

OPTIMIZING WHEAT YIELD AND WATER PRODUCTIVITY USING AQUACROP AND APSIM-WHEAT MODELS IN NORTH NILE DELTA, EGYPT

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ABSTRACT: *The calibration of APSIM-Wheat and AQUACROP models had been done manually for anthesis date, maturity date, grain yield and total biomass of one recent spring wheat cultivar (T. aestivum) under irrigated conditions in Egypt. Various treatments of planting dates, irrigation and fertilization were applied during two successive growing seasons of 2014/2015 and 2015/2016 in a split split plot design replicated three times. The calibration of APSIM-Wheat and AQUACROP was done for Misr3 cultivar using genetic parameters based on observed field data. Both models simulated anthesis, maturity dates, grain yield and total biomass accurately, with high values of determination coefficient (R^2), and D-index greater than 0.8 as well as lower values of root mean square deviation (RMSD) in most cases. The calibrated models were then employed to explore wheat yield and water productivity in response to irrigation and nitrogen fertilization options. Scenarios analysis indicated that water productivity and yield of wheat ranged from (1.2-2.0 kg m⁻³) and (6.8-8.7 t ha⁻¹) respectively. Application of 0.8 from actual evapotranspiration along with 120 % from recommended nitrogen dose was the best predicted scenario achieving the highest value of crop water productivity. Investigating the suitable option achieving the current wheat yield by farmers (7.4 t ha⁻¹), models demonstrated that application of 1.4 from actual evapotranspiration with 80 % from the recommended nitrogen dose was the best option to achieve this yield. At this point predicted water productivity was low and recorded 1.5 kg m⁻³. Quantifying wheat yield in all districts of the studied area was also predicted using both models. APSIM-Wheat and AQUACROP can be used to drive the best management strategies in terms of N-fertilizer and water regime for wheat under Egyptian conditions.*

Key words: *Calibration, Quantification, Management, Scenarios, Water productivity*

INTRODUCTION

Wheat is considered the most important crop in the world and Egypt. Irrigated wheat in Egypt represents most of the total wheat lands while the arid and semi-arid is the dominant climate. However, irrigation water resources are very limited. Hence, enhancing crop yield, and water productivity through using a suitable irrigation scheduling program is an urgent necessary. In addition, there is a relationship between irrigation and fertilization and their influence on yield production particularly in Egyptian soils which suffers from low

fertility. Both water and nitrogen are exposed to losses by many methods if not managed well. So, it is important to find new strategies and scenarios that could improve crop yield and crop water productivity through enhancing nitrogen use efficiency and irrigation management. Compost is very beneficial as it can be used as a soil conditioner and a slow release nutrient source (Hargreaves *et al.*, 2008; Sullivan *et al.*, 2003; Sullivan *et al.*, 2002). Depending on compost as a source of N instead of mineral N on organic and clean agriculture, the rate of N mineralization

must be taken into consideration. The N mineralization in compost could be characterized mainly by the C:N ratio, generally C:N ratio less than 25:1 in compost refers to the release of mineral N because the gross mineralization is higher than the microbial immobilization of N (Franklin *et al.*, 2015; Prasad, 2009). Providing a satisfactory way to study the complexed systems could be achieved mathematically by crop models (Holzworth *et al.*, 2014). It is becoming an assessment tool for optimizing crop physiology and ecology (Dong *et al.*, 2014). Different crop models have been assessed and enhanced before to predict the potential wheat under various environments among of them APES (Donatelli *et al.*, 2002), APSIM (Keating *et al.*, 2003), CERES (Ritchie *et al.*, 1998), CROPGRO (Godwin and Singh, 1998), DSSAT (Basso *et al.*, 2016; Jones *et al.*, 2003) EPIC (Wang *et al.*, 2012) and STICS (Brisson *et al.*, 2003).

Crop models should be validated first in current locations before using in other areas. Using multi-models is very interested to select the appropriate model that could be used successfully to predict crop production at the specific location (Martre *et al.*, 2015). Wheat crop growth and development could be predicted daily in easily steps by APSIM-Wheat. APSIM-Wheat has been developed from integration of the approaches used in previous APSIM-Wheat modules (Asseng *et al.*, 1998a; Asseng *et al.*, 1998b; Wang *et al.*, 2003). APSIM-Wheat model was used and tested under different management strategies such as water deficit, CO₂ levels, nitrogen fertilization and temperature (Asseng *et al.*, 2004). The recent version of FAO AQUACROP model (Steduto *et al.*, 2012) is a user friendly and easy to use in high accuracy and robustness, in addition it requires a relatively small number of parameters. AQUACROP has been tested well in different locations on the world

(Hsiao *et al.*, 2009) and showed a good fitness on simulating CC, biomass development, and grain yield of different cultivars of maize. Also, respecting irrigation management and crop response to deficit irrigation, AQUACROP has been evaluated and parameterized globally (Khoshravesh *et al.*, 2013), to enhance the scheduling of deficit irrigation (Paredes *et al.*, 2014), to assess increasing of crop production responding to agricultural field management (Mhizha *et al.*, 2014), to evaluate and assess the impacts of climate change on crop yield as well as evaluating the water quality on crop yield (Kumar *et al.*, 2014).

The assessment of APSIM-Wheat and AQUACROP models has not been implemented with wheat production in Egypt, particularly with evaluating the effects of agricultural management practices on yield and water productivity and optimizing these practices. In addition, crop and water productivity under water stress requires evaluation using different management scenarios. Therefore, the main objectives of this study could be summarized as: (i) to calibrate APSIM-Wheat and AQUACROP models for a recent wheat cultivar from CIMMYT in Egypt. (ii) to predict spring wheat yield subjected to N-fertilizer and water interactions for maximizing water productivity. (ii i) potential quantify of wheat yield in a big agricultural governorate of Egypt using these models.

MATERIALS AND METHODS

1. Study location and soil properties:

A field experiment was carried out at Sakha Agricultural Research Station, Kafr El-Sheikh Governorate (KFS), Sakha, Egypt (Fig. 1) during two successive wheat growing seasons of 2014/2015 and 2015/2016 on wheat cv. Misr3 (*triticum*

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aestivum). Soil type of the experimental site was clay textured, it is Egyptian alluvial soils and classified by soil taxonomy as order vertisol (Abdel Kawy and Ali, 2012). The preceding crop in

both was maize. Soil samples at depths of 0-20, 20-40 and 40-60 cm were taken before treatments application in both seasons according to the methods described by (Klute, 1986) (Tables 1&2).

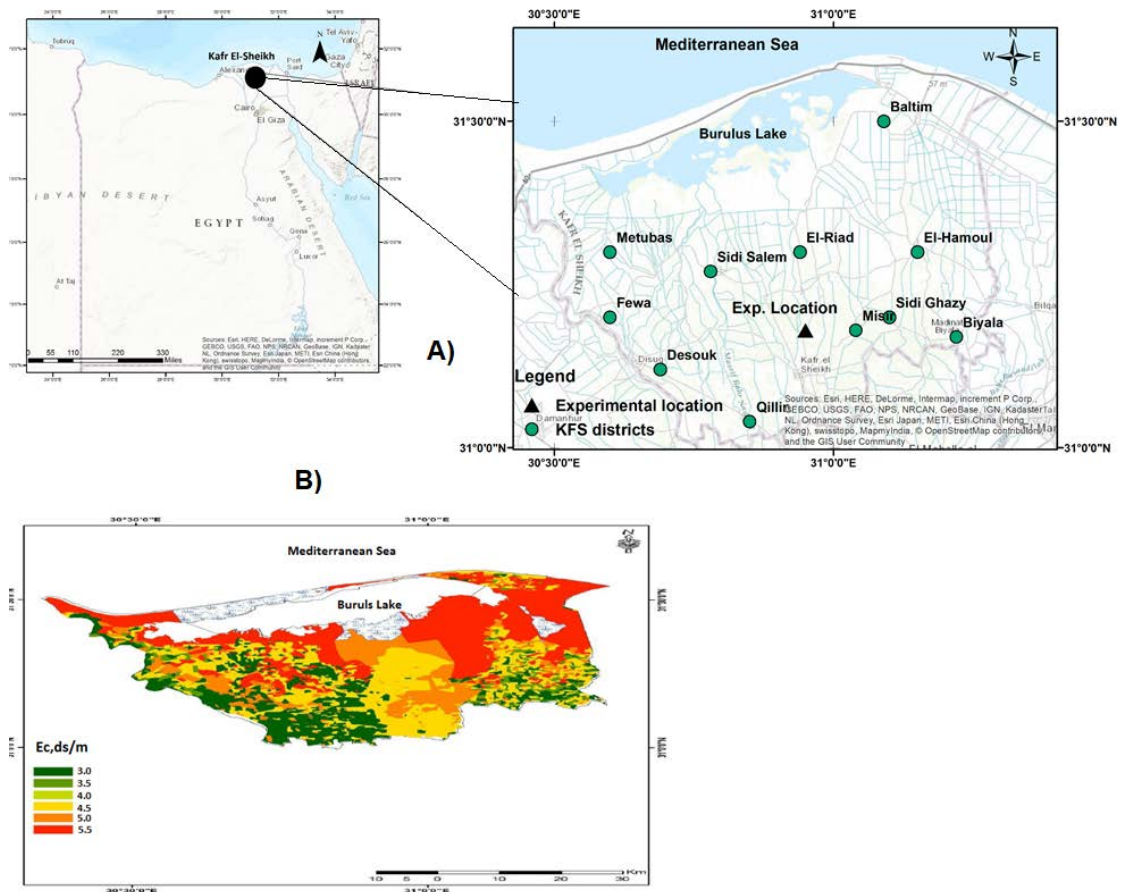


Fig. (1). Map of the studied area at River Nile North delta, Kafr El- Sheikh Governorate (A) and its soil salinity of the effective root zone (B).

Table (1): Soil physical properties of the studied soils before treatment application.

Soil Depth (cm)	Particle size distribution (%)			Texture class	O.M(%)	CaCO ₃ (%)	Water constants (%)		
	Sand	Silt	Clay				FC	WP	AW
0-20	18.7	31.5	49.8	clay	1.54	2.56	42.9	22.9	20.0
20-40	15.7	32.6	51.7	clay	1.47	2.43	40.3	19.7	20.6
40-60	16.5	35.1	48.2	caly	1.13	2.08	38.8	18.9	19.9

FC: field capacity; WP: wilting point; AW: available water

Table (2): Soil chemical properties of the studied soils before treatment application.

Soil depth (cm)	pH (1:2.5)	EC (soil paste extract, dS/m)	SAR	Soluble Cations (meq l ⁻¹)				Soluble Anions (meq l ⁻¹)				Available NPK (mg kg ⁻¹)		
				Na ⁺	K ⁺	Ca ⁺²	Mg ⁺²	CO ₃ ⁻²	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁻²	N	P	K
0-20	8.12	3.18	9.43	21.6	0.7	6.7	3.8	0	2	18	12.8	62	10.71	249
20-40	8.25	4.53	11.28	30.8	0.9	9.5	5.4	0	3.5	24	19.1	48	9.93	241
40-60	8.39	5.22	12.07	35.5	1.2	11	6.3	0	5.5	27	21.5	35	8.54	206

2. Agricultural practices and experimental design:

This experiment was carried out in a split split plot design with three replicates. The main plots were assigned to planting dates; November, 1th (early), November, 15th (the recommended) and November, 30th (late). Sub plots were irrigation treatments as a quantity from actual evapotranspiration (ET_c) i.e. 1.5, 1.0 and 0.5 ET_c. While, the sub sub plots were fertilization as a combination between mineral nitrogen as recommended by Ministry of Agricultural and Land Reclamation (MALR) which represents 120 kg N ha⁻¹ and compost as an organic fertilizer as:

- 1- Control (without mineral N fertilization and with 15 ton/ha of compost), "N0"
- 2- 100 % from recommended N (120 kg N/ha) with 9.2 ton /ha of compost, "N1"
- 3- 70 % from recommended N with 11.5 ton/ha of compost, "N2"
- 4- 50 % from recommended N with 13.8 ton/ha of compost, "N3"

The detailed analysis of the used compost is shown in Table 3.

A recent common high yield wheat cultivar (Misr 3) was chosen in this study. It is a modern variety added recently from The International Maize and Wheat Improvement Center (CIMMYT) to the Egyptian cultivars. Yield and phenology attributes such as grain yield, total final

biomass, anthesis date (DAS) and maturity date (DAS) were measured and recorded. These parameters were then used to calibrate the used models under current conditions. Potential evapotranspiration was calculated from pan evaporation method and translated hereafter to actual evapotranspiration by multiplying the potential values of ET by crop coefficient (K_c). Data were statistically analyzed using fisher's analysis of variance technique (P ≤ 0.01) in Sigma Plot version 13.0 from Systat Software, Inc., San Jose California USA, (www.systatsoftware.com). Where the F- test showed significant differences among means Least Significant Differences (LSD) test of 0.05 level of probability to compared means.

3. Weather conditions:

Data of daily maximum, minimum temperatures and solar radiation were obtained from an automated weather station in Sakha Agricultural Research Station, (Fig. 2). Sakha region is located at the first ecological zone in Egypt which characterizes by thermic soil temperature regime and torric soil moisture regime according to (USDA, 2010). Maximum temperature, minimum temperature and solar radiation through the wheat growing season ranged from (15 to 35 °C), (9 to 20°C) and (3 to 22 MJ m⁻² day⁻¹) respectively, (Fig. 2).

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Table 3: The detailed chemical and nutritional analysis of the used compost, according to (Page *et al.*, 1982).

<i>Characteristics</i>	<i>Values</i>
Dry weight (kg m ⁻³)	650.0
Moisture content (%)	26.80
Odour and colour	Acceptable and dark
pH (1:10 compost-water suspension w/v)	7.16
EC (1:5 compost – water extraction w/v, dS/m)	4.76
Saturation percentage % (g/100g)	175.0
CEC (cmole kg ⁻¹)	64.34
Total organic – c %	25.5
Total organic matter %	43.96
C/N ratio	16.64
Total macro-nutrients %	
Total – nitrogen %	1.79
Total – phosphorus %	1.68
Total – potassium %	1.28
Available macro-nutrients (mg kg⁻¹ compost)	
Available – N (potassium sulfate)	706
Available – P (0.5 M NaHCO ₃ - pH 8.5)	50
Available – K (ammonium acetate pH 7)	85
Available micro-nutrients (mg kg⁻¹ compost)	
Available – Fe	450
Available – Mn	100
Available – Zn	35
Available – Cu	135
Total micro-nutrients (mg kg⁻¹ compost)	
Total –Fe	753
Total – Mn	361
Total – Zn	297
Total – Cu	168
Available heavy metals (mg kg⁻¹ compost)	
Available – Cd	13.2
Available – Ni	62.7
Available – Pb	120

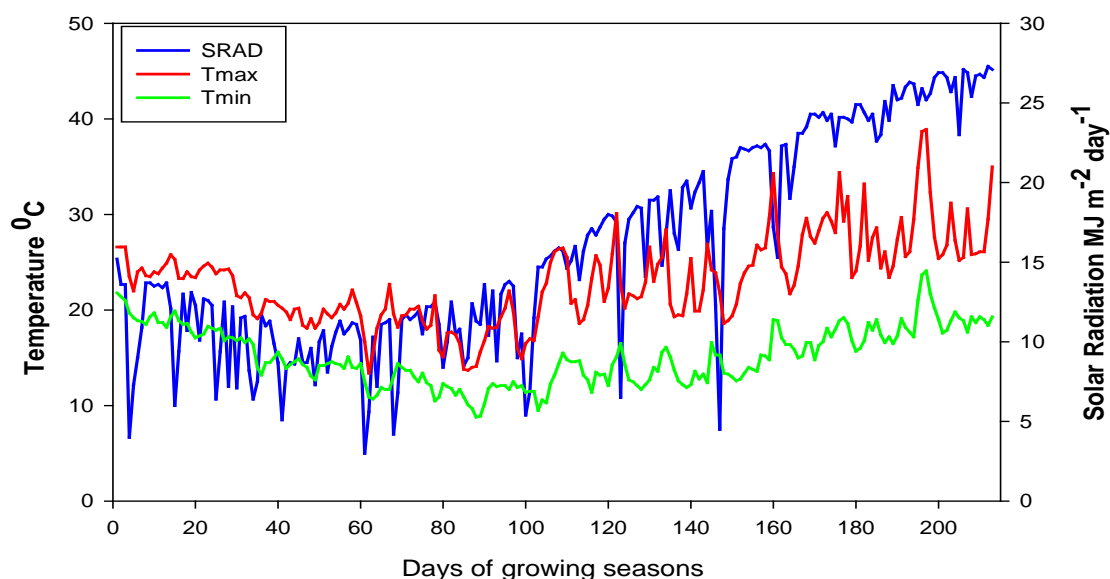


Fig. (2). Daily maximum and minimum temperature ($^{\circ}\text{C}$) and solar radiation ($\text{MJ m}^{-2} \text{day}^{-1}$) data of Sakha as average of two growing seasons 2014/2015 and 2015/2016.

The required weather data for the other eleven districts in KFS governorate which are necessary for model predictions generated from NASA website (<http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi?email=agroclim@larc.nasa.gov>) based on their coordinates, Fig.3.

4. Water measurements:

Soil water content was monitored using acquisition system composed by probes of Time Domain Reflectometry (TDR), (Heimovaara *et al.*, 2004). Water productivity is used to define the relationship between crop produced and the amount of water involved in crop production (Ali and Talukder, 2008). Irrigation efficiency defined as ratio between water consumed by plant during the growing season (evapotranspiration) except effective rainfall and irrigation water applied.

5. Modeling study:

In this study, we used two models AQUACROP and APSIM-Wheat (Keating

et al., 2003). These models were chosen because they are widely used and well accepted in the crop modelling community (Tubiello and Ewert, 2002). Nevertheless, they have not been seen or tested under the Egyptian conditions. These models were mainly used to extend the results for other locations in the same agro-climatic zone. Moreover, they are used to simulate different nitrogen and irrigation split scenarios. Both models are calibrated and tested with Misr 3 wheat cultivar in the current study. The calibration was done through checking the optimal set of parameters in models. The evaluation and performance of calibrated models have been done using coefficient of determination (R^2), root mean square deviation (RMSD) and model index of agreement (d) as explained by (Jacovides and Kontoyiannis, 1995; Moriasi *et al.*, 2007; Willmott, 1984). Following model calibration during two growing seasons, we applied different scenarios to predict the best water and N application practices that could achieve higher

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values of grain yield and WP. Scenarios included the following wide options (0.5,0.6,0.7,0.8,0.9,1.0,1.1,1.2,1.3,1.4 and 1.5 ET_c) of the required crop water and (50,60,70,80,90,100,110,120 % from the

recommended nitrogen fertilizer dose). After calibration and application of both models, they are used to predict wheat yield for all agricultural districts in Kafrelsheikh governorate.

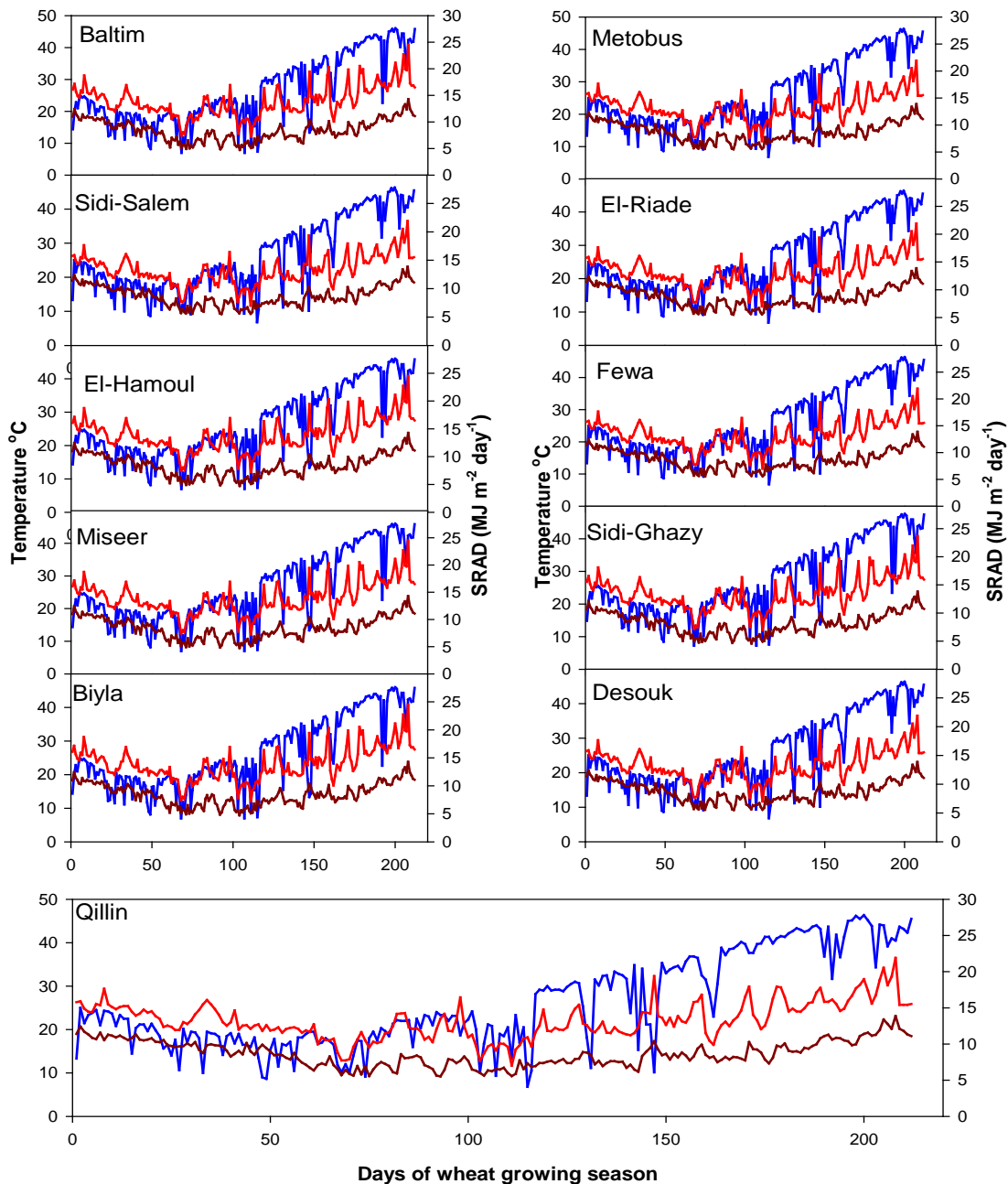


Fig. (3). Daily maximum and minimum temperature (°C) and solar radiation (MJ m⁻² day⁻¹) data of all studied districts in KFS. Data is required for yield predictions by the studied models. Colors of blue, red and dark red represent solar radiation, maximum and minimum temperatures respectively.

RESULTS AND DISCUSSION

1. Observed wheat yield and phenology :

As shown in Figs. (4 and 5) that values of wheat grain yield and final biomass were higher under optimum planting date, P2 (November, 15th), N1, and I2. The highest grain yield obtained was 8.1 t ha⁻¹ achieving an increase by 55 % comparing with the lowest grain yield 3.7 t ha⁻¹ under early planting date (P1), deficit irrigation (I3) and without nitrogen fertilizer application (N0),(Fig.4). The final biomass increased also with optimum planting date (P2), fertilization (N1) and irrigation regime (I2) achieving 16.5 t ha⁻¹ . Meanwhile, the lowest value 7.9 t ha⁻¹ was noticed using deficit irrigation regime

(I3), lately planting date (P3) and without adding nitrogen fertilizers (N0), (Fig.5). The higher yield under P2 is mainly due to the environmental conditions particularly temperature through the sensitive growth stage (Asseng *et al.*, 2015). On the other hand, the lowest yield was noticed under P1(the first planting date,November,1th), without any additions of nitrogen fertilizers as well as under extra irrigation (1.5 ET_c). The marked increase in wheat yields indicated clearly the vital role of N and compost in plant life and contribution for cell division and elongation. Statistical analysis in (Table 4) shows high significant effects of different treatments on wheat yield.

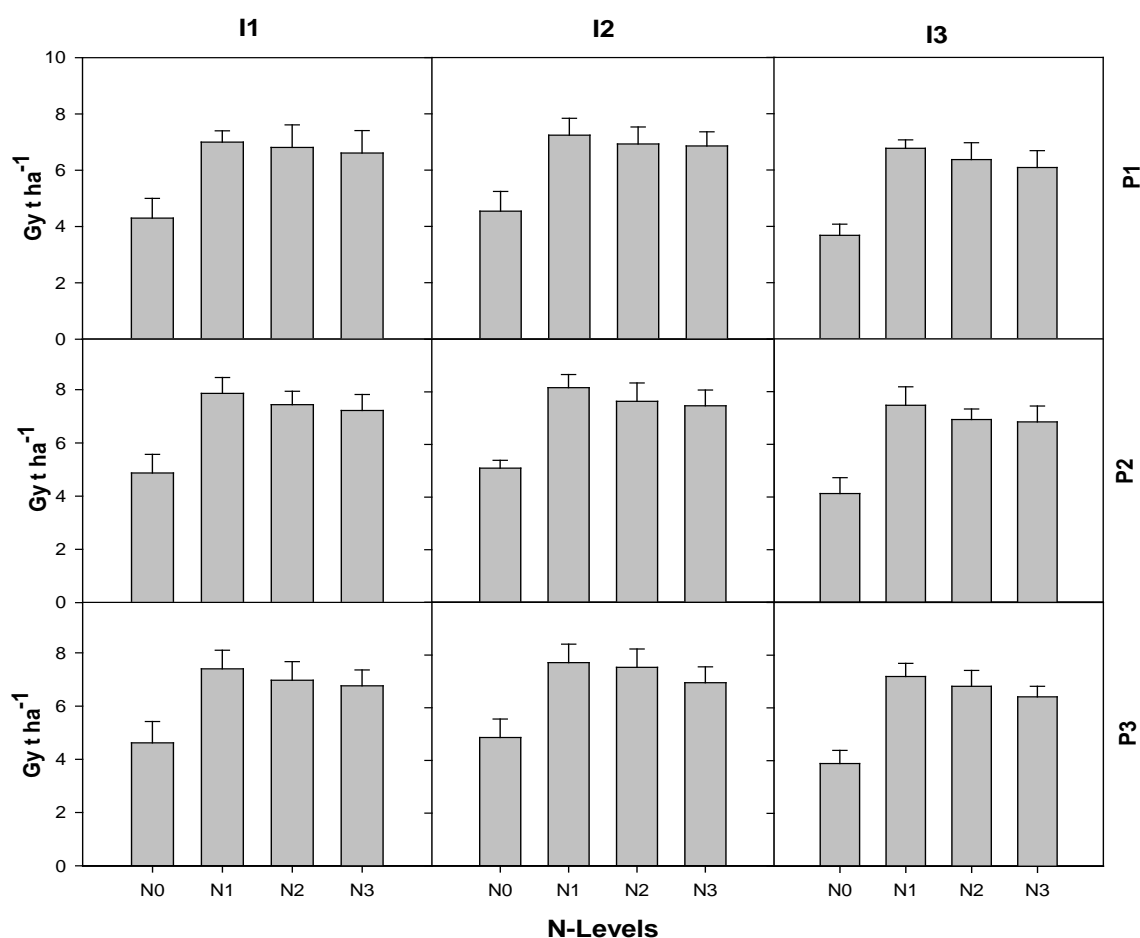


Fig. (4). Wheat grain yield as affected by irrigation, fertilization and planting dates (data represent the average of both seasons).

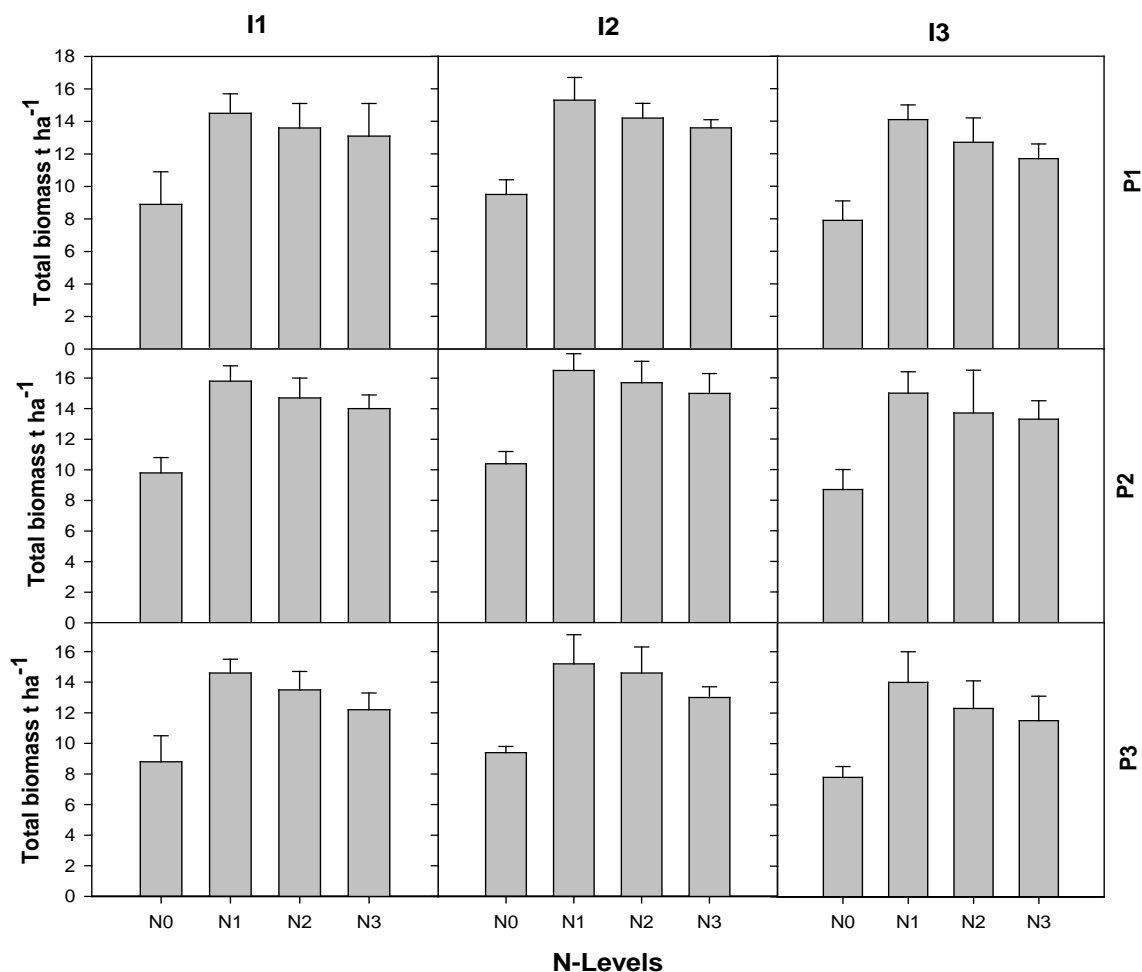


Fig. (5). Final total biomass of wheat (t/ha) as affected by irrigation, fertilization and planting dates, (data represent the average of both seasons).

Table (4): Main effects of planting dates, irrigation and fertilization on wheat grain and biomass yields, (data represent the average of two seasons).

Levels	Grain Yield, Kg ha ⁻¹			Total biomass, kg ha ⁻¹		
	Planting dates	Irrigation	Nitrogen	Planting dates	Irrigation	Nitrogen
1	6100.2	6488.7	4444.9	12369.6	12740.9	9037.2
2	6763.5	6750.5	7422.4	13577.3	13544.5	14943.4
3	6427.4	6051.9	7052.1	12255.4	11916.9	13893.3
4			6802.1			13062.5
F-test	225.14	254.93	2788.72	99.0	122.3	922.9
L.S.D 0.05	**	**	**	**	**	**

The phenological development of wheat from emergence passing by flowering to maturity is mainly affected by temperature, as well as day length and potential physiological stresses, (Olesen *et al.*, 2012). Optimum planting date (P2), Irrigation (I2) and fertilization (N1) achieved the highest value of anthesis (115 days) and maturity (144 days) as shown in Figs (6 and 7) respectively. This is mainly attributed to decreasing the mean temperature at these specific growth stages. Meanwhile, the lowest values were observed at 105 and 128 days for anthesis and maturity respectively under the first planting date

(P1), the third irrigation treatment (I3) and without mineral nitrogen fertilization (N0).

Increasing the yield and phenological stages in wheat under the optimum planting date, irrigation and fertilization is mainly due to the optimum environmental conditions, the role of N fertilization for cell division and elongation and the specific role of compost on increasing soil available water. Where, under P2 the values of available N after harvest as well as N uptake by whole plants were higher than those in P1 and P3 (Figs. 8 & 9). In the same case errors as standard deviation in P2 were lower than those under P1 and P3, (Figs 4 to 7).

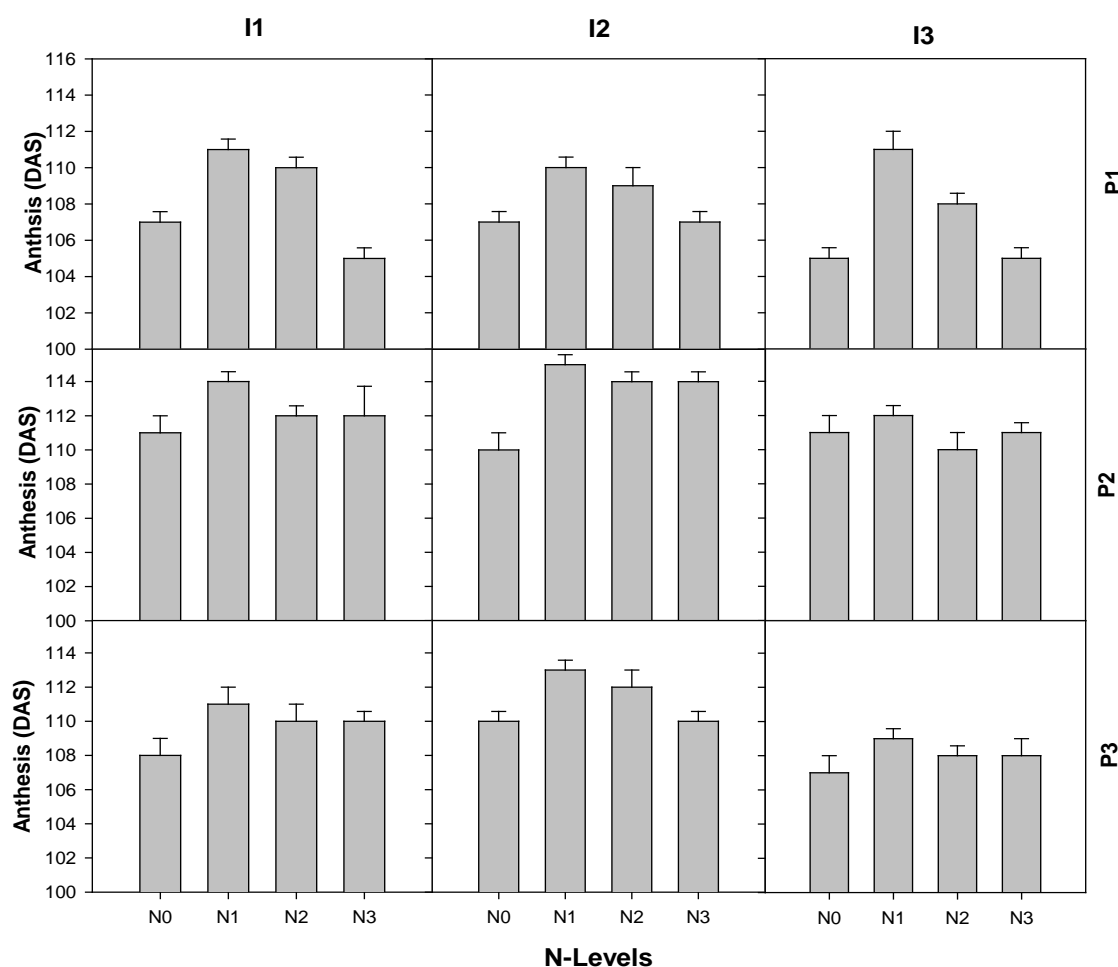


Fig.6. Anthesis date (DAS) as affected by irrigation, fertilization and planting dates.

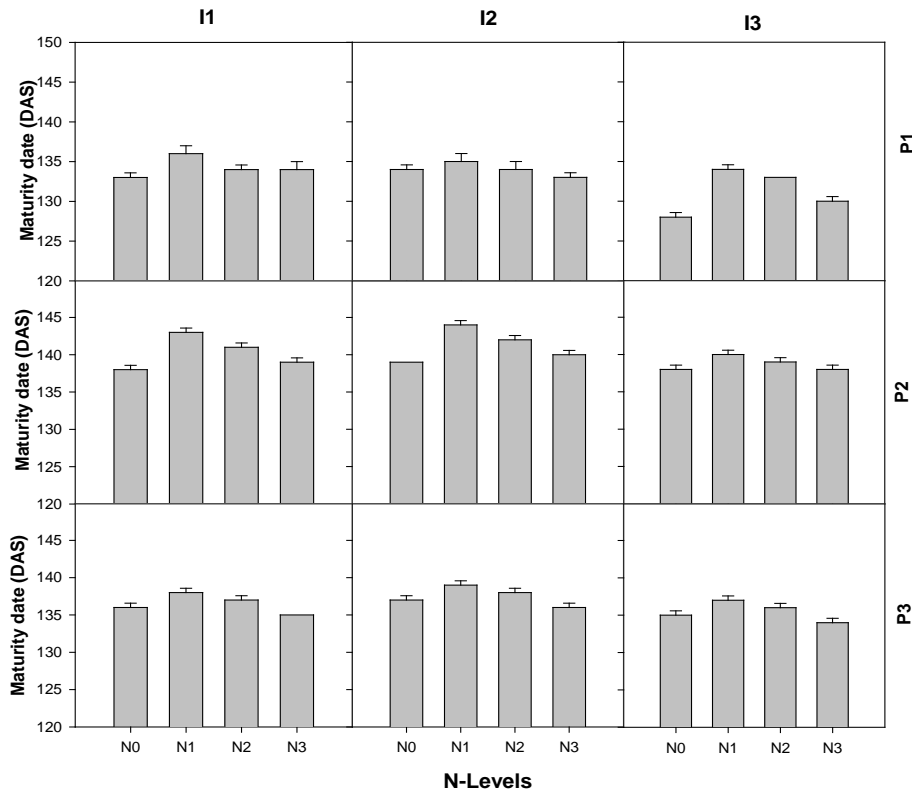


Fig. (7). Maturity date (DAS) as affected by irrigation, fertilization and planting dates, (data represent the average of both seasons).

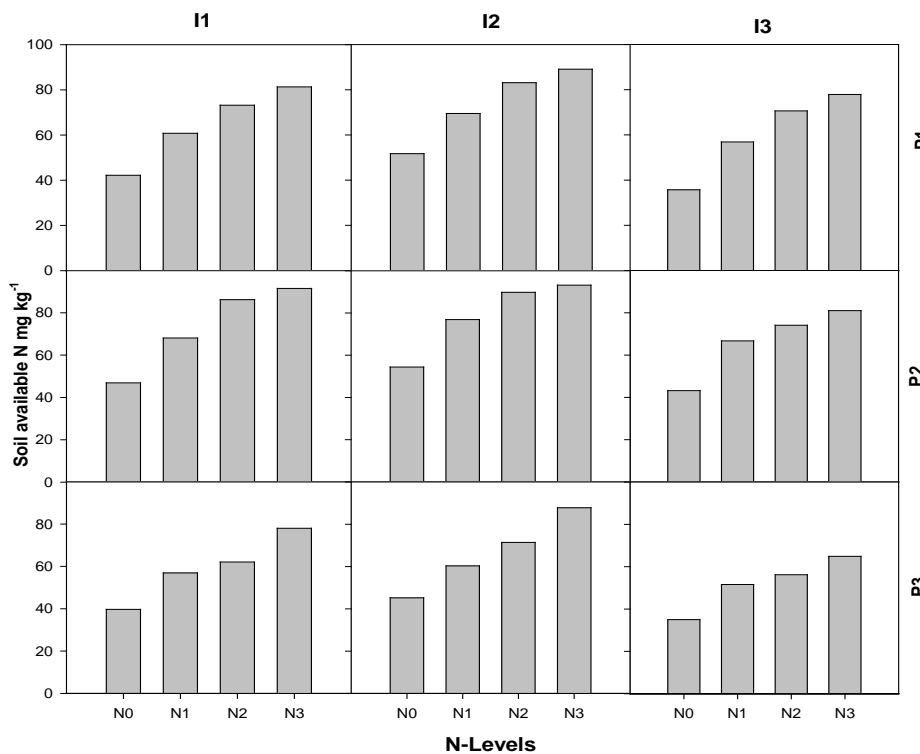


Fig. (8). Soil available mineral N remained in soil after wheat crop harvest, (data represent the average of both seasons).

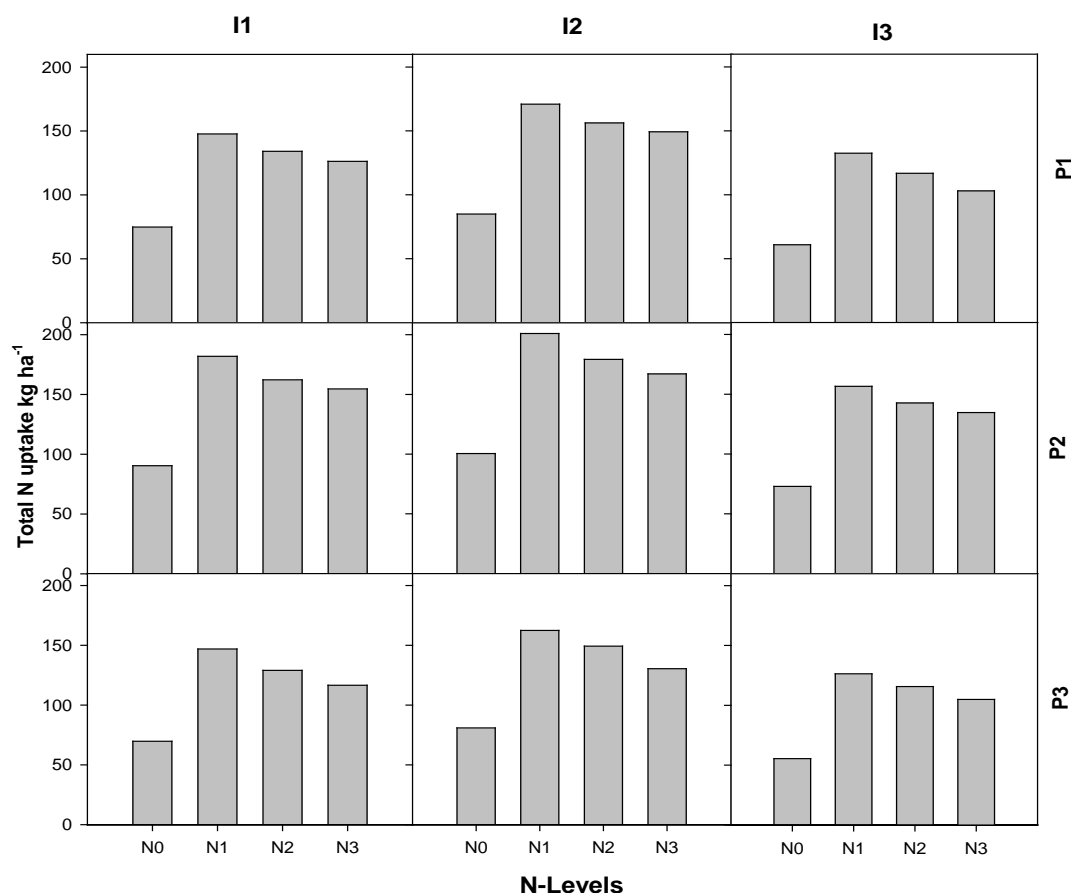


Fig. 9: Total N uptake in whole wheat under different treatments, (data represent the average of both seasons).

Referring to the contribution of compost on mineralization rates and the actual contribution of compost on N availability, data in (Fig. 10 A) show that each one ton of compost can add about 0.7 kg of mineral N. This value had been already deducted from the initial analysis of compost (Table. 3), where the available mineral N equal to 706 mg kg⁻¹ of compost. Consequently, compost can add 10.5, 6.4, 8 and 9.7 kg N ha⁻¹ for the following treatments N0, N1, N2 and N3 respectively. Such values have been already added with those came from mineral fertilizer (Fig. 10 B).

2. Wheat water productivity and water relations:

Currently, the need to increase crop water productivity is very necessary, due

to the limited water resources and population increase, (Kijne *et al.*, 2003; Saad *et al.*, 2014). The results showed that planting date, irrigation and fertilization affected on WP, (Fig. 11). The highest value of observed water productivity (1.6 kg m⁻³) was recorded under the second planting date (P2, the recommended), the second irrigation treatment (I2) and with the first fertilizer treatment (N1). Meanwhile, the lowest value (0.7 kg m⁻³) was noticed under the first planting date, the third irrigation treatment and without applying nitrogen fertilization, N0 (Fig. 11). This is mainly due to increasing crop life period and thus increasing mean seasonal irrigation water applied (Fig. 12 A) under early planting date (P1) as well as decreasing yield due to the unsuitable environmental

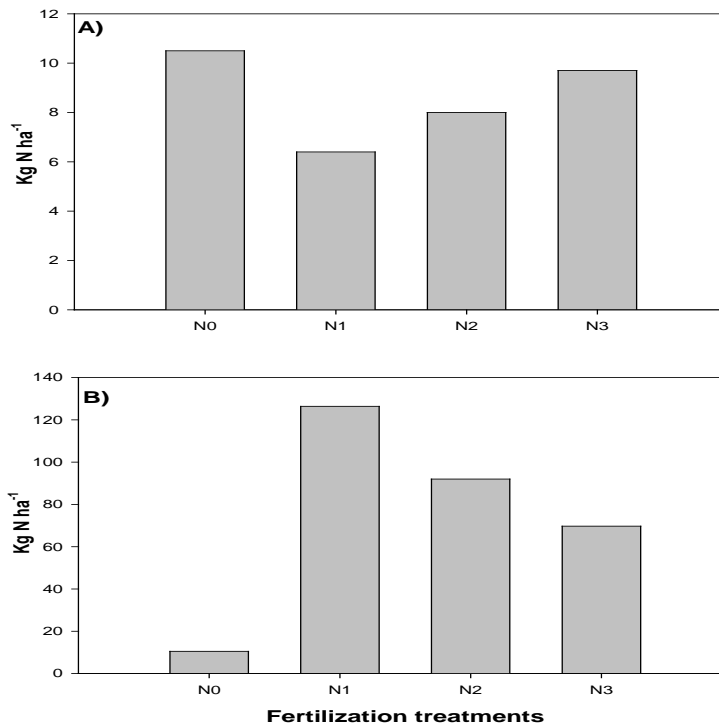


Fig. (10). The added mineral N to soil from compost (A) and from both compost and mineral nitrogen fertilization (B) under different treatments.

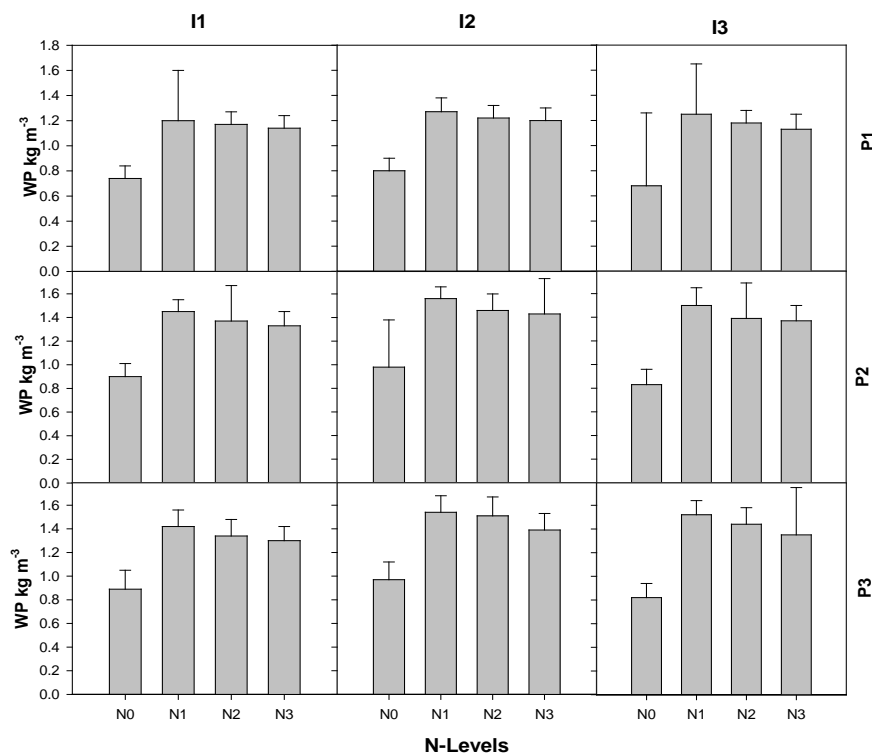


Fig. (11). Wheat water productivity as affected by irrigation, fertilization and planting dates, (data represent the average of both seasons).

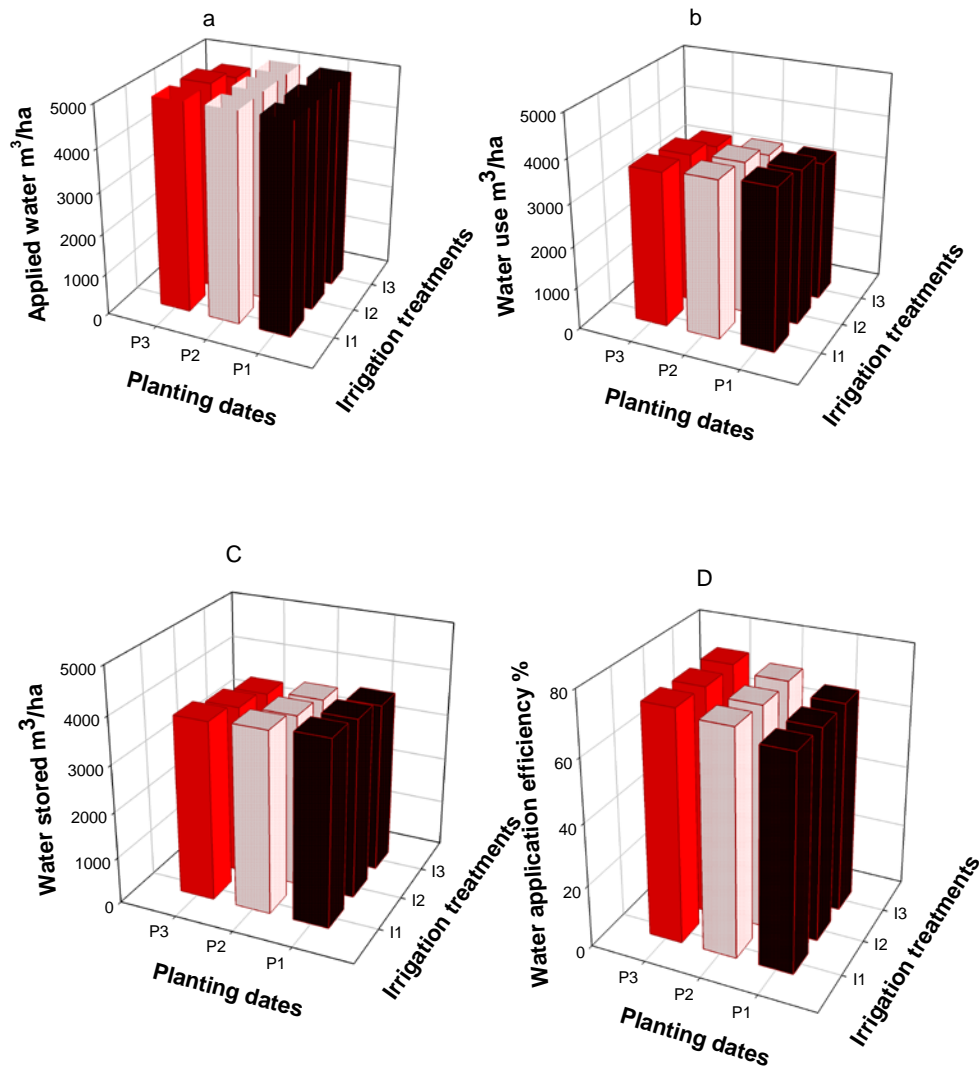


Fig. (12). Wheat water applied (a), use (b), stored(c) and application efficiency (d) as affected by irrigation, and planting dates.

conditions. Different studies have shown that wheat can be grown with deficit irrigation without significant yield reduction (Zhang *et al.*, 1998). Similar to applied water, mean values of water use and water stored decreased with delaying planting dates from early to lately. Where, the highest values of water use and water stored were 3591.9 and 3826.5 $m^3 ha^{-1}$ respectively under the first planting date (Fig.12). These values decreased gradually under delay planting dates. This is also a reason for decreasing water productivity in case of the first

planting date. Water application efficiency appeared in an opposite trend, where the highest value was recorded 73.5 % under the third planting date (P3) and decreased to 67.8 % under the first planting date (P1) passed by 71.3 % in case of the second planting date (Fig.12).

3. Model calibrations:

AQUACROP and APSIM- Wheat models were calibrated using the dataset of 2014/2015 and 2015/2016 growing seasons with Misr3 cultivar. The calibration had been done manually

through modifying the cultivar parameters to agree with field dataset under all treatments. (Tables 5 and 6) supply the list of calibrated cultivar parameters for Misr3 for both used models. The coefficients were obtained step by step for this calibration. First, we started with phenological parameters, then with grain and biomass yields. The genetic parameters determination according to (Godwin and Singh, 1998) have been done manually. The values were modified based on reaching the minimum root mean square deviation (RMSD) between predicted and observed field data. (Fig. 13) shows that calibrations of AQUACROP and APSIM works well and robust. Where, the calibration of both models gave a high agreement of grain yield, total biomass, anthesis and maturity dates. Both crop models reproduced grain yields well with $R^2 0.84$. Also, RMSD values were 555 and 500 kg ha⁻¹ and high agreement index (d) 0.93 and 0.94 for AQUACROP and APSIM respectively (Table 7). Therefore, the models showed a high yield simulation under the current conditions. Also, total biomass simulations were predicted well under both models. Where, R^2 values of simulated biomass were 0.96 and 0.84, RMSD values were 309 and 613 kg ha⁻¹. In addition, (d) values were 0.99 and 0.97 for both AQUACROP and APSIM wheat respectively, (Table 7). Regarding the simulations of wheat phenology (anthesis and maturity), plotted data in (Fig. 13) and statistical indicators in (Table 7) showed a good agreement between simulated and observed values. Therefore, the outcomes from AQUACROP and APSIM-Wheat models in this study could be used successfully as a decision support tool to select the fit cultivars. As well known that wheat phenology has a high impact on yield growth and development (Ceglar *et al.*, 2011). Anthesis and maturity dates were simulated well by both models (Fig.13 and Table 7). In APSIM-Wheat, anthesis date was calibrated using Vern_Sens and

Photo_Sens, meanwhile maturity date was controlled by tt_end_of Juvenile (Table 5). Therefore, we usually need to use these parameters for APSIM calibration (Ahmed *et al.*, 2016; Asseng *et al.*, 1998). While in case of AQUACROP anthesis and maturity dates could be modified and controlled by time to flowering and time to maturity (Table 5). Accurate phenology is considered the first priority for model calibration (Archontoulis *et al.*, 2014). Due to achieving high accuracy and low uncertainty of phenology, the genotypic variations could be captured by models which affect yield, biomass and leaf area development (Robertson *et al.*, 2002). Solar radiation interception (RI) and radiation use efficiency (RUE) are considered the main factors that can influence on biomass production. Our findings showed a high accuracy to predict total biomass similar to achieved by (Arora *et al.*, 2007). Due to the correlation between biomass and grain yield (Dettori *et al.*, 2011), simulations of biomass based on crop models are accurate and robust. In these results, biomass in APSIM-Wheat was determined using tt_floral_initiation (Table 6), meanwhile in AQUACROP it was controlled by plant density and maximum canopy cover (Table 5).

Grain yield is resulting from crop canopy and its RI, HI and RUE. Both models achieved a high robust in simulating grain yield. In APSIM-Wheat, the parameters that responsible for determining grain yield are grain growth rate, maximum grain size, and potential rate of grain filling (Table 5). Meanwhile, in case of AQUACROP, harvest index is the required parameter for grain yield calibration. Therefore, by modifying these parameters grain yield of the specific cultivar could be increased or decreased, provided that it must be modified after process of crop phenology calibration (Ma *et al.*, 2011).

Table (5): Cultivar parameters of cv. Misr3 calibrated for AQUACROP model.

Model	Parameter	Parameter definition	Misr3
AQUACROP	HI	Harvest Index, %	48
	TF	Time to flowering, day	110
	TM	Time to maturity, day	145
	PD	Plant density, plants ha ⁻¹	250000

Table (6): Cultivar parameters of cv. Misr3 calibrated for APSIM-Wheat model.

Name	Unit	Misr 3
Photo_Sens (Photoperiod sensitivity)	-	3.7
Vern_Sens (Vernalization sensitivity)	-	0
tt_end_of_juvenile (thermal time needed from sowing to end of juvenile)	°C days	660
tt_flowering (thermal time needed in anthesis phase)	°C days	175
tt_floral_initiation (thermal time from start of grain filling to maturity)	°C days	910
tt_start_grain_fill (thermal time from start of grain filling to maturity)	°C days	1000
Max_grain_size (maximum grain size)	g	0.066
Potential_grain_growth_rate (grain growth rate from flowering to grain filling)	g grain ⁻¹ day ⁻¹	0.002
Potential_grain_filling_rate (potential daily grain filling rate)	g grain ⁻¹ day ⁻¹	0.007
Grains_per_gram_stem (grain number per stem weight at the start of grain filling)	g	60

Table (7): Models evaluation indices of evaluating the performance of AQUACROP and APSIM-Wheat for Misr 3 spring wheat

Models evaluation indices	AQUACROP model		APSIM-Wheat model	
	Grain yield	Total biomass	Grain yield	Total biomass
R ²	0.84	0.96	0.84	0.84
RMSD	555 kg ha ⁻¹	309 kg ha ⁻¹	500 kg ha ⁻¹	613 kg ha ⁻¹
D	0.93	0.99	0.94	0.97
	Anthesis	Maturity	Anthesis	Maturity
R ²	0.38	0.59	0.62	0.48
RMSD	3 days	3 days	2 days	3 days
D	0.75	0.55	0.89	0.72

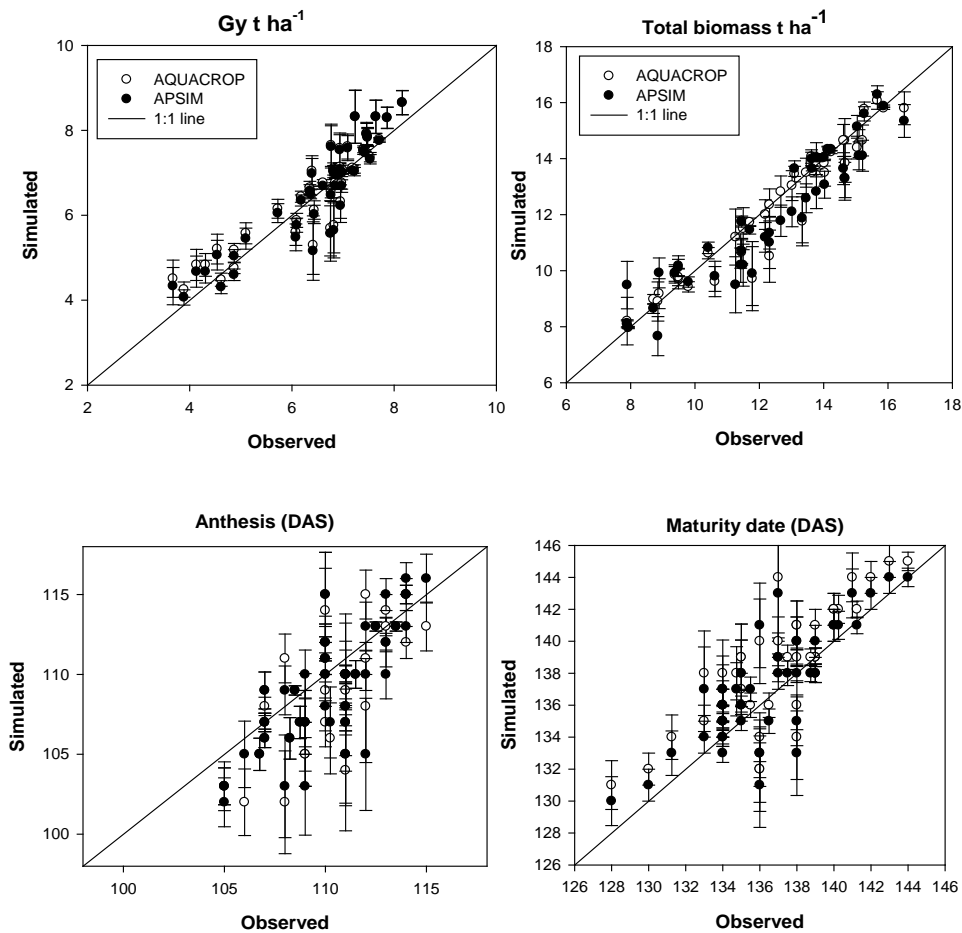


Fig. (13). Calibrations of AQUACROP (opened circles) and APSIM-Wheat (closed circles) models under different treatments (planting dates, irrigation and fertilization) in Sakha location. symbols, mean; (error bars, +/- 1 s.d.).

4. Model applications:

After model calibrations using various experimental dataset in the studied area, we used both models to predict GY and WP in response to various options of nitrogen and water as treatment inputs in crop models. This is to find out which scenario can maximize yield and water productivity. The data in (Figs 14 A & B) show the predicted wheat yield and water productivity respectively under various scenarios of water regime and N fertilizer doses. Data showed that the highest yield 8.7 t ha⁻¹ was predicted under 120 % from recommended N in combination with irrigation by 1.2 ET_c (Fig.14 A). Meanwhile, the highest value of WP 2.0

kg m⁻³ was noticed under 120 % from recommended N with deficit irrigation 0.8 ET_c (Fig.14 B). Also, it is necessary and importantly to observe that WP value under irrigation with 100 % from actual evapotranspiration (1.0 ET_c) and 100 % from recommended nitrogen fertilizer, 1.8 kg m⁻³ was quite like to that obtained under (120 %) N and deficit irrigation (0.7 ET_c), (Fig.14 B). It was also noticed from model simulations that the farmer wheat productivity 7.4 t ha⁻¹ could be obtained by adding 80 % from recommended doses of nitrogen fertilizer and 1.2 ET_c as irrigation water applied, at this point WP will be 1.5 kg m⁻³. In arid and semi-arid

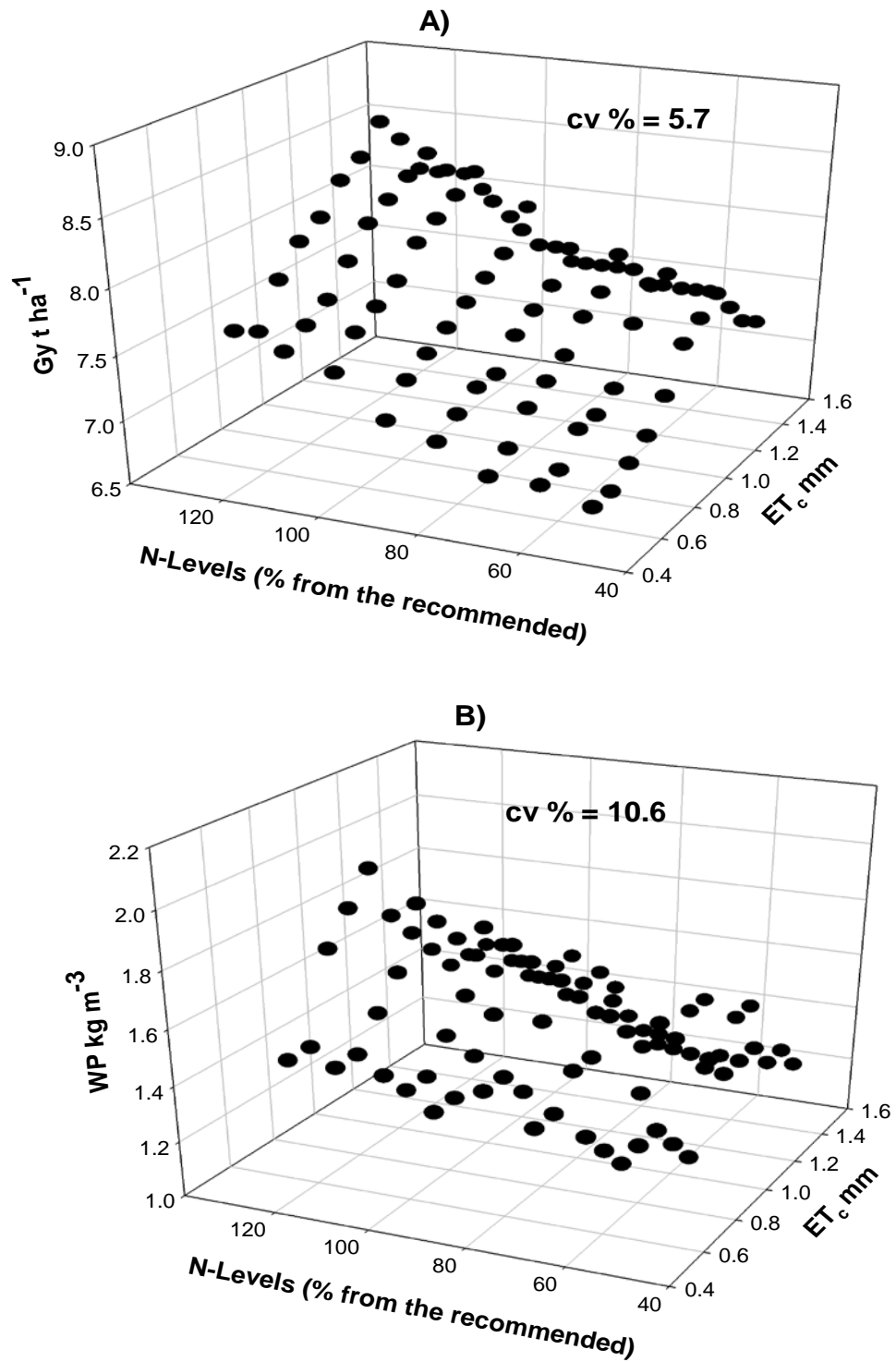


Fig. (14). Simulated grain yield (A) and water productivity (B) as an overall prediction of both models (Aquacrop and Apsim) under different water regime and N management scenarios.

climate region like Egypt, where water resources are limited deficit irrigations could produce satisfactory and substantial yield provided that increase nitrogen dose. The study findings show an increase in WP under deficit irrigation. Consequently, combination between less water applied quantity and appropriate management of N fertilizer will increase wheat water productivity in the region. In conclusion, we have two recommended management practices from this study that can enhance wheat yield and water productivity. The first recommendation, which resulted from two growing seasons (field experiment) suppose that N1 (100 % from recommended N combined with 9.2 t ha⁻¹ compost) and I2 (1.0 ET_c) gave the highest yield and water productivity. Meanwhile, the second recommendation which extracted from different predicted scenarios of water and N management, suppose that using (120 % from recommended N) in combination with 0.8 ET_c gave the highest value of water productivity as predicted by both crop models. The first recommended treatment gave 8.2 t ha⁻¹ of grain yield and 1.6 kg m⁻³ for WP. Meanwhile, the second treatment increased the yield to reach 8.5 t ha⁻¹ and sharp increase in WP by 2.0 kg m⁻³.

Therefore, we have used the previous two main recommendations separately to predict wheat yield in all districts (11 sites) of the governorate (Figs 15 A & B) and Table 8. Based on the World Reference Base for Soil Resources, the main soil group is Fluvisols (Fl) with

main texture clay and loamy clay (Taha, 2000) and (FAO, 1998). Meanwhile, climatic data for all locations were generated from NASA, AgCFSR climate dataset

(<http://data.giss.nasa.gov/impacts/agmipcf/>) and used for simulations, Fig.3. The overall wheat yield as predicted by two crop models using the first recommended treatments (Fig.15A) was slightly lesser than that predicted by the second recommended treatments (Fig.15 B). This is mainly attributed to increasing the nitrogen fertilizer dose in case of the second scenario 120 % from recommended which equal 144 kg N ha⁻¹ and its role in maximizing the yield and irrigation with 0.8 ET_c. Meanwhile, the first recommended treatment supposes adding 100 % from recommended N combined with 9.2 t ha⁻¹ from compost achieving 126.4 kg N ha⁻¹ with irrigation at 1.0 ET_c. The studied districts that already cover the agricultural area in KFS are (Baltim, El-Hamoul, Metobus, El-Riad, Sidi Salem, Sidi Ghazy, Fewa, Biyala, Desouk, Miseur and Qillin). As demonstrated in (Figs 15 A & B) that wheat yield decreased on the North direction and increasing towards the South direction, however temperature increase on the south trend. This is mainly attributed to increasing soil salinity which resulting from sea water intrusion in locations close to Mediterranean Sea, (Fig.1B.) Therefore, AQUACROP and APSIM-Wheat predicted the yield and maximized its value at the North delta of Egypt successfully.

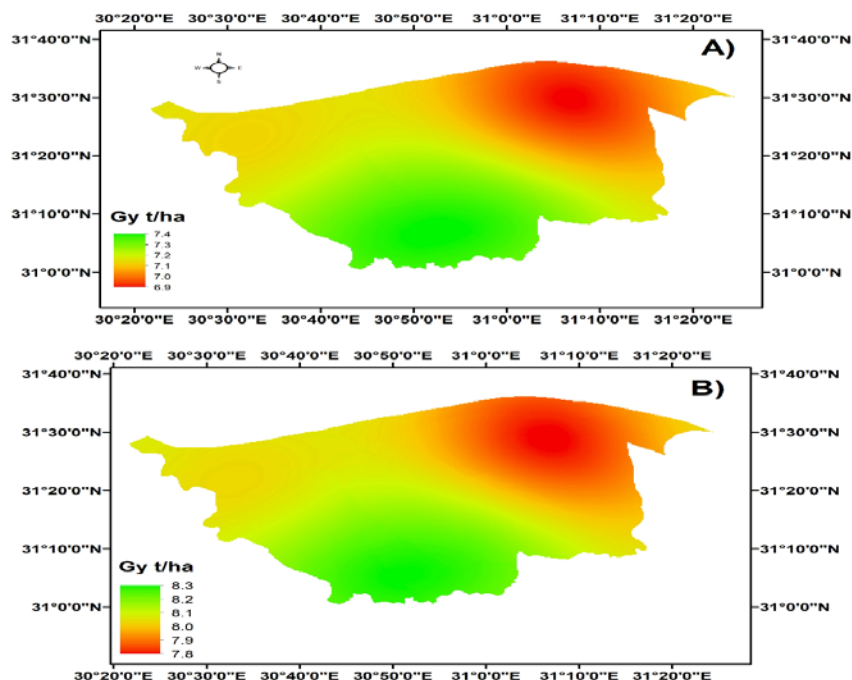


Fig. (15). Predicted wheat yield cross all wheat cultivated districts in Kafrelsheikh governorate as an overall of both models. A) represents the optimum treatments of irrigation (I2) and fertilization (N1) that gave the highest yield under experiment conditions. B) represents the optimum treatments of irrigation (I 0.8ET_c) and fertilization (N120 % from recommended N) that gave the highest yield under predicted scenarios. The data interpolated using the model outputs of 11 districts in the governorate (Table 8).

Table (8): Predicting wheat yield for different locations in the studied province using the calibrated AquaCrop and Apsim models under better treatments.

Location	Lat	Long	Gy t ha ^{-1*}	Gy t ha ^{-1**}
Baltim	31.50	31.09	4.3	4.6
El-Hamoul	31.30	31.15	5.8	6.1
Metobus	31.30	30.60	6.3	6.5
El-Riad	31.30	30.94	7.6	8.1
Sidi Salem	31.27	30.78	7.5	8.0
Sidi Ghazy	31.20	31.10	8.1	8.7
Fewa	31.20	30.60	7.3	7.6
Biyala	31.17	31.22	7.0	7.5
Desouk	31.12	30.69	8.3	8.5
Miseer	31.18	31.04	8.1	8.7
Qillin	31.04	30.85	8.1	8.8
Stdev			1.2	1.3

*Simulated grain yield by average both models using the best treatments explored from the field experiment. Treatments here included adding 100 % from recommended N along with 9.2 t ha⁻¹ from compost achieving 126.4 kg N ha⁻¹ with irrigation at 1.0 ET_c.

**Simulated grain yield by average both models using the best treatments explored from different scenarios. The treatments here are adding 120 % from recommended dose which equal 144 kg N ha⁻¹ and irrigation with 0.8 ET_c.

CONCLUSION

Wheat production in regions suffering from limited water resources like Egypt is influencing essentially by deficit irrigation, and nitrogen fertilization. In this study, APSIM-Wheat and AQUACROP showed a high accuracy in simulating anthesis date, maturity date, grain yield and total biomass. Where, the statistical indicators R^2 , RMSD and D confirmed such accuracy for both models. These models are used after that to predict yield and water productivity under various scenarios of irrigation and nitrogen fertilization. Generally, WP decreased with applied water increase, due to decreasing grain yield than ET increase. A field experiment conducted in two successive growing seasons demonstrated that the highest WP 1.6 kg m^{-3} was achieved under the recommended planting date (P2), the recommended nitrogen fertilizer combined with 9.2 ton ha^{-1} of compost (N1) as well as using the actual evapotranspiration 1.0 ET_c as applied irrigation water (I2). Different scenarios of irrigation and nitrogen fertilization were used as model inputs to explore the best option achieving the maximum water productivity. Consequently, the highest value of WP 2.0 kg m^{-3} was predicted by using 120 % from recommended N and 0.8 ET_c as water application. Importantly, under all scenarios used of irrigation and fertilization, WP ranged $1.7 - 2.0 \text{ kg m}^{-3}$, meanwhile grain yield ranged from $6.8 - 8.7 \text{ t ha}^{-1}$. This wide range was mainly attributed to the interaction effects of irrigation and fertilization on yield and WP. Noticeably, the farmers yield in North delta of Egypt 7.4 t ha^{-1} was predicted by adding 80 % from recommended N and 1.4 ET_c as irrigation water resulted in lower value of WP 1.5 kg m^{-3} . Following the specifying of the best recommended options of irrigation and nitrogen fertilization in both field

experiments and modeling prediction scenarios, we predicted the wheat yield in all districts in Kafrelsheikh governorate. APSIM-Wheat and AQUACROP models could be used as tool to predict and optimize wheat yield and water productivity under different treatments of irrigation and fertilization in Egypt.

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تعظيم انتاجيه القمح والانتاجيه المائيه باستخدام النماذج الرياضيه الاكواروب و الابسيم في شمال دلتا النيل - مصر

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الملخص العربي

تم اختبار صلاحية نوعين من اهم النماذج الرياضيه الحديثه وذلك مع صفات زمن التزهير، زمن النضج، محصول الحبوب وكذلك المحصول البيولوجي للقمح تحت ظروف الاراضي المروييه في شمال دلتا النيل. ولاتمام ذلك تم اجراء تجريه حقلية بمعاملات مختلفه تشمل مواعيد زراعه، وري وتسميد خلال موسمي زراعه ٢٠١٤/٢٠١٥ ، ٢٠١٥/٢٠١٦ في قطع منشقه مرتين بثلاث مكررات. تم اجراء معايره واختبار صلاحية النماذج الرياضيه (الاكواروب و الابسيم) مع صنف قمح حديث (مصر ٣) وذلك من خلال تعديل العناصر اللازمه لاختبار الصلاحيه باستخدام البيانات الخاصه بالتجريه الحقلية. تم التأكد من صلاحية استخدام هذه النماذج الرياضيه في التنبؤ من خلال الوصول الي اعلي قيمه لكلا من معامل التقدير R2 ومعامل التوافق d واقل قيمه للانحراف المعياري RMSD وذلك بين البيانات الحقلية والنظريه (المتنبئ بها) اثناء عمليه المعايره. عقب اختبار صلاحية هذه النماذج ، تم استخدامها للتنبؤ بأعلي انتاجيه للقمح وكذلك اعلي قيمه لانتاجيه وحده المياه من خلال استخدام عدده سيناريوهات من كميات مياه الري المضافه والتسميد النيتروجيني. ووضحت هذه السيناريوهات ان مدي انتاجيه وحده المياه وكذلك محصول القمح تراوح بين (١,٢ - ٢ كجم/م^٣) ، (٦,٨ - ٨,٧ طن /هكتار) علي الترتيب وذلك كمتوسط عام من مخرجات كلا النموذجين الرياضيين المستخدمه. وفي هذا السياق اوضحت النماذج الرياضيه ان اعلي قيمه لانتاجيه وحده المياه يمكن الحصول عليها من خلال الري بمعدل ٨٠ % من البخرنتج الفعلي مع اضافته ١٢٠ % من التسميد النيتروجيني الموصي به. وحيث ان اعلي انتاجيه للقمح عند المزارعين في كفرالشيخ باستخدام الاصناف الحديثه يتم الحصول عليها من خلال الري بمعدل ١٤٠ % من السماد النيتروجيني الموصي به والتي عندها تكون انتاجيه وحده المياه منخفضه (١,٥ كجم/م^٣) ، لذا فيمكن تعظيم انتاجيه وحده المياه من خلال زياده التسميد النيتروجيني بمعدل ٢٠ % عن المعدل الموصي به وتقليل مياه الري بمعدل ٢٠ % عن البخر نتج الفعلي.

ايضا تم استخدام هذه النماذج الرياضيه للتنبؤ بانتاجيه القمح في المراكز الاخرى في محافظه كفرالشيخ وذلك لامكانيه عمل تقدير كمي للانتاج باستخدام النماذج الرياضيه. لذا تعتبر النماذج الرياضيه (الاكواروب و الابسيم) اداه جيده لاداره المياه والتسميد تحت ظروف الاراضي المصريه.

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