Evaluation of CSM-Ceres-Maize Model for Simulating Maize Production in Northern Delta of Egypt

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Abstract: There is widespread consensus that Egypt is among the developing countries that are most vulnerable to the likely negative impacts of climate change. Northern Egypt is the most threaten area under Egyptian conditions. The expected climate change impacts are the driving force to investigate the suitable sowing date and irrigation requirements to face the food security needs. A field study was conducted in 2011 and 2012 at El-Bosaily farm in the Northern coast of Egypt. The main objectives of this study were to adapt maize production under expected climate change impacts via evaluating the response of the Single Cross 10 maize (*Zea mays* L.) hybrid to three different sowing dates (SD) (1st and mid of May and 1st of June) and four applied irrigation levels 0.6, 0.8, 1.0 and 1.2 of ET_c which applied by drip irrigation system. No. of leaves, leaf area index, number of days for 50 % tasseling and silking, grain yield (g/plant), average weight of 100 seeds and straw yield (g/plant) were determined beside water use efficiency. The obtained results showed that the 0.6 and 0.8 of (ET_c) irrigation treatments attributed to decline vegetative growth as well as growth yield. Nevertheless, the 1.2 irrigation treatments gave the highest grain yield and vegetative growth which was compensated the amount of water consumed. The highest yield was obtained by the second sowing date followed by the third one. The final results show that the 0.6 irrigation level gave the highest water use efficiency; increasing irrigation water above 0.6 from ET_c led to decrease water use efficiency. The lowest value of seasonal water consumption was recorded by the first sowing date while the second date gave the highest seasonal water consumption. Calibration and validation of CERES-Maize crop simulation model using experimental datasets of years 2011 and 2012 were done successfully giving very excellent values for RMSE and d-Stat evaluation indexes. Environmental modification option of the model was used to rise maximum and minimum temperature by 1.5°C and 3.5°C for both seasons. Reductions in grain yield for 1.5°C scenario arrived to -25.1 than 2011 year and -31.9% than 2012 year. Using 3.5°C scenario caused declines in grain yield arrived to -54.8% than 2011 year and -66.2% than 2012 year.

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1. Introduction:

Maize is one of the most important cereal crops grown principally during the summer season in Egypt. Compared to other crops, maize is more efficient in water use **(Jensen, 1973)**. Maize and other C4 crop species have nearly 2-fold higher water use efficiency than C3 species **(Begg and Turner 1976)**. The efficient use of water by modern irrigation systems is becoming increasingly important in arid and semi-arid regions with limited water resources (**El-Hendawy *et al.,* 2008**).

Egypt is very dependent on natural resources that are vulnerable to climate change. The Nile Delta region is considered under many studies as a homogenous agriculture region in Egypt. Whereas, the Northern Nile Delta could be the highest vulnerable sub-region in the Nile Delta due to the combination effect of natural, human, agriculture management, and economical and political conditions. Crop yields and crop water use could be affected by climate change (**Medany and Attaher, 2009**).

In environments of high light intensity and temperature, the higher water use efficiency (WUE) is due mainly to higher rates of photosynthesis by C4 crops, which results in more dry matter (DM) accumulation. However, because maize produces larger quantities of DM per acre than most other crops, soil moisture deficit can occur quickly, especially during reproductive growth. Water loss in maize fields is primarily by surface evaporation from bare soil during early vegetative growth but shifts to evapotranspiration as the tassel begins to emerge and reproductive growth begins **(Howell *et al.*, 1990; Yordanov *et al.*, 1997; Sadler *et al.*, 2000)**. Soil moisture deficit has been considered an economic and efficient means of utilizing drought-prone areas when appropriate management practices to reduce water losses are needed **(Turner, 1991)**. **Shani and Dudley**

(2001) & Kijne *et al.* (2003) refer to the economic grain yield divided by the volume of water consumed in the production of that yield expressed in kg grain per cubic meter of water. The applied water-yield relationship is more complex. At low levels of applied water, up to about 50 percent of full irrigation, yields increase more or less linearly with applied water. Beyond the point of maximum yield the yield turns downward, reflecting yield losses from anaerobic root zone conditions, disease and leaching of nutrients from excessive water use particularly in the heavy clay soil **(Vaux and Pruitt, 1983; Norwood, 2000; Erdem *et al.,* 2006)**. **Al-Kaisi and Yin (2003)** tested the effect of different water regime on maize vegetative growth and yield. They found that the differences between 0.80 ETc and 1.00 ETc treatments were not significant while the lowest plant growth and yield was obtained from 0.60 ETc treatment in the two seasons. The same authors added that the 0.80 irrigation treatment had the same or even greater WUE than 1.00 ETc and 0.60 ETc. **Al-Bakeir (2003)** found that excessive water application significantly reduced N, P and K absorption of maize plants. In addition, **Al-Kaisi and Yin (2003)** found that maize leaf N concentrations were reduced with increasing applied water quantity, even though N was applied with drip irrigation, leaf N concentrations with the 0.80 treatment were generally equal to or higher than the concentrations with 1.00 ETc.

Killi and Altanbay (2005) observed that seed weight was significantly affected by the sowing dates. The plants planted during the early part of the year (February-April) passed through lower temperature during early phases and completed their life cycle taking longer period, and they had higher seed weight, and the plants planted during the later section of the year, July-August, had higher temperature during the early phases and completed their life cycle rapidly, and therefore had lower seed weight. **Andrade, (1995)** and **Dahmardeh, (2012)** reported that seed weight decreased due to the change in sowing dates. The differences in seed weight might be due to the environmental conditions, mostly observed during the plant life cycle (**Beiragi *et al.*, 2011**). Environmental changes associated with different sowing dates (sunshine, temperature, relative humidity and etc.,) have a modifying effect on the growth and development of maize plants. Each hybrid has an optimum sowing date, and the greater the deviation from this optimum (early or late sowing), the greater the yield loss (**Berzsenyi and Lap 2001;** and **Beiragi *et al.*, 2011)**. Sowing date was reported to affect the growth and yield of maize significantly. To date, the challenge for maize growers is finding the narrow window between sowing too early and sowing too late (**Abdrabbo *et al.,* 2013**). Therefore, this study was designed to study the behavior of maize hybrid under different sowing dates and irrigation levels using drip irrigation system.

CERES-Maize model is one of the Decision Support System for Agrotechnology Transfer (DSSAT) package of models (**Jones *et al.*, 2003**), and it's one of the original crop models implemented in DSSAT by **Jones and Kiniry (1986)**. It has been chosen as one of the most used models in the field of crop simulation and one of the most efficient models that marked with: a friendly interface, more input details leads to more accurate simulation, and had open source software obtained by visiting DSSAT website **(www.dssat.net)**. This model has also ability to modify easily in weather data input files through an option called "environmental modification", which facilitates drawing different future scenarios of climate change. Aim of evaluating this model was to calibrate and validate it using the experimental input data of both years 2011 and 2012, in order to be ready as a tool for future predictions of maize crop growth and yield under forecasting climate changes.

2.Material and Methods:

The experiments were carried out at El- Bosaily (31° 40' N; 30° 40' E), Protected Cultivation Experimental Farm, Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center (ARC), at Behaira Governorate, in the Northern Coast of Egypt**.** Maize (*Zea mays L.*) hybrid (Single Cross 10 (SC 10)) seeds were used under this study.

Data in Table (1) shows the measured climatic factors (Maximum air temperature **°C** (Max. temp.), minimum air temperature **°C** (min. Temp.), average relative humidity % (Ave. RH), soil temperature **°C** (Soil Temp.) and wind speed (m/sec.) during the experimental period; these data collected from automated climatic station allocated at the experimental site.

The treatments comprised three sowing dates (SD)(1st of May, mid of May and 1st of June of 2011 and 2012 for the first and second seasons, respectively) and four irrigation levels (0.6, 0.8, 1.0 and 1.2 of ETc). Calculations of irrigation levels were done weekly while the irrigation control done via manual valves for each experimental plot. The total amount of irrigation water was calculated by Penman method (**Penman, 1984).** The potential evepotranspiration was calculated as follows:

ET_o = C {W. Rn (1-w)-F (u) (Ea-Ed)}……………mm/day

ET_o = Reference evapotranspiration [mm d^1].

C = the adjustment factor (ratio of U day to U night).

Rn = Net radiation in equivalent evaporation expressed as mm/day.

W = temperature of altitude related factor.
F (U) = Wind related function.
Ea – ed= Vapour pressure deficit (m. bar).
Ea =Saturated vapour pressure (m.bar).
Ed = Mean actual vapour pressure of the air (m. bar).

The second step was to obtain values of water consumptive use (ET_{crop}) as following **(Doorenbos and Pruitt, 1977)**:

$ET_c = ET_o \times K_c \times L \% \times 100/ IE$.......mm / day

Where
ET_c = ET for crop mm/day
K_c = Crop coefficient [dimensionless].
ET_o = Reference crop evapotranspiration [mm/day].
L% = Leaching fraction (assumed 20% of total applied water).
IE = Irrigation efficiency of the irrigation system in the field, (assumed 80% of the total applied water).

Table (1): Average monthly climatic data of the El-Bosaily location during the two studied seasons 2011 and 2012**.**

First season (2011)					
Month	**Max. temp.**	**Min. temp.**	**Ave. RH**	**Soil temp.**	**Wind speed**
	°C	**°C**	**%**	**°C**	**m/sec.**
May	27.2	14.75	73.3	23.6	0.53
June	30.9	17.9	76.1	26.6	0.63
July	30.1	20.9	77.7	29.5	0.67
August,	31.8	23.2	82.9	30.6	0.52
September,	31.1	21.1	79.1	28.7	0.53
October	31.2	19.3	79.4	27.2	0.35
Second season (2012)					
May	28.0	11.8	76.2	25.2	0.51
June	33.1	16.2	78.6	29.3	0.49
July	35.1	20.3	78.8	32.0	0.54
August,	36.0	22.6	77.4	30.9	0.47
September,	34.5	20.5	78.6	27.8	0.37
October	31.3	19.7	82.3	25.1	0.27

Each total amount of irrigation water was measured by water flow-meter for each treatment. Table (3) and Figure (1) shows the seasonal water consumption (ET_{crop}) for single cross 10 maize hybrid under different irrigation treatments for the three sowing dates at El-Bosaily site during the two seasons. Plants were irrigated by using drippers of 2 l/hr capacity. The chemical fertilizers were injected within irrigation water system.

The experiment was designed in a split plot arrangement with three replications. Sowing dates were distributed in the main plots, and irrigation levels allocated in the sub plots. Plot area was 15 m length x 14 m width, occupying an area of 210 m^2. Plant distances were 0.30 m apart; the distances between rows were 0.70 m. A distance of 2m was left between each two irrigation treatments as a border among the treatments.

Table (2): Seasonal irrigation quantities for single cross 10 maize hybrid under experimental conditions for seasons 2011 and 2012.

Sowing date	**First season (2011)**				
	Irrigation level				
	0.6	**0.8**	**1.0**	**1.2**	**Average**
1^{st}	1367	1822	2278	2734	**2050**
2^{nd}	1464	1952	2440	2928	**2196**
3^{rd}	1440	1920	2400	2880	**2160**
Average	**1424**	**1898**	**2373**	**2847**	
	Second season (2012)				
1^{st}	1457	1942	2428	2914	**2185**
2^{nd}	1517	2023	2529	3035	**2276**
3^{rd}	1492	1990	2487	2984	**2238**
Average	**1489**	**1985**	**2481**	**2978**	

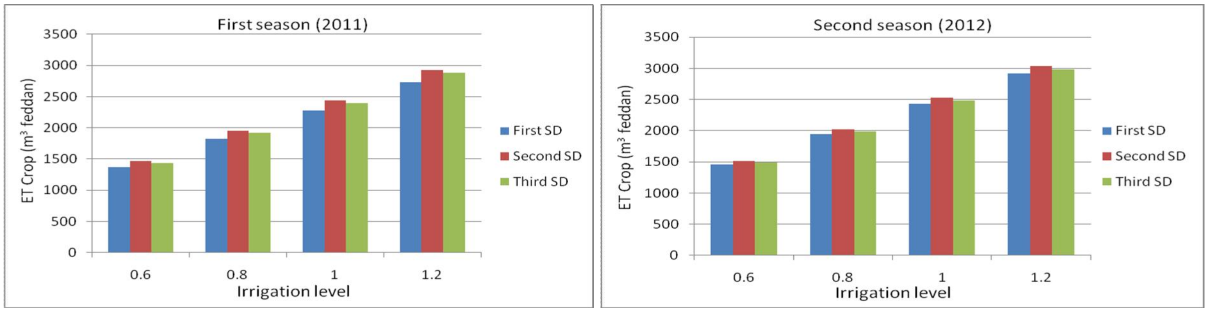

Figure (1): Seasonal irrigation quantities under different water levels for single cross 10 maize hybrid under experimental conditions for seasons 2011 and 2012.

Table (3) shows the rates of fertilizers were added in both seasons. The total amount of phosphorus (Super phosphate form) was applied with the soil preparation (30 kg P_2O_5/ feddan). Fifteen kilograms of K_2O (Potassium sulphate form) and twenty kilograms of N (Ammonium sulphate form) per feddan were applied as starter fertilizer added also with soil preparation. Remained quantity of N (Ammonium nitrate form) and K fertilizers (Potassium sulphate form) was injected into irrigation system by using venture during the season. The same fertilization schedule was added for all sowing dates and all irrigation treatments.

Table (3): Applied fertilization rates for maize at summer season of 2011 and 2012.

Fertilizer application	N-P-K fertilization (kg/ feddan)		
	P_2O_5	K_2O	N
Base fertilizers	30	15	20
Season fertilizer	0	12	126
Total fertilizers	30	27	146

Samples of ten plants of each experimental plot were taken to determine some growth parameters after 75 days from sowing, i.e. no. of leaves, leaf area index and number of days for 50 % tasseling and silking. At harvest time, the grain yield (g/plant), average weight of 100 seeds and straw yield (g/plant) were determined from each plot.

The water use efficiency (WUE) was calculated according to **FAO (1982)** as follows: The ratio of crop yield (Y) to the total amount of irrigation water use in the field for the growth season (IR); WUE (kg/m^3) = Y (kg)/IR (m^3). Water use efficiency and seasonal water consumption were determined after harvesting. Harvesting time was done after 120 days from sowing.

Chemical properties of the experiment's soil were analyzed before cultivation according to **Chapman and Pratt (1961)** and the results are tabulated in Tables (4). The permanent wilting point (PWP) and field capacity (FC) of the trial soil were determined according to **Israelsen & Hansen (1962).**

Plant samples were dried at 70 ^{o}C in an air forced oven for 48 h. Dried leaves and fruits were digested in H_2SO_4 and N,P and K contents were estimated in the acid digested solution by colorimetric method (ammonium molybdate) using spectrophotometer and flame photometer (**Chapman and Pratt, 1961**). Total nitrogen was estimated by Kjeldahl method, whereas phosphorus was determined by spectrophotometer and potassium by flame photometrical method according to **Chapman and Pratt (1961)**.

Table (4) Chemical and physical properties of the experiment's soil analyzed before cultivation.

Physical properties									
Sand (%)	Silt (%)	Clay (%)	Texture	F.C. (%)	W.P. (%)	pH	O. M. (%)	B. D.	E.C. (dS m^{-1})
84.5	5.6	9.9	Sandy	17	8	7.75	0.31	1.21	1.25

Chemical properties									
pH	ECe (dS/m)	Cations (meq /l)				Anions (meq /l)			
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	CO_3^{--}	HCO_3^{-}	SO_4^{--}
7.75	1.25	2.80	2.15	6.69	0.9	4.50	-	1.90	6.14

Analysis of data was done, using SAS program for statistical analysis. The differences among means for all traits were tested for significance at 5 % level according to **Waller and Duncan (1969).** All other agriculture practices of maize cultivation were done in accordance with standard recommendations for commercial growers by the Ministry of Agriculture.

Field data of the grown maize experiment for both seasons were used to calibrate and validate a model specialized in crop simulation. CERES-Maize crop simulation model was the model used from DSSAT Package software (**Jones *et al.*, 2003 and Hoogenboom *et al.*, 2012**). A latest version of the software package (DSSAT v. 4.5) was used for this simulation study. Data of season 2011 was used to calibrate the model, while data of season 2012 was used to validate the model performance. Table (5) shows genetic coefficients used in cultivar file of the model after calibration and validation processes. Evaluation of model simulation performance compared with observed values of the experiment was done using two statistical indexes, which are the Root Mean Square Error (RMSE) (**Loague and Green, 1991**) and d-Stat index of agreement (**Willmott *et al*,. 1985**). These two indications were checked several times through running the model by changes of genetic coefficient until we arrived to the optimum values between observation and simulation, controlling that under all experimental conditions of sowing dates (SD1, 2, 3) and irrigation levels (Irr. 0.6, 0.8, 1.0, & 1.2).

For future prediction, two different climate scenarios have been implemented in CERES-Maize model files in order to study the effects of future climate changes on maize plant growth and yield. Scenarios were done by adding 1.5°C and 3.5°C to maximum and minimum temperatures of the summer season of years 2011 and 2012 starting from the three different sowing dates indicated at conducted field experiments and finishing by the end of growing cycle.

Table (5): Genetic coefficients used in SCIO maize cultivar file of the model after calibration and validation processes.

Cultivar	**Coefficinet**	**Definition**	**Value**
Single Cross 10	**P1**	Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8^{o}C) during which the plant is not responsive to changes in photoperiod.	190.0
	P2	Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours).	1.000
	P5	Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8^{o}C).	1000
	G2	Maximum possible number of kernels per plant.	850.0
	G3	Kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day).	7.00
	PHINT	Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances.	49.00

3.Results and Discussion:

Vegetative growth and yield

The effect of different irrigation levels and sowing dates on vegetative growth characteristics of maize hybrid is illustrated in Table (6).

The differences among the sowing dates for SC 10 hybrid were significant; data show that second sowing date had the highest vegetative growth in terms of leaf area index followed by the third sowing date with significant difference between them. The number of leaves had a different trend; first sowing date had the highest number of leaves along with the second sowing date. The number of days to 50 % tasseling and silking shows that; the longest time for 50 % tasseling and silking was obtained by first sowing date followed by second sowing date.

Regarding the effect of different irrigation treatments, data showed that increasing irrigation level up to 1.20 of ETc increased maize number of leaves, and leaf area index significantly followed by 1.00 and 0.80 treatments. The lowest vegetative growth was obtained by 0.60 irrigation level treatment during the two studied seasons. Regarding the number of days to 50 % tasseling and silking; differences between 1.2, 1.0 and 0.8 ETc were not significant only for numbers of days for 50 % tasseling in the 1st season.

Regarding the interaction effect between different irrigation levels and different sowing dates, data showed that the highest values for number of leaves was obtained by using 1.20 irrigation level combined with first date followed by 1.20 irrigation level with the second sowing date. On the other hand, the lowest vegetative growth characters were obtained by using 0.60 irrigation level treatment with third sowing dates.

Highest values of number of leaves / plant and LAI in both season were achived form 1.2 ETc. sufficient irrigation level may be necessary to face the high evapotranspiration rate of maize plant in summer season and to increase photosynthesis, meristemic activity and nutrient uptake of plant. These results agree with **Beiragi *et al.* (2011)** who found that increase water quantity led to increase in plant growth in comparison with low irrigation levels. Furthermore, vegetative growth of different sowing date had different response to water levels, because of the change of climate conditions under each sowing date. This may reduce the loss in yield as well (**Dahmardeh, 2012**). **El-Marsafawy Samia *et al.* (2012)** added that select appropriate maize variety with optimum sowing date can achieve maximum benefit from this variety. While, **Abdrabbo *et al.* (2013)** mentioned that, too early or too late sowing date led to decrease the vegetative growth and productivity of maize. **Ihsan *et al.* (2005)** also reported significant genetic differences for morphological parameter for maize genotypes. This variability is a key to crop improvement. Environmental changes associated with different sowing dates (sunshine, temperature) have a modifying effect on the growth and development of maize plants **(Killi and Altanbay, 2005)**.

The effect of the studied treatments on maize yield was presented in Table (7). Regarding the effect of different sowing dates on grain yield/plant, weight of 100 grains and straw weight/plant, data showed that the highest grain yield/plant, weight of 100 grains and straw weight/plant obtained by the second sowing date followed by the third one. The lowest grain yield, weight of 100 grains and straw weight was obtained by the first sowing date.

Referring the effect of different irrigation levels, data showed that using 1.2 irrigation level increased grain yield/plant, weight of 100 grains and straw weight/plant significantly followed by 1.0 and 0.80 irrigation levels. There were no significant differences between 1.0 and 0.8 treatments for weight of 100 grains and straw weight.

Regarding the interaction effect between different sowing dates and irrigation levels, data showed that the highest grain yield, weight of 100 grains and straw weight obtained by 1.20 irrigation level combined with second sowing date followed by 1.20 irrigation level with third sowing date. The 1.00 irrigation level with second sowing date came in the third position. The lowest yield was obtained by 0.60 irrigation level with the first sowing date.

These results might be due to adequate moisture availability in the soil which might have lead to increase various physiological processes, better uptake of nutrients and higher rates of photosynthesis, which might reflected on more number and area of leaves and higher grain yields. These results are confirmed with those obtained by **Al-Kaisi and Yin (2003); Erdem *et al.* (2006)** and **El-Hendawy *et al.* (2008)**. On the other hand, applying irrigation requirements by using drip irrigation in this study led to increase availability of the nutrient at root zone and increase the crop yield **(Ashraf, 2001 and Al-Bakeir, 2003)**.

The effect of different sowing dates on WUE showed in Table (8) revealed that there were significant differences between treatments. The highest WUE was observed by the second sowing date, while the first sowing date had the lowest WUE value.

In regard to the effect of different irrigation levels on water use efficiency, data in Table (8) showed that increasing irrigation quantity led to a decrease in WUE for all irrigation treatments.

The highest WUE obtained by 0.6 irrigation level with second sowing dates, followed by 0.6 irrigation level with first and third sowing dates. The lowest WUE was obtained by 1.2 irrigation level with the second and third sowing dates. Results of this study in general agreed with the observations of **Vaux & Pruitt (1983), Norwood (2000); Shani & Dudley (2001); Erdem *et al,* (2006), El-Marsafawy Samia *et al,* (2012),** whom concluded that increasing irrigation water level led to decrease in WUE value.

Nutrient content:

The effect of sowing date and irrigation level on maize leaf nutrient content is presented in Table (9).

As N, P and K percentage, differences among the studied treatments were significant. Cultivation in the second sowing date led to increase N, P and K percentage followed by third sowing date. The lowest N, P and K percentage was obtained by the first sowing date. The increases of the NPK percentage in maize leaf in the second and third sowing dates due to the proper climatic conditions for the maize growth in these dates in Northern Egypt. These results are in line with those obtained by **Killi and Altanbay, (2005), Ihsan *et al.* (2005) and Abdrabbo *et al.* (2013)** whom concluded that, the proper sowing date led to increase plant growth, yield and nutrient content of maize plants.

Regarding the effect of different irrigation levels on N, P and K content in maize leaf, data showed that increasing irrigation level up to 1.2 ETc led to a decrease in N, P and K percentage. The lowest N, P and K were obtained by 1.20 (ETc) irrigation treatments during the two studied seasons.

Referring the interaction effect between planting sowing dates and different irrigation levels, there were significant differences among treatments during the two studied seasons. The highest N, P and K percentage was obtained by second sowing date with 0.6 (ETc). Using 1.2 irrigation level in first sowing date gave the lowest N, P and K percentage. such results were agreed with the observations that increasing irrigation level up to 1.2 (ETc) decreased N,P and K percentage, whereas decreasing irrigation level led to increase N, P and K percentage (**Porro and Cassel, 1986, Ibrahim *et al*, 1992 and Liu *et al*, 2002**). This might be because of increase irrigation level led to increase maize growth and canopy weight, this led to dilute the percentage of the NPK percentage in maize leaves (**Al-Kaisi and Yin,2003**). On the other hand, **Al-Bakeir (2003)** concluded that increase water application significantly reduced N, P and K absorption by plants.

Simulation of maize growth and productivity under current and future climate conditions

1.1. CERES-Maize Model calibration and validation

Calibration of CERES-Maize model using experimental data of year 2011 is shown in Tables 10 and 12, while validation of the model using experimental data of year 2012 is shown in Tables 11 and 13 of the following calibration and validation results part. These results were closed to **El-Marsafawy, Samia (2012)** findings concerning model evaluation as well as impacts of temperature rises.

Growth stages

Plants under experimental conditions needed, in average, 64 days in year 2011 and 60 days in year 2012 in order to convert from vegetative stage to flowering stage. Simulation of this stage among different treatments gave a difference from 1 to 3 days in both years between observed and simulated anthesis day with RMSE values of 1.9 and 1.7, and excellent d-Stat values of 0.835 and 0.891 for years 2011 and 2012, respectively (Tables 10 & 11).

Reaching the physiological maturity of maize plants under experimental conditions needed 121 days in year 2011 and 111 days in year 2012. Difference between simulated and observed number of days to physiological maturity was between 1 and 2 days in both years giving RMSE values of 1.7. D-Stat values between observed and simulated duration of physiological maturity were 0.786 and 0.749 for years 2011 and 2012, respectively (Tables 10 & 11).

Leaf Area Index

Simulation of the maximum leaf area index is one of the important indications about model ability and accuracy in crop simulation. Comparing values of maximum leaf area index between the two years of the experiment showed an average value of 3.26 for year 2011, while for year 2012 it arrived to an average of 4.23 under different sowing dates and different irrigation levels of the experiment. Plants observed values compared with simulated values from the model and this comparison showed a very low RMSE value (0.2 for year 2011, and 0.5 for year 2012) which a very indication for the excellent performance of the simulation model used. D-Stat values confirmed this result, giving values very near to 1, which were 0.862 and 0.819 for years 2011 and 2012, respectively (Tables 10 & 11). Giving closed values between observation and simulation of the maximum leaf are index under different experimental conditions means that model is able to simulate plant growth and yield in a very accurate manner.

By-product dry weight

Plants observation data showed for the by-product dry weight an average of 7864 kg ha-1 in year 2011 and an average of 7951 kg ha-1 for year 2012. These values compared separately under each experimental condition with the model simulation after calibration and showed RMSE value of 722 and d-Stat value of 0.826 for year 2011. The same comparison was done for year 2012 and showed RMSE of 1662 and d-Stat value of 0.577, which showed lower simulation performance for this specific parameter compared with simulation of year 2011 (Tables 12 & 13).

Above ground dry weight

Comparing actual dry weight of above ground part of the plant with its simulated weight showed very good model simulation performance. Average observed weight for year 2011 was 16040 kg ha-1 and for year 2012 it was 16208 kg ha-1. Observed values of this parameter under different sowing dates and irrigation levels were compared with simulated values giving RMSE values of 1440 and 1458 for years 2011 and 2012, respectively. D-Stat index of comparison gave as well excellent values simulation performance as they were 0.882 for year 2011 and 0.873 for year 2012 (Tables 12 & 13).

Grain yield

Tables 12 and 13 showed comparison between observed grain yield and simulated grain yield of a crop simulation model as a part of its important testing steps for simulation performance. Grain yield of maize under experimental conditions showed a great production under both years climate conditions (an average of 8226 kg ha-1 for year 2011, and an average of 8308 kg ha-1 for year 2012). Such comparison using simulation performance indexes showed low RMSE values of 912 and 875 for years 2011 and 2012, respectively. D-Stat index values as well shoed excellent simulation performance as for year 2011 it was 0.866 and for year 2012 it was 0.847. Giving such a small difference between observed and simulated values gave a positive indication about model ability to simulate different plants growth stages as well as plant parts size and productivity in the optimum way even under different agronomic conditions and different weather conditions.

1.2. Prediction of maize growth and production under future climate change

Growth stages

Durations needed by maize plants to convert from one growth stage to another are affected by air temperature and consequently that affect the dry matter accumulation of different plant parts, especially grain yield as economical part. Rising air temperature by 1.5°C of seasons 2011 and 2012 leaded to a reduction in days needed to reach anthesis between -6% and -6.7% of year 2011 and between -3.6% and -8.1% of year 2012 (Tables 14 & 15). Plants under conditions of rising temperature by 3.5°C of the same seasons leaded to a decrease in the growing days till reaching physiological maturity, which declined in a range between -10% and -14.9% for year 2011 and between 14.4% and 15.1% for year 2012 (Tables 14 & 15). This reduction in growth stages duration will affect days of sowing as well as days of harvesting, which are of high importance when linked with economic and prices issues.

Above ground dry weight

Maize plants under future conditions of rising temperature will be affected negatively. This is also due to rising of water needs as well as changing of weather conditions at the current sowing dates. Rising temperature by 1.5°C gave a reduction in the weight of above ground plant part with of a range between -8.1% and -13% of the current weight of 2011 under different sowing dates and irrigation levels, as explained in Table 16. Increasing 1.5°C on the current temperature conditions of year 2012 caused more reduction in weight of above ground plant part reaching -11.6% and -22.2% of reduction (Table 17). Plants were more affected by rising temperature of the year 2011 by 3.5°C, as reduction in the above ground plant part ranged between -20.9% and -37% of the current weight (Table 16). Table 17 shows more reduction in weight was observed by increasing temperature of year 2012 by 3.5 °C, reaching a reduction between -26.5% and -45.3%.

Grain yield

Grain formation and accumulation under such conditions will be also affected negatively by such increase in temperature. Plants under conditions of rising temperature by 1.5°C had a reduction in grain yield ranged between -15.1% and -25.3% for year 2011 and between -26.4% and -31.9% (Tables 16 & 17). Greater reduction was observed by rising temperature by 3.5°C, which caused a reduction in grain yield ranged between -43.4% and -54.8% of year 2011 and a reduction ranged between -51.6% and -66.2% of year 2012 (Tables 16 & 17). These reductions reflected clearly the possible negative impacts of future changes in air temperature on maize plants growth and productivity in the area studied and under experimental conditions tested.

Water productivity

Maize plants under current conditions of seasons 2011 and 2012 were affected by ET ratios of the experiment's location, and subsequently had different water productivity according to different irrigation treatments and weather conditions of different sowing dates. Table (18) shows the comparison of water productivity for both seasons, as well as declines in water productivity when we increase maximum and minimum temperature for both seasons by 1.5oC and 3.5oC. Plants of year 2011 under increasing conditions of 1.5oC in temperature were less in water productivity with a minimum of -10.77% under the second sowing date with 0.6 of irrigation conditions, whereas it arrived to a maximum of -20.39% under the first sowing date with 0.6 of irrigation conditions. In year 2012, plants under increasing conditions of 1.5oC in temperature gave less water productivity than current conditions with a minimum of -23.98% under the first sowing date with 0.8 of irrigation conditions, while it gave a maximum reduction in water productivity of -27.62% under the second sowing date with 0.6 of irrigation conditions. Plants under conditions of rising temperature by 3.5oC would have a dramatic decrease in their water productivity. This showed a minimum reduction arrived to -38.16% for year 2011 under the first sowing date with 0.6 of irrigation conditions and -47.06% for year 2012 under the first sowing date with 1.2 of irrigation conditions. Maximum reductions were -48.21% for year 2011 under the second sowing date with 0.6 of irrigation conditions, and -61.34% for year 2012 under the third sowing date with 0.6 of irrigation conditions.

Reductions in water productivity reflected great loss will be caused for farmers if temperature rises than current averages for such growing seasons. Three of the minimum reductions in water productivity occurred under cultivating in first and second sowing dates, which shows necessity of anticipating current sowing dates in order to avoid great loss in yield. To get efficient use for the amount of irrigation water added to plants, we need to reduce normal amounts to be 0.6 or 0.8 of the ET.

Table (6): Effect of different sowing dates and irrigation treatments on vegetative growth of single cross 10 maize hybrid.

Sowing Date (A)	First season (2011)					Second season (2012)				
	No of leaves									
	Irrigation level (B)				**Mean**	**Irrigation level (B)**				**Mean**
	0.6	**0.8**	**1.0**	**1.2**		**0.6**	**0.8**	**1.0**	**1.2**	
First	15.1 f	16.9 cd	17.2 c	18.5 a	**16.9 A**	15.3 g	16.3 e	17.3 c	18.8 a	**16.9 A**
Second	13.8 g	16.5 e	16.9 d	17.6 b	**16.2 A**	14.0 h	15.9 f	16.9 d	17.9 b	**16.1 A**
Third	10.2 f	11.5 h	11.3 e	11.8 h	**11.2 B**	10.3 k	11.0 j	11.3 j	12.1 i	**11.2 B**
Mean	**13.0 C**	**15.0 B**	**15.1 B**	**16.0 A**		**13.2 C**	**14.4 B**	**15.1 B**	**16.3 A**	
	Leaf area index									
First	2.53 g	3.15 e	3.29 d	3.56 c	**3.13 C**	3.30 h	4.10 f	4.20 e	4.65 c	**4.06 C**
Second	2.86 f	3.36 d	3.51 c	3.85 a	**3.40 A**	3.68 g	4.40 d	4.55 c	5.07 a	**4.43 A**
Third	2.59 g	3.37 d	3.34 d	3.71 b	**3.25 B**	3.37 h	4.32 d	4.31 d	4.84 b	**4.21 B**
Mean	**2.66 D**	**3.29 C**	**3.38 B**	**3.71 A**		**3.45 D**	**4.27 C**	**4.35 B**	**4.85 A**	
	Number of days for 50 % tasseling									
First	61.2 e	62.6 c	63.3 b	64.3 a	**62.9 A**	59.8 d	61.2 c	61.4 b	63.6 a	**61.5 A**
Second	59.4 h	62.5 c	62.3 d	62.2 d	**61.6 B**	55.9 g	57.7 d	57.6 d	59.4 b	**57.7 B**
Third	57.3 i	59.7 g	59.9 f	59.9 f	**59.2 C**	53.8 h	56.2 f	56.0 g	57.1 e	**55.8 C**
Mean	**59.3 B**	**61.6 A**	**61.8 A**	**62.1 A**		**56.5 C**	**58.4 B**	**58.3 B**	**60.0 A**	
	Number of days for 50 % silking									
First	63.0 f	64.3 c	65.1 b	66.0 a	**64.6 A**	60.6 d	61.9 c	62.3 b	64.3 a	**62.3 A**
Second	61.3 h	62.9 f	63.4 e	64.1 d	**62.9 B**	55.9 f	57.5 d	57.5 d	59.4 b	**57.6 B**
Third	58.4 i	61.1 h	61.6 g	61.8 g	**60.7 C**	54.0 h	56.7 g	56.7 g	58.1 e	**56.4 C**
Mean	**60.9 C**	**62.8 B**	**63.4AB**	**64.0 A**		**56.8 C**	**58.7 B**	**58.8 B**	**60.6 A**	

Means followed by the same letter within column are not significantly different (P<0.05)

Table (7): Effect of different sowing dates and irrigation treatments on yield of grain and straw and weight of 100 seeds of single cross 10 maize hybrid.

	First season (2011)					Second season (2012)				
	Grain (g/plant)									
Sowing Date (A)	**Irrigation level (B)**				**Mean**	**Irrigation level (B)**				**Mean**
	0.6	**0.8**	**1.0**	**1.2**		**0.6**	**0.8**	**1.0**	**1.2**	
First	107 h	134 f	139 e	150 c	**133 C**	108 h	136 f	140 e	153 b	**134 C**
Second	121 g	144 d	149 c	164 a	**145 A**	122 g	145 d	149 c	167 a	**146 A**
Third	110 h	142d	142 d	158 b	**138 B**	110 h	143 de	142 de	161 b	**139 B**
Mean	**113 D**	**140 C**	**143 B**	**157 A**		**113 D**	**141 C**	**144 B**	**160 A**	
	Weight of 100 seeds (g)									
First	19.5 h	24.5 f	25.4 e	27.4 c	**24.2 C**	19.7 h	24.7 f	25.4 e	28.0 b	**24.5 C**
Second	22.1 g	26.2 d	27.3 c	30.0 a	**26.4 A**	22.3 g	26.5 d	27.3 c	30.6 a	**26.7 A**
Third	20.0 h	25.9de	25.9de	28.7 b	**25.1 B**	20.2 h	26.1de	25.9de	29.3 b	**25.4 B**
Mean	**20.5 C**	**25.5 B**	**26.2 B**	**28.7 A**		**20.8 C**	**25.8 B**	**26.2 B**	**29.3 A**	
	Straw weight (g/plant)									
First	102.5 h	128.3 f	132.9e	143.6c	**126.8C**	103.8 i	129.6g	133.0 f	146.4c	**128.2C**
Second	115.7 g	137.3d	142.7c	157.0a	**138.2A**	116.9h	138.6e	143.2d	160.1a	**139.7A**
Third	104.9 h	135.5d	135.4d	150.3b	**131.5B**	105.9 i	136.9e	135.8e	153.3b	**133.0B**
Mean	**107.7 C**	**133.7B**	**137.0B**	**150.3A**		**108.9C**	**135.0B**	**137.3B**	**153.3A**	

Means followed by the same letter within column are not significantly different (P<0.05)

Table (8): Water use efficiency of single cross 10 maize hybrid as affected by different sowing dates and irrigation treatments.

Sowing Date (A)	**First season (2011)**				**Mean**	**Second season (2012)**				**Mean**
	Irrigation level (B)					**Irrigation level (B)**				
	0.6	**0.8**	**1.0**	**1.2**		**0.6**	**0.8**	**1.0**	**1.2**	
First	1.96 b	1.84 d	1.53 e	1.37 g	**1.67 B**	1.85 b	1.75 d	1.44 e	1.31 f	**1.59 B**
Second	2.07 a	1.84 d	1.53 e	1.40 g	**1.71 A**	2.01 a	1.79 c	1.47 e	1.38 f	**1.66 A**
Third	1.91 c	1.85 d	1.48 f	1.37 g	**1.65 B**	1.84 b	1.80 c	1.43 e	1.35 f	**1.60 B**
Mean	**1.98A**	**1.84B**	**1.51C**	**1.38D**		**1.90A**	**1.78B**	**1.45C**	**1.35D**	

Means followed by the same letter within column are not significantly different (P<0.05)

Table (9) NPK percentages of single cross 10 maize hybrid as affected by different sowing dates and irrigation treatments.

Sowing Date (A)	First season (2011)				Mean	Second season (2012)				Mean
	Irrigation level (B)					Irrigation level (B)				
	0.6	0.8	1.0	1.2		0.6	0.8	1.0	1.2	
	N % in leaves									
First	1.51 b	1.37 c	1.33 d	1.10 g	**1.33 C**	1.42 bc	1.37 bc	1.29 c	1.03 e	**1.28 B**
Second	1.68 a	1.49 b	1.40 c	1.26 e	**1.46 A**	1.69 a	1.39 bc	1.34 c	1.16 d	**1.39 A**
Third	1.57 b	1.54 b	1.36 cd	1.13 f	**1.40 B**	1.46 b	1.44 bc	1.25 c	1.17 d	**1.33AB**
Mean	**1.59 A**	**1.47 B**	**1.36 C**	**1.16 D**		**1.52 A**	**1.40 B**	**1.29 B**	**1.12 C**	
	P % in leaves									
First	0.81 c	0.62 e	0.57 f	0.55 f	**0.64 B**	0.72 d	0.63 e	0.56 f	0.51 f	**0.60 B**
Second	1.11 a	1.11 a	0.91 b	0.73 d	**0.97 A**	1.09 a	1.05 b	0.94 c	0.54 f	**0.91 A**
Third	1.05 a	0.66 e	0.60 ef	0.53 f	**0.71 B**	1.07 b	0.61 e	0.54 f	0.55 f	**0.69 B**
Mean	**0.99 A**	**0.80 B**	**0.69 C**	**0.60 D**		**0.96 A**	**0.76 AB**	**0.68 B**	**0.53 C**	
	K % in leaves									
First	1.00 d	0.78 f	0.79 f	0.59 h	**0.79 C**	0.93 d	0.72 f	0.77 f	0.61 h	**0.76 C**
Second	1.37 a	1.17 b	1.17 b	0.81 f	**1.13 A**	1.28 a	1.20 b	1.11 c	0.76 f	**1.09 A**
Third	1.17 b	1.11 c	0.95 e	0.72 g	**0.99 B**	1.11 c	0.93 d	0.86 e	0.67 g	**0.90 B**
Mean	**1.18 A**	**1.02 B**	**0.97 B**	**0.71 C**		**1.11 A**	**0.95 B**	**0.91 B**	**0.68 C**	

Means followed by the same letter within column are not significantly different ($P<0.05$)

Table (10): Calibration of CERES-Maize model for anthesis day, maturity day and leaf area index (LAI) using observed data of season 2011.

Treatment	Anthesis day		Maturity day		LAI (maximum)	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
SD1 - Irr. 0.6	64	67	121	122	2.53	2.97
SD1 - Irr. 0.8	65	67	122	122	3.15	3.23
SD1 - Irr. 1.0	66	67	123	122	3.29	3.23
SD1 - Irr. 1.2	67	67	124	122	3.56	3.23
SD2 - Irr. 0.6	62	64	119	119	2.86	3.25
SD2 - Irr. 0.8	64	64	121	119	3.36	3.5
SD2 - Irr. 1.0	64	64	121	119	3.51	3.5
SD2 - Irr. 1.2	65	64	122	119	3.85	3.5
SD3 - Irr. 0.6	59	60	116	118	2.59	2.56
SD3 - Irr. 0.8	62	60	119	118	3.37	3.49
SD3 - Irr. 1.0	63	60	120	118	3.34	3.52
SD3 - Irr. 1.2	63	60	120	118	3.71	3.52
RMSE	**1.9**		**1.7**		**0.2**	
d-Stat*	**0.835**		**0.786**		**0.862**	

*The Index of Agreement (d) as described by Willmott *et al.* (1985).

Table (11): Validation of CERES-Maize model for anthesis day, maturity day and leaf area index (LAI) using observed data of season 2012.

Treatment	Anthesis day		Maturity day		LAI (maximum)	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
SD1 - Irr. 0.6	62	62	112	112	3.3	3.22
SD1 - Irr. 0.8	63	62	113	112	4.1	4.14
SD1 - Irr. 1.0	63	62	113	112	4.2	4.16
SD1 - Irr. 1.2	65	62	115	112	4.65	4.16
SD2 - Irr. 0.6	57	58	108	109	3.68	3.06
SD2 - Irr. 0.8	59	58	110	109	4.4	4.06
SD2 - Irr. 1.0	59	58	110	109	4.55	4.08
SD2 - Irr. 1.2	60	58	111	109	5.07	4.08
SD3 - Irr. 0.6	55	56	108	109	3.37	2.68
SD3 - Irr. 0.8	58	56	111	109	4.32	4.15
SD3 - Irr. 1.0	58	56	111	109	4.31	4.36
SD3 - Irr. 1.2	59	56	112	109	4.84	4.36
RMSE	**1.7**		**1.7**		**0.5**	
d-Stat*	**0.891**		**0.749**		**0.819**	

*The Index of Agreement (d) as described by Willmott *et al.* (1985).

Table (12): Calibration of CERES-Maize model for by-product dry weight, tops dry weight and grain yield using observed data of season 2011.

Treatment	**By-product dry weight (kg ha^{-1})**		**Tops dry weight (kg ha^{-1})**		**Grain yield (kg ha^{-1})**	
	Observed	**Simulated**	**Observed**	**Simulated**	**Observed**	**Simulated**
SD1 - Irr. 0.6	6099	7141	12430	12640	6381	5546
SD1 - Irr. 0.8	7634	8529	15572	16950	7988	8470
SD1 - Irr. 1.0	7908	8536	16113	17781	8256	9294
SD1 - Irr. 1.2	8544	8473	17419	17718	8925	9294
SD2 - Irr. 0.6	6884	7806	14019	14794	7185	7040
SD2 - Irr. 0.8	8169	8996	16687	18476	8568	9534
SD2 - Irr. 1.0	8491	9064	17321	18981	8880	9971
SD2 - Irr. 1.2	9342	8913	19064	18830	9773	9971
SD3 - Irr. 0.6	6242	6915	12707	13889	6515	7022
SD3 - Irr. 0.8	8062	8862	16446	18753	8434	9947
SD3 - Irr. 1.0	8056	8967	16440	18969	8434	10059
SD3 - Irr. 1.2	8943	8851	18264	18853	9371	10059
RMSE	**722**		**1440**		**912**	
d-Stat*	**0.826**		**0.882**		**0.866**	

*The Index of Agreement (d) as described by Willmott *et al.* (1985).

Table (13): Validation of CERES-Maize model for by-product dry weight, tops dry weight and grain yield using bserved data of season 2012.

Treatment	**By-product dry weight (kg ha^{-1})**		**Tops dry weight (kg ha^{-1})**		**Grain yield (kg ha^{-1})**	
	Observed	**Simulated**	**Observed**	**Simulated**	**Observed**	**Simulated**
SD1 - Irr. 0.6	6176	8468	12552	13975	6426	5564
SD1 - Irr. 0.8	7711	10083	15738	17124	8077	7106
SD1 - Irr. 1.0	7914	10132	16164	17764	8300	7698
SD1 - Irr. 1.2	8711	10132	17764	17764	9104	7698
SD2 - Irr. 0.6	6956	8080	14179	14247	7274	6222
SD2 - Irr. 0.8	8247	9887	16809	17930	8613	8108
SD2 - Irr. 1.0	8520	9989	17351	18367	8880	8443
SD2 - Irr. 1.2	9526	9989	19427	18367	9951	8443
SD3 - Irr. 0.6	6301	7081	12811	13518	6560	6489
SD3 - Irr. 0.8	8146	9817	16619	18972	8523	9221
SD3 - Irr. 1.0	8080	10193	16464	19443	8434	9319
SD3 - Irr. 1.2	9121	10193	18621	19443	9550	9319
RMSE	**1662**		**1458**		**875**	
d-Stat*	**0.577**		**0.873**		**0.847**	

*The Index of Agreement (d) as described by Willmott *et al.* (1985).

Table (14): Prediction of CERES-Maize model for anthesis day andmaturity day comparing simulated data of season 2011 with data obtained from 1.5 °C and 3.5 °C increase in temperature.

Treatment	**Anthesis day**					**Maturity day**				
	Current	**+ 1.5°C**	**Diff. %**	**+ 3.5°C**	**Diff. %**	**Current**	**+ 1.5°C**	**Diff. %**	**+ 3.5°C**	**Diff. %**
SD1 - Irr. 0.6	67	63	-6.0	57	-14.9	122	114	-6.6	104	-14.8
SD1 - Irr. 0.8	67	63		57		122	114		104	
SD1 - Irr. 1.0	67	63		57		122	114		104	
SD1 - Irr. 1.2	67	63		57		122	114		104	
SD2 - Irr. 0.6	64	60	-6.3	55	-14.1	119	111	-6.7	101	-15.1
SD2 - Irr. 0.8	64	60		55		119	111		101	
SD2 - Irr. 1.0	64	60		55		119	111		101	
SD2 - Irr. 1.2	64	60		55		119	111		101	
SD3 - Irr. 0.6	60	56	-6.7	54	-10.0	118	108	-8.5	101	-14.4
SD3 - Irr. 0.8	60	56		54		118	108		101	
SD3 - Irr. 1.0	60	56		54		118	108		101	
SD3 - Irr. 1.2	60	56		54		118	108		101	

Table (15): Prediction of CERES-Maize model for anthesis day and maturity day comparing simulated data of season 2012 with data obtained from 1.5 ^{o}C and 3.5 ^{o}C increase in temperature.

Treatment	Anthesis day					Maturity day				
	Current	+ 1.5^{o}C	Diff. %	+ 3.5^{o}C	Diff. %	Current	+ 1.5^{o}C	Diff. %	+ 3.5^{o}C	Diff. %
SD1 - Irr. 0.6	62	57	-8.1	53	-14.5	112	104	-7.1	97	-13.4
SD1 - Irr. 0.8	62	57		53		112	104		97	
SD1 - Irr. 1.0	62	57		53		112	104		97	
SD1 - Irr. 1.2	62	57		53		112	104		97	
SD2 - Irr. 0.6	58	54	-6.9	52	-10.3	109	101	-7.3	101	-7.3
SD2 - Irr. 0.8	58	54		52		109	101		101	
SD2 - Irr. 1.0	58	54		52		109	101		101	
SD2 - Irr. 1.2	58	54		52		109	101		101	
SD3 - Irr. 0.6	56	54	-3.6	50	-10.7	109	102	-6.4	93	-14.7
SD3 - Irr. 0.8	56	54		50		109	102		93	
SD3 - Irr. 1.0	56	54		50		109	102		93	
SD3 - Irr. 1.2	56	54		50		109	102		93	

Table (16): Prediction of CERES-Maize model for tops dry weight and grain yield comparing simulated data of season 2011 with data obtained from 1.5 ^{o}C and 3.5 ^{o}C increase in temperature.

Treatment	Tops dry weight (kg ha^{-1})					Grain yield (kg ha^{-1})				
	Current	+ 1.5^{o}C	Diff. %	+ 3.5^{o}C	Diff. %	Current	+ 1.5^{o}C	Diff. %	+ 3.5^{o}C	Diff. %
SD1 - Irr. 0.6	12640	10993	-13.0	8888	-29.7	5546	4155	-25.1	2999	-45.9
SD1 - Irr. 0.8	16950	15502	-8.5	12738	-24.8	8470	6742	-20.4	4374	-48.4
SD1 - Irr. 1.0	17781	16192	-8.9	13631	-23.3	9294	7400	-20.4	4823	-48.1
SD1 - Irr. 1.2	17718	16192	-8.6	13673	-22.8	9294	7400	-20.4	4866	-47.6
SD2 - Irr. 0.6	14794	13225	-10.6	9524	-35.6	7040	5974	-15.1	3180	-54.8
SD2 - Irr. 0.8	18476	16705	-9.6	12938	-30.0	9534	7925	-16.9	4661	-51.1
SD2 - Irr. 1.0	18981	17182	-9.5	13569	-28.5	9971	8324	-16.5	5019	-49.7
SD2 - Irr. 1.2	18830	17182	-8.8	13569	-27.9	9971	8324	-16.5	5019	-49.7
SD3 - Irr. 0.6	13889	11395	-18.0	8746	-37.0	7022	5368	-23.6	3233	-54.0
SD3 - Irr. 0.8	18753	16752	-10.7	13415	-28.5	9947	8346	-16.1	5258	-47.1
SD3 - Irr. 1.0	18969	17334	-8.6	14894	-21.5	10059	8591	-14.6	5686	-43.5
SD3 - Irr. 1.2	18853	17334	-8.1	14907	-20.9	10059	8591	-14.6	5689	-43.4

Table (17): Prediction of CERES-Maize model for tops dry weight and grain yield comparing simulated data of season 2012 with data obtained from 1.5 ^{o}C and 3.5 ^{o}C increase in temperature.

Treatment	Tops dry weight (kg ha^{-1})					Grain yield (kg ha^{-1})				
	Current	+ 1.5^{o}C	Diff. %	+ 3.5^{o}C	Diff. %	Current	+ 1.5^{o}C	Diff. %	+ 3.5^{o}C	Diff. %
SD1 - Irr. 0.6	13975	11264	-19.4	8457	-39.5	5564	3989	-28.3	2443	-56.1
SD1 - Irr. 0.8	17124	14611	-14.7	11661	-31.9	7106	5145	-27.6	3389	-52.3
SD1 - Irr. 1.0	17764	15132	-14.8	12848	-27.7	7698	5557	-27.8	3663	-52.4
SD1 - Irr. 1.2	17764	15132	-14.8	13048	-26.5	7698	5557	-27.8	3723	-51.6
SD2 - Irr. 0.6	14247	11091	-22.2	8741	-38.6	6222	4236	-31.9	2232	-64.1
SD2 - Irr. 0.8	17930	14475	-19.3	11842	-34.0	8108	5564	-31.4	3040	-62.5
SD2 - Irr. 1.0	18367	15007	-18.3	12830	-30.1	8443	5865	-30.5	3281	-61.1
SD2 - Irr. 1.2	18367	15007	-18.3	12934	-29.6	8443	5865	-30.5	3296	-61.0
SD3 - Irr. 0.6	13518	11221	-17.0	7398	-45.3	6489	4610	-29.0	2194	-66.2
SD3 - Irr. 0.8	18972	16212	-14.5	11381	-40.0	9221	6662	-27.8	3538	-61.6
SD3 - Irr. 1.0	19443	17169	-11.7	12731	-34.5	9319	6857	-26.4	3769	-59.6
SD3 - Irr. 1.2	19443	17195	-11.6	13146	-32.4	9319	6861	-26.4	3799	-59.2

Table (18): Comparison of current (2011 and 2012 weather conditions) and future (+1.5oC and +3.5oC) impacts under different experimental treatments on water productivity of Maize plants.

Treatment	Water productivity (kg [grain yield]/m^{3} [ET])									
	2011					2012				
	Current	+ 1.5^{o}C	Diff. %	+ 3.5^{o}C	Diff. %	Current	+ 1.5^{o}C	Diff. %	+ 3.5^{o}C	Diff. %
PD1 - Irr. 0.6	1.52	1.21	-20.39	0.94	-38.16	1.60	1.21	-24.38	0.79	-50.63
PD1 - Irr. 0.8	1.93	1.59	-17.62	1.10	-43.01	1.71	1.30	-23.98	0.90	-47.37
PD1 - Irr. 1.0	1.95	1.61	-17.44	1.11	-43.08	1.72	1.30	-24.42	0.90	-47.67
PD1 - Irr. 1.2	1.92	1.59	-17.19	1.09	-43.23	1.70	1.28	-24.71	0.90	-47.06
PD2 - Irr. 0.6	1.95	1.74	-10.77	1.01	-48.21	1.81	1.31	-27.62	0.73	-59.67
PD2 - Irr. 0.8	2.19	1.90	-13.24	1.21	-44.75	1.95	1.42	-27.18	0.81	-58.46
PD2 - Irr. 1.0	2.20	1.89	-14.09	1.20	-45.45	1.94	1.41	-27.32	0.81	-58.25
PD2 - Irr. 1.2	2.16	1.86	-13.89	1.18	-45.37	1.92	1.40	-27.08	0.80	-58.33
PD3 - Irr. 0.6	2.03	1.67	-17.73	1.07	-47.29	1.94	1.46	-24.74	0.75	-61.34
PD3 - Irr. 0.8	2.38	2.11	-11.34	1.38	-42.02	2.27	1.70	-25.11	0.97	-57.27
PD3 - Irr. 1.0	2.33	2.06	-11.59	1.37	-41.20	2.22	1.66	-25.23	0.95	-57.21
PD3 - Irr. 1.2	2.31	2.04	-11.69	1.36	-41.13	2.21	1.66	-24.89	0.95	-57.01

Conclusion:

In general, 0.6 irrigation level accompanied with second sowing date was the best combination for maize production aimed at maximum WUE in this study. This recommendation is slightly different in irrigation from our recommendation aiming at optimum grain yield obtained by 1.2 irrigation level accompanied by second sowing date. The adoption of 0.6 irrigation level will be superior to 1.0 irrigation level if the irrigation water is the limiting factor or at farmer facing water scarcity.

Using CERES-Maize simulation model leaded to a great understanding of maize plant behaviors under different sowing dates and different irrigation levels. Model was able to simulate phenology, plant growth and yield in a very efficient way with high levels of accuracy indicated by evaluation indexes used. Evaluation parameters were divided into: growth stages parameters and dry matter accumulated in different plant parts. Rising air temperature above the current averages of years 2011 and 2012 by 1.5^{o}C caused a reduction in growth stages durations to both anthesis and physiological maturity. This reduction was duplicated by increasing air temperature of same years by 3.5^{o}C giving both shorter growing period length as well as losses in plant weight and yield. That reduction in yield arrived in some cases to more than half of normal or current levels, which reflected a great economical loss for maize growers under such conditions. Adaptation strategies for such future conditions of rising in air temperature are needed by changing both sowing dates as well as irrigation regimes given to grown maize of this region.

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