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Determining the Productivity of Water and Wheat Using AquaCrop Model under the Fixed Sprinkler Irrigation System in Basrah Governorate / Al-Luhais Region

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Abstract:

A field experiment was conducted during the season 2021/2022 in Basrah governorate/ Al-Zubair - Al-Luhais region. The experiment was designed according to a randomized complete block design (RCBD) with three replicates, it uses the results of regional climate models to knowledge how climate change effects on the region through the AquaCrop model and repeat the same process for another regional climate model and another scenario to assess the impact using climate projections and analyze the impact of climate change on water resources The results are as follows:

1. The seasonal water consumption under the fixed sprinkler irrigation system reached 717 mm in the Al-Zubair -Al-Luhais region

2. A decrease in the amount of annual rainfall during the two periods (2021-2035) and (2035-2050) amounted to -7.04 and -11.65 mm, and -6.37 and -12.24 mm, respectively, compared to the base period (1985-2005) as an average of climate models (EC-Earth, CNRM-CM5, GFDL-ESM2M) for RCP4.5 and RCP8.5 scenarios respectively.

3. An increase in the maximum and minimum temperatures of 2.31 and 1.64°C, respectively, during the period (2021-2035) compared to the base period, with a clear increase in temperatures during the period (2035-2050) compared to the base period of 2.63 and 1.87°C for degrees maximum and minimum temperatures, respectively and an increase in both the maximum and minimum temperatures of 2.78 and 1.80° C, respectively, during the period (2021-2035) compared to the base period, with a clear increase in temperatures during the period (2035-2050) compared to the base period, amounting to 3.70 and 2.12° C for the maximum and minimum temperatures, respectively, as an average of the climate model values (EC-Earth, CNRM-CM5, GFDL-ESM2M) under the RCP4.5 and RCP8.5 scenarios.

4. The calibration gave a good agreement for most of the approved standards, and the correlation coefficient R^2 reached a very good agreement of 0.98. The RMSE gave a good agreement of 0.15. The value of the Woltman coefficient for comparison between the measured productivity and the expected productivity recorded a very good agreement, amounting to 0.96.

5. An increase in productivity in the scenario RCP 4.5 and RCP 8.5 when comparing the base period with the two periods (2021-2035) and (2035-2050), in addition to an increase in the relative change in productivity with non-significant differences between productivity during the base period and the simulation period, as the highest value of productivity during the period (2021-2035) amounted to 8.22 and 7.68 Ton ha^{-1} of the wheat crop during the simulation period. The increase in the production

rate between the periods (2021-2035) and (2035-2050) compared to the base period was 30.21, 28.48%, 32.87, and 30.64%.

6. Increasing water productivity in the RCP 4.5 and RCP 8.5 scenarios, and comparing the base period with the two periods (2021-2035) and (2035-2050), highest value of water productivity during the period (2021-2035) amounted to 7.72 and 7.70 kg m^3, respectively.

Keywords: water productivity, wheat, AquaCrop, Basrah governorate.

تحديد كفاءة أنتاجية المياه والحنطة بإستخدام نموذج AquaCrop تحت نظام الري بالرش الثابت في محافظة البصرة/منطقة اللحيس

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الخلاصة

نفذت تجربة حقلية خلال الموسم الزراعي 2022/2021 في محافظة البصرة/ قضاء الزبير-منطقة اللحيس، لدراسة تأثير نظام الري بالرش الثابت بإستخدام أنموذج AquaCrop. صممت التجربة وفق تصميم القطاعات العشوائية الكاملة RCBD بواقع ثلاث مكررات، بأستخدم نتائج النماذج المناخية الإقليمية لإبراز كيفية تأثير تغيّر المناخ في المنطقة من خلال أنموذج AquaCrop وتكرار العملية نفسها لنموذج مناخي إقليمي آخر وسيناريو آخر لتقييم الأثر باستخدام إسقاطات المناخ وتحليل تأثير تغيّر المناخ على الموارد المائية، وكانت النتائج كالاتي:

1. بلغ الاستهلاك المائي الموسمي تحت منظومة الري بالرش الثابت 717 مم في منطقة اللحيس / قضاء الزبير.
2. أنخفاض في كمية التساقط المطري السنوي خلال الفترتين (2021-2035) و(2035-2050) بلغت -7.04 و -11.65 مم، و-6.37 و -12.24 مم على الترتيب مقارنةً بفترة الاساس (1985-2005) كمتوسط لقيم النماذج المناخية (EC-Earth,CNRM-CM5,GFDL-ESM2M) عند سيناريو RCP4.5 وRCP8.5 على الترتيب.
3. زيادة درجات الحرارة العظمى والصغرى 2.31 و 1.64°م ، على الترتيب خلال المدة (2021-2035) بالمقارنةً مع فترة الاساس مع وجود زيادة واضحة بدرجات الحرارة خلال الفترة (2035-2050) بالمقارنةً مع فترة الاساس بلغت 2.63 و 1.87°م لدرجات الحرارة العظمى والصغرى، على الترتيب وزيادة في كل من درجات الحرارة العظمى والصغرى 2.78 و 1.80°م ، على الترتيب خلال المدة (2021-2035) بالمقارنةً مع فترة الاساس مع وجود زيادة واضحة بدرجات الحرارة خلال الفترة (2035-2050) بالمقارنةً مع فترة الاساس بلغت 3.70 و 2.12°م لدرجات الحرارة العظمى والصغرى، على الترتيب كمتوسط لقيم النماذج المناخية (EC-Earth,CNRM-CM5,GFDL-ESM2M) عند سيناريو RCP4.5 وRCP8.5.
4. اعطت المعايرة توافق جيد لاغلب المعايير المعتمدة وبلغ معامل التحديد R^2 توافق جيد جداً بلغ 0.98. أما جذر متوسط مربع الخطأ RMSE فقد اعطى توافق جيد بلغ 0.15. وسجلت قيمة معامل ولتمان للمقارنة بين الانتاجية المقاسة والانتاجية المتوقعة توافق جيد جداً بلغت 0.96.
5. زيادة الإنتاجية عند السيناريو RCP 4.5 وRCP 8.5 عند مقارنة فترة الاساس مع الفترتين (2021-2035) و(2035-2050) بالاضافة الى زيادة في التغير النسبي للانتاجية مع وجود فروق غير معنوية بين الإنتاجية خلال فترة الاساس وفترة المحاكاة، إذ إن أعلى قيمة للإنتاجية عند فترة (2021-2035) بلغت 8.22 و7.68 طن هكتار$^{-1}$ لمحصول الحنطة خلال فترة المحاكاة. كما بلغت الزيادة بنسبة الانتاج بين فترتي (2021-2035) و(2035-2050) بالمقارنة مع فترة الاساس 30.21 و28.48% ، 32.87 و30.64%.
6. زيادة الإنتاجية المائية عند السيناريو RCP 4.5 و RCP 8.5 ومقارنة فترة الاساس مع الفترتين (2021-2035) و(2035-2050)، وكانت أعلى قيمة للإنتاجية المائية عند فترة (2021-2035) بلغت 7.72 و7.70 كغم م$^{-3}$ على الترتيب.

الكلمات المفتاحية: **انتاجية مياه، الحنطة، AquaCrop، البصرة.**

Introduction

The wheat crop in Iraq is one of the most important field crops in general, and grain crops in particular, in terms of cultivated area and production, reaching 9.464.225 dunums and 4.233.714 Ton, respectively [Directorate of Agricultural Statistics, 2021]. The suitable soils for wheat cultivation are silty loam and clay loam soils with a low salt content, and the date of its cultivation in irrigated areas is during the month of November. There are many studies in Iraq on the water consumption of the wheat crop grown in different climatic environments and textures from northern to southern Iraq, but they were limited to surface irrigation only and did not study the water consumption under the fixed or pivot sprinkler irrigation system, which is almost very limited. The values of crop water consumption for wheat ranged between 300-800 mm when they applied management systems, irrigation intervals, and different fertilizer treatments [Ati *et al.*, 2019]. [Al-Ghubari, 2016] defined sprinkler irrigation as giving water to the land in the form of spray or rain, the size of which is commensurate with the type of soil, and is used to irrigate medium to large areas. This system is characterized by its flexibility, high efficiency, and the possibility of using it to irrigate most crops and most lands. The system also has another advantage, it can be used in most climatic conditions, Sprinkler irrigation is an irrigation method in which water is pumped into a network of pipes of different diameters that end with fixed openings or sprayer through which water exits into the air in the form of droplets that fall on the ground and plants in the form of rain. [Strong *et al*., 2018] found a relationship between the height of the sprinkler and the wind speed. When the height of the sprinkler is increased, it allows the water to move to a farther distance due to the increase in the wind speed. [Al-Ghobari and Dewidar, 2021] confirmed that an increase in the operating pressure at the sprayer opening decreases the coefficient of homogeneity, because an increase in pressure leads to splitting of the water droplets emerging from the extruders and turning them into droplets with small diameters, which makes them more affected by the wind. Forecasting the level of water added for irrigation and the productivity response is of great importance in determining the most appropriate amount of water under conditions of water scarcity. The International Food and Agriculture Organization (FAO) has expressed this importance by introducing the AquaCrop model, which is a computer model that simulates the interrelationship between plants, soil and water, developed by the organization to address the problem of food security and assess the effects of environment and management on crop production, It is an important and effective program that contributes to simulating water productivity in an easy and simplified manner, away from the complex procedures that are used in estimating water productivity and its relationship to the amount of water added and agricultural management methods [Dirk and Gaelen, 2016].

The AquaCrop model is considered one of the effective and successful means in forecasting agricultural productivity. It serves as a tool for planning and managing both rainfed and irrigated cultivation. When running the program, it needs a set of inputs, which include climatic data for the study area, crop characteristics, description of the soil profile, its initial moisture, and the conditions in which the crop grow. For the purpose of determining the basic variables of wheat, the AquaCrop model was calibrated based on climatic and field data and the approved planting dates in the Al-Luhais region, in addition to the climatic conditions for the ten years (2011-2021).The aim of study to evaluate the agricultural production of the wheat crop in Basrah governorate /Al-Zubair - Al-Luhais region as a result of changing the water and climatic changes in order to Providing scientific rationale for decision-makers to take possible measures and draw more comprehensive future strategies, through calibration and evaluation of the AquaCrop model for wheat productivity in the Luhais region, and determining the water productivity of the wheat crop to reached the best productivity using fixed spraying.

Materials and Methods

A field experiment was conducted for the season 2021/2022 in one of the fields of Al-Zubair/ Al-Luhais region, located within latitude 30°56'48" N north and longitude 46°96'87" E east, at a height of 11 m above the level of the surface of the sea. The soil was classified as (*Typci Torrifluvent*) according to [Soil survey staff., 2014]. The soil was as loamy sand texture (sand=792, silt=80, clay=128 gkg^{-1}), Soil samples were taken from the soil at a depth of 0-0.30 m, air dried, and passed through a sieve with an opening diameter of 2 mm to determine some physical and chemical properties according to standard methods [Black, 1965] (EC=5.20 dSm^{-1}, pH=7.19, O.M.= 6.5 gkg^{-1}, $CaCO_3$ = 254 gkg^{-1}), in addition to a description of the study area (Tables 1).

Table 1. Description of location and agricultural characteristics

Location	Al-Luhais region / Al-Zubair / Basrah governorate
cultivated variety	Babylon 113
Seeding rates	160 kg ha^{-1}
irrigation method	Fixed sprinkler irrigation
Planting date	8/12/2021
cultivation method	Seeding machine
fertilization	Fertilizer recommendation followed in the national program for the development of wheat cultivation in Iraq
leveling	without leveling
The number of irrigations	61

The field was cultivated with seed wheat cultivar Babylon 113 on 12/8/2021 at seeding rate of 160 kg ha^{-1}. All crop management operations were manually and periodically during the growing season, and the plants harvested on 10/5/2022. The method of fertilization by spraying was used to provide the crop with the necessary macro and micronutrients for growth and production. The experimental land was fertilized with chemical fertilizers at the rate of 200 kg P_2O_5 ha^{-1} in the form of DAP (P_2O_5 46%) before planting, and nitrogen fertilizer 200 kg ha^{-1} by adding urea N 46% in two times, the first after two week germination and the second after 40 days of planting and potassium fertilizer at an average of 240 kg ha^{-1} in the form of potassium sulfate, the microelements were sprayed in two stages: the first is the vegetative growth stage and the second is the flowering stage, with a concentration of 60 ppm each of Zn, Fe and Mn, and 20 ppm Cu in one spray, noting that the spraying process takes in the early morning (National program for the development of wheat cultivation in Iraq).

Evaluation of the Sprinkler Irrigation System: Several tests were conducted to evaluate the discharge of the sprinklers and water distribution under the sprinkler system. Plastic cans (radius = 0.20 m and height = 0.10 m with distance 3 m), in order to collect the water flowing from it during the operation of the sprinkler irrigation system. The tests were carried out at different operating pressures. Three operating pressures were chosen: 100, 150, and 200 kPa. The pressure was measured by mechanical gauge with a capacity of 1000 kPa. The amounts of water collected in each cans were measured to determine the discharge of the sprinklers during the 30-minute runtime. The sprinkler irrigation system has been calibrated at an operating pressure of 150 kPa in order to achieve the best uniformity of water distribution at this pressure. According to the water consumption, based on the evaporation data from the American evaporation pan, class A, to calculate the amount of water to be added to the field from the water consumption based on the evaporation data from the pan [Christiansen, 1942; Hajim and Haqi, 1992 and Allen *et al*., 1998] in the equations as follows:

$$ET_0 = K_p \times E_p \qquad (1)$$

Where:

ET_0= reference evapotranspiration (mm day $^{-1}$)

Kp = evapotranspiration coefficient of 0.85.

Epan = daily evapotranspiration from pan (mm-day).

$$ET_c = ET_0 \times K_c \qquad (2)$$

Where:

ETc = evapotranspiration of the crop (mm day $^{-1}$).

ET_O = reference evapotranspiration (mm day $^{-1}$).

Kc = crop coefficient (0.40, 0.87, 1.15, and 0.70) according to growth stages, germination, vegetative growth, flowering, and maturity, respectively.

The depth of water applied to each irrigation method was calculated.

$$GDI = \frac{NDI}{Ea} \qquad (3)$$

Where:

GDI = Gross depth irrigation (mm)

NDI= Net depth irrigation (mm)

Ea = Irrigation efficiency (%)

The quantities of irrigation water for each experimental unit were calculated according to the following formula:

$$Qt = Ad \qquad (4)$$

Q = discharge (m^3 sec^{-1})

t = irrigation time (sec)

A = Area of the experimental unit (m^2)

d = depth of water added (m)

water productivity was calculated according to the equation [Allen *et al*., 1998]:

$$WUE_f = \frac{Yield}{Waterapplied} \qquad (5)$$

where:
WUE_f = water productivity (kg m^{-3}).
Yield = total yield (kg ha^{-1}).
Water applied Water added (m^3 ha^{-1}).

Statistical Analysis

In this study, the AquaCrop 6.0 model obtained from the official web location of the Food and Agriculture Organization (www.fao.org/nr/water/aquacrop) was used to estimate the water consumption of wheat and to estimate the yield under drought conditions using the fixed sprinkler irrigation method to evaluate Aqua Crop's performance, the following equations were used:

1. Root Mean Square Error (RMSE): The closer its value is to zero, this better the simulation performance of the model. The root mean square error (RMSE) is calculated according to [Loague and Green, 1991].

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(O_i - S_i)^2}{N}} \qquad (6)$$

Si = simulated value

Oi = measured value

N = number of observations

O_i= average value of Oi

$\overline{S_\iota}$ = mean value of Si

2. Coefficient of Determination (R^2): A measure used in statistical analysis that evaluates how well a model can explain and predict future results. It indicates the level of variance in the data set. It is used to explain the amount of variance in one factor that can result from its relationship to another factor, as indicated by [Windmeijer and Cameron, 1995]. R^2 takes values between (0 and 1), the closer the value is to one, the better the relationship between the two factors, where the value (1) indicates perfect correspond, and the value (0) indicates no correspond at all.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(oi - si)^2}{\sum_{i=1}^{n}(oi - o_{avg})^2} \qquad (7)$$

3. Compatibility Index

[Willmott, 1982] proposed the compatibility index as a standard measure that expresses the degree of error in predicting the model, and its value ranges between (0-1), this represents the percentage of the expected average error, and the degree of compatibility indicates 1 to complete agreement, while the number 0 indicates no compatibility, and its formula is:

$$d = 1 - \frac{\sum_{i=1}^{n}(Si - Mi)^2}{\sum_{i=1}^{n}\left(Si - \bar{M}\,\middle|\, + \; Mi - \; \bar{M}\,\middle|\right)^2} \qquad (8)$$

M= average of the measured values

Regional Climate Model (RCM)

The regional climate model is a climate model with high spatial resolution (the spacing is less than 50 km) that is applied to a specific region and the outputs of the GCMs (Global Climate Model) are used as initial and oceanic conditions. Regional climate models take into account topographic changes and land use more accurately than global climate models.

Climate Models Used

In this study, the RCA4 regional climate model was used for three cases:

1-The RCA4 regional model using circumferential conditions from the EC-EARTH global circulation model.

2- RCA4 regional model using circumferential conditions from the CNRM global circulation model.

3- RCA4 regional model using circumferential conditions from the GFDL-ESM global circulation model.

Climate Modeling Results

The results of climate changes were adopted on a daily basis, for future climate models for the expected change in the average annual rainfall and the maximum and minimum temperatures during the two periods:

- The near future (2021-2035).

The distant future (2035-2050).

- The reference period (1986-2005) compared to the base period.

In order to evaluate the impact of climate changes on the productivity of the wheat crop, the AquaCrop model will be used for the three climate models, and then the average of the three results will be calculated to estimate (average productivity or water consumption). For both the medium emissions scenario RCP4.5 and the high emissions scenario RCP8.5. The primary source for this data is bias-corrected data from the RCM adapted from the RICCAR-Coordinated Downscaling Regional Climate Model Experiment (CORDEX) [ESCWA *et al.*, 2017].

Results and Discussion

Water Requirements and Wheat yield

Table 2 shows the amount of seasonal water consumption for the wheat crop (Babylon 113), the amount of irrigation water and the number of irrigations at the different stages of growth (Tillering, vegetation, flowering and physiological maturity) during the season 2021/2022. It is noted that the total water consumption amounted to 717 mm, and the depth of consumption during the growth stages reached 122, 180, 300, and 115 mm, with a number of irrigations of 11, 20, 22, and 8 irrigations, at the tillering, vegetation, flowering, and physiological maturity stage, respectively. It is clear from the results that the water consumption was high during the flowering stage, and this may be due to the increase in evaporation from the soil and transpiration from the plant, transpiration through exposed leaf surfaces was greater at this stage, as well as higher temperatures and the influence of wind, which caused moisture loss during day and night hours [Al- Lami *et al.,* 2023]. The results show that the needs of the wheat crop differ according to the stages of its growth, and the rate of evapotranspiration of the wheat crop increases with the increase in the age of the crop. As the water consumption reaches its maximum depth in the months of March and April, and the influence of climatic factors increases in these months, such as temperature and wind speed, and then leads to a rise in the values of the depth of the irrigation water added during these stages.

Table 2. Seasonal water consumption under a fixed sprinkler system

Growth stage/growth period (day)	irrigation number	Depth of water consumption (mm)	The amount of water ($m^3\ ha^{-1}$)
Tillering (32 days)	11	122	1220
vegetation (45 days)	20	180	1800
flowering (52 days)	22	300	3000
Physiological maturity (39 days)	8	115	1150
Total 168	61	717	7170

Projected Future Climate Changes until the end of 2050 (Simulation Period)

Table 3 shows the effect of the expected climate changes for each of the annual and seasonal precipitation and minimum and maximum temperatures for the two periods (2021-2035) and (2035-2050) in the near future and the medium future, respectively, compared to the base period (1985-2005) according to the three climate models EC-Earth, CNRM-CM5, GFDL-ESM2M at climate change scenario RCP4.5 (medium emissions scenario) for wheat crop under fixed sprinkler system. Table (3) shows the decrease in the amount of annual rainfall during the two periods (2021-2035) and (2035-2050) amounting to -7.04 and -11.65 mm, respectively, compared to the base period (1985-2005) as an average for the three models used. For RCP4.5 climate change scenarios, Table (3) also shows that there was an increase in each of the maximum and minimum temperatures of 2.31 and 1.64°C for the maximum and minimum temperatures, respectively, during the period (2021-2035) compared to the base period, with a clear increase also in temperatures during the period (2035). -2050) compared to the base period of 2.63 and 1.87°C for the maximum and minimum temperatures, respectively (as average values of climate models).

Table 3. The expected climate changes in precipitation and minimum and maximum temperatures for the two periods (2021-2035) and (2035-2050) compared to the base period (1985-2005) for the regional climate cycle models EC-Earth, CNRM-CM5, GFDL-ESM2M according to the scenario RCP4.5 of the wheat crop, Basrah governorate

Parameter	2021-2035	2035-2050
CNRM-CM5		
Rain (mm), Annual	2.06	-6.28
Maximum temperature (◦C)	1.97	1.99
Minimum temperature (◦C)	1.55	1.86
EC-Earth		
Rain (mm), Annual	-10.90	-13.07
Maximum temperature (◦C)	2.73	2.98
Minimum temperature (◦C)	1.76	1.92
GFDL-ESM2M		
Rain (mm), Annual	-12.28	-15.61
Maximum temperature (◦C)	2.22	2.91
Minimum temperature (◦C)	1.60	1.82

Table 4 shows the impact of the expected climate changes for each of the annual and seasonal precipitation and the minimum and maximum temperatures for the two periods (2021-2035) and (2035-2050) in the near future and the medium future, respectively, compared to the base period (1985-2005) according to the three EC climate models. -Earth, CNRM-CM5, GFDL-ESM2M under climate change scenario RCP8.5 (medium emissions scenario) for wheat crop under fixed sprinkler system. Table (4) shows that there is a decrease in the amount of annual rainfall during the two periods (2021-2035) and (2035-2050) amounting to -6.37 and -12.24 mm, respectively, compared to the base period (1985-2005) as an average for the three models used. For the climate change scenario RCP8.5 Table (4) also shows that there was an increase in each of the maximum and minimum temperatures, which amounted to 2.78 and 1.80 °C for the maximum and minimum temperatures, respectively, during the period (2021-2035) compared to the base period, with a clear increase also in temperatures during the period (2035 -2050) compared to the base period of 3.70 and 2.12°C for the maximum and minimum temperatures, respectively (as average values of climate models) [Al Hasnawi *et al*., 2022; Ati *et al.*, 2016; Al-Lami *et al*., 2023; Razzak *et al.*, 2018; Hassan *et al*., 2021; Hassan *et al*., 2023].

Table 4. The expected climate changes in precipitation and minimum and maximum temperatures for the two periods (2021-2035) and (2035-2050) compared to the base period (1985-2005) for the regional climate cycle models EC-Earth, CNRM-CM5, GFDL-ESM2M, according to the scenario RCP8.5 of the yield of wheat crop, Basrah governorate

Parameter	2021-2035	2035-2050
CNRM-CM5		
Rain (mm), Annual	2.82	-7.49
Maximum temperature (◦C)	2.15	2.30
Minimum temperature (◦C)	1.39	1.63
EC-Earth		
Rain (mm), Annual	-10.44	-13.90
Maximum temperature (◦C)	2.97	4.02
Minimum temperature (◦C)	1.98	2.10
GFDL-ESM2M		
Rain (mm), Annual	-11.48	-15.32
Maximum temperature (◦C)	3.23	4.78
Minimum temperature (◦C)	2.02	2.64

Statistical criteria

Table 5 shows the productivity calibration of the wheat crop for comparison between the measured and expected productivity. The standard gave a good agreement with most of the approved standards, where the determination coefficient R^2 between the data reached a very good agreement of 0.98. The Root Mean Square Error (RMSE) gave a good agreement of 0.15. The value of the Woltman coefficient for comparison between the measured productivity and the expected productivity recorded a very good agreement, amounting to 0.96.

Table 5. Statistical criteria for comparison between measured and expected yield of wheat crop

Standards	Value	Interpretation
RMSE	0.15	good
R^2	0.98	very good
D	0.96	very good

The AquaCrop model was able to simulate the total yield of wheat crop and this is reflected by the good agreement between the measured and simulated yields in the statistical analysis of R^2, RMSE and D. The values of the statistical coefficients that were applied showed the accuracy of the program and its ability to simulate the data, where the RMSE is an indicator of the amount of difference between the measured and expected values and its limits are between (∞-0), and the simulation is good if it is close to infinity. As for Waltman's index (D), it indicates the range of acceptability between the measured values to the expected values and its limits (0-1), and the closer it is to one, the better the simulation.

The measured and expected future total productivity of the wheat crop

Table (6) shows an increase in productivity under scenario RCP 4.5 when comparing the base period with the two periods (2021-2035) and (2035-2050), in addition to an increase in the relative change in productivity with non-significant differences between productivity during the base period and the simulation period. As the highest value of productivity during the period (2021-2035) was 8.22 Ton ha^{-1} of the wheat crop during the simulation period. The increase in the production rate between the periods (2021-2035) and (2035-2050) compared to the base period was 30.21 and 28.48%, as for when applying the scenario RCP 8.5 when comparing the base period with the two periods (2021-2035) and (2035-2050), there is an increase in productivity in addition to an increase in the relative change in productivity with the presence of non-significant differences between productivity during the base period and the simulation period. As the highest value of productivity was recorded during the period (2021-2035), which amounted to 7.68 Ton ha^{-1} during the simulation period. The increase in the production rate between the periods (2021-2035) and (2035-2050) compared to the base period reached 32.87 and 30.64%. We also note that the increase was higher in the RCP4.5 scenario than in the RCP8.5 scenario for the same simulation period.

The average measured and expected future water productivity of the wheat crop

Table 7 and figure 1 shows the increase in water productivity under the RCP 4.5 scenario when comparing the base period with the two periods (2021-2035) and (2035-2050), as the highest value of water productivity was recorded during the period (2021-2035), reached 7.72 kg m^{-3} The increase in water productivity during the two periods (2021-2035) and (2035-2050) compared to the base period was 10.04 and 8.89%, ss for applying the scenario RCP 8.5 when comparing the base period with the two periods (2021-2035) and (2035-2050), it recorded the highest value of water productivity during the period (2021-2035), reached 7.70 kg m^{-3}. The increase in water productivity during the two periods (2021-2035) and (2035-2050) compared to the base period was 10.79 and 8.47%. We also note that the increase in scenario RCP4.5 was higher than that in scenario RCP8.5 for the same simulation period.

Table 6. Average wheat yield and expected change in yield under RCP4.5 and RCP8.5 scenarios

RCP 4.5		
Average change during the period (2035-2050)	**Average change during the period (2021-2035)**	
5.00		Production in the base period (Ton ha^{-1})
2.90	3.22	**Absolute change** (Ton ha^{-1})
28.48	30.21	**Relative change (%)**
RCP 8.5		
Average change during the period (2035-2050)	**Average change during the period (2021-2035)**	
5.25		Production in the base period (Ton ha^{-1})
2.26	2.43	**Absolute change** (Ton ha^{-1})
30.64	32.87	**Relative change (%)**

Table 7. Average water productivity under RCP4.5 and RCP8.5 scenarios

RCP 4.5		
Average change during the period (2035-2050)	**Average change during the period (2021-2035)**	
7.17		Water productivity (kg m^{-3})
0.32	0.55	Absolute change (kg m^{-3})
8.89	10.04	Relative change (%)
RCP 8.5		
Average change during the period (2035-2050)	**Average change during the period (2021-2035)**	
6.98		Water productivity (kg m^{-3})
0.70	0.72	Absolute change (kg m^{-3})
8.47	10.79	Relative change (%)

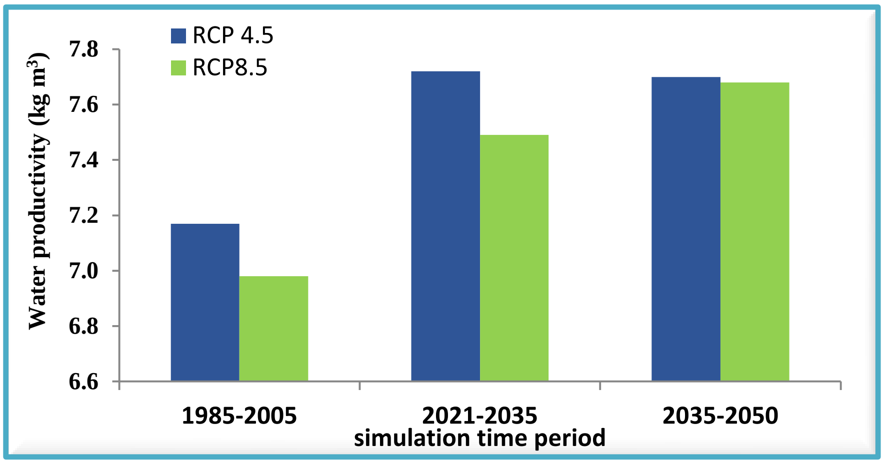

Figure 1. Average water productivity during the base period 1985-2005 and the periods (2021-2035) and (2035-2050) for the wheat crop.

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