CJES
Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Impact of future climate change on land and water productivity for wheat crop (Wasit Governorate, Iraq)

Ammar Daham Ayada[1]*, Shatha Salim Majeed[2], Alaa Salih Ati[3]

1. Al-Farahidi University, Baghdad, Iraq
2. Ministry of Resources, Baghdad, Iraq
3. College of Agriculture Engineering Sciences University of Baghdad, Iraq

** Corresponding author's E-mail : drammar611@uoalfarahidi.edu.iq*

ABSTRACT
In AquaCrop model was used to calibrate and verify the performance of the winter wheat crop in south of Iraq Al-Suwaira Research Station using data recorded in period 1/1/2008 and 31/12/2017. The results showed an increase in both annual and monsoon rains at the mid and end century periods for both RCP4.5 and REP8.5 scenarios implementing model GFDL-ESM2M. The annual and monsoon rains decreased in the EC-Earth model for both the RCP4.5 and RCP8.5 scenarios, while increased slightly in the CNRM-CM5 model under RCP4.5 and dropped with RCP8.5. Highest yield was recorded at the base period (2.36 ton/hectare) during the simulation period. The water productivity increased compared to the base period 2040-2050, while it was equal for both base period and the period 2020-2030 and in the RCP8.5 scenario.

Keywords: Climate change , Water productivity, Aquacrop model.
Article type: Research Article.

INTRODUCTION
Wheat is considered as a very important crop in achieving food in Iraq, several programs were used to develop wheat cultivation and increase production for many years ago. The method of developing wheat cultivation was adopted through government support, where about one million hectares were used for wheat production. The study area (Al- Suwaira District, south of Baghdad) is one of the most important area that are famous for cultivating this crop. The climate of this region is hot, arid lowland , and the precipitation does not exceed 200 mm per year. Accordingly, irrigation is necessary for this area to avoid water stress and increase crop yield, as numerous researchers have reported that wheat is not sensitive to drought at different growth stages (Zhang & Oweis 1999; Sezen & Yazar 2008; Nassif *et al.* 2023; Al-Atrash *et al.* 2023). Its cultivation consumes a large amount of water resources worldwide (Geerts & Raes 2009; Andarzian *et al.* 2011), since the production depends almost entirely on irrigation, especially in dry conditions (Musick *et al.* 1994; Steven & Tolk 2009). Studying plant responses to different irrigation strategies in the field is challenging and expensive. In the same role, crop water productivity models are important to assess the effects of water on crop production (Heng *et al.* 2007; Farahani *et al.* 2009; Andarzian *et al.* 2011; Levidow *et al.* 2014; Hamza *et al.* 2021). The FAO AquaCrop is a simple, accurate, and easy to use model that can be used by water managers, water use organizations, economists, and policmakers to plan and analyze irrigation scenarios (Hsiao *et al.* 2009). Besides, the AquaCrop model predicts the yield response to water (Heng *et al.* 2009; Vanuytrecht *et al.* 2014). AquaCrop has been tested for different crops under many environmental conditions (Heng *et al.* 2009; Todorovic *et al.* 2009; Araya *et al.* 2010; Zeleke *et al.* 2011; Amoah *et al.* 2013; Ahmadi *et al.* 2015; Trombetta *et al.* 2016; Toumi *et al.* 2016). However, AquaCrop calibration and validation were focused on using experimental field data in this study. In Iraq several irrigation methods are used

Caspian Journal of Environmental Sciences, Vol. 22 No. 1 pp. 31-41 Received: May 15, 2023 Revised: Aug. 06, 2023 Accepted: Oct. 26, 2023
DOI: 10.22124/cjes.2023.7335

Publisher: University of Guilan,

to irrigate wheat crop (sprinkler irrigation, rain-fed, and surface irrigation). The northern and western region, which includes the governorates (Nineveh, Salah al-Din, Kirkuk, and Anbar) are among the governorates that specialized in cultivating this crop.

MATERIALS AND METHODS

The study was carried out in the AL-Suwaira district, a part of the Wasit Governorate of Iraq and its distance is 35 km south-east of Baghdad , located at latitude 32° 56’ 25” N and 044° 38’ 04” E (Fig. 1). Aquacrop model was used to calibrate and verify the performance of the winter wheat crop , using data recorded from the period of 1/1/2008 - 31/12/2017.

Table 1. The productivity of wheat for the Governorate of Wasit and AL-Suwaira district for the year 2016.

Total Production Of Iraq (thousand tons)	**Production of Wasit Governorate (thousand tons)**	**Its proportion To the total production**	**Production of AL-Suwaira District (study area) Thousand tons**	**Its proportion to the production of the province**
3052	631	% 20.7	136	% 20

The approved parameters and treatments used for the wheat crop

The parameters are divided into two parts: (i) Conservative Crop parameters, which are parameters that do not change significantly with the change of time, management procedures, geographical location, climate, and variety. Thus, they do not need to be calibrated; (ii) Variable (unstable) crop parameters that need to be modified when choosing a variety different from the one chosen when calibrating, or if the environmental conditions differ from those assumed when calibrating.

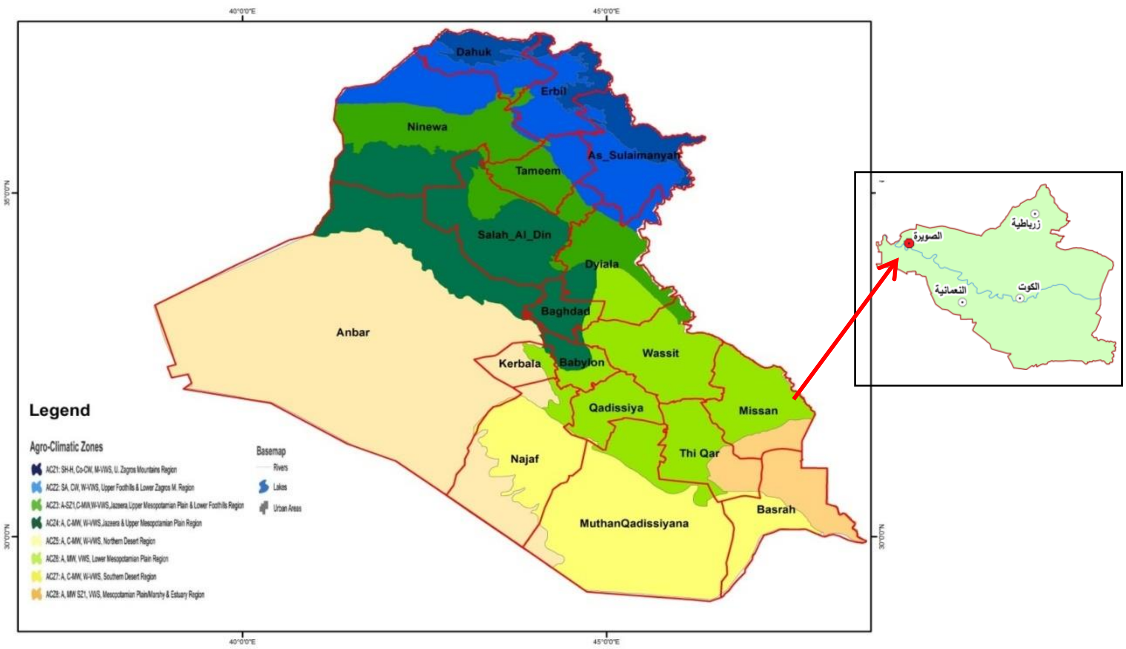

Fig. 1. A site map of the study area.

Parameters types

Parameters affected by agriculture and management are presented in Table 2. Parameters that are affected by the characteristics of the soil section maximum effective rooting depth (Zx; 0.35 m) and time to reach a maximum effective rooting depth (75 day) are presented in Table 3.

Field irrigation management for wheat crop

Surface irrigation was adopted using plots 0.25 m high from the soil surface, with a moisture content of 70% of the soil surface, and an irrigation interval according to Table 5.

Table 2. Cultivation parameters of wheat crop.

Seq.	Parameters	Crop data
1	Planting method	Seeding
2	Planting density	2100000 plant ha^{-1}
3	Maximum canopy cover (CCx)	90%
4	Time to reach 90% of germination	15 day
5	Time required to reach Maximum canopy cover (CCx)	63 day
6	Time required for plants to begin shedding leaves	135 day
7	Time required for physiological ripening (crop cycle length)	160
8	Flowering start time	105 day
9	Flowering time	14 day
10	Reference harvest index (HI_0)	38%

Table 3. Parameters that are affected by the soil section of the wheat crop.

Seq.	Parameters	Data affected by the characteristics of the soil section
1	Maximum effective rooting depth (Zx)	0.35 m
2	Time to reach a maximum effective rooting depth	75 day

Planting soil data

Table 4. Soil parameters of wheat crop.

Depth	Soil data	
0-25 cm	Soil water content at saturation SAT (%)	46.35
	Soil water content at field capacity FC (%)	24.73
	Soil water content at permanent wilting point PWP (%)	12.33
25-120 cm	Soil water content at saturation SAT (%)	45.74
	Soil water content at field capacity FC (%)	25.13
	Soil water content at permanent wilting point PWP (%)	12
0-25 cm	Sand (%)	15.02
	Silt (%)	53.15
	Clay (%)	31.83
25-120 cm	Sand (%)	13.89
	Silt (%)	52.71
	Clay (%)	33.40
Hydraulic conductivity (Ksat) for depth 0-1.5 m (m day^{-1})		1.16

Soil layers and depth of each layer	1

Field management of wheat crop

Fertility level was about half of the fertilization at 50%, without soil surface mulching and moderate weed management (relative mulching of weed 25%).

Climatic data

The climatic data used are historical for the study area for the period from 1/1/2008 to 31/10/2017, which was recorded from the climatic station in region, such as besides, solar radiation speed, atmospheric pressure, wind speed and direction, soil temperature, and soil moisture, in addition to other information such as evapotranspiration (ET), thermal aggregation, and dew point temperature network center. Then, the data were transferred from the climatic station to the center (the Agricultural Meteorology Center) using the satellite system according to the following climatic elements.

Table 5. Irrigation interval for wheat cultivation

Seq.	Irrigation date	Irrigation time (day)	Net Irrigation Depth (mm)	Water salinity (dS m^{-1})
1	11.1	1	45	1.2
2	11.18	18	33	1.2
3	12.6	36	30	1.3
4	12.26	56	35	1.4
5	1.14	75	38	1.3
6	2.3	95	38	1.3
7	2.23	115	40	1.3
8	3.11	133	60	1.3
9	4.5	156	82	1.3

Statistical standards that have been adopted

It was calculated according to the following equations (Bhattacharyya *et al.* 2021; Lalit *et al.* 2021)

Pearson correlation coefficient (R)

$$\mathrm{r} = \left[\frac{\sum(\mathrm{O_i} - \overline{\mathrm{O}})(\mathrm{P_i} - \overline{\mathrm{P}})}{\sqrt{\sum(\mathrm{O_i} - \overline{\mathrm{O}})^2 \sum(\mathrm{P_i} - \overline{\mathrm{P}})^2}}\right] \qquad (\mathbf{1})$$

Root Mean Square Error (RMSE)

$$\mathrm{RMSE} = \sqrt{\frac{\sum(\mathrm{P_i} - \mathrm{O_i})^2}{\mathrm{n}}} \qquad (\mathbf{2})$$

Normalized Root Mean Square Error (NRMSE)

$$\mathrm{CV\ (RMSE)} = \frac{1}{\overline{\overline{\mathrm{O}}}} \sqrt{\frac{\sum(\mathrm{P_i} - \mathrm{O_i})^2}{\mathrm{n}}} \times 100 \qquad (\mathbf{3})$$

Nash-Sutcliffe model efficiency coefficient (EF)

$$EF = 1 - \frac{\sum(P_i - O_i)^2}{\sum(O_i - \bar{O})^2} \quad (4)$$

Willmott's index of agreement (d)

$$d = 1 - \frac{\sum(P_i - O_i)^2}{\sum(|P_i - \bar{O}| + |O_i - \bar{O}|)^2} \quad (5)$$

RESULTS AND DISCUSSION

Calibration of the AquaCrop Model of Wheat

Fig. 2 shows the extent to which the current yield of the wheat crop decreased compared to the observed yield, due to the presence of sharp differences in production for the study area. In addition to the lack of farmers marketing the crop to be recorded in the Ministry of Agriculture, and the fact that two readings of the crop during the years 2007 and 2008 were excluded due to inaccuracy of the yield results.

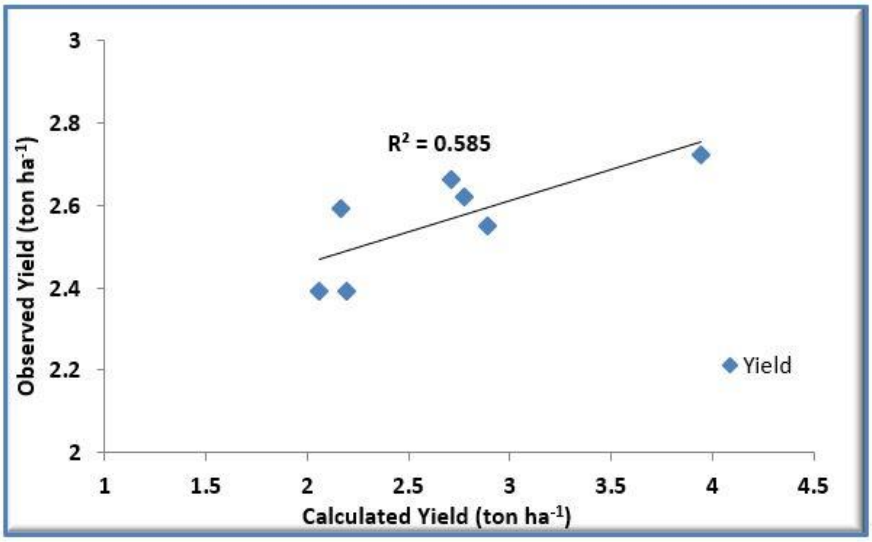

Fig. 2. Comparison between the calculated yield and the observed yield of wheat.

The statistical criteria that were adopted according to each of the equations (1, 2, 3, 4, and 5) are listed in Table 7. Calibrating the productivity of the wheat crop indicates that there is a weakness in the total production. It is despite the availability of suitable conditions for cultivation in terms of the quality and quantity of water and the soil quality as well as the availability of conditions and other criteria for cultivation for the study site. This may due to the lack of accurate information for recording the total yield of the area and the poor management of the farmer.

Table 7. Statistical standards for wheat crop.

Statistical standards	Value	Interpretation
r	0.757	Moderate good
RMSE	0.530	Moderate poor
CV	19.790	Moderate good
EF	0.226	Moderate poor
D	0.460	Poor

Studying the impact of climate change on productivity

The scenario is a set of conditions that represent different future situations. Scenarios are often used to estimate potential future outcomes and the willingness or response of individuals and organizations to them. For example, business people use scenarios to decide whether certain strategies are appropriate or not. In the climate field, scenarios are used because of the high uncertainty in climate change at the regional level. Regional climate means the climate at the level of a subcontinent or the level of a region or a country. Although the temperature will rise in many regions of the world, significant changes in climate, such as precipitation, are uncertain in many regions. So the scenarios help to understand regional climate change and the response of ecosystems to these changes. There are different models to predict future climate data according to expected climate changes such as the Centre National de Recherches Météorologiques (CNRM), Geophysical Fluid Dynamics Laboratory (GFDL), Earth climate (EC_EARTH). There are four different CO_2 files from RCP's (Representative Concentration Pathways) present in the AquaCrop database and these files are RCP 2.6 CO_2, RCP 4.5 CO_2, RCP 6.0 CO_2, RCP 8.5 CO_2. The RCP's represent a broad range of climate outcomes and each RCP file results from a different combination of economic and technology policies.

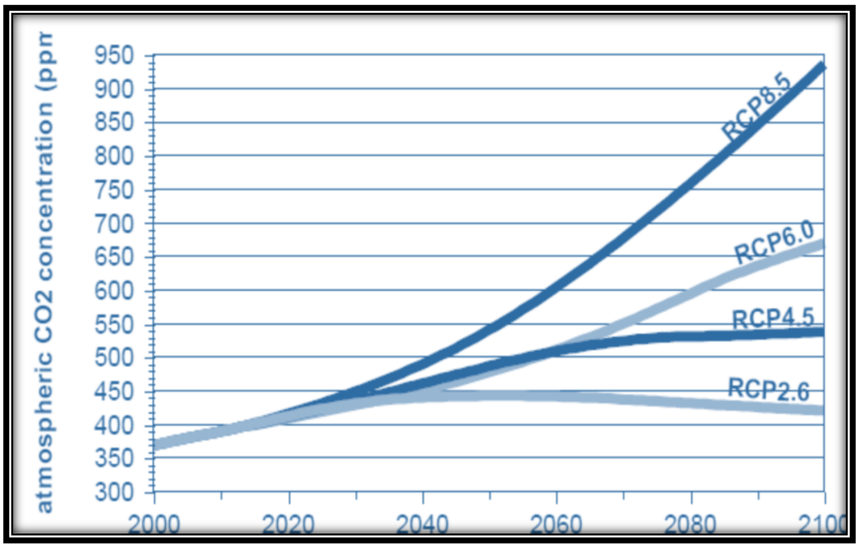

Fig. 3. CO_2 concentration chart according to four RCP scenarios.

Predicted climatic changes in the study area

Tables 8 and 9 show an increase in both annual and monsoon rains at the mid-century and end-of-century period for each of the scenarios RCP 4.5 and RCP 8.5 at the GFDL-ESM2M model, with a clear increase during the period 2040-2050 compared to the base period at Script RCP 4.5. Annual and monsoon rains decrease in EC-Earth for RCP 4.5 and RCP 8.5, while annual and monsoon rains increase slightly in CNRM-CM5 under RCP 4.5 and drop in RCP 8.5. However, the maximum and minimum temperature changes are higher during the period 2040-2050 than the period 2020-2030 compared to the base period for both scenarios RCP 4.5 and RCP 8.5 together.

Table 8. Predicted climatic changes of precipitation and minimum, maximum temperature for the periods 2020-2030 and 2040-2050 compared to the base period 1985-2005 for the models EC-Earth, CNRM-CM5, GFDL-ESM2M according to the scenario RCP4.5 for the wheat crop.

Parameter	2020-2030	2040-2050
CNRM-CM5		
Rain annual (mm)	+ 18.3	+ 10.8
Rain seasonal (mm)	+23.3	-8.9
Maximum temperature (◦C)	0.6	1.3
Minimum temperature (◦C)	0.6	1.2
EC-Earth		
Rain annual (mm)	-7.9	-16.8
Rain seasonal (mm)	-12.2	-23.6

Maximum temperature (◦C)	0.5	1.4
Minimum temperature (◦C)	0.4	1.1
GFDL-ESM2M		
Rain annual (mm)	+ 25.1	+ 43.9
Rain seasonal (mm)	+ 25.1	+ 40.4
Maximum temperature (◦C)	0.4	0.7
Minimum temperature (◦C)	0.4	0.7

Impact of climate change on the wheat crop

Results of the RCP4.5 scenario implementation

Table 10 shows the decline in productivity in the RCP 4.5 scenario when comparing the base period with the periods 2020-2030 and 2040-2050, as well as the relative change with significant differences between productivity during the base- and the simulation- periods, as the highest value of productivity recorded at the base period of 2.36 (ton/ha) during the simulation period.

Table 9. Predicted climatic changes of precipitation and minimum, maximum temperature for the periods 2020-2030 and 2040-2050 compared to the base period (1985-2005) for the models EC-Earth, CNRM-CM5, GFDL-ESM2M according to the scenario RCP8.5 for the wheat crop.

Parameter	2020-2030	2040-2050
CNRM-CM5		
Rain (mm), Annual	-5.1	-3.4
Rain (mm), Seasonal	-6.6	-7.1
Maximum temperature (◦C)	0.7	1.4
Minimum temperature (◦C)	0.7	1.2
EC-Earth		
Rain (mm), Annual	-1.4	-4.7
Rain (mm), Seasonal	-2.8	-19.9
Maximum temperature (◦C)	0.7	1.6
Minimum temperature (◦C)	0.6	1.3
GFDL-ESM2M		
Rain (mm), Annual	+ 24.5	+ 21.2
Rain (mm), Seasonal	+ 18.2	-3.2
Maximum temperature (◦C)	0.6	1.4
Minimum temperature (◦C)	0.6	1.3

Table 10. Average productivity of wheat and predicted change in productivity for scenario RCP4.5

	Average change during the period 2020-2030	Average change during the period 2040-2050
Production in base year (ton ha^{-1})	2.36	
Absolute change (ton ha^{-1})	-0.03	-0.06
Relative change (%)	-1.23	-2.54
T-test	$4.9E^{-02}$**	$3.6E^{-04}$**

Note: * N.S.;** S.

Table 11 shows the increase in the water productivity of the wheat crop during the simulation period at the scenario RCP 4.5 compared to the base period, as the highest value of water productivity was recorded in the period 2040-2050, reaching 0.9 kg m^{-3}.

Table 11. Water productivity during the base period 1986-2005 and the periods 2020-2030 and 2040-2050 for the scenario RCP 4.5.

	During the base period 1986-2005	During the period 2020-2030	During the period 2040-2050

Water productivity (kg m^{-3})	0.8	0.8	0.9

Results of the RCP 8.5 scenario implementation

In the case of the scenario RCP 8.5, it was observed in Table 12 that the average production of the wheat crop increased during the base period. Then, it decreased during the subsequent periods of the simulation with a significant difference in productivity, where the decrease reached during the period 2020-2030 with a relative change of -2.56%. However, it was also noticed a decline in productivity with a relative change of 3.65%, in the period 2040-2050 with a significant difference at a significant level of 0.05 between the average production during the base period and the period 2040-2050.

Table 12. Average productivity of wheat and predicted change in productivity for scenario RCP8.5

	Average change during the period 2020-2030	Average change during the period 2040-2050
Production in base year (ton ha^{-1})	2.36	
Absolute change (ton ha^{-1})	-0.06	-0.09
Relative change (%)	-2.56	-3.65
T-test	4.0E^{-03}**	**4.51E^{-05}

Table 13 also shows that the water productivity increased compared to the base period in the period 2040-2050 as a result of the elevation in productivity during this period and recorded the highest value of 0.9 kg m^{-3}. Even though, it was equal in both the base period and the period 2020-2030 for the RCP scenario 8.5.

Table 13. Water productivity during the base period 1986-2005 and the periods 2020-2030 and 2040-2050 for scenario RCP8.5.

	During the base period 1986-2005	During the period 2020-2030	During the period 2040-2050
Water productivity (kg m^{-3})	0.8	0.8	0.9

Impact of the shortage of water resources available for irrigation on the productivity of the wheat crop

Irrigation reduction 20 and 40% for scenarios RCP 4.5 and RCP 8.5

Fig. 4 shows the decrease in the amount of productivity during the period 2020-2030 for the scenario RCP 4.5 as a result of reducing the amounts of added irrigation water by 20% of the total irrigation during that period. In addition, when reducing irrigation by 40% during the period 2040-2050 also led to the occurrence of a clear reduction in productivity. Moreover, the productivity of the wheat crop for the scenario RCP8.5 decreased during the period 2020-2030 as a result of reducing irrigation by 20% of the total irrigation. In the case of the period 2040-2050, a decline was noticed in productivity. In a very clear way, it is a result of a decline in irrigation by 40% of the total irrigation, exhibiting the impact of climatic changes on the plant productivity of the crop during the simulation period.

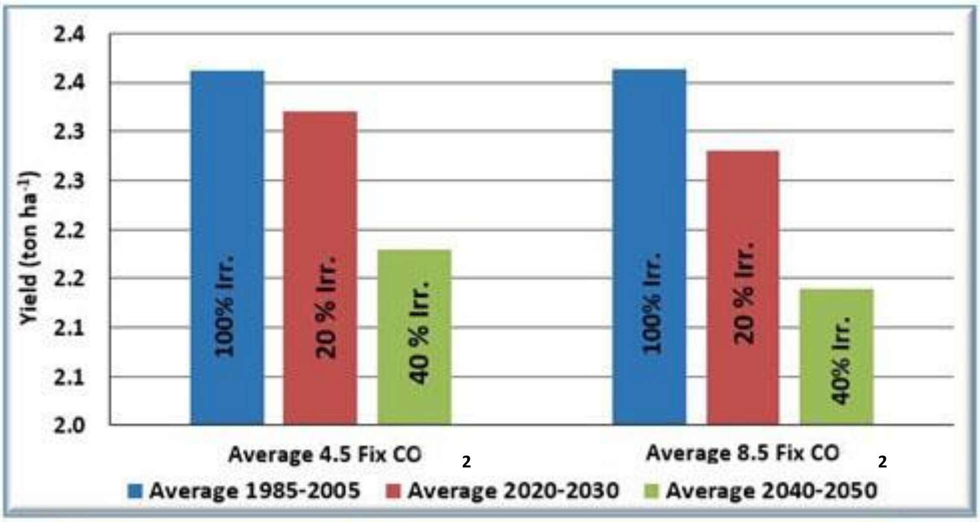

Fig. 4. Changes in the yield of wheat according to the reduction of irrigation to 20 and 40%.

Table 14 shows that the reduction in productivity during the period 2020-2030 had an absolute and relative change of -0.05 and -2.0, respectively. In the case of the period 2040-2050, the reduction in productivity as an absolute and relative change amounted to -0.18 and -8.0, respectively. Furthermore, there is a clear significant difference between the two periods compared to the base period 1985-2005 at a significant level of 5%.

Table 14. Average productivity of wheat and the predicted change in productivity when irrigation is reduced by 20 and 40% for the scenario RCP4.5

	Average change during the period 2020-2030	**Average change during the period 2040-2050**
Production in base year (ton ha^{-1})	2.36	
Irrigation reduction (%)	20	40
Absolute change (ton ha^{-1})	-0.05	-0.18
Relative change (%)	-2.0	-8.0
T-test	$3.3E^{-03}$**	$1.97E^{-06}$**

Table 15 shows that the decrease in productivity for the RCP8.5 scenario amounted to 8-0.0 and 3.36% for both the absolute and relative change, respectively, during the period 2020-2030 when the water supply decreased by 20% from the total irrigation. Besides, a decrease of - 0.22 and - 9.34 % for the absolute and relative change, respectively, during the period 2040-2050 when the water supply decreased by 40% of the total irrigation, with a significant difference in productivity during the simulation period at a significant level 5%.

Table 15. Average productivity of wheat and the predicted change in productivity when irrigation is reduced by 20 and 40% for the scenario RCP8.5.

	Average change during the period 2020-2030	**Average change during the period 2040-2050**
Production in base year (ton ha^{-1})	2.36	
Irrigation reduction (%)	20	40
Absolute change (ton ha^{-1})	-0.08	-0.22
Relative change (%)	-3.36	-9.34
T-test	$1.2E^{-03}$**	$1.8E^{-08}$**

Fig. 5 shows an increase in the water productivity of wheat crop in scenario RCP4.5 more than in scenario RCP8.5. It gave the highest value in the period 2040-2050 compared to the base period and for the case of the scenario RCP4.5 that amounted to 10.87 kg m^{-3} despite the decline in irrigation 40% of the total irrigation. It also increased at the scenario RCP8.5 and in the case of irrigation reduction of 40% of the total irrigation, which amounted to 0.873 kg m^{-3} for the crop. This is mainly due to the decrease in the amount of reference evapotranspiration and actual evapotranspiration in increasing water productivity.

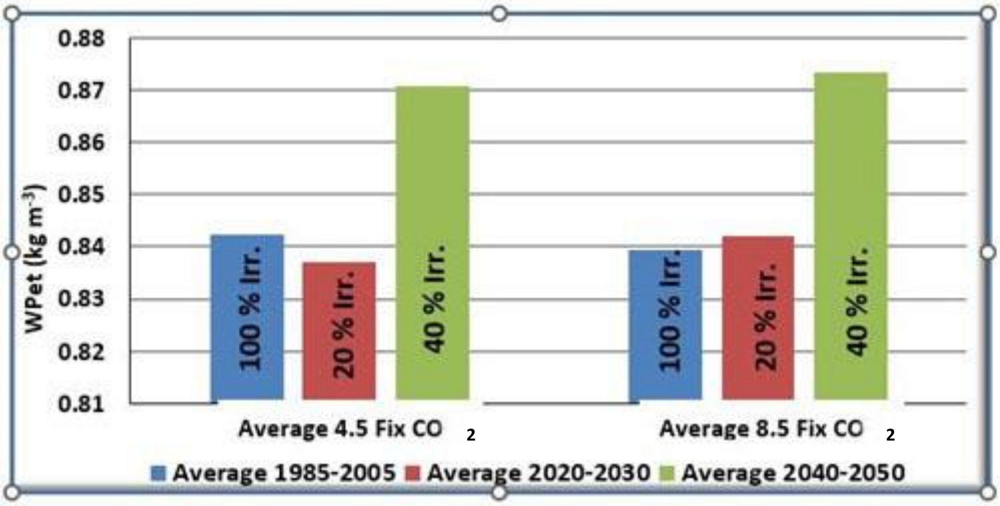

Fig. 5. Water productivity during the base period 1986-2005 and during the periods 2020-2030 and 2040-2050 for scenarios RCP4.5 and RCP8.5 when irrigation is reduced to 20 and 40%.

REFERENCES

Ahmadi, SH, Mosallaeepour, E, Kamgar, AA, Ali, H & Sepaskhah, R 2015, Modeling maize yield and soil water content with AquaCrop under full and deficit irrigation management. *Water Resources Management*, 29: 2837-2853.

Al-Atrash, MK, Abd Algabar, FA & Abbod, LS 2023, Assessment of soil microbial properties in some regions affected by climate change. *Caspian Journal of Environmental Sciences*, 21: 623-628.

Amoah, LK, Darko, RO & Owusu Sekyere, JD 2013, Calibration and validation of Aqua crop for full and deficit irrigation of hot pepper. *Journal of Agriculture and Biological Science*, 8: 175-178.

Andarzian, B, Bannayan, M, Steduto, P, Mazraeh, H, Barati, ME, Barati, MA & Rah nama, A 2011, Validation and testing of the AquaCrop model under full and deficit irrigated wheat production in Iran. *Agricultural Water Management*, 100: 1-8.

Araya, A, Habtu, S, Hadgu, KM, Kebede, A & Dejene, T 2010, Test of AquaCrop model in simulating biomass and yield of water-deficient and irrigated barley (Hordeum vulgare). *Agricultural Water Management*, 97: 1838-1846.

Bhattacharyya, B, Biswas, R, Sujatha, K & Chiphang, DY 2021, Linear regression model to study the effects of weather variables on crop yield in manipur state. *International Journal of Agricultural and Statistical Sciences*, 17: 317-320.

Farahani, HJ, Izzi, G & Oweis, T, 2009, Parameterization and evaluation of the AquaCrop model for full and deficit irrigated cotton. *Agronomy Journal*, 101: 469-476.

Geerts, S & Raes, D 2009, Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agricultural Water Management*, 96: 1275-1284.

Hamza, S, Al Mazirah, HS & Hamed, N 2021, The effect of planting date and spraying with liquid humus and their interactions on the growth of coriandrum sativuml. and its yield from oil and fruits. *International Journal of Agricultural and Statistical Sciences*, 17: 1297-1304.

Heng, LK, Asseng, S, Mejahed, K & Rusan, M 2007, Optimizing wheat productivity in two rainfed environments of the West Asia-North Africa region using a simulation model. *European Journal Agronomy*, 26: 121-129.

Heng, LK, Hsiao, TC, Evett, S, Howell, T & Steduto P 2009, Validating the FAO AquaCrop model for irrigated and water-deficient field maize. *Agronomy Journal*, 101: 488-498.

Hsiao, TC, Heng, LK, Steduto, P, Rojas Lara, B, Raes, D & Fereres, E 2009, AquaCrop-the FAO crop model to simulate yield response to water: III. Parameterization and testing for maize. *Agronomy Journal*, 101: 448-459.

Lalit, V, Sharma, S, Dagar, V & Kharinta, K 2021, Impact of national income and public expenditure on employment and its public- private sector composition in indian economy. *International Journal of Agricultural and Statistical Sciences*, 17: 213-222.

Levidow, L, Pimbert, M & Vanloqueren, G 2014, Agroecological research: Conforming or transforming the dominant agro-food regime. *Agroecology and Sustainable Food Systems*, 38: 1127-115.

Musick, JT, Jones, OR, Stewart, BA & Dusek, DA 1994, Water-yield relationships for irrigated and dry land wheat in the US Southern Plains. *Agronomy Journal*, 86: 980-986.

Nassif, WG, Lagenean, FHS & Al-Taai, OT 2023, Impact of vegetation cover on climate change in different regions of Iraq. *Caspian Journal of Environmental Sciences*, 21: 333-342.

Sezen, SM & Yazar, A 2008, The global warming impact on wheat yield in the Mediterranean climate using the Ceres-Wheat model. Agricultural Drought Assessing Monitoring and Damages Mitigation Turkish-Israel Joint Project Final Conference, 16-27 June, İzmir, Turkey, pp. 28-30.

Steven, RE & Tolk, JA 2009, Introduction: Can water use efficiency be modeled well enough to impact crop management? *Agronomy Journal*, 101: 423-425.

Todorovic, M, Albrizio, R, Zivotic, L, Saab, MT, Stöckle, C & Steduto P 2009, Assessment of AquaCrop CropSyst and WOFOST models in the simulation of sunflower growth under different water regimes. *Agronomy Journal*, 101: 509-521.

Toumi, J, Er Raki, S, Ezzahar, J, Khabba, S, Jarlan, L & Chehbouni, A 2016, Performance assessment of AquaCrop model for estimating evapotranspiration soil water content and grain yield of winter wheat in Tensift Al Haouz

(Morocco): Application to irrigation management. *Agricultural Water Management*, 163: 219-235.

Trombetta A, Iacobellis V, Tarantino E & productivity and yield response model. *Environmental Modelling & Software*, 62: 351-360.

Zeleke, KT, Luckett, D & Cowley, R 2011, Calibration and testing of the FAO AquaCrop model for canola. *Agronomy Journal*, 103: 1610-1618.

Zhang, H & Oweis T1999, Water yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. *Agricultural Water Management*, 38: 195-211.

Gentile, F 2016, Calibration of the AquaCrop model for winter wheat using MODIS LAI images. *Agricultural Water Management*, 164: 304-316.

Vanuytrecht, E, Raes, D, Steduto, P, Hsiao, TC, Fereres, E, Heng, LK, Vila, MG & Moreno, PM 2014, AquaCrop:FAO's crop water.

Bibliographic information of this paper for citing:

Ayada, AD, Majeed, SS, Ati, AS 2024, Impact of future climate change on land and water productivity for wheat crop (Wasit Governorate, Iraq). Caspian Journal of Environmental Sciences, 22: 31-41.