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CROPSYST SIMULATION AND RESPONSE OF SOME WHEAT CULTIVARS TO LATE SEASON DROUGHT

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Abstract

Drought has a significant impact on crop growth and production, especially wheat as one of the world major crops. The objectives of this study were to assess the impact of different irrigation treatments on wheat grain yield and calibrate CropSyst model to simulate wheat under normal and deficit irrigation. The field experiment was carried out during 2010/2011 wheat growing season at El-Beheira, Egypt. Two irrigation treatments were applied: normal (full irrigation) and deficit (late season drought). Results indicated that, the deficit irrigation has a trivial (significant) impact on anthesis (physiological maturity) days and their corresponding Growing Degree Days (GDD) for all wheat cultivars. Under the deficit irrigation conditions, the maximum decreasing in wheat grain yield were recorded for Sakhs93, Sakha61, and Sakha94 by 63.85, 56.14, and 50.84 % respectively. While, the minimum decreasing in wheat grain yield were observed for Gemmiza9, Gemmiza7, Sids1, Gemmiza10 and Giza168 with 37.73, 33.12, 30.55, 26.56 and 24.40 % respectively. It is obvious that, the last cultivars are more tolerant to water deficit than Sakha cultivars. Henceforth, it is highly recommended to be cultivated under water scarcity conditions. The calibration of CropSyst revealed that, the Model Percentage Error ranged from -0.139 to 0.222 % and 0.282 to 0.068% for normal and deficit irrigation respectively. As well as, the values of Normalized Root Mean Square Error and Normalized Mean Bias were 0.030-0.192 %, and 0.147-0.104 % respectively. These results prove that, the CropSyst gives a reasonable prediction for wheat grain yields under normal and deficit irrigation.

Key words: *Normal and deficit irrigations, late-season drought, CropSyst model, wheat cultivars, growing degree-days.*

INTRODUCTION

Climate change is observed in the last decades without any doubt, and it is an ongoing process in the 21st century, causing changes in the hydrological cycle by affecting precipitation and evaporation (IPCC, 2013). One of the largest climate change impacts is expected to be on agriculture sector (Piao et al., 2010; Wang et al., 2013; Barros et al., 2014), because its indirect impacts on freshwater resources and availability. In recent years, droughts and water scarcity problems are considered as a limiting factor for agricultural production (Zhang et al., 2015; Ali et al., 2011a and Ali et al., 2011b). In addition, drought is a most damaging and widespread climate index that negatively affecting agricultural production, ecosystem function, water resources, and human lives around the globe (Dai, 2011; Munsif et al., 2011). In addition to the potential impact of climate change, also the biological variables, such as the lengths of the crop growth periods and the crop cycle, play and have an important and vital role on crop production. Around the world, agriculture is challenged with an increased frequency of drought periods and reduction of available water, which stagnates and decreases the crop yields (Becker and Schmidhalter, 2017). About 72% of available global fresh water is consumed by agriculture (Geerts and Raes, 2009; Andarzian et al., 2011), since 85% of total available water in Egypt is consumed in agriculture and it should be adequately applied to crops to avoid water waste (Noreldin et al., 2015). Due to the world increase in population, the world agricultural products and fresh water demand increases every year (Tilman et al., 2011; Godfray, 2014) and it has become a necessity for an increase in food and water production (Kale, 2016). Many studies showed that, one of the encouraging irrigation strategies to increase water productivity might be deficit irrigation (Kipkorir, 2002; Debaek and Aboudrare, 2004; Fereres and Soriano, 2007; Ali and Talukder, 2008; Farre and Faci, 2009; Behera and Panda, 2009; Blum, 2009; Geerts and Raes, 2009; Noreldin et al., 2015). Where, adopting deficit irrigation treatment implies the acceptance of a certain level of reduction in yield level (Hamdy et al., 2005).

In the Mediterranean region, where water resources are limited, the irrigation management must be optimized to maximize economic water use efficiency and reduce waste (Bouazzama et al., 2017). In addition, the irrigation under limited water supply decreases photosynthesis, claws, leaf area, biomass, number of grain per an ear, thousand-kernel weight and grain yield (Zubaer et al. 2007). In Egypt, the rainfall provides only 30% of crop water requirements for winter wheat, while the rest 70% comes from irrigation water (Ouda, 2016). Wheat (Triticum aestivum L.) is one of the most world extensive cultivated cereals that is often under abiotic stress (Cossani and Reynolds, 2012) and has a critical role in the world food supplies (Shiferaw et al., 2013), as well as in Egypt.

Drought or water deficit limits crop growth and yield more than any other environmental stress (Zhu 2002; Wang et al. 2003), especially in arid and semi-arid regions like Egypt. Water stress is the most common environmental stress affecting about 32% of the cultivated wheat in the developing countries (Rajaram, 2000). Drought affects wheat grain yield through shortening most wheat growth stages (Dadbakhsh and YazdanSepas, 2011) and the early grain development stage is more vulnerable to water stress than latter grain development stage (El-Kholy et al., 2005). Where, decreased number of irrigation or increased moisture stress showed accelerated the grain filling rate (GFR) and hastened the grain filling duration (GFD) of bread wheat (Ejaz et al., 2007) and decreased the wheat phenological life (Roohul et al., 2012). In addition, drought affected the plant water status during the spike formation and flowering stages, resulting in reduced grain yield by 37% and straw yield by 18% (Katerji et al., 2009). The investigation of crop response to different irrigation treatments and its optimal time in the field and carried out experiments on different crop management practices is costly, time consuming and laborious (Sen et al., 2017; Ali et al., 2012; Arif et al., 2012). Where, the irrigation scheduling significantly change depending on sowing date, nitrogen fertilization, and the irrigation system in use (Bouazzama et al., 2017). The crop simulation models (CSMs) are considering this kind of limitations and represent an effective tool in agricultural research, especially in the decision support systems. It evaluate the effects of water deficits on crop productions, and optimizing the irrigation with the available limited water (Boote et al., 1996; Zairi et al., 2000; Kipkorir et al., 2001; Lobell and Ortiz-Monasterio, 2006; Benli et al., 2007; Heng et al., 2007; Lorite et al., 2007; Pereira et al., 2009; Blum, 2009; Qi et al., 2013). These crop models are offered to investigate the multiple interactions between soil, climate, genotype and crop management (Rizzo et al., 1992), as well as to examining different management scenarios (Zare et al., 2014) and their impact on crop growth and productivity (Lenka and Singh, 2011).

One of the most important CSMs at present that can be used in this regard is CropSyst model (Stöckle et al. 1999). CropSyst model has validated and widely applied to simulate cereals under different cropping systems (Confalonieri et al. 2004; Wang et al. 2006; Benli et al. 2007; and Singh et al. 2008). CropSyst model was largely used to simulate wheat yield (Pannkuk et al. 1998; Wang et al. 2006; Moriondo et al. 2007; Singh et al. 2008). Under Egyptian conditions, many Egyptian scholars have used the model to simulate wheat yield (Khalil et al. 2009; Ouda et al. 2010; Ouda et al., 2012; Taha, 2012; Ibrahim et al. 2012; Abdrabbo et al., 2013; Morsy, 2015; Oudaet al., 2015a). These researches reported that the CropSyst model performed fairly well in wheat biomass production and grain yield simulation. CropSyst model is a perfect sample of simulation model that ever used in the world and one of its significant features is that it can connect to GIS software (Zare et al., 2014). Consequently, the CropSyst model can assist in determining the expected wheat yield losses due to reducing number of applied irrigations.

The current experiment was designed to study the effects of different water irrigation treatments on different wheat cultivars growth stages and the grain yield and to calibrate and validate the performance of CropSyst model to simulate wheat yield in response to different irrigation supplemental treatments.

MATERIAL AND METHODS

Field Experiment: The field experiment was carried out at El-Bostan experimental farm, Faculty of Agriculture, Damanhour University, Egypt. El-Bostan region is a newly reclaimed area and recently became an important agricultural region in El-Beheira Governorate. Where, the sowing and harvesting were on 23/11/2010 and 20/04/2011 respectively. All cultural practices, except irrigation, were applied as recommended for the experimentation site. Mono–super phosphate (15.5 % $P_2O_5$with rate 22.5 kg/fed), potassium sulfate (48 % K_2O with rate 24 kg/fed) and ammonium sulfate (20.5 % N with rate 100 kg/fed); one hectare (ha) = 2.4 feddan (fed). The experiment included eight wheat cultivars and its identification and pedigree are shown in Table (1).

Table (1): Identification and pedigree of the studied eight-bread wheat

ID No.	Name	Pedigree
1	Sakha93	Sakha 92 / TR 810328.
2	Sakha61	Inia / RL4220//7C / Y R"S".
3	Sakha94	Opata / Rayon // Kauz.
4	Gemmeiza9	ALd"S"/Huac"S"//CMH74A. 630/5X.
5	Gemmeiza7	CMH 74 A. 630 /5X // Seri 82 / 3/ Agent.
6	Sids1	HD 2172/ pavon "S" //1158.57/Maya 74 " S".
7	Gemmeiza10	Maya47"S"/On//1160-147/3/Bb/GLL/4/CHAT"S"/5/CROW "S".
8	Giza168	Mil /Buc // Seri.

Two different irrigation treatments were applied on the studied wheat cultivars as follow:

a) Normal irrigation, and

b) Withholding irrigation from tillering until full maturity (late season water stress).

This experimental was carried out in a split-block system, with four replicates (blocks) for each irrigation treatment. These blocks were split into sub blocks; each one consists of six rows with 2-meters long and 30 cm spacing, with seeding rate of 65 kg/Feddan (about 1.038 acres). Each type of wheat was planted within a randomly selected sub-block.

Physical and chemical properties of El-Bostan experimental site at an average of soil depth 0–60 cm are shown in table (2). As well as, the applied irrigation treatments are shown in table (3).

Table (2): Soil analysis of El-Bostan experimental site at an average of soil depth 0–60 cm

Soil properties	Value
Sand %	92.05
Clay %	4.06
Silt %	3.89
pH (1:2.5, soil : water)	8.15
EC (1:2) dS/m	1.38
Total CO_3 %	3.77
Organic matter- C %	0.652
Available nitrogen (µg/g soil)	49.35
Available potassium (µg/g soil)	101
Available phosphorus (µg/g soil)	4.95

Table (3): Number and dates of irrigation treatments during the growing season

No. of days from sowing to irrigation	Irrigation No.	Date	Normal irrigation	Late water stress
At sowing	1st	23/11/2010	√	√
29	2nd	21/12/2010	√	√
56	Rain event	17/01/2011	√	√
66	3rd	27/02/2011	√	X
99	4th	01/03/2011	√	X
123	5th	25/03/2011	√	X

√ and X = applied and not applied irrigations respectively.

Weather data: Daily weather data of solar radiation, maximum and minimum temperature, and precipitation for the study location were collected from renewable energy resource at NASA power website for the growing season.

CropSyst calibration: The required input weather, soil, crop and management files to run the CropSyst model for wheat simulation were prepared in its combatable format. Some crop parameters input were taken either from the experimental observation or from the CropSyst manual (Stockle and Nelson, 2000). For model calibration purpose, the aboveground biomass-transpiration coefficient (kPa kg/m3) and light to aboveground biomass conversion (g/MJ) parameters were adjusted in the model, to reflect reasonable simulation. To investigate the goodness of fit between the measured and simulated wheat cultivars, the Model Percentage Error (MPE), Normalized Root Mean Square Error (NRMSE %), and Normalized Mean Bias (NMB %) were calculated. These statistical calculations give a good overall measure of model performance, indicate the model absolute fit to the observed data, and estimate the degree of correspondence between the mean prediction and the mean observation. The MPE, NRMSE, and NMB equations and its percentages are given by:

$$\mathrm{MPE} = \frac{\mathrm{X_p} - \mathrm{X_o}}{\mathrm{X_p}} * 100 \quad (1)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(\mathrm{X_p} - \mathrm{X_o})^2}{n}} \quad (2)$$

$$NRMSE\% = \frac{RMSE}{\bar{X}_o} * 100 \quad (3)$$

$$MB = \frac{\sum_{i=1}^{n}(\mathrm{X_p} - \mathrm{X_o})}{n} \quad (4)$$

$$NRMSE\% = \frac{MB}{\bar{X}_o} * 100 \quad (5)$$

Where $\mathrm{X_o}$ and $\mathrm{X_p}$ represent the observed and simulated values, n represents the number of observations used in comparison and $\bar{X}_o$ is the observed average.

RESULTS AND DISCUSSION

Wheat productivity under different irrigation treatments: Table (4) represents the observations of different crop parameters that measured during the field experiment. These were days to anthesis (flowering), days to physiological maturity, and wheat productivity (ton/ha) for each cultivar under the two applied irrigation treatments. In addition to, the Growing Degree Days (GDD) in degree centigrade from planting to anthesis and to physiological maturity for each wheat cultivar are calculated and presented in table (4) too. Where, GDD is calculated from accumulation of daily average temperature minus base temperature (3ºC for wheat) for each crop growth stage from planting until maturity.GDD can be regarded as an index relates the development of crop with air temperature. In addition, the GDD is an indication of the length of growing season that indirectly reflected on the final yield.

Table (4): Days to anthesis, physiological maturity, corresponding GDD (ºC) and wheat productivity (ton/ha) for each wheat cultivar under the two applied irrigation treatments

Crop parameter	Irrigation treatments	Wheat Cultivar (ID)							
		1	2	3	4	5	6	7	8
Days to anthesis	Normal	81	77	85	85	79	85	86	81
	Deficit	79	75	84	83	78	83	84	79
GDD to Anthesis (ºC)	Normal	1119	1025	1071	1119	1049	1119	1131	1071
	Deficit	1092	999	1049	1105	1038	1092	1105	1049
Days to maturity	Normal	137	129	136	140	131	139	139	136
	Deficit	122	122	126	128	124	124	126	125
GDD to maturity (ºC)	Normal	1912	1743	1877	1860	1783	1931	1912	1860
	Deficit	1659	1630	1630	1690	1659	1724	1690	1674
Grain yield (ton/ha)	Normal	7.11	5.54	6.51	8.72	7.79	7.66	8.36	8.32
	Deficit	2.57	2.43	3.2	5.43	5.21	5.32	6.14	6.29

It is obvious from table (4) that, there are significant differences in days to anthesis, days to physiological maturity, GDD and grain yield for each wheat cultivar under deficit than normal irrigation treatment. These differences are shown in table (5), where the difference in days to anthesis for whole cultivars was one or two days and their corresponding GDD were ranged between 11 to 26.7 ºC. These differences are small because of the wheat under normal treatment took one more irrigation than the one under deficit. Therefore, this trivial decrease in the anthesis days or GDD would not have a significant impact on the final grain yield. While, the maximum effect appears in the decreased physiological maturity days that ranges from 7 to 15 days with corresponding GDD of 113 to 253 ºC. This decrement in the maturity days or its GDD led the wheat grain yields decrease between 2.03 (ton/ha) and 4.54 (ton/ha) with ratios 24.4% and 63.85% respectively. These decreases might be because of the variability of each cultivar to resist heat and water stress.

Table (5): Differences in days and GDD to anthesis and maturity with wheat grain yields between the two applied irrigation treatments

Crop parameter	Wheat Cultivar (ID)							
	1	2	3	4	5	6	7	8
Days to anthesis	-2	-2	-1	-2	-1	-2	-2	-2
GDD to Anthesis (ºC)	-27	-26	-22	-14	-11	-27	-26	-22
days to maturity	-15	-7	-10	-12	-7	-15	-13	-11
GDD to maturity (ºC)	-253	-113	-247	-170	-124	-207	-222	-186
Grain yield (ton/ha)	-2.34	-3.11	-4.54	-3.31	-2.58	-3.29	-2.22	-2.03
Grain yield (%)	- 63.85	- 56.14	- 50.84	- 37.73	- 33.12	- 30.55	- 26.56	- 24.40

The wheat cultivars grain yield and their differences under the normal and deficit irrigation are shown in figure (1). It is noticed from figure (1) and table (5) that, Sakhs93, Sakha61, and Sakha94 cultivars have the maximum grain yield decrement with percentages 63.85, 56.14, and 50.84 respectively under the deficit than normal irrigation. As well as, Sakha cultivars already have a small grain yields under normal conditions. It can be deduced that, Sakha is not resistant to water and environmental stress, i.e. it is not recommended to be cultivated under the water scarcity conditions. While, the percentage decrement of grain yield due deficit irrigation for Gemmiza9, Gemmiza7, Sids1, Gemmiza10, and Giza168 were 37.73, 33.12, 30.55, 26.56, and 24.40 respectively. Therefore, these cultivars are recommended to be cultivated under the water scarcity conditions.

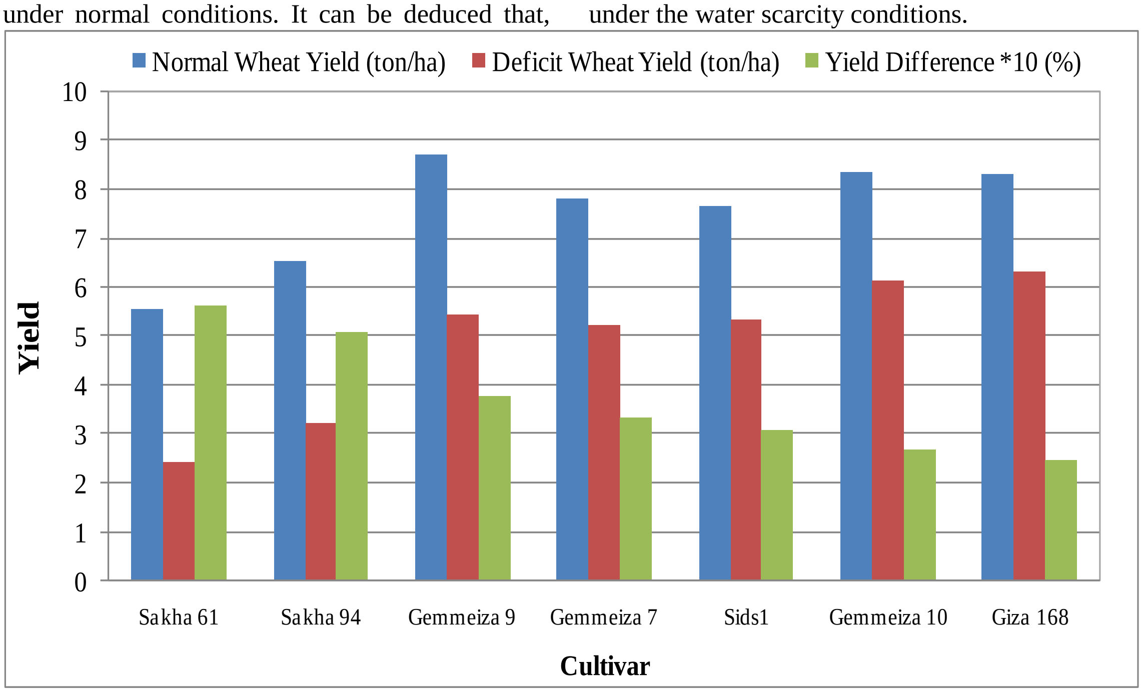

Figure (1): Grain yield and their differences (%) under the normal and deficit irrigation.

CropSyst simulation under normal and deficit irrigation: The MPE, NRMSE, and NMB between measured and predicted grain yield for wheat cultivars are shown in table (6). One may notice that, the MPE ranged from -0.139 to 0.222 % and 0.282 to 0.068% for normal and deficit irrigation treatments respectively. In addition, NRMSE and NMB were between 0.030 to 0.192 % and -0.147 to 0.104 %. These statistical comparisons gave very small differences between the measured and simulated wheat grain yield using the CropSyst model. Henceforth, CropSyst proves has high performance in wheat yield prediction under normal and deficit irrigation conditions.

Table (6): Measured and predicted wheat grain yield (ton/ha) under normal and deficit irrigation

Genotypes	Irrigation Treatments	Yield (Ton/ha)		MPE (%)	NRMSE (%)	NMB (%)
		Measured	Predicted			
Sids1	Normal Deficit	7.660 5.320	7.659 5.324	-0.007 0.068	0.040	0.024
Sakha 61	Normal Deficit	5.540 2.430	5.538 2.423	-0.030 -0.282	0.125	- 0.107
Sakha 93	Normal Deficit	7.110 2.570	7.100 2.566	-0.139 -0.167	0.158	- 0.147
Sakha 94	Normal Deficit	6.510 3.200	6.508 3.199	-0.029 -0.028	0.030	- 0.029
Gemmeiza 7	Normal Deficit	7.790 5.210	7.807 5.206	0.222 -0.072	0.192	0.104
Gemmeiza 9	Normal Deficit	8.720 5.430	8.714 5.434	-0.068 0.068	0.069	- 0.016
Gemmeiza 10	Normal Deficit	8.360 6.140	8.355 6.144	-0.065 0.065	0.066	- 0.010
Giza 168	Normal Deficit	8.320 6.290	8.313 6.285	-0.087 -0.082	0.086	- 0.084

MPE = Model Percentage Error; NRMSE = Normalized Root Mean Square Error; NMB = Normalized Mean Bias

These results indicate that, the model is good and reasonable for wheat simulation and can be used for further testing under current and future conditions. In the same time, the simulation of CropSyst model for wheat grain yield under different irrigation treatments was in a good compatibility with the previous studies (e.g., Ouda et al., 2015b; Noreldin et al., 2016).

CONCLUSIONS

The effect of deficit irrigation (late season water stress) does not have a big effect on the anthesis days and its GDD, but lead to a significant decrement in the required days to physiological maturity and corresponding GDD for all cultivars and consequently the wheat grain yield. These decreases might be because of each cultivar has its resistance to heat and water stress.

Sakha cultivars have small grain yield under normal conditions and decreased over 50% under deficit irrigation. While, under deficit irrigation decrement in other cultivars is less 38% than normal one. It may conclude that, the other cultivars could be cultivated under the water scarcity conditions than Sakha.

The CropSyst model is an important tool in agricultural research, to investigate different assumptions before taking cultivation decisions for specific agricultural sites. This will save a lot of time, money, and effort. In addition, the smallest values of MPE, NRMSE, and NMB between the measured and simulated wheat grain yield proved its capability to be used in wheat grain yield prediction under different irrigation treatments.

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