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Implementation of the AquaCrop Model for Forecasting the Effects of Climate Change on Water Consumption and Potato Yield Under Various Irrigation Techniques

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ABSTRACT

In this study, the AquaCrop model was employed to analyze the impact of projected future climate changes on the water usage and biomass production of potato crops in Babylon, Iraq, under varying irrigation methods. The irrigation techniques evaluated included sprinkler irrigation, surface drip irrigation, and subsurface drip irrigation at depths of 10 cm and 20 cm. The study involved simulating and forecasting conditions for the year 2050, comparing them to current conditions. The model measured and predicted the evapotranspiration (ETa) and actual biomass of potato crops for 2050 using the RCP 8.5 scenarios, which outline different trajectories for greenhouse gas emissions. The AquaCrop model was calibrated and validated using statistical measures such as the R2, RMSE, CV, EF, and D, achieving a 99% accuracy level in its performance. The findings suggest that using drip irrigation systems and applying the AquaCrop model significantly mitigates the adverse effects of environmental stress on desert soils and enhances sustainable agricultural practices in arid regions.

INTRODUCTION

The potato crop (Solanum tuberosum L.) is one of the four most important crops in the world in terms of nutritional importance after wheat, corn, and rice. It tops the tuberous crops. It is believed that the original home of potatoes is the Andes mountains in Bolivia. The southern coast of Chile is its original home. Production is 388,191 million tons worldwide, increasing by 15.5% on an area of 19.303 million hectares (FAO, 2017). Potatoes occupy a large place in global agriculture and contain approximately 80% water, 2% protein, and 18% starch (Qasim et al. 2013). Mohammed et al. (2019) referred to the shift from sprinkler irrigation systems of different types and lawn irrigation to the subsurface drip irrigation system for large areas of corn cultivation in the US. The process has been going on successfully for more than 10 years and production has been increased saving the amounts of water used by 35-55% compared to sprinkler and irrigation systems. In a study conducted by Hassan et al. (2020) to compare the drip irrigation system surface and subsurface, there was a clear effect in the removal of salts from part of the soil parts and keeping it outside the root zone, which contributed to alleviating the effect of osmotic pressure on the plant. It led to an increase in production per unit area and an increase in water use efficiency (Bamohani 2011).

Patel et al. (2010) found that the simulated AquaCrop software with the measured above-ground values after the main crop growth stages during the period 2009-2010 found that the simulated values above-ground dry biomass are in good agreement with the measured values with a low mean error. The corresponding values of the different coefficients were also well simulated with the measured yield giving correlation coefficients of 0.74 and 0.72. A leaf area index and the use of values of water productivity that are validated to demand atmospheric evapotranspiration and concentration of CO_2 give the model the ability to extrapolate to diverse locations and seasons. Although the model is simple, it pays special attention to the basic processes involved in crop productivity and responses to water, from a perspective of the physiological and agricultural background of the plant. The researcher also obtained a significant response and a good comparison by AquaCrop in simulating the productivity of the potato crop under full irrigation and water deficit (when 80 and 60% of the available water is depleted). In simulating production under extreme water stress, the model had less of an impact (Hassan et al. 2023, Ali et al. 2021, Steduto et al. 2009). It is very helpful for designing and evaluating under-irrigation strategies and water management options, as well as for researching the effects of site, soil type, irrigation management, and seeding history on plant production in semi-digestive and irrigated agriculture because AquaCrop can simulate moderate water stress of a potato crop under dry conditions that occur at different stages of growth. By utilizing the AquaCrop model, the study aims to assess the canopy cover and its impact on crop growth, water consumption, and overall agricultural productivity in Babylon governorate. This evaluation will provide valuable insights into the suitability of AquaCrop for estimating these variables in this specific region Mohammed et al. (2022).

MATERIALS AND METHODS

Sampling

The field study carried out in the Medhatiya area of Babylon Governorate during the spring of 2021 examined the soil properties of a private plot. Results detailing the soil particle size distribution are presented in Table 1.

Water Consumption

The values of meteorological data can be obtained from the Meteorological Department of the Iraqi Ministry of Agriculture. On land used for agriculture, an experiment was conducted. After that, it was separated into three major sectors, with a 2 m gap between each section. Twelve experimental units, each measuring 4 by 4 meters, were separated into each area. On January 10, 2021, potato seeds were planted, with each tuber being 0.25 m apart and 0.10 m deep. According to the recommended fertilizer amounts of 100 kg P H^{-1} and 300 kg K H^{-1}, the experimental area was treated with triple superphosphate fertilizer (20% P) before planting. According to the fertilizer guideline of 300 kg N H^{-1}, urea fertilizer (46% N) was added in three batches: the first after 20 days of planting, the second after 30 days, and the third after 25 days of the second batch (Soil Survey Staff, 2016). On December 5, 2021, potato tubers were physically removed.

Table 1: Properties of experimental soil during the seasons of 2016 and 2017.

Characteristic		2016	
		Soil depth	
		0-30 cm	30-60 cm
Ece	DSM^{-1}	2.65	2.7
PH		7.6	7.7
Sand	$g.kg^{-1}$	762	705
Silt		137	145
Clay		101	150
$CaCO_3$	$g.kg^{-1}$	280	291
OM		4.51	2.37
CEC	$Cmol.kg^{-1}$	16.31	18.45
N	$mg.kg^{-1}$	23.42	19.32
P		12.21	11.72
K		121.32	117.47
Ca^{++}	$meq .L^{-1}$	14.62	12.22
Mg^{++}		9.73	8.23
Na^{+}		4.41	5.18
k^{+}		3.24	2.07
SO_4^{-2}		14.61	13.25
HCO_3^{-1}		3.19	2.67
Cl^{-1}		14.30	11.09
Bulk Density		1.39	1.45
Total Porosity	%	47	44
Water Content at 1500 kPa		0.10	
Water Content at 33 kPa	$cm^3.cm^{-3}$	0.30	
Available Water		0.20	

Statistical Comparison

Five statistical measures were applied to test the performance of the model and compare the simulated and measured results.

First is the root mean square error (RMSE):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Si - Mi)^2} \quad ...(1)$$

Where Si and Mi are simulated and measured values, respectively, and n is the number of observations.

Second is the coefficient of determination (R^2):

$$R^2 = \frac{\sum Si\ Mi\ - \sum Si + \sum Mi}{\sqrt{\sum Si^2 - (\sum Si)^2} x \sqrt{\sum Mi^2 - (\sum Mi)^2}} \quad ...(2)$$

Third is the mean bias error (MBE):

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(Si\ Mi) \quad ...(3)$$

Fourth is the index of agreement (d):

$$d = 1 - \frac{\sum_{i=1}^{n}(Si - Mi)^2}{\sum_{i=1}^{n}(Si - \bar{M}| + Mi - \bar{M}|)^2} \quad ...(4)$$

Where: $\overline{M}$ is the mean of the n measured values. The value of d ranges from -∞ to 1.0.

Fifth is the Coefficient of Efficiency (E):

$$E = 1 - \frac{\sum_{i=1}^{n}(Si - Mi)^2}{\sum_{i=1}^{n}(Mi - \bar{M})^2} \quad ...(5)$$

RESULTS AND DISCUSSION

Predictable Water Consumption of the Potato Crop

When comparing the base period with the period (2050),

Table 2 and Fig. 1 show the actual water consumption of the potato crop and for all study coefficients of difference in irrigation methods according to the two scenarios (RCP 4.5) and (RCP 8.5). There is a significant increase in the consumption values of water for the period when compared with the base period. The actual water used by the potato crop varied from 215 to 326 mm, whereas the water used in the first scenario was between 242 and 380 mm. This represents an absolute difference of 27-54 mm and a relative change of between 12.56% and 16.56)%. for the scenario (RCP 4.5) when comparing the base period with the period (2050). In comparison to the water consumption of the first scenario, which ranged from 267-433 mm, the actual water consumption values for the potato crop ranged between 215 and 326 mm, with an absolute change ranging between 52 and 107 mm and a relative change ranging from 24.19 to 32.82% for the scenario (RCP 8.5). These results are consistent with previous research (Hassan et al. 2023, Jafaar et al. 2020, 2022, 2023).

Expected Biomass of the Potato Crop

Table 3 displays the actual biomass of the potato crop under various study treatments, comparing different irrigation methods across two scenarios, RCP 4.5 and RCP 8.5, between the baseline period and the year 2050. It is evident from the table that there is a notable reduction in biomass values for the future period compared to the baseline**.** The actual biomass values of the potato crop ranged between 20.3 and 25.9 tons, compared to the biomass of the first scenario, which ranged between 24.3 and 17.1 tons, with an absolute change ranging between 1.6 and 3.2 tons, and a relative change ranging between 6.15 and 15.76% for the scenario RCP 4.5 when comparing the base period with the period 2050, and the actual biomass values of the potato crop ranged between 25.9 and 20.3 tons compared to the biomass of the first scenario, which ranged between 13.1 and 21.5 tons, with an absolute change that ranged between 4.4 and 7.2 mm and a relative change ranging between 16.99 and 35.47% for the scenario RCP 8.5 when comparing the base period with the period 2050.

The results confirm that the production of the potato crop will decrease in the future (2050), as the potato crop will be affected by climate changes with the temperature rise, which will increase in the flowering stage, which is a sensitive stage, which will lead to an increase in water consumption at this stage. The deterioration of the productivity of yellow

Table 2: Water consumption for RCP4.5 and RCP8.5 till 2050.

No.	RCP 4.5					RCP 8.5			
	Treatment	Base period	2020 - 2030	Absolute change	Relative change	Base period	2020 - 2030	Absolute change	Relative change
1	Spr	326	380	54	16.56	326	433	107	32.82
2	Drip S	298	345	47	15.77	298	390	92	30.87
3	Drip Sub1	245	282	37	15.1	245	310	65	26.53
4	Drip Sub2	215	242	27	12.56	215	267	52	24.19

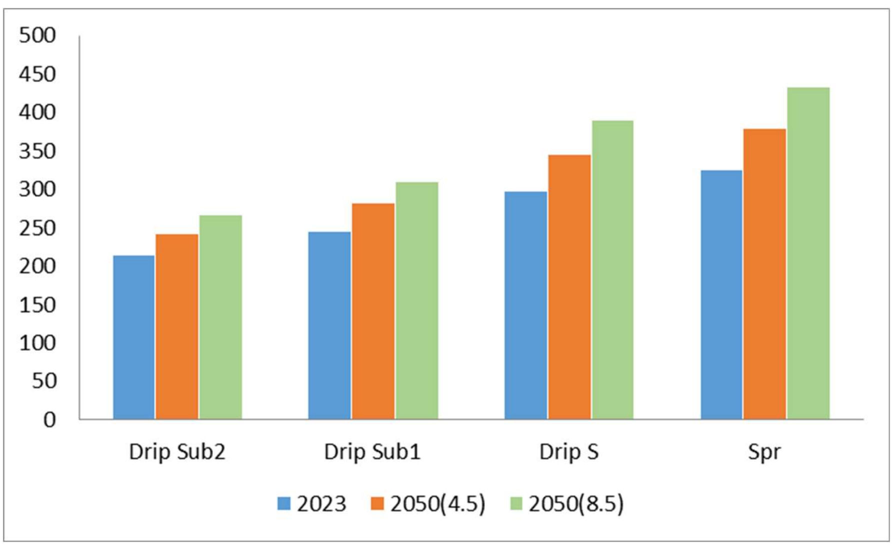

Fig. 1: Water consumption for RCP4.5 and RCP8.5 till 2050.

Table 3: Biomass RCP4.5 and RCP8.5 for (2050) compared to the base period.

No	RCP 4.5					RCP 8.5			
	Treatment	Base period	2020-2030	Absolute change	Relative change	Base period	2020-2030	Absolute change	Relative change
1	Spr	20.3	17.1	3.2	15.76	20.3	13.1	7.2	35.47
2	Drip S	22.1	19.5	2.6	11.76	22.1	16.6	5.5	24.89
3	Drip Sub1	24.5	22.3	2.2	8.98	24.5	19.4	5.1	20.82
4	Drip Sub2	25.9	24.3	1.6	6.18	25.9	21.5	4.4	16.99

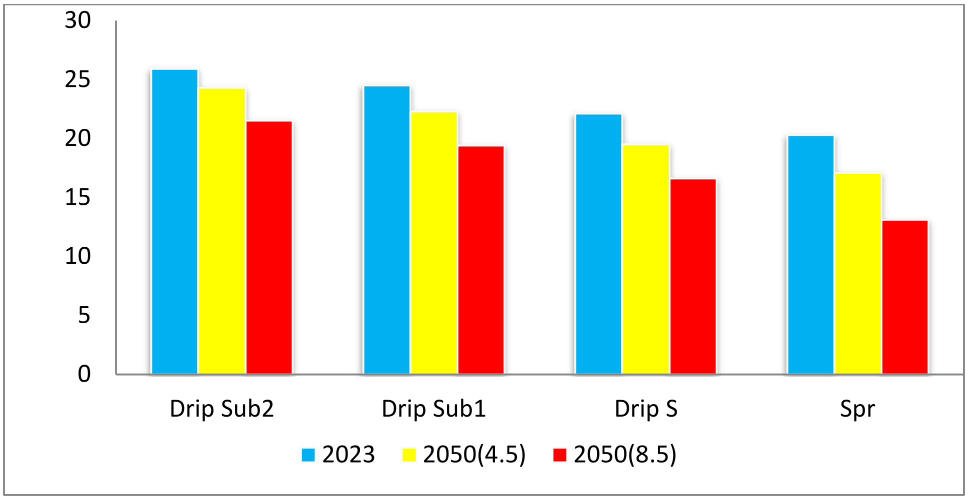

Fig. 2: Biomass for RCP4.5 and RCP8.5 till 2050.

corn is related to several factors, the most important of which is water consumption, which will increase in the future, and requires the availability of additional quantities of water. Therefore, the trend for irrigation methods such as sprinklers and drip will work to reduce the amount of water consumed. It was also noted through the results that the predictions were significantly affected by biomass and water consumption with climate change. It was also found that there are significant differences when comparing the two scenarios, as a decrease in productivity and an increase in water consumption is noted when the concentration of carbon dioxide increases, i.e. in the RCP8.5 scenario compared to the RCP4.5 scenario, and therefore these results confirm that the calibration performance and validity of the (AquaCrop) model for evaluating The effect of climatic changes on the productivity and water consumption of the crop, as it was logical and can predict good crop productivity, water consumption and other characteristics of the crop. The increase in carbon dioxide concentration as a result of climatic effects and depending on the climate change scenarios RCP4.5 and RCP8.5 for future periods had negative effects on biomass and actual water consumption, as the value of water consumption increased and the yield decreased as a result of the impact of climate change compared to the values of the reference period, and this is consistent with what it was found by Yibrah et al. (2015), Bitri et al. (2014). Water availability and production are important factors in climate change adaptation. To evaluate the effects of climate change and produce outputs, global and regional climate models have been utilized as decision-support tools. Current and future climate data are vital for simulating crop results and assessing the effects of climate change on crop yields, water balance, and food security. Climate change influences water resources by modifying the volume, variability, timing, pattern, and intensity of rainfall. It also influences the water cycle and photosynthesis in plants. Additionally, crop growth can be directly affected by factors such as relative humidity, wind speed, soil temperature, and evapotranspiration, or indirectly through their effects on a plant's physiological processes. The movement of water in the root zone and the soil moisture balance are similarly affected. Crop models, like the AquaCrop model, can be used to assess and simulate soil water balance in different soil strata under varying climatic circumstances and management techniques (Raes et al. 2006, Raes et al. 2011, Akol et al. 2021). Water coming from rain or irrigation is lost as a result of evaporation and transpiration on the soil surface. These models take into account weather factors that directly or indirectly affect the water balance in the soil, as the effects of climate change on the water balance will lead to changes in soil water storage and water level. groundwater, the level and condition of soil moisture, and can provide some information about irrigation quality, and may reduce the growth period of future crops affecting biomass and actual water consumption (Kang et al. 2009), however the effects of soil moisture resulting from climate change through the practices of modern technologies and the cultivation of varieties resistant to climate change.

Canopy Cover

The RMSE values reached 0.038 for the sprinkler irrigation treatment, 0.028 for the surface drip irrigation treatment, and 0.040 for the treatment, according to the results of the simulated Canopy Cover values and the measured Canopy Cover (Figs. 3 a,b,c,d). Drip irrigation covered a surface area of 10 cm and cost 0.034. The R2 values for all irrigation treatments for the sub-surface drip irrigation treatment

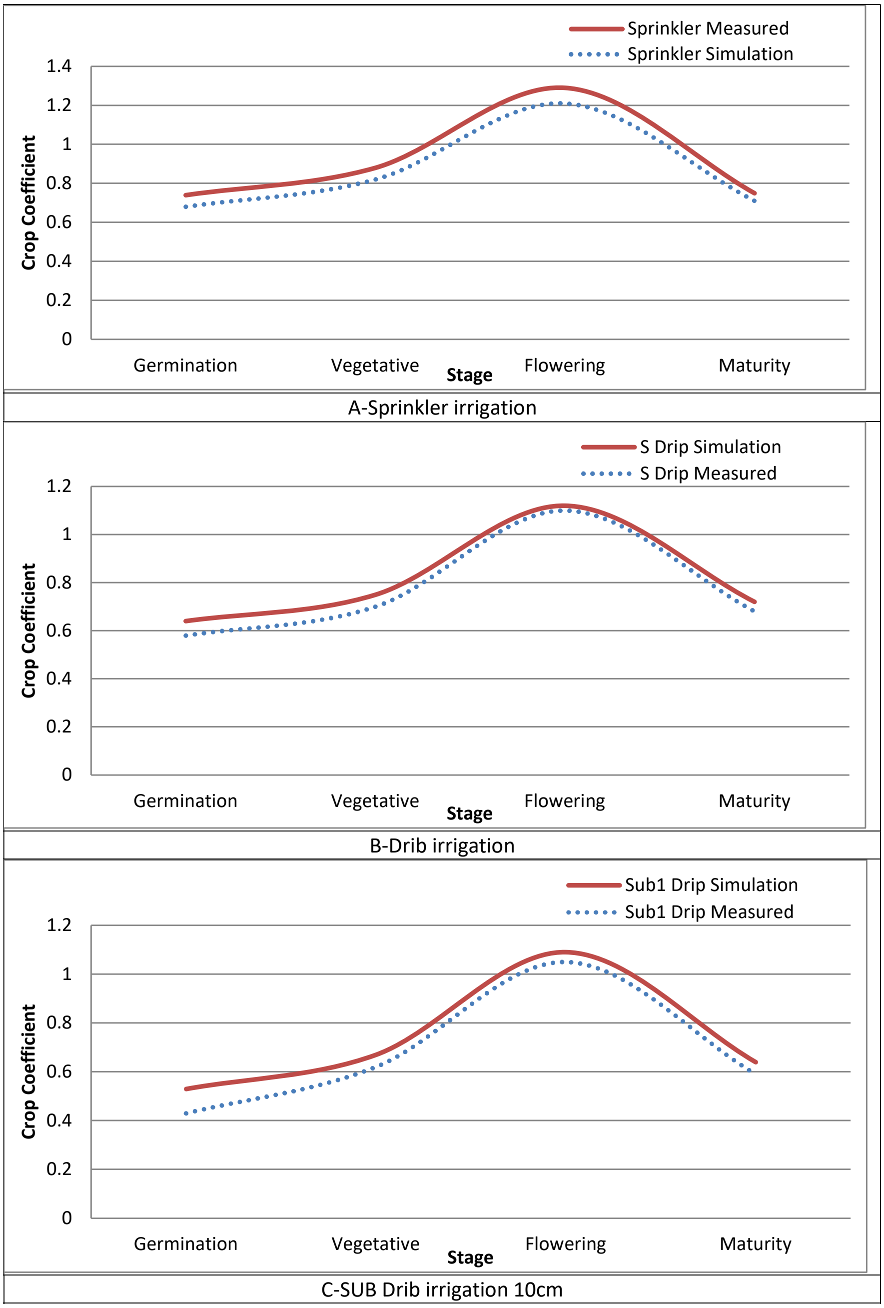

Figure Cont....

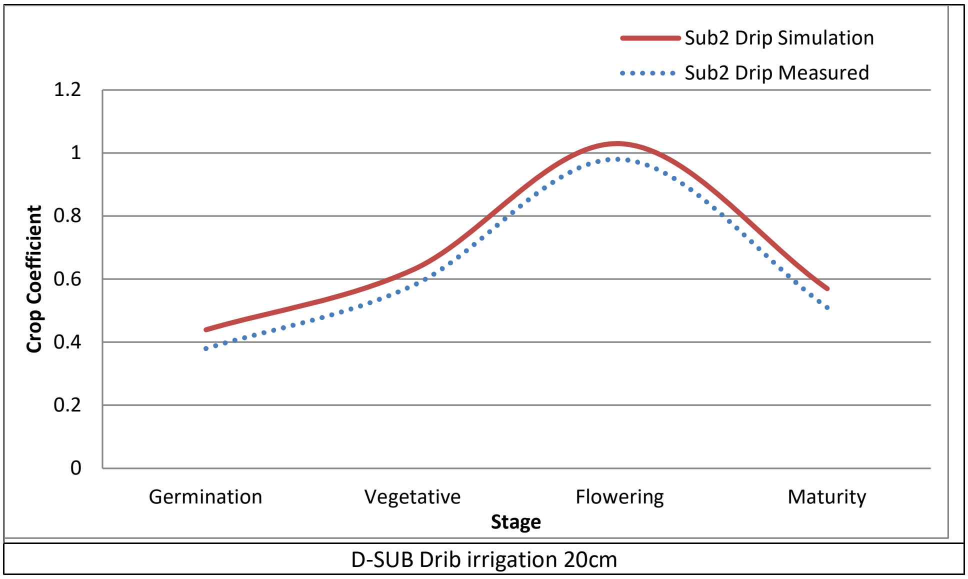

Fig. 3: Crop caver and canopy cover for methods of irrigation.

of 20 cm were 0.99, and the CV values for the sprinkler irrigation treatment were 0.045 and 0.037 for the surface drip irrigation treatment, and 0.060 for the sub-surface drip irrigation treatment of 10 cm and 0.057, respectively for 20 cm of subsurface drip irrigation treatment. For all irrigation treatments, both the EF and d values were 0.99. All irrigation treatments had EF values of 0.99. One of the reasons for the compatibility is that the phenology of potatoes adapts effectively to various climatic situations, with temperature, sun brightness, and growth duration among the major determining elements. As a result, the cultivation environment must change the inputs for vegetative cover (Pawar et al. 2017). The percentage of the soil surface covered by vegetation is measured by the canopy cover index (CC), which varies from a value of (0) when seeds are sown (or when 0% of the soil surface is covered) to a maximum value at the middle of the season, which can reach up to a value of (1) if a cover is achieved. Based on the leaf area index, the entire soil surface is covered by vegetation (100%). AquaCrop tracks the stresses that can arise in the root zone, which can affect the growth of leaves and subsequently the development of vegetation, through the daily computation of soil moisture. Moreover, if these pressures are strong, they may produce plant leaf yellowing. For the model to generate accurate predictions that take into account both the actual evapotranspiration and biomass discovered during the current investigation, this variable must be well-estimated. The Aquacrop model's simulated values for irrigation parameters were compared to measured values using the index (CC) (Greaves and Wang 2016, Ali et al. 2021).

CONCLUSIONS

AquaCrop is employed to increase water production for various irrigation techniques. There is good agreement between the measured and simulated vegetation. This study demonstrates how subsurface irrigation techniques are better than other irrigation techniques. The RCP4.5 and RCP8.5 climate change scenarios show a clear influence of future climatic changes on agricultural output. According to the RCP4.5 scenario and the RCP8.5 scenario, there will be an increase in annual and seasonal rainfall as well as a rise in maximum and minimum temperatures over the two time periods (2030) and (2050) compared to the base period (1985-2005).

REFERENCES

Akol, A.M., Nassif, N., Jaddoa, K.A., Radhi, K. and Hassan, D.F. 2021. Effect of irrigation methods, tillage systems, and seeding rate on water consumption, biological yield, and harvest index of wheat (Triticum aestivum L.). Int. J. Agric. Stat. Sci., 1: 17.

Ali, Z.A., Hassan, D.F. and Mohammed, R.J. 2021. Effect of irrigation level and nitrogen fertilizer on water consumption and faba bean growth. In: IOP Conference Series: Earth and Environmental Science, 722(1): 012043.

Bamohuni, S. 2011. Design proposal of drip irrigation system for an efficient management of irrigation water for maize improved seeds production in a part of seeds farm of loumbila. Univ. Stud. Firen. Facol. Agrar., 11: 33-40.

Bitri, M., Grazhdani, S. and Ahmeti, A. 2014. Validation of the aqua crop model for full and deficit irrigated potato production in the environmental condition of Korca Zone, South-eastern Albania. Int. J. Innov. Res. Sci. Eng. Res. Sci. Eng. Technol., 3: 12013-12020.

FAO. Food and Agriculture Organization of United Nations. Food Outlook, Need for External Assistance; June 2017.

Greaves, G.E. and Wang, Y.M. 2016. Assessment of FAO aqua crop model for simulating maize growth and productivity under deficit irrigation in a tropical environment. Water, 8: 557. doi: 10. 3390/w8120557.

Hassan, D., Thamer, T., Mohammed, R., Almaeini, A. and Nassif, N. 2020, November. Calibration and evaluation of aquacrop model under different irrigation methods for maize (Zea mays L.) in central region of Iraq. In: Conference of the Arabian Journal of Geosciences, pp. 48-43. Cham: Springer Nature Switzerland.

Hassan, D.F., Ati, A.S. and Naima, A.S. 2023. Evaluation of the performance of the aqua crop model under different irrigation and cultivation methods and their effect on water consumption. Iraq. J. Agric. Sci., 54(2): 478-490.

Jafaar, A.A., Mohammed, R.J. and Hassan, D.F. 2022. Effect of phosphorus fertilizer and irrigation level on desert soil management and potato yield. Int. J. Agric. Stat. Sci., 18(2): 609.

Jafaar, A.A., Mohammed, R.J., Hassan, D.F. and Thamer, T.Y. 2023. Effect of foliar seaweed and different irrigation levels on water consumption, growth and yield of wheat. In: IOP Conference Series: Earth and Environmental Science, 1252(1): 012057.

Kang, Y., Khan, S. and Ma, X. 2009. Climate change impacts on crop yield, crop water productivity, and food security: a review. Prog. Nat. Sci., 19: 1665-1674.

Mohammed, R.J., Abdulkadhim, K.A., Hassan, D.F. and Kadhim, T.F. 2019. Effect of wheat straw as organic matter and different water quality on some chemical soil properties and growth of pepper (Capsicum annuum). In: IOP Conference Series: Earth and Environmental Science, 344(1): 012034.

Mohammed, R.J., Hameed, I.A. and Thamer, T.Y. 2022. Effect of using different types of well water in Karbala Governorate on soil and plant. Ecological Engineering & Environmental Technology, 2*3*.

Patel, N., Kumar P. and Singh, N. 2010. Performance evaluation of aqua crop in simulating potato yield under varying water availability conditions. Indian Agric. Res., 6: 56-63.

Pawar, G.S., Kale, M.U. and Lokhande, J.N. 2017. Response of aqua crop model to different irrigation schedules for irrigated cabbage. Agric. Res., 6: 73-81.

Qasim, M., Khalid, S., Naz, A., Khan, M.Z. and Khan, S.A. 2013. Effects of different planting systems on yield of potato crop in Kaghan Valley: A mountainous region of Pakistan. Agricultral Science, 4: 175-179.

Raes, D., Steduto P., Hsiao, T.C. and Fereres E. 2011. FAO crop water productivity model to simulate yield response to water: AquaCrop version 3.1 Plus.

Raes, D., Geerts, S., Kipkorir, E., Wellens, J. and Sahli, A. 2006. Simulation of yield decline as a result of water stress with a robust soil water balance model. Agric. Water Manag., 81: 335-357.

Soil Survey Staff, 2016. Keys to soil taxonomy. USDA, Natural Resources Conservation

Steduto, P., Hsiao, T.C., Raes, D. and Fereres, E. 2009. Aqua crop: The FAO crop model to simulate yield response to water: I. Concepts and underlying principles. Agron. J., 101: 426-437. doi:10.2134/agronj2008.0139s.

Yibrah, G., Araya, B. and Amsalu, N. 2015. Performance of aqua crop model in simulating tuber yield of potato (Solanum tuberosum L.) under various water availability conditions in Mekelle area, Northern Ethiopia. J. Nat. Sci. Res., 5: 5.