Simulation of Wheat Yield Using the RZWQM as Affected by Supplemental Irrigation in the North Western Coast of Egypt

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IN ARID and semi-arid regions, the amount of rainfall and its distribution greatly affect the productivity of crops in these regions. Rainfall deficits during the critical growth stages can cause a sever crop yield losses. The study was carried out at the agricultural Experimental station, Sustainable Development Center of Matrouh Resources, Egypt, during 2014/2015 and 2015/2016 rainfall seasons to evaluate the effect of different supplemental irrigation treatments on wheat yield . The irrigation treatments included rainfall only (control), one irrigation of 50 mm at tillering or booting or grain filling, two irrigations of 100 mm at tillering and booting or tillering and grain filling or booting and grain filling, and three irrigations of 150 mm at the three stages of tillering, booting and grain filling. The obtained results showed that the application of supplemental irrigation of 150 mm at the three stages of tillering, booting and filling secured the highest significantly values of plant height (61.47 cm), spike length (9.07 cm) and number of grains/spike (46.67) in the first season only, 1000 grain weight (39.72 and 48.53 g), biological yield (5.10 and 8.72 t/ha), grain yield (1.55 and 3.40 t/ha) , straw yield (3.54 and 5.35 t/ha) and WUE (0.672 and 1.08 kg/m^3) in both seasons, respectively. Wheat yield in the second season under the different supplemental irrigation treatments was simulated using the Root Zone Water Quality Model. Results showed a very good agreement between simulated and observed yields with a Nash-Sutcliff Efficiency (NSE) of 0.93. It could be concluded that supplemental irrigation is highly important for achieving a good economic yield of wheat under the rainfed condition of Matrouh Governorate, moreover the RZWQM successfully simulated the wheat yield under water stress conditions.

Keywords: Supplemental irrigation, RZWQM, Rainfed wheat, Yield and its components, WUE.

Egypt is the world's largest wheat importer with 11 million tones for the 2015/2016 marketing year (FAO, 2016). Most of Egypt's agricultural lands is irrigated and is concentrated in the rural areas of the Nile Valley and Delta. The country is making significant efforts to close the trade gap by increasing the cultivated area of wheat. The rainfed area of the North Western Coastal Zone

(NWCZ) from Alexandria to El-Salloum on the Libyan border, has promising opportunities for sustainable agriculture development. Rainfall over the area is characterized by low annual amount (130 - 150 mm on average) , high spatial and temporal variability and unfavorable seasonal distribution for crop production.

Drought tolerant crops such as wheat, barley, fig, olive and small areas with faba bean and lentil are the predominant cultivated crops in the area. The low amount of rain during the winter wheat growing seasons only provides 30% of the crop water requirements, and almost 70% of irrigation water is required to maintain the potential yield of winter wheat (Ouda, 2016). Long dry spells usually occurs during the critical growth stages *i.e.,* flowering and grain filling which severely affect the final yield (Oweis & Hachum, 2006). The mean grain yield of wheat in this area ranges from 0.35 to 2 t/ha based on the rainfall amount and distribution, soil characteristics and used variety, which is a way far from the country average of 7.3 t/ha . Using limited amount of water as a supplemental irrigation can improve both the crop productivity and increase the water use efficiency (Man *et al.,* 2016), they found that the supplemental irrigation treatment of increasing the soil water content at depth of 40 cm to 65% of field capacity after jointing and 70% of field capacity after anthesis increased the grain yield and water use efficiency by above 40% and 15%, respectively in both seasons.

Many researchers have reported that using different supplemental irrigation quantities at certain specific growth stages of wheat increased significantly grain yield (Ilbeyi *et al.,* 2006; Benli *et al.,* 2007; Xiao *et al.,* 2007; Erekul *et al.,* 2012 and Tadayon *et al.,* 2012.). In Texas high plains, USA, Attia *et al. (*2016) showed that the triple irrigation with a total of 300 mm at jointing , booting and anthesis as well as douple irrigation of 220 mm (100 mm at jointing and 120mm at anthesis) produced a similar yield to the full irrigation (400 mm). While the highest water use efficiency of 13 kg ha^{-1} mm^{-1} was at the single irrigation of 140 mm at the grain filling stage. These results confirming that irrigation timing is critical in determining wheat production under water-limited conditions.

Crop simulation models are powerful tools to evaluate different agronomic management practices after careful calibration. RZWQM2 combined the root zone water quality model (RZWQM) (Ahuja, 2000) with the decision support system for agro technology transfer (DSSAT), (Hoogenboom *et al.,* 2004) and it has been successfully used to simulate water availability, crop production and crop management practices. In a long term simulation, Qi *et al.* (2013) used the RZWQM2 to simulate the soil water and wheat yield under different management practices, *i.e.,* tillage methods, planting dates and seeding rates. The model showed no impact of the tillage methods on the wheat yield and a reduction in the yield by delaying the planting date. Fang *et al.* (2010) evaluated various irrigation strategies in wheat-maize double cropping system in the North China plain using the RZWQM. Crop yield response to different irrigation scheduling was adequately simulated with a r^2 of 0.90 and NMSE of 0.87.

Limited information is available in the simulation of wheat water use and yield under rainfed dry conditions.

Therefore the present investigation aimed to:1) Determine the response of wheat yield and its components and the water use efficiency to different timing and quantity of supplemental irrigation and 2) Evaluate RZWQM2 for its prediction of crop yield in response to different supplemental irrigation treatments under the NWCZ of Egypt.

Materials and Methods

Experimental site

Two field experiments were conducted during the growing seasons of 2014/2015 and 2015/2016 at the Agricultural Research Station, Sustainable Development Center of Matrouh Resources, Desert Research Center that is located in Matrouh Governorate, Egypt (31.35° N, 27.18 E) and is at 9 m in altitude .The region has a typical Mediterranean environment, rainfall was 81.60 mm in the first season and 239 mm in the second season. The soil is sandy clay loam, which is strongly calcareous (17.5% $CaCo_3$), with an EC of 0.223 dS/m and pH of 8.2.

Treatments and experimental design

Wheat cultivar Giza 168 was sown in 30 Nov., 2014 for the first season and in 17 Nov., 2015 for the second season. The cultivar was chosen based on its high productivity under the rainfed condition of the area, the seeding rate was 100 kg/ha. Plot size was 6 m^2 (2 × 3 m) with row spacing of 25 cm, there were 32 plots. A 57 g/plot of grains was sown by hand.

The experiment was laid out in a randomized complete block design (RCBD) in four replicates, each replicate had seven supplemental irrigation treatments plus the control. Supplemental irrigation treatments included; T_0 is rainfed only as control (without supplemental irrigation); T_1 is one irrigation (50 mm) at tillering, T_2 is one irrigation (50 mm) at booting, T_3 is one irrigation (50 mm) at filling, T_4 is two irrigations (100 mm) at tillering and booting, T_5 is two irrigations (100 mm) at tillering and filling, T_6 is two irrigations (100 mm) at booting and filling and T_7 is three irrigations (150 mm) at the three stages of tillering, booting and filling. irrigations were applied through a drip irrigation system.

The plants were harvested from an area of 6 m^2 (plot area). Grain, straw and biological yields/ha were based on the land area. No fertilizer applications were applied to the plants as is practiced by the local farmers in the region. The plants were harvested in 3/4/2015 for the first season and in 15/4/2016 for the second season.

Sampling and measurements

During the two growing seasons, ten guarded plants were chosen randomly from each plot to record the following criteria; plant height (cm), spike length

(cm), No. grains/spike, 1000-grain weight (g). The plants from the entire plot were harvested to record grain yield (kg/ha), straw yield (kg/ha) and biological yield (kg/ha). The harvest index (%) and crop index (%) were calculated as the percentage ratio of grain yield to the biological yield and the straw yield, respectively. The water use efficiency (grain yield kg/m^3 of water) was calculated as the ratio of the unit area wheat yield to the sum of the total irrigation (rainfall + supplemental irrigation) during the growing season.

Statistical analysis

Analysis of variance (ANOVA) was performed to determine the significance of the main effects and their interaction. Least significance difference (LSD) tests were performed to determine the significant differences between individual means. All statistical analyses were performed using the Cropstat version 7.2 statistical software (CropStat, 2009).

Root zone water quality model (RZWQM2)

RZWQM2 is a one-dimensional model with emphasis on management effects on water quantity, water quality and crop production. It runs on a daily time step for crop growth, N balance and pesticide modules; a sub-hourly time step is used for soil water, soil heat transfer, and surface energy balance modules.

The model contains plant growth modules for 22 field crops from the DSSAT crop modules (Ma *et al.,* 2011). RZWQM2 originally had a generic plant growth module that could be parameterized for any annual crop. It is currently parameterized mainly for maize, soybean and winter wheat. Minimum model inputs required are rainfall (amount and intensity), daily or hourly weather, site description, soil properties, initial soil water condition, crop information and management practices. A complete description of the model use, capabilities, calibration and validation are already described in details in (Ma *et al.,* 2012a).

Soil water content is one of the most commonly measured data available in field research. The average water content at 33 kPa ($\theta_{1/3}$) suction of 0.1647 and at 1500 kPa (θ_{15}) suction of 0.0741 were used to estimate Brooks-Corey parameters. The saturated soil hydraulic conductivity (*Ksat*) of 0.31 cm/h was used. These values were collected from the literature of previous studies in the area, as these parameters have the most effect on soil water distribution. If measurements are not available, the model provides average values for these parameters based on soil texture as default values.

Model evaluation

To evaluate the model performance and compare the simulated versus the observed results, three statistical measurements were used: The coefficient of determination (R^2), Nash- Sutcliff efficiency (NSE) (Nash & Sutcliffe, 1970*),* and the root mean square error (RMSE)-observation's standard deviation ratio (SR) collectively called RSR (Eq. 1,2 and 3).

The R^2 describes the degree of collinearity between simulated and measured data and describes the proportion of the variance in measured data explained by the model. R^2 ranges from 0 to 1, with higher values indicating less error variance.

$$R^2 = \frac{\left[\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})\right]^2}{\left[\sum_{i=1}^{n}(O_i - \bar{O})^2\right]\left[\sum_{i=1}^{n}(P_i - \bar{P})^2\right]} \qquad (1)$$

The NSE measures the predictive power of the model and how well the plot of observed versus simulated value fits the 1:1 line, it ranges between $-\infty$ and 1, with NSE=1 corresponds to a perfect match between predicted and observed data, whereas values ≤ 0 indicate that the mean observed value is a better predictor than the simulated value (Moriasi, *et al.,* 2007).

$$NSE = \frac{\sum_{i=1}^{n}(O_i - \bar{O})^2 - \sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \qquad (2)$$

The RSR is a commonly used error index; it is calculated as a ratio of the RMSE and standard deviation of the measured data. The RSR value varies from the optimal value of 0, which indicates zero RMSE or residual variation and a perfect model simulation, to a large positive value, the lower the RSR, the better the model performance.

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}(O_i - P_i)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\right]} \qquad (3)$$

where, P_i are the predicted values, O_i are the observed values, n is the total number of observations, $\bar{O}$ is the mean of the observed data and $\bar{P}$ is the mean of the predicted data. $STDEV_{obs}$ is the standard deviation of observed values.

Results and Discussion

Effect of supplemental irrigation treatments on wheat grain yield, its components, and water use efficiency

Results in Tables 1 and 2 show that all yield, its components, harvest index, crop index and water use efficiency (WUE) were significantly affected by supplemental irrigation treatments. Generally, plant height (cm), number of grains/spike, 1000 grain weight (g), biological, grain and straw yields (kg/ha) as well as WUE (kg/m^3) were markedly improved with increasing the supplemental irrigation levels. So, T_7 treatment (three supplemental irrigations by 150 mm at tillering, booting and filling stages) was the most efficient treatment in this connection being recorded the highest values of the above mentioned traits in the two seasons except, spike length (cm) and number of grains/spike (in the first

season only). While, the highest values of spike length and number of grains/spike were obtained with T_6 treatment (two supplemental irrigations by 100 mm at booting and filling stages) in the second season only. T_0 treatment (without supplemental irrigation or rainfed only) was inferior treatment for all the aforementioned traits in the two seasons except, straw yield in the second season. However, T_3 treatment (one supplemental irrigation by 50 mm at filling stage) gave the lowest value for this trait in the first season only. These findings are in agreement with those of Erekul *et al.* (2012), Tadayon *et al.* (2012), Abbas *et al.* (2014), Attia *et al.* (2016) and Man *et al.* (2016).

The superiority of T_7 treatment (three supplemental irrigations by 150 mm at tillering, booting and filling stages) in biological, grain and straw yields and WUE may be resulted from the improvement in the yield components *i.e.,* spike length, number of grains/spike and 1000 grain weight (Tables 1 and 2). Water plays many essential roles in plant growth *i.e.,* helps to maintain the turgidity of cell walls necessary for cell enlargement and growth, acts as a solvent for nutrients to be absorbed by plant, is used for photosynthesis and end products are conveyed through water from cell to cell and organ to organ, so sufficient water increases dry matter, growth and the photosynthesis products accumulation in the sink (Salem *et al.,* 2003). Also, Xue *et al.* (2003 and 2006) indicated that supplemental irrigation of winter wheat between the jointing and flowering stages significantly improved grain yield and WUE due to increased photosynthetic activity and remobilization of pre-anthesis carbon reserves.

TABLE 1. Effect of supplemental irrigation treatments on wheat grain yield, its components and water use efficiency (2014/2015 growing season).

Irrigation treatments	Plant height (cm)	spike length (cm)	No. grains/ spike	1000-grain weight (g)	Bio. yield (kg/ha)	Grain yield (kg/ha)	Straw yield (kg/ha)	HI (%)	CI (%)	WUE (kg/m^3)
T_0	23.30	5.10	8.33	13.33	900.32	173.13	727.19	19.22	23.94	0.213
T_1	40.67	7.00	15.33	17.10	1853.71	435.16	1418.56	24.11	31.82	0.239
T_2	45.33	8.00	18.33	19.83	2517.35	540.89	1976.46	21.32	27.16	0.297
T_3	44.67	7.67	20.67	23.50	1257.85	586.55	671.31	46.60	87.41	0.445
T_4	48.67	5.43	25.00	23.13	2423.00	572.08	1850.92	23.60	30.90	0.434
T_5	45.67	8.67	24.00	18.40	2708.17	623.04	2085.13	22.99	29.88	0.473
T_6	48.20	6.90	31.00	27.77	3265.88	787.27	2478.61	24.13	31.82	0.445
T_7	61.47	9.07	46.67	39.72	5095.54	1552.66	3542.88	30.45	43.79	0.672
LSD	5.82	1.05	5.10	5.87	1010.9	230.1	794.64	3.07	6.05	0.127

Whereas: T_0 is rainfed only, T_1 is one irrigation 50 mm at tillering, T_2 is one irrigation 50 mm at booting, T_3 is one irrigation 50 mm at filling, T_4 is two irrigations (100 mm) at tillering and booting, T_5 is two irrigations (100 mm) at tillering and filling, T_6 is two irrigations (100 mm) at booting and filling and T_7 is three irrigations (150 mm) at the three stages of tillering, booting and filling, HI is harvest index, CI is crop index, WUE is water use efficiency, LSD is least significant differences.

TABLE 2. Effect of supplemental irrigation treatments on wheat grain yield, its components and water use efficiency (2015/2016 growing season).

Irrigation treatments	Plant height (cm)	spike length (cm)	No. grains/ spike	1000-grain weight (g)	Bio. yield (kg/ha)	Grain yield (kg/ha)	Straw yield (kg/ha)	HI (%)	CI (%)	WUE (Kg/m³)
T_0	43.25	5.50	21.75	26.50	1637.7	379.25	1258.43	23.27	30.50	0.233
T_1	56.50	7.25	26.00	30.40	4101.17	981.58	3119.58	23.91	31.57	0.373
T_2	58.00	9.00	34.00	32.13	4411.21	1354.61	3056.60	30.86	44.73	0.636
T_3	57.25	7.75	43.00	32.48	4742.02	1733.18	3008.90	36.51	57.63	0.814
T_4	59.00	8.50	47.75	33.47	5574.62	1976.70	3597.93	35.49	55.23	0.928
T_5	60.50	7.75	46.25	37.16	5837.17	2378.94	3458.23	40.77	68.84	0.905
T_6	50.00	9.50	56.50	41.50	5525.84	2599.45	2925.59	47.13	90.15	0.988
T_7	72.00	7.75	56.25	48.53	8715.21	3400.54	5350.67	38.65	63.55	1.08
LSD	4.88	1.17	4.42	4.31	516.41	383.15	357.26	4.60	12.54	0.134

Whereas; T_0 is rainfed only, T_1 is one irrigation 50 mm at tillering, T_2 is one irrigation 50 mm at booting, T_3 is one irrigation 50 mm at filling, T_4 is two irrigations (100 mm) at tillering and booting, T_5 is two irrigations (100 mm) at tillering and filling, T_6 is two irrigations (100 mm) at booting and filling and T_7 is three irrigations (150 mm) at the three stages of tillering, booting and filling, HI is harvest index, CI is crop index, WUE is water use efficiency, LSD is least significant differences.

In the dry season (2014/2015) one irrigated treatment of 50 mm at tillering or booting or grain filling, increased the grain yield by 151%, 212% and 239% and the water use efficiency by 12.2%, 39.4% and 108.9% over the rainfed only treatment, respectively. Attia *et al.* (2016) found that one irrigation treatments of 100 mm at jointing or booting or 140 mm at anthesis or grain filling produced a better grain yield as compared to no supplemental irrigation. They also highlighted the importance of deficit irrigation treatment in decreasing the yield fluctuations in dry areas, and that it increased the WUE when it was applied at the grain filling stage as compared to its application at jointing or booting. Man *et al.* (2016) concluded that suitable irrigation at jointing and anthesis increases root weight density, root triphenyl tetrazolium chloride reduction activity, and root antioxidant enzyme activity at the later stages of grain filling.

It is evident from Tables 1 and 2 that the highest values of harvest and crop index (%) exceeding the other treatments were obtained by T_3 treatment (a one supplemental irrigation by 50 mm at filling stage) in the first season and T_6 treatment (two supplemental irrigations by 100 mm at booting and filling stages) in the second season. While, the lowest values of the abovementioned traits were obtained by T_0 treatment (without supplemental irrigation) in the two seasons. These results are supported by findings of Zhang *et al.* (2008) and Attia *et al.* (2016).

Comparing the treatments of two supplemental irrigations by 100 mm on wheat yields, its components and WUE, our results reported that the T_6 treatment (two supplemental irrigations by 100 mm at booting and filling stages) secured the highest values of the abovementioned traits except, WUE (in the second season only) as compared with T_5 (two supplemental irrigations by 100 mm at tillering and filling stages) and T_4 (two supplemental irrigations by 100 mm at tillering and booting stages) treatments in both seasons as shown in Tables 1 and 2. These results are in similar trend with those of Zhang *et al.* (2008) and Attia *et al.* (2016).

RZWQM2 model evaluation to simulate wheat yield
The model was first calibrated manually to one irrigation treatment, *i.e.,* T7 then was validated for the other irrigation treatments, for these purposes we used a complete datasets related to the soil hydraulic characteristics and physical properties. Therefore the model evaluation procedures and results of this study are valid.

Data in Table 3 and Fig. 1 show the simulated and measured grain yield, biological yield and harvest index. Results show that the model tends to under predicted the grain yield and biological yields under all the irrigation treatments except for the rainfed and adding one irrigation at tillering and at filling for the grain yield, however it was at two irrigation treatments at tillering and filling (T_5) and at booting and filling (T_6) for the biological yield. The best match between measured and simulated values was at the treatment of a one supplemental irrigation at booting for both the grain and biological yields.

Goodness of fit measures, *i.e.,* R^2 and NSE revealed that there was a good match between simulated and measured yields with R^2 value of 0.98 and NSE value of 0.93 for the grain yield. However, in the case of biological yield these values were 0.923 and 0.882 for the R^2 and NSE values, respectively. The modeled poorly estimated the harvest index with a low R^2 value of 0.342 and a negative NSE value of -0.535 which means the using of the observed average is a better predictor than using the model for this parameter.

The measured and simulated biological and crop yields responded similarly to the different irrigation treatments. Moreover, the RZWQM2 adequately simulated crop yield and biological yield in response to various supplemental irrigation practices, this is clear from the data presented in Table 3 that the highest grain yield and total biomass were recorded when the crop received three irrigation treatments, Many studies addressed the successful use of the RZWQM in simulating the crop growth under water stress conditions and irrigation scheduling (Ma *et al.*, 2003 , 2012b and Fang *et al.*, 2010, 2014).

TABLE 3. Comparison between observed grain yield, biological yield and harvest index and the simulated values by the RZWQM2 in the second growing season (2015/2016).

Treatment	S_{yield} t ha^{-1}	M_{yield} t ha^{-1}	$S_{T.biomass}$ t ha^{-1}	$M_{T.biomass}$ t ha^{-1}	S_{HI} (%)	M_{HI} (%)
T_0	0.47	0.38	1.26	1.64	0.37	0.23
T_1	1.14	0.98	2.8	4.1	0.41	0.24
T_2	1.34	1.35	3.95	4.41	0.34	0.31
T_3	1.81	1.73	4.68	4.74	0.39	0.36
T_4	1.82	1.98	5.37	5.57	0.34	0.35
T_5	2.21	2.38	6.36	5.84	0.35	0.41
T_6	2.22	2.6	6.45	5.53	0.34	0.47
T_7	2.97	3.4	8.49	8.72	0.35	0.38
*R^2	0.98		0.923		0.342	
NSE	0.93		0.882		-0.535	
RSR	0.24		0.32		1.16	

S_{yield} is the simulated yield; M_{yield} is the measured yield; $S_{T.biomass}$ is the simulated total biomass; $M_{T.biomass}$ is the measured biomass, HI is harvest index; T_0 is rainfed only, T_1 is one irrigation 50 mm at tillering, T_2 is one irrigation 50 mm at booting, T_3 is one irrigation 50 mm at filling, T_4 is two irrigations (100 mm) at tillering and booting, T_5 is two irrigations (100 mm) at tillering and filling, T_6 is two irrigations (100 mm) at booting and filling and T_7 is three irrigations (150 mm) at the three stages of tillering, booting and filling, .*R^2 is the coefficient of determination, NSE: Nash- Sutcliff Efficiency, RSR: the Root Mean Square Error (RMSE)-observation's standard deviation ratio (SR).
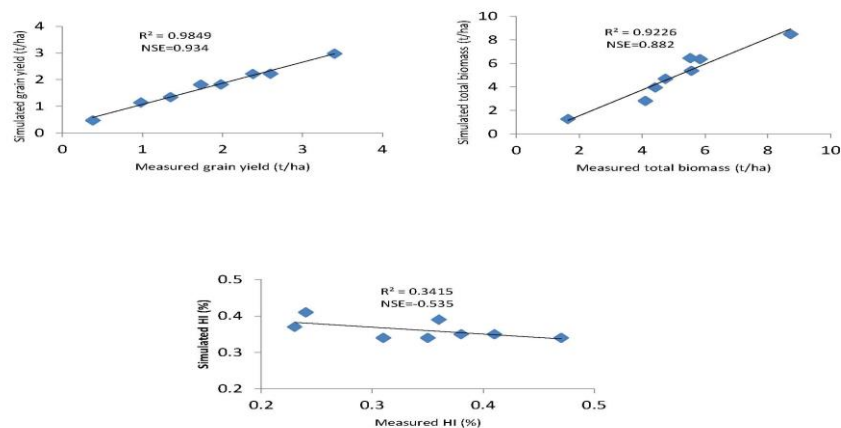
Fig. 1. Measured versus simulated grain yield (t/ha), total biomass (t/ha) and harvest index (%) and the associated values of R^2 and NSE.

Testing the RZWQM2 for the different irrigation treatments for the second season demonstrated the importance of good and comprehensive data sets for model validation. The results of evaluating the RZWQM for water stress show that the model can be calibrated well for a given irrigation treatment (e.g. T_7 irrigation treatment). But the prediction capability of the model for other treatment varies. The model well simulated the response of the crop yield to the irrigation treatments *i.e.,* increasing the number of supplemental irrigation treatments increased the grain and biological yields. This is very important for using the model to simulate the crop growth and yield under water stress and rainfed conditions.

Additional field experiments are necessary to study the effect of soil moisture conditions at planting and weather variability on winter wheat growth and yield in the arid areas of NWCZ of Egypt.

Supplemental irrigation is an effective agricultural practice to mitigated the adverse impact of dry spell during the critical growth periods. However, the amount of the added water is insufficient to produce the crop potential yield, so it is important to maximize the utilization of low rainfall in the NWCZ region by implementing different soil and water conservation practices. one of these practices include the water harvesting technology, *i.e.,* the furrow ridge water harvesting system (FRWHS) which proved to increase the crop productivity in the area (El-Sadek & Salem, 2015). Xiao *et al.* (2007) showed that using the supplemental irrigation of 40 mm and 59mm during the entire growth period combined with the FRWHS can reach 2000 and 2250 kg ha^{-1} ,respectively in the semi-arid areas of China.

Conclusion

In view of the abovementioned results, worthily clear that under the dry conditions of the North Western Coast zone of Egypt where the agriculture system mainly dependent on rainfall only, it is a dire need to supplemental irrigation to enhance the productivity of wheat grain yield under this conditions.

In the case limited of irrigation water quantities, a one supplemental irrigation by 50 mm at filling stage is the economic treatment to improve the wheat grain yield and WUE. On the other side, in the case abundant of irrigation water quantities, two supplemental irrigations by 100 mm at booting and filling stages is the potent practice to enhance the productivity of wheat grain yield and WUE. While, using three supplemental irrigations by 150 mm at tillering, booting and filling stages is the best cardinal method in order to attain the highest productivity of wheat grain yield and WUE.

RZWQM adequately simulated crop yield, total biomass and in some cases harvest index in response to the supplemental irrigation. The high correlation between simulated and measured crop yield (R^2 = 0.985 and NSE = 0.934) and between simulated and measured aboveground biomass (R^2 = 0.923 and NSE = 0.882) showed that the model correctly simulated crop responses to irrigation scheduling at various growth stages.

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تقدير إنتاجية القمح باستخدام النموذج الرياضى **RZWQM** تحت تأثير الرى التكميلى بالساحل الشمالى الغربى لمصر

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تؤثر كميات مياه الأمطار وتوزيعها بشكل كبير على إنتاجية المحاصيل بالمناطق القاحلة وشبه القاحلة. يؤدى عدم كفاية مياه الأمطار خلال فترات النمو الحرجة إلى خسائر كبيرة فى المحصول. أجريت الدراسة بمحطة التجارب الزراعية بمركز التنمية المستدامة لموارد مطروح، مصر خلال موسمى ٢٠١٥/٢١٠٤ و٢٠١٥/ ٢٠١٦ لتقييم تأثير مختلف معاملات الرى التكميلى على محصول القمح. أشتملت معاملات الرى على: الأمطار فقط (بدون رى تكميلى)- رية واحدة

بمقدار ٥٠ مم (طور التفريع القاعدى، طور ما قبل طرد السنابل، طور إمتلاء
الحبوب)- ريتين بمقدار ١٠٠ مم عند (طور التفريع القاعدى وطور ما قبل طرد
السنابل، طور التفريع القاعدى وطور إمتلاء الحبوب، طور ما قبل طرد السنابل
وطور إمتلاء الحبوب)- ثلاث ريات بمقدار ١٥٠ مم فى الثلاثة أطوار (طور
التفريع القاعدى وطور ماقبل طرد السنابل وطور إمتلاء الحبوب).

أظهرت النتائج المتحصل عليها أن الرى التكميلى بمعدل ١٥٠ مم موزعة
على الأطوار الثلاثة (طور التفريع القاعدى وطور ماقبل طرد السنابل وطور
إمتلاء الحبوب) أحرزت أعلى القيم المعنوية لصفات ارتفاع النبات، طول السنبلة
وعدد الحبوب بالسنبلة (فى الموسم الأول فقط)، وزن الألف حبة، محصول
الحبوب والمحصول البيولوجى و محصول القش وكفاءة إستخدام الماء فى كلا
الموسمين.

تمت محاكاة نمو وانتاجية محصول القمح فى الموسم الثانى تحت مختلف
معاملات الرى التكميلى باستخدام نموذج RZWQM، وقد أوضحت النتائج وجود
تقارب كبير بين كمية المحصول المقدرة فعليا وكمية المحصول المحاكاة باستخدام
النموذج وكانت قيمة مقياس NSE هو ٠,٩٣.

يمكن استنتاج أن الرى التكميلى هام للغاية لتحقيق محصول أقتصادى جيد من
القمح تحت الظروف المطرية لمحافظة مطروح، علاوة على ذلك نجاح النموذج
RZWQM فى تقدير انتاجية محصول القمح تحت ظروف الاجهاد المائى
بالساحل الشمالى الغربى لمصر.