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Research Article
Simulating Wheat Response to Different Climate Change Scenarios under Different Nitrogen Fertilizer Supply in Northern Egypt

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Abstract

Background and Objective: Crop models are important tools for simulating crop growth in response to climate change. The objective of the current study was to assess the impact of different climate change scenarios on yield and yield components of a spring wheat in Northern Egypt. **Materials and Methods:** Two field experiments were carried out in Northern Egypt during winter seasons of 2012/2013 and 2013/2014 to investigate the response of wheat grain yield to different scenarios of climate change under three fertilization treatments (control, 180 and 240 N kg ha^{-1}). Two scenarios were used by generating daily weather data using LARS-WG stochastic weather generator software based on historical weather data from 1997-2012. The scenarios included the increase in minimum and maximum temperatures by 2, 3, 4 and 5°C as well as two concentrations of CO_2 (550 and 750 µmole mole^{-1}) according to the Special Report on Emission Scenarios (SRES) A2 and B2. **Results:** The output of DSSAT 4.6 crop simulation model showed that increasing temperature from current climate to +2, +3, +4 and +5°C resulted in a decrease in grain yield, however, increasing the concentration of CO_2 from 550-750 µmole mole^{-1} resulted in an increase in grain yield meaning that CO_2 caused a mitigation of the adverse impact of climate change on wheat grain yield. The reduction in grain yield in response to increasing temperature was mainly due to the reduction in number of spikes per meter square and the reduction in number of grains/spike, however, weight of 1000 grains was not affected by the increase in temperature. Also, the results indicated that the scenarios of climate change shortening the growing season of wheat. **Conclusion:** Alleviating the adverse impact of climate change on wheat productivity may be achieved by either late sowing or cultivating long season varieties.

Key words: Climate change, crop models, Gen Calc, DSSAT, *Triticum aestivum*

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The temperature of our planet 'Earth' has been raised by 0.7°C since 1900, human activities were responsible for the warming since 1950 as a result of elevated greenhouse gases[1]. Khalil *et al.*[2] have stated that climate change will adversely affect wheat grain yield by 30% in the Nile Delta and valley in Egypt. In addition, the adverse effect of climate change on wheat productivity is expected to be higher in low fertility soil. Innes *et al.*[3] reported 5.3% reduction in wheat yield for each 1°C increase in average daily temperature during wheat growing season. Crop models are used increasingly in different areas of researches in agriculture. Models of crop growth, like cereal model simulate crop growth in response to soil conditions, weather and agronomic practices[4]. Crop models have been used and applied in agriculture in many fields of research[5], like evaluating the impact of climate change on crop productivity[6], estimating the performance of different cultivars[7], assessing the adaptation of a new cultivar to a specific location[8], understanding the genotype environment interaction[9], forecasting of crop yield and optimizing crop management[10].

CERES-wheat which embedded in DSSAT v4.6 crop simulation model is a well-known crop growth model that could be used to investigate the effect of different options about crop management[11]. The HadCM3 model [a coupled atmosphere-ocean general circulation model (AOGCM)] developed at the Hadley Centre for Climate Prediction and Research (United Kingdom)[12,13] provided information about possible changes in climate all over the entire world during the 21st century in three time periods: 2010-2040, 2040-2070 and 2070-2100. The IPCC Nakicenvic *et al.*[14] has developed emission scenarios known as SRES (Special Report on Emission Scenarios). The SRES scenarios combined two sets of divergent tendencies; one set varies between strong economic values and strong environmental values, while the other set varies between increasing globalization and increasing regionalization[15]. The current experiment was conducted to investigate the effect of climate change on yield and yield components of wheat.

MATERIALS AND METHODS

Two field experiments in micro plots were conducted at Soil Salinity and Alkalinity Laboratory, Alexandria, Egypt during 2012/2013 and 2013/2014 winter seasons to simulate the effect of different scenarios of climate change on grain yield of wheat cultivar Giza 168 under three levels of nitrogen fertilizer (control, 180 and 240 N kg ha^{-1}). The design of the experiment randomized complete block (RCBD) with four replicates, each micro plot area was 1.125 m^2 containing sandy loam soil and every micro plot contains four rows, the grains were sown in mid-November in each year, before sowing all micro plots were fertilized by adding super phosphate (15.5% P_2O_5) at a rate of 240 kg ha^{-1}, potassium sulphate (48% K_2O) at a rate of 120 kg ha^{-1} and the nitrogen fertilizer rates were added in the form of ammonium sulphate (20.5% N) in three doses, at the first, second and third irrigation. At the end of the experiment, number of grain/spike, number of spikes m^{-2}, 1000 grain weight (g), grain yield (g/micro plot) and straw yield (g/micro plot) were measured and since more than 95% of tillers were having spikes, it considered the number of spikes as the number of tillers. Two climate change scenarios were considered in this study, A2 and B2. These selected two scenarios took into consideration rise in winter season mean temperature by 2, 3, 4 and 5°C in the Mediterranean region (Fig. 1). CO_2 concentration may reach ~550 and ~750 µmole $mole^{-1}$ as an average during 2040-2070 and 2070-2100, respectively.

Daily rainfall, solar radiation, maximum and minimum temperature were obtained from the NASA website and presented in Fig. 2. Using monthly deviations from baseline observations, LARS-WG[16] can generates synthetic daily weather data under a series of future climate scenarios by perturbing historical climate databased on the parameters obtained from the historical observations (Fig. 3). For the climate change impact assessment, three time periods were considered: 1997-2012 (baseline), 2040-2070, 2070-2100.

RESULTS AND DISCUSSION

Model calibration (estimating cultivar coefficients): CERES-wheat model has different cultivars, species and ecotype coefficients which define phenology and growth of the crop in relation to time[11]. These coefficients are cultivar specific and it cannot use the same coefficients under different environments. They are calibrated by users (Table 1) and in this recent study these coefficients were calibrated using measured data obtained during 2012-2013 winter season. The cultivar coefficients were calibrated sequentially, first for phenological development coefficients related to flowering and maturity dates (P1V, P1D, P5 and PHINT), followed by crop growth coefficients (G1, G2 and G3). Meanwhile, ecotype and species parameter files were also adjusted to have perfect model calibration[11]. Gen Calc software under DSSAT version 4.6 was used for the calculation of cultivar coefficients[17] in CERES-wheat model which has 7 cultivar coefficients that describe growth and development

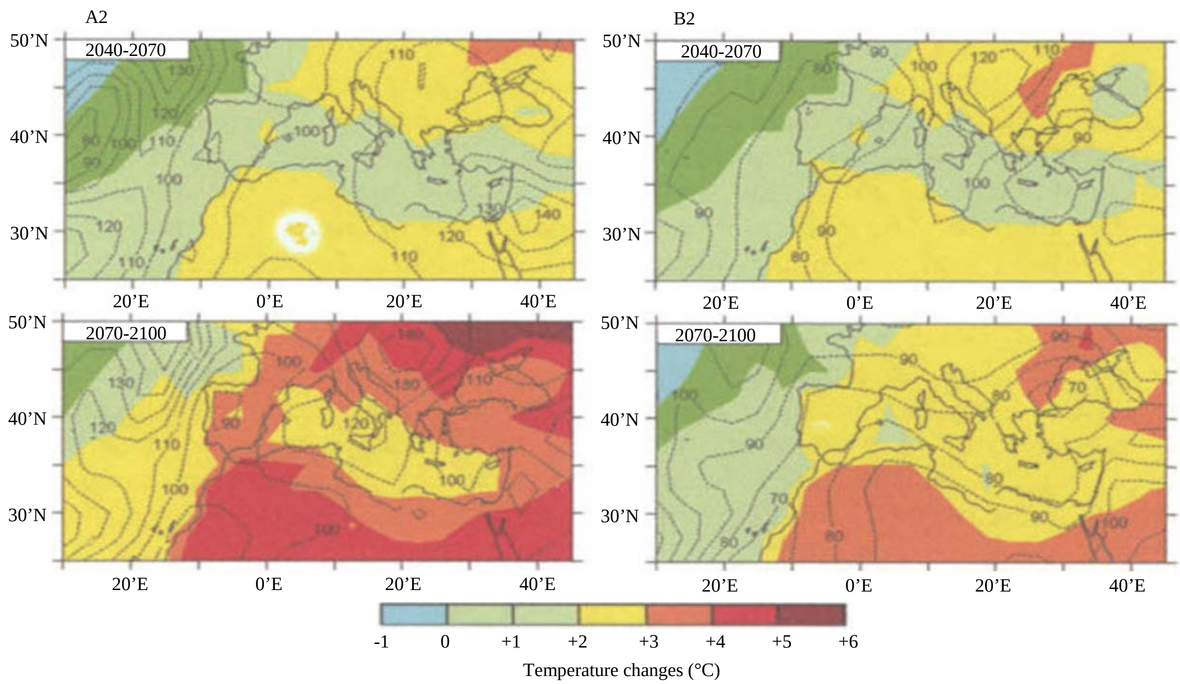

Fig. 1(a-b): Average winter season temperature changes for A2 and B2 SRES emissions scenarios

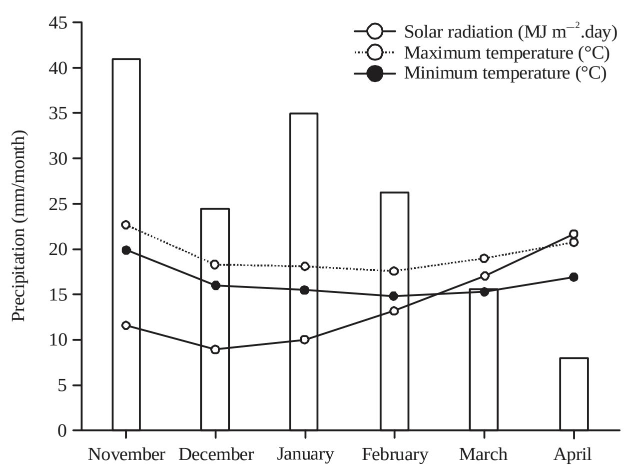

Fig. 2: Weather data of current climate 2013/2014 winter season

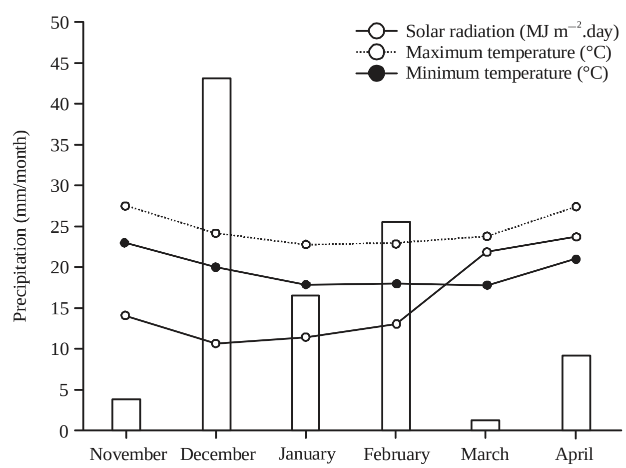

Fig. 3: Weather data for climate change scenario +5°C generated by LARS-WG

of a wheat cultivar (Table 1) which were calibrated according to Ibrahim *et al.*[18] as follows, Set P1V (required days for vernalization) to 0 since cultivar Giza 168 is a spring wheat and do not need vernalization, adjusting days to anthesis (ADAP), adjusting days from anthesis to maturity (MDAP), adjusting interval between subsequent leaf tip appearances (PHINT) based on leaf number on main stem, adjusting standard non-stressed mature tiller weight including grain (G3) based on number of spikes m^{-2}, adjusting the standard kernel size under optimum conditions (G2) based on single grain weight, adjusting Kernel number per unit canopy weight at anthesis (G1) based on number of grains m^{-2}. Calibrated cultivar coefficients were validated to confirm CERES-wheat model robustness by adjusting the parameters to minimize RMSE between simulated and observed data of anthesis and maturity dates as well as yield and yield components.

Days to anthesis and maturity: Model performance is verified by validation[19] which involved comparison between observed end of season data and the simulated output by the model[20,21] and expressed as RMSE (root mean square of error) or MAE (mean absolute error). Observed anthesis and maturity days after planting, LAI, grain yield and its components derived from field experiment during the 2013-2014 growing season were used to validate model performance. The observed days to anthesis and maturity for wheat cultivar were 104 and 149 and the simulated values were 106 and 151, respectively. CERES wheat model simulated the days to anthesis and maturity with good accuracy.The increased temperature lead to shortening of growth season where days to anthesis were 96, 90, 84 and 78 days to maturity were 140, 132, 124 and 115 as temperature increases from current climate to +2, +3, +4 and +5°C, respectively. Alexandrov and Hoogenboom[22] reported that higher temperature resulted in shortening of growth season and yield loss.

Grain yield: The grain yield ratio response to elevated temperature was calculated by considering grain yield at current climate and 397 µmole mole^{-1} CO_2 concentration as baseline. The results show that grain yield ratio decreases from 1.0 to 0.74, 0.79, 0.84 and 0.82 as temperature increases from current climate to +2, +3, +4 and +5°C, respectively under control treatment. When wheat plants were fertilized with 180 (N kg ha^{-1}) the grain yield ratio decreases from 1.0 to 0.93, 0.84, 0.88 and 0.81, however, the grain yield ratio decreases from 1.0 to 0.93, 0.84, 0.88 and 0.81 when wheat plants were fertilized with 240 (kg N ha^{-1}). Increased CO_2 had a positive effect on the grain yield of wheat where the grain yield was increased even with increased temperature (Table 2). In the present study, cultivar Giza 168 showed yield loss with increased temperature. Since increased temperature is a major future yield-determining factor, crop models could provide an opportunity to face this risk by supplying options related to the cultivar management. The results are in accordance with a number of simulation studies under different climatic scenarios[23-25], reported a yield reduction due to increased temperature. Reduction in wheat yield due to the increase in temperature by 2-4°C was also reported by earlier studies[26]. Elevated CO_2 resulted in an increase in crop yield due to increasing photosynthesis rates and reducing transpiration[27]. Furthermore, the combined effect of increased temperature and CO_2 led to higher wheat yield but after a 4°C increase in temperature, yield started to decrease with elevated CO_2 in temperature (Table 2 and Fig. 4). The present results confirm that the negative impact of increasing temperatures could be countered by elevated atmospheric CO_2[26].

Straw yield: Table 3 shows that straw yield (kg ha^{-1}) was inversely affected by increasing temperature, the reductions in straw yield were 16.6, 21.1, 19.7 and 32.0% when temperature was increased by +2, +3, +4 and +5°C, respectively under control treatment. When wheat plants were fertilized with 180 kg ha^{-1} the reductions were 14.2, 16.3, 8.8 and 22.8% meanwhile when wheat plants were fertilized with 240 kg ha^{-1} the reductions were17.7, 19.9, 12.8 and 25.6%. However, increased CO_2 concentration from 550-750 µmole mole^{-1} resulted in an increase in straw yield even with increasing temperature.

Grain yield components: The effect of increasing temperature on grain yield components is shown in Table 4, 5 and 6.

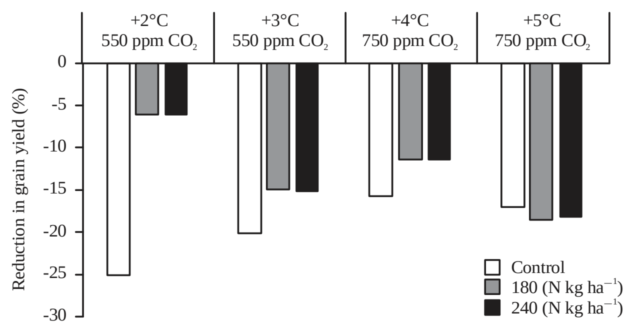

Fig. 4: Reduction in grain yield as affected by different climate change scenarios

Table 1: Final values of genetic coefficients used in the study for cultivar Giza 168

Cultivar coefficients after calibration using Gen Calc software	
P1V	0.000
P1D	52.500
P5	470.800
G1	11.750
G2	43.250
G3	1.625
PHINT	114.000

P1V: Days required for vernalization under optimum vernalizing temperature, P1D percentage: Reduction in rate/10 h drop in photoperiod relative to that at threshold which is 20 h, P5: Grain filling phase duration (°Cd), G1: Kernel number per unit canopy weight at anthesis (# g^{-1}), G2: Standard kernel size under optimum conditions (mg), G3: Standard and non-stressed mature tiller weight (including grain) (g d.wt.), PHINT: Interval between subsequent leaf tip appearances (°C.day)

Table 2: Grain yield (kg ha^{-1}) as affected by different climate change scenarios

N kg ha^{-1}	Observed	Simulated	+2°C 550 µmole mole^{-1} CO_2	+3°C 550 µmole mole^{-1} CO_2	+4°C 750 µmole mole^{-1} CO_2	+5°C 750 µmole mole^{-1} CO_2
Control	1485	1207	902	962	1015	999
180	4457	4421	4151	3748	3914	3599
240	4145	4421	4150	3747	3914	3610

Table 3: Straw yield (kg ha^{-1}) as affected by different climate change scenarios

N kg ha^{-1}	Observed	Simulated	+2°C 550 µmole $mole^{-1}$ CO_2	+3°C 550 µmole $mole^{-1}$ CO_2	+4°C 750 µmole $mole^{-1}$ CO_2	+5°C 750 µmole $mole^{-1}$ CO_2
Control	5160	4375	3650	3453	3514	2976
180	10193	10300	8838	8625	9396	7954
240	10555	10803	8887	8647	9414	8032

Table 4: Number of tillers m^{-2} as affected by different climate change scenarios

N kg ha^{-1}	Observed	Simulated	+2°C 550 µmole $mole^{-1}$ CO_2	+3°C 550 µmole $mole^{-1}$ CO_2	+4°C 750 µmole $mole^{-1}$ CO_2	+5°C 750 µmole $mole^{-1}$ CO_2
Control	223	216	214	204	202	184
180	300	276	286	268	264	250
240	275	276	286	268	264	250

Table 5: Number of grains/spike as affected by different climate change scenarios

N kg ha^{-1}	Observed	Simulated	+2°C 550 µmole $mole^{-1}$ CO_2	+3°C 550 µmole $mole^{-1}$ CO_2	+4°C 750 µmole $mole^{-1}$ CO_2	+5°C 750 µmole $mole^{-1}$ CO_2
Control	18	21.4	18.0	17.1	17.0	15.8
180	35	37.1	33.6	32.4	34.3	33.3
240	40	37.1	33.6	32.4	34.3	33.4

Table 6: 1000 grains weight as affected by different climate change scenarios

N kg ha^{-1}	Observed	Simulated	+2°C 550 µmole $mole^{-1}$ CO_2	+3°C 550 µmole $mole^{-1}$ CO_2	+4°C 750 µmole $mole^{-1}$ CO_2	+5°C 750 µmole $mole^{-1}$ CO_2
Control	37	26	23	28	30	34
180	43	43	43	43	43	43
240	40	43	43	43	43	43

Table 7: Reduction in grain yield as affected by different climate change scenarios

N kg ha^{-1}	+2°C 550 µmole $mole^{-1}$ CO_2	+3°C 550 µmole $mole^{-1}$ CO_2	+4°C 750 µmole $mole^{-1}$ CO_2	+5°C 750 µmole $mole^{-1}$ CO_2
Control	-25.27	-20.30	-15.91	-17.23
180	-6.11	-15.22	-11.47	-18.59
240	-6.13	-15.25	-11.47	-18.34

Increasing temperature was negatively affected number of tillers m^{-2}, however, both number of grains/spike and 1000 grains weight were not negatively affected by increasing temperature. These findings demonstrated that the reduction in grain yield was mainly due to the reduction in number of tillers m^{-2}.

The present results about number of grain/spike are in Contrary with De Oliveira *et al.*[28], who reported that elevated CO_2 increases grain yield in wheat by enhancing grain number per spike. They stated that elevated CO_2 resulted in increased net leaf photosynthetic rate and availability of carbon assimilates to floret. This reduced the rates of floret death and increased the potential number of grains up to 42%. They suggested breeding of cultivars with a greater potential number of florets to have higher CO_2 fertilization effect under heat and terminal drought stress.

The negative impact of increased temperature on grain yield of wheat cultivar Giza 168 was evaluated using four temperature levels (Table 7 and Fig. 4). Giza 168 depicted decreased grain yield with the rise in temperature where the decrease was gradual as temperature increases. The decrease in grain yield was alleviated by nitrogen fertilizer as compared to the control treatment (without nitrogen fertilizer). However, increasing nitrogen fertilizer from 180-240 (N kg ha^{-1}) resulted in no alleviation in grain yield loss due to rising temperature. The effect of increased CO_2 on spring wheat simulated by CERES model showed a trend of increasing grain yield even with increasing temperature meaning that CO_2 act as compensating factor against rising temperature (Table 7 and Fig. 4). The current research work suggests that late sowing and/or sowing of long season varieties may alleviate the negative impact of global warming on wheat yield. Further studies are needed on many varieties and in many locations to ensure the adverse effect of climate change on wheat yield.

CONCLUSION

The results showed that increasing temperature to +2, +3, +4 and +5°C resulted in a remarkable decrease in grain yield. On the other hand, increasing concentration of CO_2 to 550 and 750 µmole $mole^{-1}$ resulted in an increase in grain yield meaning that CO_2 may mitigate the adverse impact of global warming on wheat grain yield. The loss in wheat grain yield in response to global warming was mainly due to the loss in both number of spikes m^{-2} and number of grain/spike even the weight of 1000 grains was not affected. It could be concluded that late sowing and long season varieties may counter the global warming based on the output of DSSAT cropping system model.

SIGNIFICANT STATEMENT

The current study showed that climate change will negatively affect wheat grain yield and CO_2 may mitigate the negative effect of climate change. Increasing the applied nitrogen fertilizers over the recommended dose (180 kg ha^{-1}) may not mitigate the adverse effect of global warming. Late sowing and long season varieties may be a strategy to mitigate the adverse effect of global warming based on DSSAT cropping system model.

REFERENCES

1. IPCC., 2001. Summary for Policymakers. In: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer and P.J. van der Linden *et al.* (Eds.)., Cambridge University Press, USA., pp: 944.
2. Khalil, F.A., H. Farag, G.S. El Afandi and S.A. Ouda, 2009. Vulnerability and adaptation of wheat to climate change in middle Egypt. Proceedings of the 13th Conference on Water Technology, March 12-15, 2009, Hurghada, Egypt, pp: 71-88.
3. Innes, P.J., D.K.Y. Tan, F. van Ogtrop and J.S. Amthor, 2015. Effects of high-temperature episodes on wheat yields in New South Wales, Australia. Agric. For. Meteorol., 208: 95-107.
4. Miao, Y., D.J. Mulla, W.D. Batchelor, J.O. Paz, P.C. Robert and M. Wiebers, 2006. Evaluating management zone optimal nitrogen rates with a crop growth model. Agron. J., 98: 545-553.
5. Tsuji, G.Y., G. Hoogenboom and P.K. Thornton, 1998. Understanding Options for Agricultural Production. Kluwer Academic Publishers, Dordrecht, The Netherlands.
6. Mall, R.K., M. Lal, V.S. Bhatia, L.S. Rathore and R. Singh, 2004. Mitigating climate change impact on soybean productivity in India: A simulation study. Agric. Forest Meteorol., 121: 113-125.
7. Banterng, P., A. Patanothai, K. Pannangpetch, S. Jogloy and G. Hoogenboom, 2006. Yield stability evaluation of peanut lines: A comparison of an experimental versus a simulation approach. Field Crops Res., 96: 168-175.
8. Chapman, S.C., G.L. Hammer, D.W. Podlich and M. Cooper, 2002. Linking Bio-Physical and Genetic Models to Integrate Physiology, Molecular Biology and Plant Breeding. In: Quantitative Genetics, Genomics and Plant Breeding, Kang, M.S. (Ed.). CABI Publishing, New York, pp: 167-188.
9. Phakamas, N., A. Patanothai, K. Pannangpetch, S. Jogloy and G. Hoogenboom, 2008. Dynamic patterns of components of genotype x environment interaction for pod yield of peanut over multiple years: A simulation approach. Field Crops Res., 106: 9-21.
10. Paz, J.O., C.W. Fraisse, L.U. Hatch, A.G.Y. Garcia and L.C. Guerra *et al.*, 2007. Development of an ENSO-based irrigation decision support tool for peanut production in the southeastern US. Comput. Electr. Agric., 55: 28-35.
11. Jones, J.W., G. Hoogenboom, C.H. Porter, K.J. Boote and W.D. Batchelor *et al.*, 2003. The DSSAT cropping system model. Eur. J. Agron., 18: 235-265.
12. Gordon, C., C. Cooper, C.A. Senior, H. Banks and J.M. Gregory *et al.*, 2000. The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley centre coupled model without flux adjustments. Climate Dynam., 16: 147-168.
13. Pope, V.D., M.L. Gallani, P.R. Rowntree and R.A. Stratton, 2000. The impact of new physical parametrizations in the Hadley centre climate model: $HadAM_3$. Climate Dynam., 16: 123-146.
14. Nakicenovic, N., J. Alcamo, G. Davis, B. de Vries and J. Fenhann *et al.*, 2000. IPCC Special Report on Emission Scenarios. Cambridge University Press, USA., Pages: 599.
15. IPCC-TGCIA., 1999. Guidelines on the use of scenario data for climate impact and adaptation assessment, version 1. Prepared by Carter, T.R., M. Hulme and M. Lal, Intergovernmental Panel on Climate Change, Task Group on Scenarios for Climate Impact Assessment, pp: 69.
16. Semenov, M.A., R.J. Brooks, E.M. Barrow and C.W. Richardson, 1998. Comparison of the WGEN and LARS-WG stochastic weather generators for diverse climates. Climate Res., 10: 95-107.
17. Hunt, L.A., S. Pararajasingham, J.W. Jones, G. Hoogenboom, D.T. Imamura and R.M. Ogoshi, 1993. GENCALC: Software to facilitate the use of crop models for analyzing field experiments. Agron. J., 85: 1090-1094.
18. Ibrahim, O.M., A.A. Gaafar, A.M. Wali, M.M. Tawfik and M.M. El-Nahas, 2016. Estimating cultivar coefficients of a spring wheat using GenCalc and GLUE in DSSAT. J. Agron., 15: 130-135.
19. Andarzian, B., M. Bannayan, P. Steduto, H. Mazraeh, M.E. Barati, M.A. Barati and A. Rahnama, 2011. Validation and testing of the AquaCrop model under full and deficit irrigated wheat production in Iran. Agric. Water Manage., 100: 1-8.

20. Singh, A.K., R. Tripathy and U.K. Chopra, 2008. Evaluation of CERES-wheat and CropSyst models for water-nitrogen interactions in wheat crop. Agric. Water Manage., 95: 776-786.
21. Amiri, E., M. Rezaei, M. Bannayan and S. Soufizadeh, 2013. Calibration and evaluation of CERES rice model under different nitrogen-and water-management options in semi-mediterranean climate condition. Commun. Soil Sci. Plant Anal., 44: 1814-1830.
22. Alexandrov, V.A. and G. Hoogenboom, 2000. The impact of climate variability and change on crop yield in Bulgaria. Agric. For. Meteorol., 104: 315-327.
23. Dettori, M., C. Cesaraccio, A. Motroni, D. Spano and P. Duce, 2011. Using CERES-wheat to simulate durum wheat production and phenology in Southern Sardinia, Italy. Field Crops Res., 120: 179-188.
24. Ozdogan, M., 2011. Modeling the impacts of climate change on wheat yields in Northwestern Turkey. Agric. Ecosyst. Environ., 141: 1-12.
25. Palosuo, T., K.C. Kersebaum, C. Angulo, P. Hlavinka and M. Moriondo *et al*., 2011. Simulation of winter wheat yield and its variability in different climates of Europe: A comparison of eight crop growth models. Eur. J. Agron., 35: 103-114.
26. Wheeler, T.R., P.Q. Craufurd, R.H. Ellis, J.R. Porter and P.V.V. Prasad, 2000. Temperature variability and the yield of annual crops. Agric. Ecosyst. Environ., 82: 159-167.
27. Asseng, S., P.D. Jamieson, B. Kimball, P. Pinter, K. Sayre, J.W. Bowden and S.M. Howden, 2004. Simulated wheat growth affected by rising temperature, increased water deficit and elevated atmospheric CO_2. Field Crops Res., 85: 85-102.
28. De Oliveira, E.D., J.A. Palta, H. Bramley, K. Stefanova and K.H.M. Siddique, 2015. Elevated CO_2 reduced floret death in wheat under warmer average temperatures and terminal drought. Front. Plant Sci., Vol. 6. 10.3389/fpls.2015.01010.