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ADAPTATION OF MODELLING TO IRRIGATION SYSTEM AND WATER MANAGEMENT FOR CORN GROWTH AND YIELD

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Abstract

The Environmental Policy Integrated Climate Simulation Model (EPICSIM) is an important tool for prediction and simulation of climate change for crops in different environments. The Egyptian western desert of Egypt-USA joint program (Using Simulation Models for the Improvement of Strategic Crops in Egypt) aims to analyze the interactions between different irrigation systems and crop evapotranspiration (ETc) water requirements, comparing the EPICSIM predicted values and data from corn. Most people living in the newly reclaimed land areas in western Egypt depend directly or indirectly on agricultural production activities. Crop production in the region is often adversely affected by droughts and low soil fertility levels. The climate of the study area can be characterized as a hyper arid climate were the annual evapotranspiration reaches 1450 mm, and the annual precipitation is only 18.5 mm per year. An experiment based on using different quantities of irrigation from the Nile as a result of the negligible rainfall was performed. The measured values of grain yield were 34% larger relative to simulated values by the EPICSIM model when using all irrigation systems. For stover yield, the measured values were 35 % larger than simulated values by the EPICSIM model for all irrigation systems. The EPICSIM simulation model can reproduce the variability in the growth and yield for corn crops in the western desert region of Egypt. It is possible to adapt the EPICSIM simulation model to the characteristics of growth and yield of corn, but it is not yet possible for the EPICSIM simulation model to deal with regions within different conditions than Egypt. Regarding the limitations of the EPICSIM simulation model, enhancements are needed to be able to simulate fertilizer and soil fertility characteristic impacts in the western desert of Egypt.

***Keywords*:** EPICSIM, Environmental, Integrated Climate, ETC, Crop Growth Models, Desert Lands.

Introduction

Regularly, the rainy season itself has an erratic rainfall distribution. Even in years with good precipitation, dry spells from up to three weeks might occur and endanger agricultural production. These leads, together with often found low soil fertility, to a high risk for agricultural production. Small-scale farmers, with no access to irrigation or other improved production methods, depend on the natural resources and precipitation. On the other hand, agricultural production is the most important economic activity in the rural areas of WesternEgypt. The adverse conditions in this area lead to a migration process from the rural areas to regional and national urban centers, causing great disturbance in the Egyptian society.Work began using simulation models of crops in the sixties and was designed in the beginning to the formation of integrated physiological knowledge of agricultural crops by many groups and teams, many simulation models have evolved over time, such as CERES-1986, EPIC-1989, Crop Sys- 1992, -DASSAT 1992 and finally by APSIM (Stockle *et al*., 2003) and the APSIM models (Keating *et al*., 2003).

Simulation models are used for crops in different purposes, such as prediction and simulate the water and fertilizers productivity, provided the simulation models used to interpret the results of practical experience as a research tool in the field of agricultural sciences. In the case of research that needs field trials conducted over a long period of time and many costs and with a very large number of transactions. It can be evaluating and simulating by a good model, through the evaluation of field trials and reduce costs for all parameters under study (Whisher *et al.,* 1986). There is another application for the use of simulation models for crops in decision support for the management of an integrated farming system to reach the administrative practices of the optimal either planning or method of scientific and technical (e.g. choice of planting date and choice of a particular class and methods of propagation or the use of water and the use of fertilizers types also has other uses such as agricultural policy planning analysis so that it can benefit from, (Boot *et al*., 1996). Many simulation models of agricultural crops specialize in studying crop water response evaluation. And those models were an important tool for many of the intended users, such as counselors and private associations farmers the guidance of Agricultural Engineers of Irrigation and Water Consultants and engineers of irrigation water and farm managers and all those interested in the agricultural economy. An example of this simulation model is Aqua Crop which depends on adequate transparency and to achieve better accuracy and balance simply and durability has been developed and calibrated simulation model Aqua Crop and use of many field crops by (Raes, 1982; Raes *et al*., 1988 and Raes *et al*., 2009). Tests with EPICSIM in other environments showed satisfactory simulation results (Cabelguenne and Debaeke, 1998; Roloff *et al*., 1998) but EPICSIM never was tested under the conditions of western Egypt. Preliminary test with data from rice on a site in ElNubaria showed reasonable results for some treatments (Gaiser, and Hilger, 1997), but also showed the necessity to adapt the model to the local conditions. Therefore, it was the task of the working group AGRONOMY within the WAVES project to test and calibrate the EPICSIM model to simulate crop production under the conditions of western Egypt.

The objective of the current research work is to analyze the interactions between different irrigation systems and different water amounts from ETc (Crop Evapotranspiration), to comparing between the prediction and the actual data of the corn crop by the EPICSIM simulation model.

Material and Methods

Field work: The field experiments were conducted at the experimental farm of National Research Centre, Elnubaria, Elbuhaira, Egypt. The design of field experiments was split in randomized complete block design with four replicates. The field tests were carried out using line length of 40m, and the following three irrigation systems used were drip, sprinkler and micro-tubes irrigation systems. Table (1) show the soil physical characteristics. Figure (1) shows details of the location of the experimental area; Egypt (A), Kom Hamada District (B), NRC Farm (C).

Table 1 : Soil physical characteristics.

Depth, cm	Particle Size distribution, %				Texture class	θ_S % on weight basis			HC (cmh^{-1})	BD (g/cm^3)	P (cm^3 voids /cm^3 soil)
	C. Sand	F. Sand	Silt	Clay		F.C.	W.P.	AW			
0-15	8.4	77.6	8.5	5.5	Sandy	14	6	8	6.68	1.69	0.36
15-30	8.6	77.7	8.3	5.4	Sandy	14	6	8	6.84	1.69	0.36
30-45	8.5	77.5	8.8	5.2	Sandy	14	6	8	6.91	1.69	0.36
45-60	8.8	76.7	8.6	5.9	Sandy	14	6	8	6.17	1.67	0.37

Particle Size Distribution after (Gee and Bauder, 1986) and Moisture retention after (Klute, 1986), C.L.: Clay Loam F.C.: Field Capacity, W.P.: Wilting Point, AW: Available Water.

Irrigation networks included the following components: 1. Control head: It was located at the water source supply. It consisted of a centrifugal pump 3`` /3``, driven by an electric engine (pump discharge of 80m^3/h and 40m lift), sand media filter 48``(two tanks), screen filter 2`` (120 mesh), backflow prevention device, pressure regulator, pressure gauges, flow-meter, control valves and chemical injection, 2. Main line: PVC pipes of 100 mm in (ID) Ø to convey the water from the source to the main control points in the field, 3. Sub-main lines: PVC pipes of 50mm in (ID) Ø were connected to with the main line through a control unit consists of a 2`` ball valve and pressure gauges, 4. Manifold lines: PVC pipes of 50 mm in (ID) Ø were connected to the sub main line through control valves 1.5``, 5. Lateral lines: PE tubes of 16 mm in (ID) Ø were connected to the manifolds through the beginnings stalled on manifolds lines, 6. Emitters: These emitters (GR) built in PE tubes 16mm in (ID) Ø, an emitter discharge of 4.0l ph at 1 bar, operating pressure and 30 cm spacing in-between.

The components of the micro-tube system are the same as the drip irrigation system with supply lines, control valves, and the distribution or lateral lines with micro-tubes 5.0 mm(ID) Ø in 35 cm length, and 18.0 lph at 1.0 bar. Micro-tubes replaced by the same emitters location, installed at 30 cm space on lateral lines, as shows in Figure (2).

The components of the sprinkler irrigation system used are shown in Fig. No.2 sprinkler system consisting of the following components: (i) A pump unit(50 m3/h), (ii) Tubing- main/submains and laterals (inside diameters are 150, 110, 90 mm, respectively., (iii) Couplers, (iv) sprinker head (l/h), (v) Other accessories were valves, bends, plugs and risers, as shows in Figure (3).

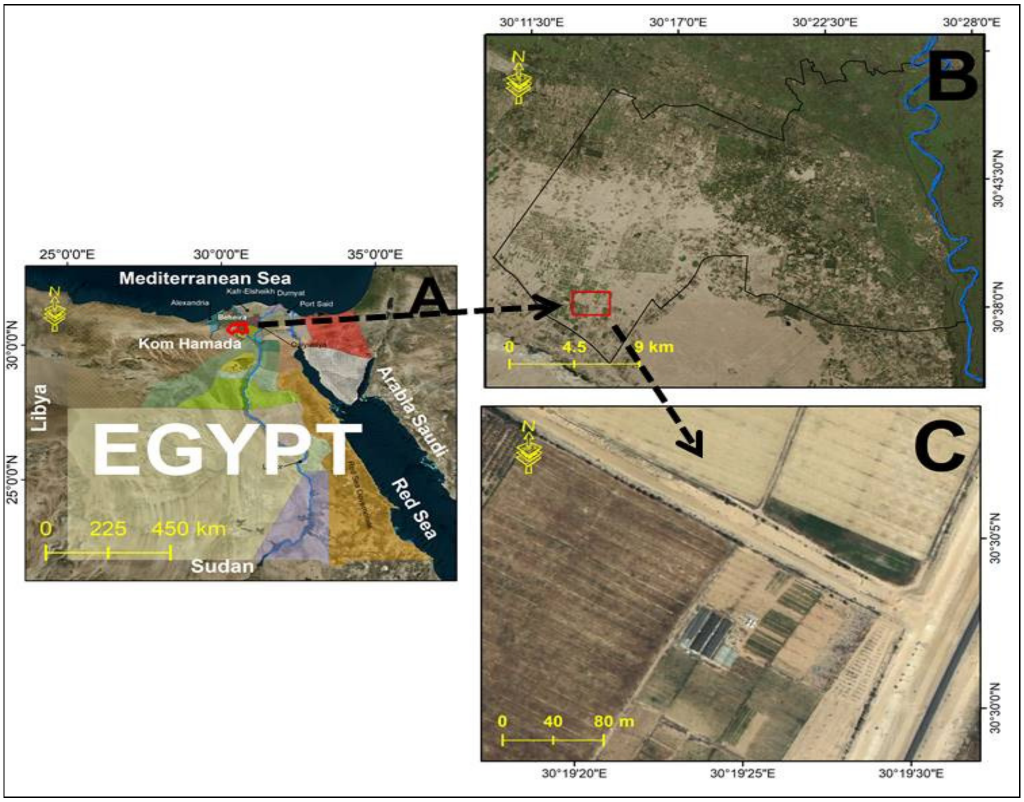

Fig. 1 : Location of the experimental area; Egypt (A), Kom Hamada District (B), NRC Farm (C).

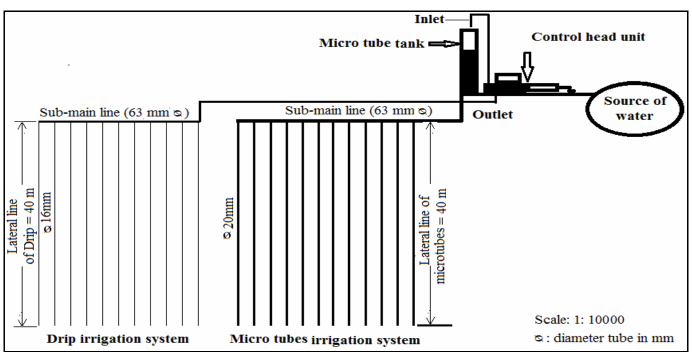

Fig. 2 : Layout drip and micro-tubes irrigation systems

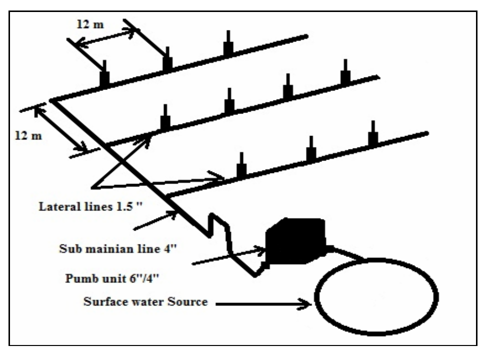

Fig. : 3 Layout of sprinkler irrigation system

Design of the automation controller system was based on subsurface and surface of drip irrigation system presented by Ashok and Ashok, (2010). The key elements that should be considered while designing a mechanical model:

The trials were installed in various locations around the western desert of Egypt, covering the main purposes of study. The influence of several treatments of growth and yield were observed: (i) competition in mixed cropped systems, (ii) effect of fertilizer application, (iii) planting density, (iv) spatial distribution and (v) different crop varieties. During the growing season, dry matter production and leaf area development were periodically determined. At harvest, total dry matter production (above ground) and grain yield were determined. These data were used to test and calibrate the models.

Simulation: To adapt the model's calculations to the local conditions, two main tools are available. The first is the Main Input File. It considers all site specific data, such as physical and chemical soil characteristics, weather data for the western desert of Egypt generated by the model or as daily input form measured data for the western desert of Egypt and all cultivation data from land preparation to harvest including irrigation amounts. The second tool is the EPICSIM file. It contains data blocks for each crop that can be simulated by EPICSIM. The Agronomy working group studied the crop growth and yield in the western desert of Egypt related components in the EPICSIM model. For the simulations, the EPICSIM version 0941 was used. Hilger *et al*. (1999a) and figure (4) describes the interfaces with other western desert of Egypt models, the demand of in-formation from other models and how the EPICSIM output is aggregated in other western desert areas of Egypt models.

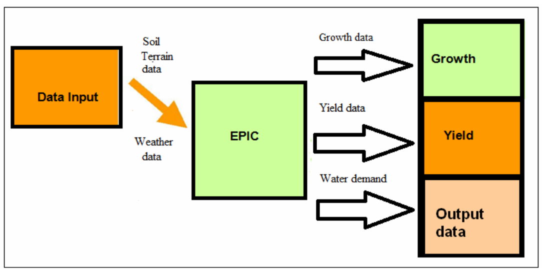

Fig. 4: Overview of links from EPICSIM within the integrated models.

The EPICSIM simulation model for corn was started by using the existing EPICSIM crop file; for corn, as this species was not considered in the model yet. This first test version of corn was developed by Egyptian counterparts in Fortaleza from the Federal University of Wadi El-Natroon (UFC). It's based on the field pea file of the EPICSIM model.

The MSTATC program (Michigan State University) was used to carry out statistical analysis. Treatment means were compared using analysis of variance (ANOVA) and the least significant difference (L.S.D) between systems at 1 % was done. The randomized complete block design according to Steel and Torrie (1980).

Results and Discussion

Figure (5) shows the volumetric graph of the climate station for the study area. The data include Tm, mean temperature in Celsius; P, precipitation (mm); ETo, potential Evapotranspiration (mm); GS, Growing season; Ari, Aridity index.

Table (2) illustrates the climatic parameters of the climate station of the study area. These include Tm, mean temperature (OC); Tmax, maximum temperature (OC); Tmin, minimum temperature (OC); P, precipitation (mm).

Agroclimatic factors such as potential evapotranspiration and aridity index (ARi, numbers of arid months in which the actual precipitation is lower than the evapotranspiration) were calculated from the data of the closest weather station to the study area from the period of the last 20 consecutive years (1997-2017).

The monthly distribution of precipitation mean temperature and evapotranspiration of the climatic analysis is shown in Figure (5) The data were joined into the climate database CDBm of MicroLEIS DSS (De la Rosa *et al*., 2004), where the elementary data of CDBm are the mean values of daily data set for a specific month such as maximum, minimum and mean temperatures, as well as daily precipitation.

Potential evapotranspiration was calculated based on two methods; Hargreaves (Hargreaves, 1985) and Thornthwaite (Thornthwaite, 1948). Hence, the climate of the study area can be characterized as a hyper arid climate where the annual evapotranspiration reached 1450 mm (by Hargreaves, 1985) and the annual precipitation represent only 18.5 per year Table (2). Therefore, the experiment based on using different quantities of irrigation from the Nile as a result of the negligible rainfall.

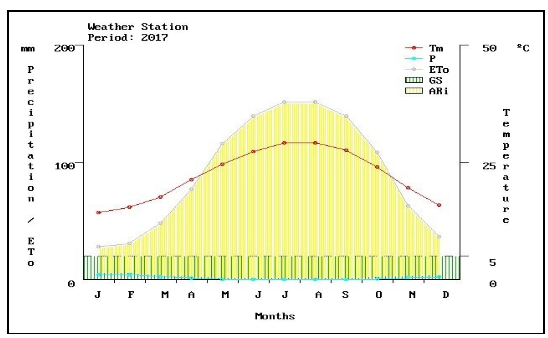

Fig. 5 : Volumetric graph of the climate station for the study area where Tm, mean temperature in Celsius; P, precipitation (mm); ET0, potential Evapotranspiration (mm); GS, Growing season; Ari, Aridity index.

Table 2 : Climatic parameters of the climate station of the study area where Tm, mean temperature (OC); Tmax, maximum temperature (OC); Tmin, minimum temperature(OC) ; P, precipitation (mm),

Months	Tm	Tmax	Tmin	P, mm	ET_0(T)	ET_0(H)	HUi	ARi	GS	PCi	MFi	AKi
January	14.3	20.0	8.6	4.2	28	90.1	---	---	---	---	---	---
February	15.5	21.5	9.4	4.5	31.3	99.9	---	---	---	---	---	---
March	17.6	24.4	10.9	2.4	48.3	113.2	---	---	---	---	---	---
April	21.3	28.7	13.9	1.3	77.3	127.7	---	---	---	---	---	---
May	24.6	32.2	16.9	0.4	116.1	132.3	---	---	---	---	---	---
June	27.4	35.0	19.9	0.0	139.5	134.9	---	---	---	---	---	---
July	29.2	36.4	21.9	0.1	151.7	139.2	---	---	---	---	---	---
August	29.2	36.1	22.3	0.0	151.7	143.7	---	---	---	---	---	---
September	27.7	34.3	21.0	0.0	139.5	142.8	---	---	---	---	---	---
October	24.0	30.2	17.8	1.0	108.8	126.8	---	---	---	---	---	---
November	19.7	25.6	13.8	1.8	63.0	107.8	---	---	---	---	---	---
December	15.9	21.4	10.4	2.8	37.0	91.6	---	---	---	---	---	---
Annual	**22.2**	**28.8**	**15.6**	**18.5**	**1092.2**	**1450.1**	**0.02**	**12**	**12**	**17**	**3**	**4.5**

Field measurements and simulated values of the EPICSIM model for corn vegetative growth are displayed in Figures (6-8), which shows the effect of three irrigation systems (drip, sprinkler; micro-tubes) and three water amounts (60, 80; 100% of ETc) in leaf area, leaf length and No. of leaves. All characteristics were taken the same trends as ranked in the following ascending order: Drip>Sprinkler>Micro-tubes and 60>80>100. The measured values of leaf area were 10% larger than simulated values by the EPICSIM model when using all irrigation systems. Simulated values of the EPICSIM model of leaf length and number of leaves decreased by 14% and 23%, in the same sequence, relative to measured values under all irrigation systems. According to LSD values in Table (2 and 3) of corn vegetative growth values, the differences were significant at the 5 % level between all values. Also, the interaction between the different factors were significant at the 5 % level. The data obtained agreed with data from (Adrien *et al.*, 2013 and N'Dayegamiye 2006).

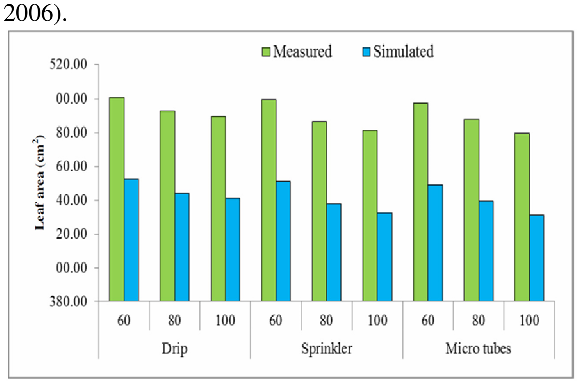

Fig. 6 : Simulated and measured leaf area of cornplants in the western desert of Egypt region, El-Nubaria, Egypt.

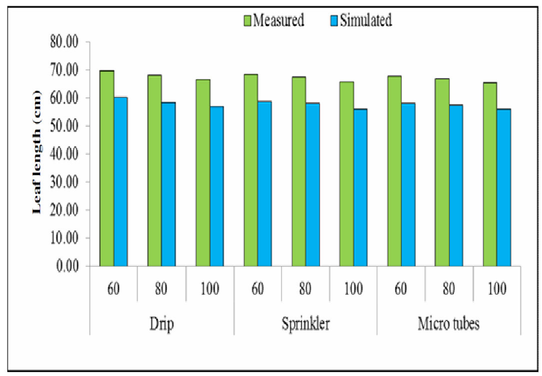

Fig. 7 : Simulated and measured leaf length of corn in the western desert of Egypt region, El-Nubaria, Egypt.

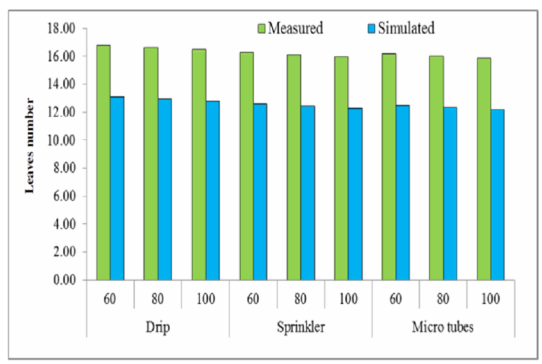

Fig. 8 : Simulated and measured number of leaves for corn in the western desert of Egypt region, El-Nubaria, Egypt.

Figures (6 to 10) also showed that, looking at each experimental unit, simulation results for the vegetative growth parameters were more predictable than the results for the corn yield and stover. There, in two from five growth and yield parameters, the observed corn characteristics were drastically underestimated by the model simulation. For further examination, it was necessary to exclude other simulation errors in the model. In this case, the weather generator is able to reproduce the erratic irrigation water distribution from input data, normally measured in the desert region of western Egypt, using the average values from a nearby weather station. This measured data determines the maximum and minimum values for the ETc calculation. Within this given range the generator randomizes the ETc irrigation water. Obviously, the simulated weather data were fit exactly with the weather in the year when the field data were observed, but under the field conditions in the Western desert of Egypt. Therefore, if the model has to be tested and calibrated, measured weather data should be used. The model accepts external weather files as input in the calculation process.

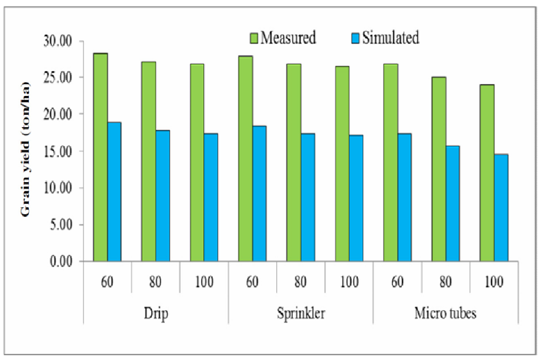

Fig. 9 : Simulated and measured corn grain yield in the western desert of Egypt region, El-Nubaria, Egypt.

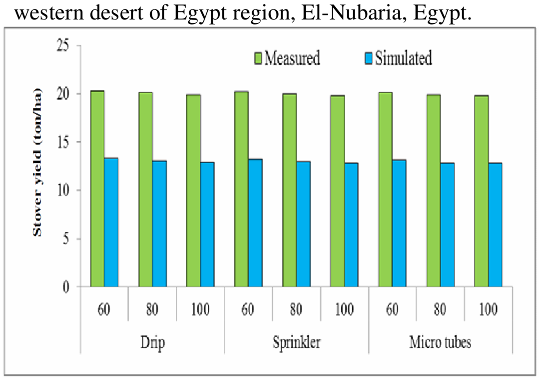

Fig. 10 : Simulated and measured corn stover yield in the western desert of Egypt region, El-Nubaria, Egypt.

Measured and simulated corn grain and stover of corn yield are displayed in Table (4) and Figures (8 and 9), which show the effect of three irrigation systems (drip, sprinkler; micro-tubes) and three water amounts (60, 80,100% of ETc) on corn grain and stover yields. Simulated or measured stover and grain yield follow the same trends of vegetative growth characteristics as ranked in the following ascending order: Drip> Sprinkler> Micro-tubes, and 60>80>100.

The measured values of grain yield were 34% larger than simulated values by EPICSIM model when using all irrigation systems. For Stover yield, the measured values increased by 35 % relative to simulated values by the EPICSIM model with all irrigation systems.

According to LSD of corn grain and stover yields, the differences were significant at the 5% level between all values. Also the interaction between the different factors were significant at the 5 % level. The data obtained agreed with (Adrien *et al.*, 2013, Mansour 2016, Mansour 2012, Mansour *et al.*, 2013, Mansour 2015, Mansour *et al.*, 2015 a, b; c and N'Dayegamiye 2006).

The problem is the EPICSIM model's calculation of the amounts of irrigation water. The current version of the EPICSIM model considers irrigation water amounts in over corn ETc 60 %. The most important limiting factor in the western desert of Egypt is the localized irrigation systems. Therefore, the other factors, such as sandy soil fertility, were considered. As a consequence, the manure fertilizer applications have important impacts on the calculation of the crop growth and yield characteristics, while the simulation of the EPICSIM model, considering the sandy soil conditions in the western desert of Egypt, and localized irrigation systems for the trials field, a significant effect could be observed.

Beside this input water amount, irrigation systems, supply in the model is assessed by the relative concentration of water amounts to corn plants. Under the desert conditions in western Egypt, the EPICSIM model has reduced drastically the simulated growth and yield characteristics.

Low water amounts as a stress reduces crop growth to a rate where even the smallest amount of water amounts in the western desert of Egypt sandy soils are not sufficient for water saving, or the water amounts supplying at that level has been always in optimum for the EPICSIM model. Therefore, water amount effects are reproduced. Simulated and measured yield of corn plants. Figures show that the standard deviation of simulated and measured data on growth and yield characteristics of the corn. EPICSIM simulation with three irrigation systems and three water amounts, the values for the growth and yield showed in the standard deviation of observed data, found significant differences.

However, calculating of water amounts using measured daily weather data as input, simulated and observed growth and yield characteristics still showed contrasting results. A hint for this was found comparing the sandy soil fertility of the different locations (Hilger *et al*., 1999b). It was found that the simulation with the EPICSIM model considering more fertile soils, like in the valley area in the western desert of Egypt, showed a better performance, than simulations with the soils of the western desert of Egypt.

Conclusions

The Environmental Policy Integrated Climate Simulation Model (EPICSIM) is an important model for prediction and simulation of climate change impacts on crop production in different areas. The Egyptian western desert of Egypt-USA joint program (Using Simulation Models for the Improvement of Strategic Crops in Egypt) aims to analyze the interactions between different irrigation systems and water amounts based on Crop Evapotranspiration (ETc) by comparing the EPICSIM predicted values and observed data from corn. The climate of the study area can be characterized as a hyper arid climate where the annual evapotranspiration reaches 1450 mm, and the annual precipitation represents only 18.5 mm per year. Therefore, an experiment explored using different quantities of irrigation from the Nile as a result of the negligible rainfall. Under different irrigation systems and water amounts, the characteristics of corn growth, yield and stover were improved in the western desert region of Egypt. The actual performance of the EPICSIM model to simulate yield under the conditions in western Egypt leads to the following conclusions.

The EPICSIM simulation model can reproduce the variability in the growth and yield production for corn in the western desert region of Egypt. The EPICSIM simulation model can be adapted to the characteristics of growth and yield of corn. Regarding the limitations for the EPICSIM simulation model, the possibility of new modifications is possible which will lead to further studies on soil fertility, nutrients and fertilizers and is expected to be used more widely to create accurate scenarios for many future years under these conditions and according to previous studies.

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