Journal of Applied Horticulture, 23(2): 101-105, 2021
https://doi.org/10.37855/jah.2021.v23i02.19

Journal
of Applied
Horticulture
ISSN: 0972-1045

Impact of climate change on water use, growth and production of tomato crop in Bahrain: A simulation case study

A.M.R. Abdel-Mawgoud[1,2]*, A.S. Tantawy[1], S.D. Abou-Hussein[1] and Y.N. Sassine[3]

*[1]Department of Vegetable Researches, Agricultural and Biological Research Division, National Research Center (NRC), 33 El-Buhouth st., 12622 Dokki, Giza, Egypt. [2]Agriculture Affair Agency, Ministry of Works, Municipalities Affairs and Urban Planning, Manama, Kingdom of Bahrain. [3]Department of Horticulture Production, Faculty of Agriculture and Veterinary Medicine, Lebanese University, Beirut, Lebanon. *E-mail: DR_Abdelmawgoud@yahoo.com.*

Abstract

This work aimed to study the response of tomato (*Solanum lycopersicum* L.) crop to different climate change scenarios using the AquaCrop simulation model. AquaCrop calibration was performed using data from a tomato crop transplanted on October 1, 2015 in the Kingdom of Bahrain's north. Crop yield production during the period from 2006 to 2015 was used for model testing using recorded climate data for the same period. Generated climate data for the periods of 2020-2030 and 2040-2050 using three climate models; namely, CNRS- CM, EC-Earth and GFDL with two climate scenarios RCP 4-5 and RCP 8-5 were used as inputs for AquaCrop for the specified periods compared with the reference period of 1986-2005. AquaCrop calibration showed good fitting with actual data (R^2= 0.93; RMSE= 0.6 t. ha^{-1}; NRMSE= 0.2 and d = 0.97) as well as with testing period for the yield of 2006-2015 (R^2= 0.85; RMSE= 0.33 t ha^{-1}; NRMSE= 0.093 and d = 0.936). All climate simulation models predicted an increase in both minimum and maximum air temperatures and CO_2 concentration. AquaCrop simulated the response of tomato plants as an increase in total biomass and yield production compared to the reference period. The crop water requirement was reduced due to a shorter crop cycle, which was predicted to be 12-17 days shorter depending on the climate scenario and simulated period.

Key words: AquaCrop, biomass, CO_2, temperature, *Solanum lycopersicum,* climate changes, tomato, yield, water use

Introduction

Nowadays, the world is experiencing many phenomena of climate change, such as floods, heatwaves, storms, and/or drought waves. The Intergovernmental Panel on Climate Change (IPCC) has reported some of these changes, which are happening with an accelerating rate (IPCC, 2001, 2007). Climate change is a worldwide concern, and its impact on food production may change the agricultural plans in many regions of the world. According to IPCC studies, the Middle Eastern countries, including Kingdom of Bahrain, will be among the most negatively affected by climate change, mainly through a high reduction in rainfall, an increase in temperature, and more frequent drought waves (IPCC, 2007). These phenomena will negatively affect agricultural production and food security in the region.

Moderate heat stress inhibits stomatal conductance and net photosynthesis in many plant species (Crafts-Brandner and Salvucci, 2002; Morales *et al.*, 2003) including vegetables which are sensitive to environmental extremes and may cause a reduction in crop yield (Peet and Wolfe, 2000; Hatfield *et al.*, 2008) due to failure in fruit setting (Foolad, 2005). Knowing that many vegetables are good sources of proteins, vitamins, and minerals, reduced crop yields will negatively affect human nutrition and wellbeing. Therefore, it is important to evaluate the crop response and consequent production under changing climate conditions, to present alternative solutions for decision-makers and farmers.

In this study, different predict scenarios of climate changes produced by three global climate models will be used as input in the plant growth model AquaCrop developed by FAO to study the effects of climate changes on tomato crop grown in Bahrain. AquaCrop model simulates yield response to water in some strategic crops such as tomato specially when water is a limiting factor. Tomato is one of the main growing crops in Bahrain with an average annual production of 4,114 tons (FAOstat, 2018).

AquaCrop model was used with many crops including tomato mainly to assess the effect of different irrigation strategies on the production with good predication results (Rinaldi *et al.*, 2011; Takcas *et al.*, 2018; Hendy *et al.*, 2019). However, simulated climate- change scenarios were not yet studied particularly for Bahraini agricultural system.

Material and methods

Description of AquaCrop model: AquaCrop (ver. 6.0) is a water-driven crop growth model which simulates crop biomass growth as a linear function of transpiration through the water productivity function (biomass per unit of water transpired) driven from FAO Paper No.33, relating yield to the consumed water. It simulates the green canopy cover and uses reference evapotranspiration ET0 and crop coefficient to calculate transpiration. Then, yield is calculated from the dry matter production and harvest index.

Field characteristics and agricultural procedures: Input data for AquaCrop model were adopted from standard agricultural procedures for growing tomato crop in Budayia area, Northern Governorate, Kingdom of Bahrain during the growing season of 2015. Input data included site specifications such as soil physical and chemical properties, as well as irrigation water quality, and tomato crop characteristics. Tomato (*Solanum lycopersicum* L.) seedlings of the hybrid Nawara 206 were transplanted at a five-leaf stage on 1st October 2015 at a distance of 0.5 m between plants, and 1.25 m between rows. Plants were fertilized as per recommended package of practices for the area by the authorities. Drip irrigation using water with an EC of 3400 ppm was applied at a rate of 3.0 $mm.day^{-1}.plant^{-1}$. Destructed samples were taken at one-month interval by selecting randomly three plants to be dried at 105 °C for three cycles of 12 hours each to determine the total dry weight.

Calibration and testing of AquaCrop model: Performance of AquaCrop in simulating total dry weight was evaluated by comparing simulated results against observed data from the growing season of 2015. AquaCrop model was set to work at the mode of "Calendar days" until the calibration process was completed then the mode was set to work on "Growing degree-days" for the testing periods and investigating the new predicted climate scenarios. During calibration, certain model parameters, such as soil layer wetness, were adjusted to make the simulation results match the observed values. The crop parameters used for calibration were date of planting, plant density, initial and maximum crop covers, number of days until 90 % of transplants recovery, days to reach maximum canopy cover, time to canopy senescence, time to maturity, time to flowering, duration of flowering, depth and time of maximum active root, and harvest index. It is noteworthy that unavailable crop parameters have been set by the model default values. Days to maximum CC were estimated visually. To validate the AquaCrop model, the model output was tested against the total yield expressed as dry matter production, for ten years (2006-2015), in the Kingdom of Bahrain. Performance of AquaCrop in simulating yield and total biomass was evaluated by comparing simulated results against observed data. The statistical indices used in the validation were: coefficient of determination (R^2), root mean square error (RMSE), normalized RMSE (NRMSE), and index of agreement *d* according to the following formula

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Predicted - Actual)^2}{n}}$$

$$NRMSE = \frac{\mathrm{RMSE\ X\ 100}}{n}$$

$$d = 1 - \frac{\sum_{i=1}^{n}(S_i - M_i)^2}{\sum_{i=1}^{n}(|S_i - \bar{M}| + |M_i - \bar{M}|)^2}$$

where, M_i and S_i are the measured and simulated values, $\overline{M}$ is the average of the M_i values, *n* is the number of measurements done. Model performance improves as RMSE goes toward zero. As (*d*) value gets closer to one, the better the agreement between measured and simulated values and *vice versa* (Willmott, 1982). The coefficient of determination R^2 explains the amount of the variance explained by the model in comparison to the observed values. Its value ranges from 0 to 1, with values close to 1 indicating a good model performance.

Planting procedures were set as mentioned earlier. Climate data of the weather station (26' 16" N) as the monthly average of the maximum and minimum temperatures, wind speed, and relative humidity, as well as daily precipitation for the period of 2006-2015, were used for calibration and testing stage.

The soil of the experimental site was loamy sand with the following characteristics: percentages of sand, silt and clay were 87.7, 5.4, and 6.9 %, respectively, volumetric water content at saturation= 38, field capacity= 14.6, plant permanent wilting point= 6.9, and hydraulic conductivity= 840 mm day^{-1}.

Initial soil and salinity conditions of AquaCrop were fixed at field capacity, with two layers of soil as 0.0-50.0 cm and 50.0-100.0 cm, of respective water contents 14.0 and 6.9 %, and an EC of 3.85 dS m^{-1}. Fertilization was set at a "very good" level.

Climate models: Data of three global climate models; namely, CNRM-CM5, EC-Earth, and GFDL-ESM2M, were generated for Budayia site (26°13'00.2" N, 50°27'27.9" E), and used as inputs for AquaCrop growth model. The predicated data of the three models were based on two scenarios of climate change, depending on predicted CO_2 concentration in the year 2100 (Representative Concentration Pathway) (RCP). The optimistic scenario is when CO_2 increase will cease at 550 ppm (RCP 4-5), and the dramatic one is when CO_2 will continue to rise above 900 ppm (RCP 8-5).

Simulation periods: AquaCrop model was run using the generated climate data with the two proposed scenarios for the periods of 1986-2005 (as a referenced period), 2020-2030, and 2040-2050.

Results and discussion

Model calibration and testing: The simulated output of AquaCrop model for the year 2015 is plotted against measured data of tomato crop grown in the same season (Fig. 1a). The results showed a good fitting of the two data (R^2= 0.93) with an RMSE value of 0.6 $t.ha^{-1}$, NRMSE of 0.20, and an index of agreement *d* of 0.971. The testing phase of the model using the yield data of the growing seasons 2006-2016 is shown in Fig. 1b. There was a quite good fitting between the two data (R^2 = 0.85). The calculated RMSE value of 0.33 $t.ha^{-1}$ indicated good forecasting with NRMSE of 0.093 and an index of agreement *d* of 0.936.

Forecasted climate factors: Climate patterns, as forecasted by the three climate models (Table 1), showed that while CO_2 concentration recorded 354 ppm in the reference period, it averaged 423 and 463 ppm for RCP 4-5 and RCP 8-5, respectively for the two periods of 2020-2030 and 2040-2050 in the specified location. Also, minimum and maximum temperatures in 2020-2030 and 2040-2050 were higher compared to the reference period (1986-2005) by about 0.9-1.9 and 1.1-2.2 °C, respectively. With the exception to the GFDL model output in the period of 2020-2030, annual rainfall is expected to be severely reduced by at least 30 %, reaching maximum reduction of 75 %, compared to the reference period of 1986-2005. Climate change has been recorded for many decades and temperature has increased at an average rate of 0.07 °C per decade since 1880; however, the average rate of increase since 1981 (0.18 °C) is more than twice (NOAA, 2019). It seems that the rainfall pattern is uncertain and depends on the model used. However, most expectations are reductions in the amount of precipitation, as previously reported (IPCC, 2008).

Simulation of crop responses to different climate scenarios: The output of the three models was used for creating climate files

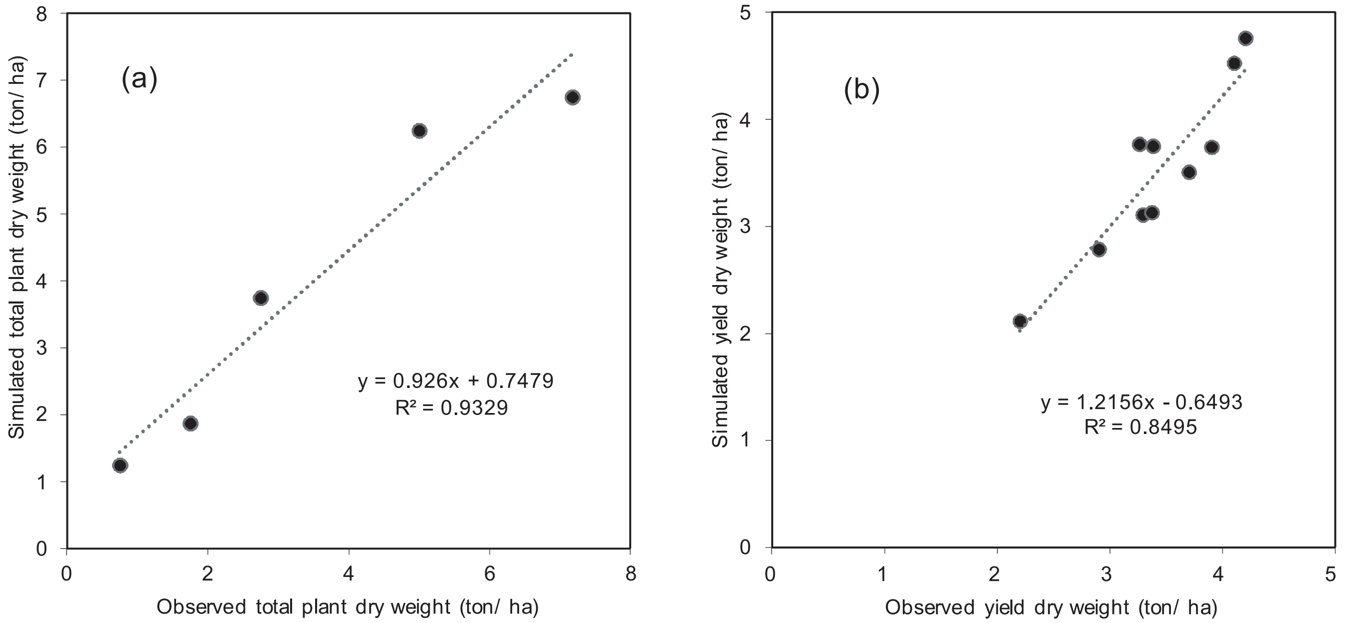

Fig. 1. Simulated *vs.* observed data of (a): tomato total dry weight of the growing season 2015, and (b): yield dry weight of the period 2006-2015

Table 1. Average of carbon dioxide (CO_2) concentrations, maximum and minimum temperatures, and annual precipitation recorded during the reference period (1986-2005) and forecasted by three climate models (CNRM, EC-Earth, and GFDL) for the two periods of 2020-2030 and 2040-2050.

Parameter / period		Reference period	CNRM		EC-Earth		GFDL	
		1986-2005	2020-2030	2040-2050	2020-2030	2040-2050	2020-2030	2040-2050
CO_2 Concentration (ppm)	RCP4-5	354	421	463	421	463	424	464
	RCP8-5	-	424	464	423	462	424	462
Maximum temperature (°C)	RCP4-5	34.1	35.4	35.9	35.6	36.3	35.2	35.6
	RCP8-5	-	35.5	35.9	35.8	36.5	35.3	36.3
Minimum temperature (°C)	RCP4-5	21.4	22.6	23.1	22.5	23.4	22.3	22.8
	RCP8-5	-	22.6	23.1	22.6	23.5	22.4	22.9
Precipitation (mm yr^{-1})	RCP4-5	42.1	18.5	26.4	14.4	18.1	52.4	25
	RCP8-5	-	24.3	29.6	10.6	22.6	52	18.8

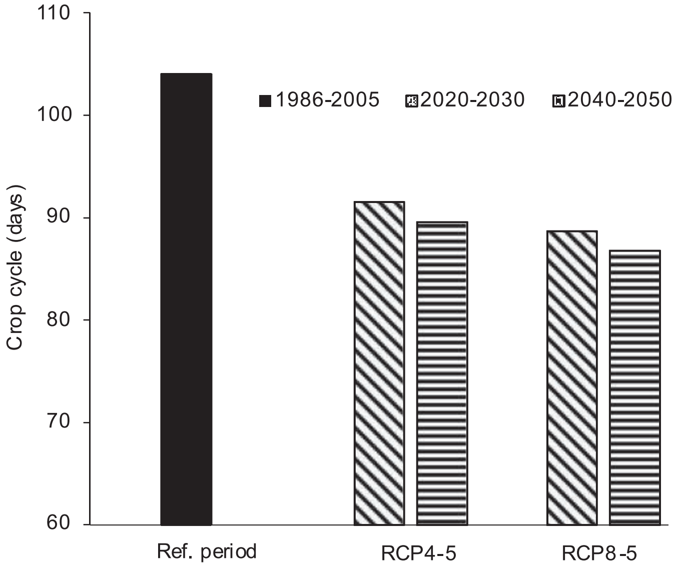

Fig. 2. Crop cycle (days) of tomato plants from transplantation to maturity, under two different RCP, compared to the reference period of 1986-2005

for the AquaCrop model. However, due to the small differences among the climate models in their forecasted CO_2 concentrations and maximum and minimum temperatures, the AquaCrop simulations were averaged for each RCP runs.

Fig. 2 shows that the crop cycle is forecasted to be reduced under RCP 4-5 and RCP 8-5, by 12-14 days and 14-17 days, for the periods of 2020-2030 and 2040-2050, respectively compared to the reference period. Crop growth and development are dependent on temperature, and the running mode of AquaCrop was set at growing degree days. Therefore, the forecasted increment in temperature by climate models resulted in faster development of the plant and shorter growth cycle with the observed shortest cycle under RCP 8-5 scenario. Many researchers have indicated an acceleration of crop life cycles as a result of rising temperature (Krug, 1997; Porter, 2005; and Hatfield *et al.*, 2008).

Total plant biomass production was improved as forecasted by the AquaCrop model under the two RCP scenarios for the two simulated periods compared to the reference one (Fig. 3). The increment in biomass production ranged from 8.6-12.9 % under RCP 4-5 and 5.7-1.6 % under RCP8-5 for the simulated periods of 2020-2030 and 2040-2050, respectively, compared to the reference period. The increment in biomass production with climate change contradicted previous studies of Guhan *et al.* (2019). However, this study has focused on climate change factors without changing the rate of irrigation to plants, which eliminates the factor of water stress and enables the growing plants to get benefit of the increment in CO_2 concentration. The stimulation of C3 photosynthesis in plants such as tomato is one of the most established aspects of rising CO_2 concentration, described in numerous studies and reviews (Bowes, 1996; Peet and Wolfe, 2000). The latter concluded that higher levels of CO_2 are likely to benefit most crops, provided temperatures are not limiting. The amount of rainfall in the studied area, as predicted by the climate models, is too small, making the changes in its pattern have a negligible effect on the growing plants, especially that the crop in the studied area is irrigation dependent. Hatfield *et al.* (2008) mentioned that it is necessary to have conditions of unrestricted root growth, optimum fertility, and excellent control of weeds, insects, and disease to maximize crop production benefits from increased atmospheric CO_2, and all these factors were at optimum in the AquaCrop model.

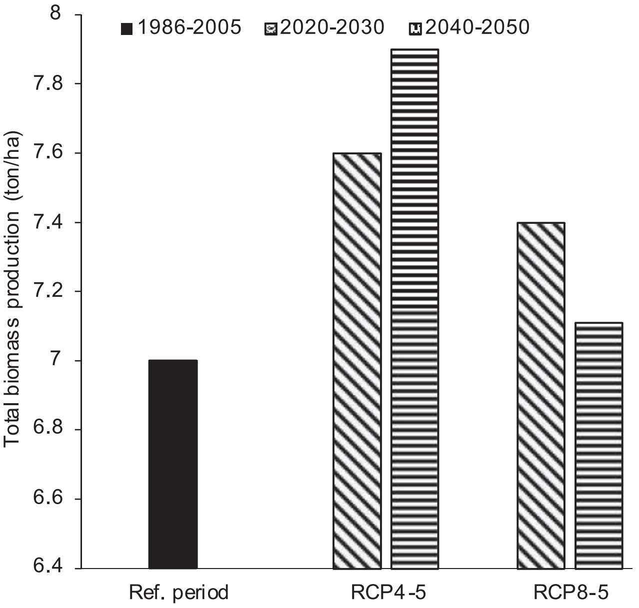

Fig. 3. Total biomass production by tomato plants as simulated by the AquaCrop model under two scenarios of climate change in two different periods compared with the reference period

A similar trend of biomass production was observed in the simulated yield expressed in dry weight (Fig. 4). Total yield dry weight increased under RCP4-5 by 9.1-13.7 % for the periods of 2020-2030 and 2040-2050 respectively, while it increased under RCP8-5 by 7.6-2.4 % for the periods of 2020-2030 and 2040-2050, respectively in comparison to the reference period. The AquaCrop model calculates the yield as a percentage of the total biomass using the harvest index of the crop (input variable by the user). Sanchez-Guerrero *et al.* (2009) reported a 19 % yield increase with cucumber from enriching greenhouse CO_2 concentration to 700 mole mol^{-1}. Krug (1997) commented that both growth rate and the rate of phenological development of vegetable crops will be accelerated by temperature and suggested that relatively larger effects on reproductive development than growth will result in smaller yields; and equivalent relative effects on both growth and reproductive development could result in a net effect of maintaining similar yields.

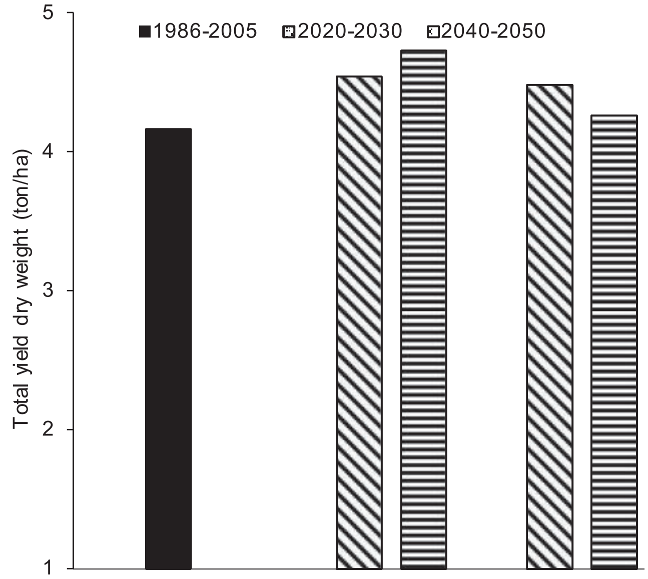

Fig. 4. Total yield of tomato plants as simulated by the AquaCrop model under two scenarios of climate change in two different periods compared with the reference period

However, in AquaCrop, crop yield is expressed as dry weight which does not indicate the quality of the fruit and whether it is marketable or not. Increment in temperature may reduce the quality of the fruits which can negatively affect its marketing chance. In addition, incidence of some physiological disorders to the fruits because of high temperatures such as blossom end rot may affect the partitioning of assimilates (Abdel-Mawgoud *et al.*, 2005), and this is not considered in the AquaCrop model.

Water productivity expressed by yield production in relation to evapotranspired water (Fig. 5) is predicted to be increased under both RCP scenarios during 2020-2030 by 12 and 7 % for RCP 4-5 and RCP 8-5, respectively, while it is forecasted to be reduced by 5 % or hardly remained the same during 2040-2050 for the scenarios RCP4-5 and RCP 8-5, respectively. The increment in water productivity in the period of 2020-2030 is consistent with the positive effect of CO_2 increase on plant biomass production observed earlier. This beneficial effect is diminished in the period of 2040-2050, probably because of the higher increment in average temperature, particularly under RCP 8-5 scenario.

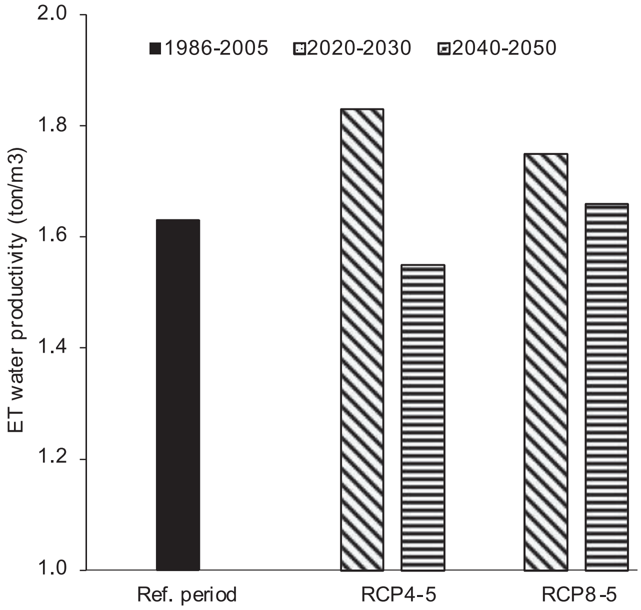

Fig. 5. ET Water productivity for yield expressed as yield (kg) produced per water evapotranspired (m^3)

The amount of water supply to the tomato crop (Fig. 6) is forecasted to be reduced by 12-15 % under RCP 4-5 and by 14-16.8 % under RCP 8-5 for the periods of 2020-2030 and 2040-2050, respectively in comparison to the reference period. This may be caused by a shorter crop growth cycle due to faster development rate under high temperatures. Döll (2002) mentioned

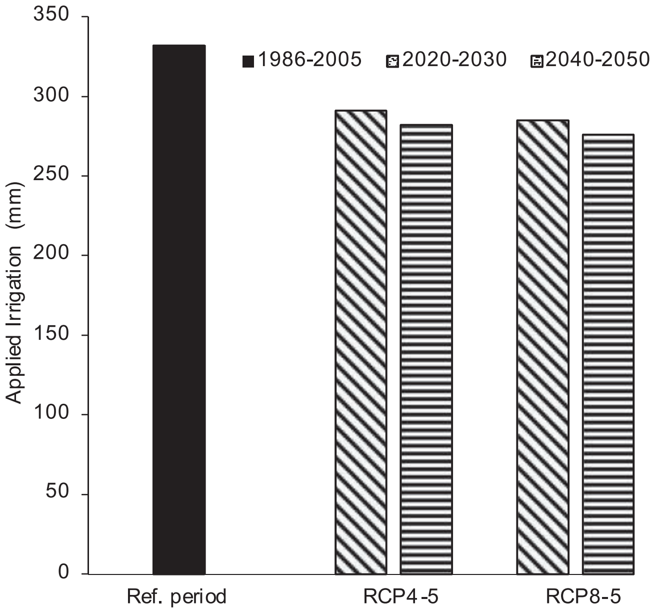

Fig. 6. Amount of applied irrigation as predicted by AquaCrop for tomato plants grown under two scenarios of RCP compared to the reference period of 1986-2005.

that irrigation requirements may positively or negatively differ (+2 to +15 % in the case of China, and by −6 to +5 % in the case of India), depending on emissions scenarios and climate model.

In conclusion, AquaCrop model is a powerful tool in predicting crop responses to different climate scenarios, in terms of biomass production. However, this does not mean that model output can be interpreted economically, because there is no guarantee that the predicted biomass production is going to be partitioned as expected neither that the produced yield is going to be marketable.

Acknowledgments

This work was carried out during a contracted period with Agriculture Affairs and Marine Resources, Ministry of Works, Municipalities Affairs and Urban Planning, Kingdom of Bahrain (2015-2021). Sincere thanks to FAO, ACSAD and ESCWA for providing a joint training course on AquaCrop model applications through “Promoting food and water security through cooperation and capacity development in the Arab region” project and providing predicated climate data. Thanks are extended to the Meteorological directorate, Ministry of Transportation and Telecommunications, Kingdom of Bahrain for providing the climate data of 2006-2015.

References

Abdel-Mawgoud, A.M.R., Y.N. Sassine, M. Böhme, A.F. Abou-Hadid and S.O. El-Abd, 2005. Sweet Pepper Biomass Production and Partitioning As Affected By Different Shoot and Root-Zone Conditions. *International Journal Botany*, 1(2): 151-157.

Bowes, G. 1996. Photosynthetic responses to changing atmospheric carbon dioxide concentration. p. 387-407. In: *Photosynthesis and the Environment,* N.R. Baker (ed.). Kluwer Publishing, Dordrecht, Netherlands.

Crafts-Brandner, S.J. and M.E. Salvucci, 2002. Sensetivity to photosynthesis in the C4 plant, maize to heat stress. *Plant Cell*, 12: 54-68

Döll, P. 2002. Impact of climate change and variability on irrigation requirements: a global perspective. *Climatic Change*, 54: 269-293.

FAOstat, 2018. http://www.fao.org/faostat/en/#data/QC

Foolad, M.R. 2005. Breeding for abiotic stress tolerances in tomato. In: *Abiotic Stresses: Plant Resistance Through Breeding and Molecular Approaches*. Ashraf, M., Harris, P.J.C. (Eds.). The Haworth Press Inc., New York, USA. p. 613-684.

Guhan, V., V. Geethalakshmi, R. Jagannathan, S. Panneerselvam, K. Bhuvaneswari, 2019. Assessing the impact of climate change in ponnaniyar basin of tamil nadu based on REGCM 4.4 simulations. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-3/W6, 2019. ISPRS-GEOGLAM-ISRS Joint Int. Workshop on “Earth Observations for Agricultural Monitoring”, 18-20 February 2019, New Delhi, India

Hatfield, J., K. Boote, P. Fay, L. Hahn, C. Izaunalde and B.A. Kimball, 2008. Agriculture In: *The effects of climate change on agriculture, land resources, water resources and biodiversity in the United States*. A report by the U.S. climate change science program and the subcommittee on Global change Research. Washington, DC, USA. Available at http://www/usda.gov/oce/global_change/files/CCSPfinal report.pdf.

Hendy, Z. M., S. M. Attaher, Salama, A. Abdelhady, A. A. Abdel-Aziz and A. M. El-Gindy, 2019. Irrigation and drainage simulation of the effect of deficit irrigation schemes on tomato crop production using AquaCrop model. *Misr J. Agri. Eng*., 36 (1): 175 - 194

IPCC (Intergovernmental Panel on Climate Change), 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson, Eds., Cambridge University Press, Cambridge, 881 pp.

IPCC (Intergovernmental Panel on Climate Change), 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Core Writing Team, R.K Pachauri and A. Reisinger, Eds., IPCC, Geneva, 102 pp. https://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml

IPCC (Intergovernmental Panel on Climate Change), 2008.“climate change and water” Technical report, Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds. IPCC Secretariat, Geneva, 210 pp. June 2008. https://www.ipcc.ch/publications_and_data/publications_and_data_technical_papers.shtml

Krug, H. 1997. Environmental influences on development, growth and yield. In: *The Physiology of Vegetable Crops*. Wien, H.C. (ed.)CAB International, Wallingford, UK, pp. 101-180.

Morales, D., P. Rodr´ıguez, J. Dell’amico, E. Nicol´as, A. Torrecillas and M.J. S´anchez-Blanco, 2003. High-temperature preconditioning and thermal shock imposition affects water relations, gas exchange and root hydraulic conductivity in tomato. *Biol. Plant.,* 47: 203-208.

NOAA, 2019. National Oceanic and Atmospheric Administration, USA. https://www.noaa.gov/climate

Peet, M.M. and D. Wolfe, 2000. Vegetable crop responses to climatic change. In: *Climate Change and Global Crop Productivity*. Reddy, K.R., Hodges, H.F. (eds). CABI Publishing: Wallingford, UK. pp 213-243.

Porter J.R. 2005. Rising temperatures are likely to reduce crop yields. *Nature*, 436:174.

Rinaldi, M., P. Garofalo, P. Rubino and P. Steduto, 2011. Processing tomatoes under different irrigation regimes in Southern Italy: agronomic and economic assessments in a simulation case study. *Italian Journal Agrometeorology,* 3: 39-59.

Sanchez-Guerrero, M.C., P. Lorenzo, E. Medrano, A. Baille and N. Castilla, 2009. Effects of EC-based irrigation scheduling and CO2 enrichment on water use efficiency of a greenhouse cucumber crop. *Agric. Water Manag.,* 96: 429-436.

Takács, S., L.A. Tuan, E. Csengeri and T. Molnár, 2018. Application of AquaCrop in processing tomato growing and calculation of irrigation water. *Acta Agraria Debreceniensis,* 74: 183-187.

Willmott, C.J. 1982. Some comments on the evaluation of model performance. *Bull. Am. Meteorol. Soc.,* 63: 1309-1313.

Received: October, 2020; Revised: December, 2020; Accepted: December, 2020