.80	49.80	65.8	1.07	4.91	20.2
May	30.47	19.57	25.02	77.20	48.60	62.90	1.14	5.87	0.00

Table 2 Particle size distribution, bulk density, some both soil–water characters and chemical soil properties of the experimental site.

Soil depth (cm)	Particle size distribution (%)			Texture classes	Soil–water constant			Bulk density (Mg/m^3)
	Clay	Silt	Sand		FC[a] (%, wt/wt)	PWP[b] (%, wt/wt)	AW[c] (%, wt/wt)	
0–15	54.50	33.3	12.30	Clay	45.64	25.69	19.95	1.03
15–30	45.60	34.2	20.20	Clay	39.51	21.66	17.85	1.06
30–45	38.20	41.4	20.40	Clay loam	37.16	20.86	16.30	1.08
45–60	37.40	41.5	21.10	Clay loam	35.60	19.78	15.82	1.15
Mean	43.92	37.6	18.50	Clay loam	39.48	22.00	17.48	1.08

	PH	E_c (dS m^{-1})	Soluble cations (meq L^{-1})				Soluble anions (meq L^{-1})			
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}
Chemical soil characteristics										
0–15	8.55	2.95	14.80	9.68	19.80	0.24	0.00	4.5	16.00	24.02
15–30	8.46	3.52	17.76	17.60	18.20	0.21	0.00	4.0	16.00	33.77
30–45	8.47	3.64	20.72	9.20	20.20	0.20	0.00	4.0	12.00	34.32
45–60	8.45	4.09	14.80	14.80	26.40	0.23	0.00	4.0	16.00	41.99
Mean	8.48	3.55	17.02	12.82	21.15	0.22	0.00	4.1	15.00	33.53

[a] FC = Field capacity.
[b] PWP = Permanent wilting point.
[c] AW = Available soil water.

Table 3 Irrigation treatments scheme.

Irrigation treatments	1st irrigation	2nd irrigation	3rd irrigation	4th irrigation	5th irrigation
I_1	+	+	+	–	–
I_2	+	+	+	+	–
I_3	+	+	+	+	+

GY = grain yield kg/fed, and
Wa = Water applied (m^3 fed^{-1}) (irrigation water + effective rainfall).

4.3. Water consumptive use efficiency (Ecu %)

The consumptive use efficiency (Ecu) was calculated as described by Doornbos and Pruit (1975) as follows:

$$Ecu = \frac{ET_c}{Wa} \times 100 \quad (5)$$

where
Ecu = Consumptive use efficiency (%),
ET_c = Total evapotranspiration ≃ consumptive use (m^3 fed^{-1}),
Wa = Water applied to the field (m^3 fed^{-1}).

4.4. Yield response factor (K_y)
The relationship between relative evapotranspiration reduction $\left(1 - \frac{ET_a}{ET_m}\right)$ and relative yield reduction $\left(1 - \frac{Y_a}{Y_m}\right)$ was determined using the method given by Doorenbos and Kassam (1979). The equations are as follows.

$$1 - \frac{Y_a}{Y_m} = K_y\left(1 - \frac{ET_a}{ET_m}\right) \quad (6)$$

or

$$Y_d = K_y ET_d \quad (7)$$

where Y_a is actual harvested yield, Y_m is maximum harvested yield, K_y is yield response factor, ET_a is actual evapotranspiration, ET_m is maximum evapotranspiration, Y_d is relative yield reduction, and ET_d is relative evapotranspiration reduction.

5. Estimating reference evapotranspiration (ET_o) using climatological data
The ET_o is a measure of the evaporative demand of the atmosphere independent of crop type, crop development and management practices. Only climatic factors affect (ET_o). Accordingly, ET_o is a climatic parameter and can be computed from meteorological data (Allen et al., 1998). Agro-climatological elements during both growing seasons through 2012/2013 and 2013/2014 were collected from the agro-meteorological station in the site.
Values of ET_o for different months were estimated using the four following methods:

5.1. Hargreaves method

$$ET_o = 0.0023Ra \cdot TD0.5\ (Ta + 17.8) \quad (8)$$

where
Ra = absolute radiation, cal. cm^{-2} day^{-1},
TD = air temperature difference between max. and min., °C,
Ta = air temperature average, °C.

Values of Ra for the area were computed depending upon the local environmental features (Ibrahim, 1995).

5.2. FAO Penman–Monteith method: as described by Allen et al. (1998) was used to calculate ET_o. The equation is given as:

$$ET_o = \frac{0.408\Delta(Rn - G) + \gamma[900/(T + 273)]U_2(\text{es-ea})}{\Delta + \gamma(1 + 0.34U_2)} \quad (9)$$

where
ET_o = Reference evapotranspiration, mm day^{-1},
Rn = net radiation (MJ m^{-2} d^{-1}),
G = soil heat flux (MJ m^{-2} d^{-1}),
Δ = slope of vapor pressure and temperature curve (kPa $°C^{-1}$),
γ = psychrometric constant (kPa $°C^{-1}$),
U_2 = wind speed at 2 m height (ms^{-1}),
es-ea = vapor pressure deficit (kPa),
T = mean daily air temperature at 2 m height (°C).

5.3. Class A pan evaporation method

$$ET_o = K_p * E_p \quad (10)$$

As:
K_p = pan coefficient, values of K_p affected with the surrounding area, where the pan is located and it was taken as an average value of 0.85.
E_p = daily evaporation rate, mm.
– Computation of crop evapotranspiration (ETc)

$$ET_c = K_c * ET_o \quad (11)$$

The dimension less crop coefficient, K_c is the ratio between the water consumed by specific crop to ET_o. Values of K_c were quoted from FAO No. 56, 1998.
Measures of the three methods performance included estimated (ET_c) and measured (ET_a) values components of the mean absolute error (MAE), and the root mean square error (RMSE) (Meyer et al., 1993).

– Statistical analysis

All data were statistically analyzed according to the technique of analysis of variance (ANOVA) as published by Gomez and Gomez (1984). Means of the treatment were compared by the least significant difference (LSD) at 5% level and 1% level of significance which developed by Waller and Duncan (1969).

Results and discussion

Water consumptive use (CU) and irrigation water applied

The amount of water consumptive use (CU) or actual evapotranspiration (ET_a) and irrigation water applied to wheat for the two growing seasons was presented in Table 4, the seasonal CU and the amount of irrigation water applied in 2012/2013 growing period were lower than in 2013/2014. This may be attributed to the differences in climatic conditions. While mean temperature and wind speed in 2012/2013 growing period were lower than in 2013/2014, precipitation and mean relative humidity in 2013/2014 growing period were higher than in 2012/2013 (Table 2). As expected, in the five irrigations treatment, I_3 the highest amount of seasonal CU and total irrigation water applied values were obtained which were 47.78, 56.48 cm in the first season and 48.18, 55.80 cm in the second season, respectively. Other treatments underwent water deficits and produced lower amount of seasonal CU and total irrigation water applied which were 37.00, 40.68 cm from I_1 and 41.91, 48.72 cm from I_2 in the first growing season and were 37.96, 41.22 cm from I_1 and 42.70, 49.47 cm from I_2 in the second growing season, respectively. The decreasing ratio of seasonal CU by the increasing water deficit in 2012/2013 growing period was higher than in 2013/2014. This situation could be explained by higher water requirement in 2013/2014 season (Table 4). The seasonal CU of the full-irrigated wheat plants in this study was similar to those obtained by Ouda et al. (2010) and Moussa and Abdel-Maksoud (2004).

Regarding the influence of nitrogen fertilization using ammonia gas data in Table 4 also show that, the both seasonal CU and the total water applied increased by increasing nitrogen level in the both growing seasons. The highest mean values of CU and total water applied were produced from N_2 addition of 120% from the recommended dose (90 kg N fed^{-1}) which were 42.74, 49.35 cm in the first growing season and were 43.45, 49.62 cm in the second growing season, respectively. While the lowest corresponding mean values were obtained from, N_1, the 100% of recommended dose of nitrogen (75 kg N fed^{-1}) which were 41.72, 49.21 and 42.44, 48.03 for the first and second growing season, respectively. Those results are fully agreement with (Fan et al., 2005) they stated that nitrogen fertilization can increase dry land winter wheat yields and CU compared to no N fertilization by better utilizing the available soil water, this is because N fertilization can increase winter wheat root growth and biomass, efficiently utilize water stored during the fallow period, and absorb more soil.

As to cultivars differences in both total water applied and CU, Sakha-94 received the highest amount of water more than the other cultivars (Misr-1 and Misr-2), where the mean values which represented in Table 4 showed that Sakha-94 > Misr-2 > Misr-1 in both actual evapotranspiration (ET_a) and total water applied values.

The interaction effects between irrigation treatments, nitrogen fertilization levels and wheat cultivars on CU and total applied water indicate that irrigating the wheat cultivar Sakha-94 five events during the growing season under addition of 90 kg N fed^{-1} in the form of ammonia gas before sowing consumed the highest amount of CU and received the highest amount of water applied compared with the other tested cultivars.

Water consumptive use efficiency (Ecu %) and water saving

Data in Table 5 show the percentage of water consumptive use efficiency (Ecu %) and water saving percentage for the different treatments. The both Ecu % and water saving percentage are increased by increasing water deficit in both the growing seasons. The highest values of Ecu % (90.97% and 92.16% in the first and the second growing seasons, respectively) and highest water saving percentage values (26.24% and 26.12% in the first and the second growing seasons, respectively) were obtained from treatment I_1 while, the lowest values of Ecu % (84.59% and 86.21% for the first and the second season, respectively.) were obtained from I_3 which no saving water percentage. These results were in agreement with obtained by Ashraf et al. (2001) who showed that irrigation scheduling saved water up to 50% compared to farmers' practices.

The data in Table 5 also indicate that no significant differences between the two levels of N in the Ecu % and water saving percentage values. Regarding differences between cultivars, Misr-1 gave the highest value of Ecu % and during both growing seasons (86.62% and 87.77% for the first and the second growing season, respectively) followed by Misr-2 and Sakha-94.

Meaningfully, irrigating the wheat cultivar Misr-1 three events during the growing season under addition of Nitrogen level up to 120% N of recommended dose (90 kg N fed^{-1}) gave the highest value of Ecu % comparing with the other treatments. Where the lowest values were obtained from irrigating the wheat cultivar Sakha-94 five events during the growing season under addition of Nitrogen level up to 100% N of recommended dose (75 kg N fed^{-1}). The obtained results are in agreement with those obtained by Ouda et al. (2010) and Moussa and Abdel-Maksoud (2004).

Yield and its components

The differences in yield components, namely plant height (cm), biological yield (kg fed^{-1}), straw yield (kg fed^{-1}), number of spikes per m^2, spike length (cm) and 1000 grain weight (g), in 2012/2013 and 2013/2014 under different treatments are listed in Table 6. Results show that, irrigation of wheat plants 5 irrigations till harvest led to significant increase and gave the highest values of plant height (cm), biological yield (kg fed^{-1}), straw yield (kg fed^{-1}), number of spikes per m^2 and 1000 grain weight (g) in both seasons compared to those irrigated of wheat plants 4 and 3 irrigations, respectively. This could be

Table 4 Wheat water consumptive use (cm) and amount of irrigation water applied (cm) for different treatments during the growing seasons.

	Water consumptive use (CU) (cm)							Water applied[a] (cm)						
N levels	N_1			N_2			Mean	N_1			N_2			Mean
Varieties	V_1	V_2	V_3	V_1	V_2	V_3		V_1	V_2	V_3	V_1	V_2	V_3	
2012–2013														
I_1	36.9	36.66	36.72	37.28	37.08	37.36	37.00	41.60	41.95	41.70	41.10	41.70	41.90	40.68
I_2	41.70	41.44	41.22	42.38	42.59	42.10	41.91	49.80	49.02	49.90	49.90	49.70	49.91	48.72
I_3	46.93	46.53	47.36	48.17	48.78	48.90	47.78	56.20	56.25	56.50	56.34	56.57	57.02	56.48
Mean	41.84	41.54	41.77	42.61	42.82	42.79		49.20	49.07	49.37	49.11	49.32	49.61	
Mean of N levels	41.72			42.74				49.21			49.35			
2013–2014														
I_1	37.00	37.58	37.98	38.11	38.18	38.90	37.96	41.14	40.33	40.21	41.90	41.38	42.38	41.22
I_2	42.40	42.12	42.44	43.18	43.02	43.02	42.70	48.19	48.89	48.05	50.23	50.48	50.96	49.47
I_3	47.44	47.66	47.38	48.88	48.83	48.90	48.18	55.56	54.46	55.46	56.86	56.30	56.14	55.80
Mean	42.28	42.45	42.60	43.39	43.34	43.61		48.30	47.89	47.91	49.66	49.39	49.83	
Mean of N levels	42.44			43.45				48.03			49.62			

[a] All amount of irrigation water applied values are included the value of the rainfall during the season.

Table 5 Efficiency of water consumptive use percentage and water saving percentage for wheat under different treatments during the both growing seasons.

Treatments	Ecu (%)							Water saving (%)						
N levels	N_1			N_2			Mean	N_1			N_2			Mean
Varieties	V_1	V_2	V_3	V_1	V_2	V_3		V_1	V_2	V_3	V_1	V_2	V_3	
2012–2013														
I_1	90.89	89.31	90.22	92.97	91.11	91.34	90.97	25.98	25.42	26.19	27.05	26.29	26.52	26.24
I_2	85.45	86.30	84.29	86.67	87.45	85.90	86.01	11.39	12.85	11.68	11.43	12.14	12.47	11.99
I_3	83.51	82.72	83.82	85.50	86.23	85.76	84.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	86.62	86.11	86.11	88.38	88.26	87.67		12.46	12.76	12.63	12.83	12.81	13.00	
Mean of N levels	86.28			88.10				12.61			12.88			
2013–2014														
I_1	89.94	93.18	94.45	90.95	92.27	92.16	92.16	25.95	25.95	27.50	26.31	26.50	24.51	26.12
I_2	87.99	86.15	88.32	85.96	85.22	86.72	86.73	13.26	10.23	13.36	11.66	10.34	9.23	11.35
I_3	85.39	87.51	85.43	85.97	86.73	86.21	86.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	87.77	88.95	89.40	87.63	88.07	88.36		13.07	12.06	13.62	12.66	12.28	11.25	
Mean of N levels	88.71			88.02				12.92			12.06			

due to irrigation of 4 or 5 events during the season supplied sufficient soil moisture in the root zone which increased the capacity of wheat plant in photosynthesis and consequently increased spike weight (g), grain weight (g). The obtained results of spike length (cm) showed that no significant differences were obtained with irrigation treatments. The previous results are in full agreement with those reported by Kamel-Nadia et al. (2007).

Regarding the influence of nitrogen fertilization, data in Table 6 show that, biological yield and 1000 grain weight of the two ammonia gas levels in the both growing seasons were significantly differed. Therefore, the highest values of these traits were achieved by 90 kg N fed^{-1} (N_2), while the rate of 75 kg N fed^{-1} (N_1) gave the lowest one. Meanwhile, no significant differences were found between both the levels in plant height (cm), Biological yield (kg fed^{-1}), straw yield (kg fed^{-1}) and number of spikes per m^2. These results are in agreement with those obtained by Mohamed et al. (2001), Abd El-Hmeed (2005), Abd El-Hmeed and Omar (2006) and Zeidan et al. (2009).

Results presented in Table 6 show that, plant height (cm), Biological yield (kg fed^{-1}), straw yield (kg fed^{-1}), number of spikes per m^2 and 1000 grain weight (g) in both seasons of the three wheat cultivars in both seasons were significantly differed. It was evident that Misr-1 wheat cultivar surpassed increasing Biological yield, straw yield, spike length and 1000 grain weight (g) than the other two cultivars (Misr-2 and Sakha-94). Meanwhile, Misr-2 surpassed increasing plant height and number of spikes per m^2 than the other two cultivars (Misr-1 and Sakha-94) Significant varietal differences regarding those traits were reported by Hassan et al. (2002) and Zeidan et al. (2005).

Grain yield

As shown in Table 7, data obtained from the study showed that wheat total grain yield was significantly affected by water. Irrigation of wheat plants 4 irrigation till harvest resulted in insignificant differences in grain yield compared to irrigation of wheat plants 5 irrigation till harvest. The highest values were obtained in I_2. Decreasing number of irrigations water resulted in a relatively lower grain yield (I_1). water saving in this study was 26.24% (I_1) and 11.99% (I_2), in the first season and were 26.12% (I_1) and 11.35% (I_2) in the second season.

From the previous results, it could be explained that irrigation 4 events till harvest supplied sufficient soil moisture in the root zone which increased the capacity of wheat plant in photosynthesis and increase in number spike m^{-2} and 1000-grain weight which reflected on increasing grain and straw yields (tons fed^{-1}.). The previous results are in full agreement with those reported by Sharaan et al. (2000), Mahgoub and Sayed (2001) and Abd El-Maksoud (2002).

The Grain yield of wheat was not significantly affected by N levels and increased by increasing N from 75 to 90 kg N fed^{-1}. In 2012/2013 and 2013/2014, the application of 90 kg N fed^{-1} resulted in increasing grain yields. This increase was much higher than the previous application of 75 kg N fed^{-1}. Grain yield was response to N levels as well as affected by irrigation frequency. In both seasons, grain yield with the application of 75 kg N fed^{-1} was not statistically different from that of 90 kg N fed^{-1} at I_1, I_2 and I_3. Grain yield of the irrigation treatments followed the descending order $I_2 > I_3 > I_1$ at 75 kg N fed^{-1}; however, it followed $I_3 > I_2 > I_1$ at 90 kg N fed^{-1} (Table 7). Salem (2005) and Zewail (2007) revealed that yield and its components of wheat were significantly increased by increasing rate of nitrogen fertilizer up to120 kg N/Fedden.

It is obvious from Table 8 that, the three wheat cultivars yielded differently, and the differences were significant in the two seasons. The superiority of Misr-1 wheat cultivar over either Misr-2 or Sakha-94 is confirmed. Moreover, Misr-I wheat cultivar out yielded the other two wheat cultivars. This was expected since it ranked the top in spike length and 1000 grain weight. The differences were reported by Zeidan et al. (2005).

A significant interaction between wheat cultivars and number of irrigations on grain yield fed^{-1} is shown in Table 8. The data indicate that, irrigating the wheat 4 events during growing seasons and application of 75 kg N fed^{-1} in from ammonia gas gave the highest values of grain yield of Misr-1 wheat cultivar

Table 6 Comparison of different yield components for various numbers of irrigations, nitrogen levels and wheat varieties in the two growing seasons.

Treatments	2012–2013						2013–2014					
	Plant height (cm)	Biological yield (kg fed^{-1})	Straw yield (kg fed^{-1})	No. of spikes (m^{-2})	Spike length (cm)	1000 Grains weight (g)	Plant height (cm)	Biological yield (kg fed^{-1})	Straw yield (kg fed^{-1})	No. of spikes (m^{-2})	Spike length (cm)	1000 Grains weight (g)
Irrigation treatments (I)												
(I_1) 3 irrigations	87.05 c	6490.00 c	3720.64 b	307.16 a	9.96 a	43.14 c	93.27 b	6840.00 c	3944.02 b	368.61 a	10.31 a	43.86 b
(I_2) 4 irrigations	90.5 b	6661.11 b	3675.75 b	298.83 b	9.96 a	44.05 b	99.1 a	7011.11 b	3992.88 b	369.44 a	10.08 a	44.69 b
(I_3) 5 irrigations	93.82 a	7681.11 a	4703.83 a	313.83 a	10.08 a	45.41 a	97.5 a	8031.11 a	4903.65 a	363.83 a	10.36 a	46.12 a
LSD (0.05)	0.47	143.31	153.38	7.01	0.16	0.87	2.98	143.31	293.41	6.97	0.78	0.91
Nitrogen levels (N)												
(N_1) 100% N	90.16 a	7045.92 a	4146.49 a	308.03 a	10.06 a	44.92 a	94.77 a	7395.92 a	4346.39 a	368.66 a	10.24 a	45.63 a
(N_2) 120% N	90.75 a	6842.22 b	3920.32 b	305.18 a	9.94 a	43.47 b	98.52 a	7192.22 b	4213.97 a	365.92 a	10.26 a	44.15 b
LSD (0.05)	0.92	131.04	86.21	5.40	0.16	0.66	4.02	131.04	241.44	5.96	0.56	0.71
Varieties (V)												
(V_1)	86.01 c	7510.00 a	4440.73 a	298.94 b	10.32 a	45.78 a	90.27 c	7860 a	4757.92 a	360.05 b	10.27 a	46.44 a
(V_2)	96.41 a	6666.66 b	3845.10 b	316.55 a	9.95 b	43.83 b	105.83 a	7016.66 b	4045.05 b	376.55 a	10.11 a	44.53 b
(V_3)	88.93 b	6655.55 b	3814.39 b	304.33 b	9.73 c	42.99 c	93.83 b	7005.55 b	4037.58 b	365.27 b	10.36 a	43.69 c
LSD (0.05)	0.80	56.63	84.87	5.66	0.16	0.62	2.39	56.63	213.28	6.27	0.45	0.61
Contrasts												
N vs. I	**	***	***	***	**	**	NS	***	NS	***	NS	**
V vs. I	***	***	***	***	**	***	**	***	***	***	**	***
V vs. N	***	***	***	***	**	**	***	***	***	***	NS	**
V and N vs. I	***	***	***	***	***	***	*	***	*	***	NS	***

*, **, *** and NS: significant at $p \leqslant 0.05$, 0.01, 0.001 or not significant, respectively. Means separated at $p \leqslant 0.05$, LSD test.

Table 7 Effects of irrigation numbers and N levels on grain yield in the two seasons.

Irrigation treatments	Grain yield[a] (kg fed^{-1})					
	2012–2013			2013–2014		
	N levels			N levels		
	N_1: 100%	N_2: 120%	Mean	N_1: 100%	N_2: 120%	Mean
I_1: 3 irrigations	2708.66 b	2783.37 b	2746.01 b	2858.67 b	2933.26 b	2895.965 b
I_2: 4 irrigations	3014.11 a	2956.72 a	2985.41 a	3164.07 a	3106.81 a	3135.44 a
I_3: 5 irrigations	2975.63 a	2978.92 a	2977.27 a	3125.82 a	3129.1 a	3127.46 a
Mean	2899.46 a	2906.33 a		3049.52 a	3056.39 a	
LSD (0.05)	88.16			88.00		

[a] Treatment means are averaged over varieties.

Table 8 Effects of irrigation numbers and cultivars on grain yield in the two seasons.

Irrigation treatments	Grain yield[a] (kg fed^{-1})							
	2012–2013				2013–2014			
	Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
I_1: 3 irrigations	2801.40 ef	2735.03 fg	2701.63 g	2746.02 c	2951.25 ef	2885.13 fg	2851.53 g	2895.97 b
I_2: 4 irrigations	3318.00 a	2860.40 de	2777.85 fg	2985.41 a	3468.00 a	3010.50 de	2927.83 fg	3135.44 a
I_3: 5 irrigations	3088.40 b	2891.53 cd	2951.90 c	2865.71 b	3238.61 b	3041.61 cd	3102.15 c	3127.45 a
Mean	3069.26 a	2828.98 b	2810.46 b		3219.28 a	2979.08 b	2960.50 b	
LSD (0.05)	79.21				79.32			

[a] Treatment means are averaged over N levels.

Table 9 Effects of irrigation numbers and N levels on water productivity (WP) and productivity of irrigation water (PIW) in the two seasons.

Irrigation treatments	WP[a] (kg m^{-3})						PIW[a] (kg m^{-3})					
	2012–2013			2013–2014			2012–2013			2013–2014		
	N levels			N levels			N levels			N levels		
	N_1	N_2	Mean	N_1	N_2	Mean	N_1	N_2	Mean	N_1	N_2	Mean
I_1	1.75	1.78	1.76	1.81	1.82	1.81	1.54	1.60	1.57	1.67	1.67	1.67
I_2	1.73	1.65	1.69	1.78	1.72	1.75	1.45	1.41	1.43	1.53	1.46	1.49
I_3	1.51	1.46	1.48	1.57	1.52	1.54	1.26	1.26	1.26	1.34	1.32	1.33
Mean	1.66	1.63		1.72	1.69		1.42	1.42		1.51	1.48	

[a] Treatment means are averaged over varieties.

while, the lowest values were obtained by Sakha-94 cv. by irrigation three events during the growing season with addition of 75 kg N fad^{-1}.

Water-yield relationship

In this study, WP and PIW values from the irrigation treatment I_1 were generally high when compared with the other treatments (I_2 and I_3) (Table 9). The findings obtained in this study are in contradiction with the observation of Sharaan et al. (2000) and Bazza (2000), who found that the low irrigation inputs resulted in higher values in Ecu than the highest irrigation inputs. WP and PIW were significantly affected by number of irrigations and nitrogen levels in the two growing seasons. WP and PIW decreased with increasing number of irrigation and nitrogen levels, and reached the minimum values when wheat plants were irrigated five irrigations till harvest and nitrogen level was 90 kg N fed^{-1}, and maximum values were recorded when irrigating three irrigations nearly equal four irrigation events till harvest and nitrogen level was 75 kg N fed^{-1} (Table 9).

To ascertain the proper irrigation frequency for maximum WP and PIW, the variables WP and PIW (kg m^{-3}) vs. irrigation frequency treatments (F) were fitted with second-degree polynomials and the equations obtained were:

Table 10 Effects of irrigation numbers and varieties on water productivity (WP) and productivity of irrigation water (PIW) of the two seasons.

Irrigation treatments	WP[a] (kg m^{-3})								PIW[a] (kg m^{-3})							
	2012–2013				2013–2014				2012–2013				2013–2014			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
I_1	1.79	1.77	1.74	1.76	1.87	1.81	1.74	1.81	1.61	1.56	1.54	1.57	1.69	1.68	1.64	1.67
I_2	1.88	1.62	1.59	1.70	1.92	1.68	1.63	1.74	1.58	1.38	1.33	1.43	1.68	1.44	1.41	1.51
I_3	1.55	1.42	1.46	1.48	1.59	1.48	1.53	1.53	1.30	1.20	1.25	1.25	1.37	1.31	1.32	1.33
Mean	1.74	1.60	1.60		1.79	1.65	1.63		1.50	1.38	1.37		1.58	1.48	1.46	

[a] Treatment means are averaged over N levels.

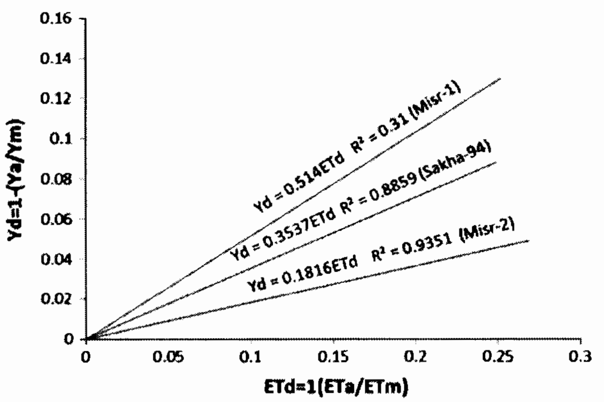

Fig. 1 Yield response factor, K_y for the three varieties.

$$\underset{(R^2=1)}{WP = -0.0673I^2} + \underset{\text{(Average of the both seasons)}}{0.4033I + 1.2126} \quad (12)$$

$$\underset{(R^2=1)}{PIW = -0.0314I^2} + \underset{\text{(Average of the both seasons)}}{0.079I + 1.6459} \quad (13)$$

On the basis of the above equations, the proper number of irrigation for maximum WP and PIW for irrigated wheat in clayey soil was 3 irrigations during the growing season. This result was obtained by taking the first derivation of each equation and equalizing to zero. There was a significant interaction between number of irrigations and nitrogen level (Table 9). In both seasons, WP and PIW of the irrigation frequency treatments followed an $I_1 > I_2 > I_3$ order at each N level.

The corresponding improvement in WP on overall mean, reached 16% and 13% in 2012/2013 and 15% and 12% in 2013/2014 under I_1 and I_2 higher than I_3, respectively. For PIW on overall mean, reached 30.7% and 12.0% in 2012/13 and 20.6% and 10.7% in 2013/14 under I_1 and I_2 higher than I_3, respectively The improvement in WP and PIW with I_1 and I_2 may be attributed to lesser water applied (summation of irrigation and rainfall) under such 3 and 4 irrigation, as compared with 5 irrigation (Table 10).

Yield response factor (K_y)

Yield response factor (K_y) was determined according to Eqs. (7) and (8) for means of the two growing seasons 2012/2013 and 2013/2014. Total grain yield and seasonal CU or actual evapotranspiration (ET_a) presented in Tables 4, 7 and 8 were used to determine relative yield reduction (Y_d) and relative evapotranspiration reduction (ET_d). A linear regression equation was fitted to the data (Fig. 1). According to the regression equations, K_y were 0.51, 0.35 and 0.18 for Misr-1, Sakha-94 and Misr-2 when the experimental years were considered together. These values were at water deficit at the mid-season to harvest and late season (I_1 and I_2, respectively). The resulted K_y value obtained in this study was in the same trend with K_y values of 0.55 and 0.25 reported by Doorenbos and Kassam

Table 11 Monthly reference evapotranspiration (ET_o, mm day^{-1}), actual evapotranspiration (ET_c, mm day^{-1}) of wheat (average of both growing seasons).

Period between irrigations	Actual evapotranspiration (ET_a), mm day^{-1} of wheat cultivars					
	Misr-1	Misr-2	Sakha-94	Hargreaves	Penman–Monteith	Class A pan
1st irrigation 13/12/2012–31/1/2013	1.02	1.03	1.06	1.13	1.09	0.97
2nd irrigation 31/1/2013–27/2/2013	2.00	2.00	2.06	1.92	1.73	1.605
3rd irrigation 27/2/2013–20/3/2013	3.43	3.42	3.48	3.73	3.70	3.17
4th irrigation 20/3/2013–9/4/2013	3.69	3.71	3.86	4.24	4.07	3.72
5th irrigation 9/4/2013–14/5/2013	3.26	3.27	3.34	3.55	3.30	3.29
Average	2.68	2.69	2.76	2.91	2.76	2.55
MAE				0.27	0.20	−0.21
RMSE				0.31	0.24	0.26
Percentage deviation from ET_a values of wheat cv. Misr 1 at I_3N_1 treatment				9.4	7.7	−8.8

(1979) when water deficit occurring during midseason and late season, respectively except cv. Misr-2 was underestimated. The obtained values of $K_y < 1$ means the tested cultivars are more tolerant to water deficit, and recover partially from stress, exhibiting less than proportional reductions in yield with reduced water use.

Evaluation of the methods

Hargreaves method and Penman–Monteith method were overestimated the actual evapotranspiration using Misr-1 by 9.4% and 7.7%, respectively. On the other hand, Class A pan method underestimated the actual evapotranspiration by 8.8% (Table 11).

Overall, based on criteria of MAE, RMES, and percentage deviation from ET_a, Penman–Monteith methods performed best for North Delta, Egypt in the winter season because of the least amount of error (MAE = 0.20, RMES = 0.24) for Penman–Monteith method and least percentage deviation (7.7%) between ET_a and ET_c. Therefore, values of MAE, RMSE, and percentage deviation from (ET_a) indicated close agreement between actual evapotranspiration (ET_a) and crop evapotranspiration (ET_c) using one of Penman–Monteith compared to the other methods.

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