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Assessment of Climate Change Impact on Water Productivity and Yield of Wheat Cultivated Using Developed Seasonal Schedule Irrigation in the Nineveh Province

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ABSTRACT

The agricultural lands that depend on supplementary irrigation methods for winter wheat cultivating in wide areas of the Nineveh province are most vulnerable to climate change concerns. Due to frequent rainfall shortages and the temperature increase recently noticed and predicted by the climate scenarios. Hence important to assess the climate effect on the crop response in terms of water consumption during the periods (2021-2040) and (2041-2060) by using high-resolution data extracted from 6 global climate data GCMs under SSP5-8.5 fossil fuel emission scenarios in changing and fixed CO_2 concentration. And validate the Aqua-Crop model to estimate the yield and water productivity. And gives the RRSME of 7.1-4.1 for the calibration and verification, respectively, d and R^2 equal 1, indicating good model performance. From findings, the predicted response to the temperature increase and variability in rainfall between increase and decrease represents an increase in irrigation water productivity to 28% in 2060 related to the reference period in the developed schedule under changing CO_2 scenario and a reduction by 13% in the near term related to the mid-term under the fixed CO_2 concentration scenario. And the simulation of yield production increased by 30 % under the scenario of changing CO_2 concentration. While a slight increase of 13 % under the fixed CO_2 concentration scenario. These findings help realize the future uncertain resilience of agriculture in Iraq to create efficient adaptation measures to benefit from climate change opportunities.

Keywords: water productivity, irrigation schedule, Aqua-crop, Nineveh province, climate change.

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تقييم تأثير التغيرات المناخية على الانتاجية المائية والمحصول للحنطة باستخدام جدولة ري موسمية مطورة في محافظة نينوى

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الخلاصة

أن الاراضي الزراعية المعتمدة على طرق الري التكميلي في محافظة نينوى والتي تزرع فيها الحنطة الشتوية بمساحات واسعة تكون اكثر تأثرا بسبب التغيرات المناخية المتمثلة بارتفاع درجات الحرارة ونقصان هطول الامطار الحالية والمتوقعة من خلال سيناريوهات المناخ العالمية. لهذا اصبح من المهم أجراء تقييم لدرجة استجابة النبات لتلك الاثار المتوقعة من حيث أنتاجية المياه و ناتج المحصول للفترات المستقبلية (2021–2040) و (2041–2060). بأستخدام بيانات مناخية عالية الدقة مستخرجة من 6 نماذج مناخية عالمية، تحت تأثير سيناريو الاكثر شدة من حيث الانبعاثات لثاني اوكسيد الكاربون SSP5-8.5. و أجراء المحاكاة تحت تأثير و بدون تأثير تغيير تركيز غاز ثاني أوكسيد الكاربون. بواسطة برنامج Aqua-Crop الذي تمت معايرته. بلغ المعامل الاحصائي RRMSE لمرحلة المعايرة 7.1 ولمرحلة التحقق 4.1و معاملا d و r^2 بلغ 1 لكلا المرحلتين وأشارت النتائج الى كفاءة محاكاة جيدة للبرنامج. من نتائج المحاكاة، الاستجابة المتوقعة لزيادة درجات الحرارة وتغير معدلات الامطار بين الزيادة والنقصان تمثلت في زيادة الانتاجية المائية للري بمقدار 28% في سنة 2060 عما كانت علية في فترة الاساس بالنسبة لسيناريو تغير ثاني اوكسيد الكاربون وجدولة ري مطورة، وبلغت مقدار النقصان 13% في مرحلة (2041–2060) عما كانت علية في مرحلة (2021–2040) تحت سيناريو التثبيت. المحصول سجل زيادة بمقدار 30% تحت سيناريو التغير وزيادة طفيفة بلغت 13% تحت سيناريو التثبيت. هذه المخرجات تساعد على توسيع النظرة لمستقبل مرونة القطاع الزراعي والمياه في ظل التغيرات المناخية المحتملة، لاستحداث طرق للتكيف والاستفادة من الفرص المتاحة مع هذه التغيرات.

الكلمات الرئيسية: التغير المناخي، الانتاجية المائية، جدولة الري، محافظة نينوى، برنامج Aqua-Crop

1. INTRODUCTION

Climate change concerns have been noticed recently in many aspects of the ecosystem in the world and investigate their effects. In focusing on the agriculture sector and the response to the irrigation requirement, the limitation of available freshwater must be considered. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, water resources were mainly stressed by climate change concerns in some parts of the world, especially those classified as arid regions. Therefore, climate change is the leading cause of the zone area of aridity increase (7.01%- 5.80%) in the arid and semiarid areas

(Zarch et al., 2017). This change represents by the four factors which modify the water use of the crops temperature increase, carbon dioxide concentration increase, variability in precipitation, and humidity **(Casson et al., 2019).** Cause evidence of a future reduction in water availability and crop production **(Kang et al., 2009)**. Those impacts have an important effect on agriculture and have influenced rain-fed agricultural lands and irrigated lands **(Adamo et al., 2018; Abdullah and Almasraf, 2020)**. To implement adaptation strategies for facing these noticeable inverse impacts and to overcome its excessive levels in the future, important to Analysis of the uncertain impact of the potential change on crop yield and water productivity. It is experienced in different global places by using various techniques in models of climate and crop **(Rosenzweig et al., 2014)**. Sustainable water management through finding an efficient consumption of irrigation and rainfall water is the crucial adaptation approach for agriculture's vulnerability to climate change **(Pereira et al., 2020)**.

(Flohr et al., 2017) indicate droughts in the years (1998-2000) and (2007-2010) also proposed the long-term trend of aridification that began or before 950 CE (common-era). The study **(Abbas et al., 2018)**, Proposed that the region could have exposure to precipitation reduction of 12.5% in the near term (2049-2069) and 21% in the distant term (2080-2099) under the RCP8.5. The Nenawa province is vulnerable to climate change in northern Iraq and depends on supplemental irrigation. Since the insufficient rainwater to cover water demand over the growing season, it is covered by the available irrigation source from the aquifer of groundwater there has functioned for irrigation purposes. It is affected inversely by the impact of climate change through the shortage of precipitation in this region **(Al-Ansari et al., 2014)** because the high precipitation rate leads to the recharge of the groundwater aquifers **(Salih et al., 2020)**. As reported in global studies in the assessment of impact studies, there is a highly different response of agricultural yield and water use efficiency depending on the crop type, geographical location, and agricultural management. When **(Zhang et al., 2022)** used the Aqua-Crop model to examine the winter wheat response cultivated in Guanzhong Plain, the results noticed an increase in the yield, and water production behaves steadily, especially in the irrigated areas related to rain-fed areas. **(Masood and Shahadha, 2021)** investigated the appropriate irrigation and nitrogen application rate as an adaptation measure to the winter wheat cultivated in AL-Rasheed county, located in the south of Baghdad. By employing the Root Zone Water Quality Model (RZWQM2) under different temperature increase scenarios, better irrigation efficiency is realized in high irrigation than in low applied under all scenarios. In the northeast of Iran **(Paymard et al., 2019)** supposed to be an increase in ET_o and CWR under the two emission scenarios and a substantial decrease in Yield and WUE of rain-fed wheat in the late of 21 century (2085) in this region under RCP8.5. Important to assess the response of water productivity, transpiration depth, and yield production of the winter wheat crop, considering the main crop cultivated in this province, to the potential changes under different scenarios of CO_2 concentration and test different irrigation regimes. And examine the predicted change in the two future horizons (2021-2040) near term and (2041-2060) mid-term related to the reference period (1995-2014) by using high-resolution 10*10 km^2 of climate data extracted from 6 GCMs models. The Aqua-Crop model drove the predicted response. This work aims to quantify the potential changes in wheat response in terms of the said indicators, to realize the future resilience of agriculture, and develop adaptation approaches for facing these changes efficiently to overcome the damage or benefit from the opportunities to the crop development.

2. METHOD AND DATA COLLECTION

2.1 Area Study

Nineveh province is considered the second biggest governorate in Iraq (**Fig.1**, is located in the northwest of the country and popular in agricultural activity to be the main source of its economy, especially since cereal crops were cultivated annually and the biggest number of lands area by winter wheat compared to the other governorates. However, this number has decreased in harvesting due to a continuous shortage in rainfall. Also, most lands are struggling to connect with the general irrigation network. Ninawa climate is the coldest, which the average temperature being 27˚C and reaching up to 44˚C in the warmer months. The study area is characterized by loamy soil agriculture. The field observed is located in Bashiqa in Mosul city, its geo-position (36˚23'46.77''N, 43˚20'51.56''E).

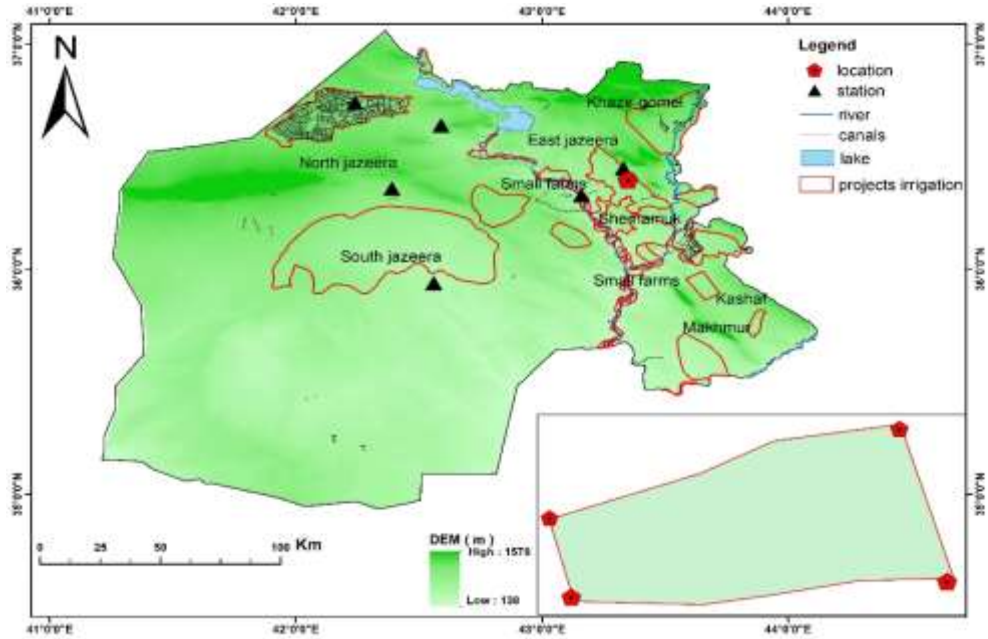


Figure 1. The map of Nineveh province and the location of the site.

2.2 Climatic Data

Required climatic data contains: observed historical data used for model validation for four years (2019-2022) in terms of daily precipitation, maximum and minimum temperature, wind speed, humidity, and reference evapotranspiration obtained from the Iraqi Agro metrological network. As well as projected data was extracted from 6 models of CMIP6-GCM Global circulation model containing EC-Earth3-Veg, CMCC-CM2-SR5, MPI-ESM1-2-LR, NorESM2-MM, CNRM-ESM2-1, and MRI-ESM2-0 and obtaining the predicted change by the ensemble approach (mean of projected data) to reduce the uncertainty consistent with these data **(Teutschbein and Seibert., 2010)**. It is based on SSP5-8.5 (Shared socioeconomic pathway 5), a combination of the fossil-fueled development scenario with the RCP8.5 (Representative concentration pathway) scenario of emissions (IPCC, AR6). It stimulates the maximum and minimum temperature and rainfall data for the reference period (1995-2014), the near term (2021-2040), and the mid-term (2041-2060).

2.3 Crop and Soil Data

The Aqua-Crop model requires crop and soil data for calibration during the observation season to construct a solid beginning for accurate simulation. The crop data contains conservative data in the model database and non-conservative parameters observed during the growing season, differentiating each cultivar in various environments. **(Steduto and Food and Agriculture Organization of the United Nations., 2012a)**, as shown in **Table 1**. And the characteristics of soil for this site are in **Table 3.** The validated model requires observed yield data provided for three years (2019-2021) and the observed season (2021-2022), as presented in **Table 2,** to validate the model performance using three statistical parameters Eqs. (1-4) as Normalizes Root Mean Square Error (NRMSE), Willmott Agreement (d), and Correlation Coefficient (R^2) **(Loague and Green, 1991; Jamieson et al., 1991)**:

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

$$NRMSE = \frac{RMSE}{\bar{O}} \quad (2)$$

$$d = 1 - \frac{\sum_{i=1}^{n}(Oi-Si)^2}{\sum_{i=1}^{n}(|Si-\bar{O}|+|Oi-\bar{O}|)^2} \quad (3)$$

$$R^2 = \frac{(n\sum O*S - \sum O*\sum S)^2}{[n\sum O^2-(\sum O)^2]-[n\sum S^2-(\sum S)^2]} \quad (4)$$

where
Oi, Si are the observation and simulated yield data, respectively,
n is the number of treatments,
$\bar{O}$ is the mean of observation yield data

Table 1. The observation crop parameters in the site.

Crop parameters	Unit	Data
Sowing date	d/m/y	13/12/2021
Plant density	kg/ha	140
Emergence date	d/m/y	25/12/2021
Flowering date	d/m/y	12/4/2022
Time to senescence	Day	150
Time to maturity	Day	176
Harvest index	Ratio	32%

Table 2. Soil parameters of cultivated area in the site.

Horizon	Type	Thickness m	FC%	PWP%	SAT%	Ksat mm/day
1	Loam	1	30.0	15.0	46.0	500.0

The FC% and PWP% are the percentages of water content at the field capacity and the permanent wilting point, and Ksat is the saturated hydraulic conductivity of soil layers.

Table 3. List of observed yield data.

Year	2019	2020	2021	2022
Yield	4.8	4	4.4	4

2.4 Aqua-Crop Model

The Food and Agriculture Organization of the United Nations has developed the crop-water model efficient for agriculture extension, consulting engineers, scientists, and associations to designate food security by measuring the production of yield and productivity of water influenced by environmental variability and management. It requires a few explicit parameters for flexible use, known as Aqua-Crop **(Steduto and Food and Agriculture Organization of the United Nations., 2012b**; **Raes et al., 2009)** simulates crop response to water stress of herbaceous crops in a good balance between accuracy and simplicity. The model design considers the root zone a water reservoir throughout its volume. It keeps tracking the incoming water fluxes as rainfall, irrigation, and capillary rise. And outgoing like the runoff, deep percolation, and evapotranspiration. Due to this process, the model simulates water depletion Dr and the water retaining Wr at every time element over the growing duration of the plant **(Raes et al., 2018)**. The model works as a connected series between the soil-plant-atmosphere components, which drive the main biological processes: the development of canopy cover and water transpiration Eq. (5). As well as biomass production B Eq. (6). Finally, the yield Y is estimated by formation Eq. (7), in which the model estimates every daily step to simulate the final yield production **(Raes et al., 2018)**.

$$Tr = Ks \cdot Kc \cdot ET_{\circ} \qquad (5)$$

$$B = WP.^{*} \cdot \Sigma\left(\frac{Tr}{ET_{\circ}}\right) \qquad (6)$$

$$Y = HI \cdot B \qquad (7)$$

where: $K_{S.}$ Represents the stress coefficient, $K_{C.}$ is the crop coefficient, and $ET_{\circ}$ is the reference evapotranspiration, WP^{*}. It is the normalized water productivity, and HI is the harvested index. Since its release in 2009, many researchers have examined its performance to simulate the response of different crops in different environments and conducted it for different purposes. For example, in the designation of water regimes in several ways to maximize the water productivity in the current yield production, developing different deficit schedules to improve water management in conditions of water stress, and observing the probability of an increase in productivity **(Vanuytrecht et al., 2014; Adeboye et al., 2019; Zhang et al., 2022)**.

2.5 Irrigation Management

The crop-water model simulates the response of the crop to the various water management, and this is a good tool for facing the challenges of water availability and its function in agricultural production in the zones of arid and semiarid **(Steduto and Food and Agriculture Organization of the United Nations., 2012a)**. The studies of impact assessment of climate change as followed by many experiments **(Andarzian et al., 2011;**

Sandhu et al., 2015; Alvar-Beltrán et al., 2021),. The current study utilized the first application of the Aqua-Crop model to develop an irrigation schedule that supplies an efficient amount of water without causing crop growth problems **(Al-haddad and Al-safi 2015).** Against the traditional one adopted on the site seasonally, where the irrigation source in this field depends on the groundwater at a level of 30m underground and extract the water for irrigation by the water well pump to solid set sprinklers planned as shown below in **Fig.2**.

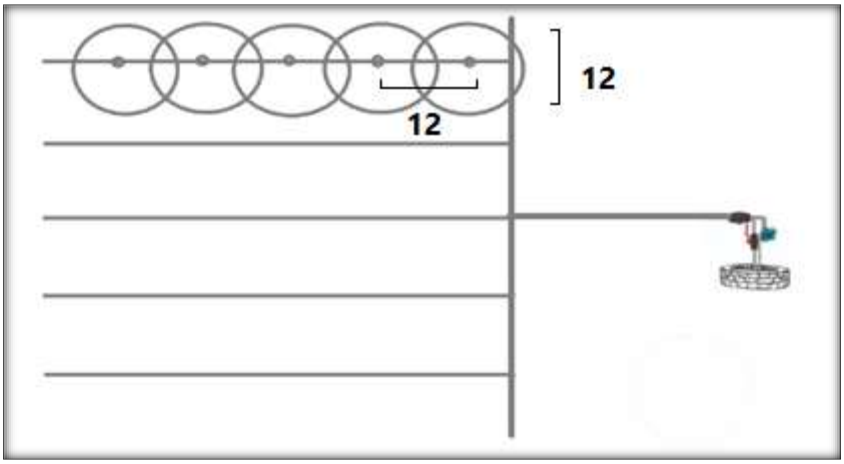
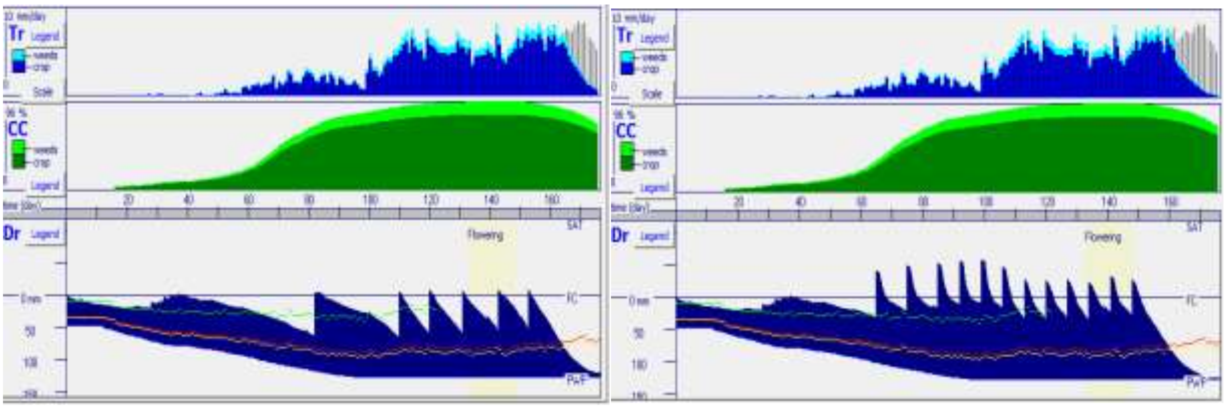


Figure 2. The plane of sprinkler distribution in the field.

The supplementary irrigation began in mid-February due to the absence of rainfall frequented by weekly net water depth, calculated by the can method. And they developed another one designed for irrigation when the water depletion in the root zone reaches 80% of the readily available water. Then, they applied net depth to reach field capacity water content. The result of the water depletion in the root zone for both irrigation treatment conditions is presented in **Fig. 3**.



(A) Seasonal traditional schedule (B) Seasonal developed schedule

Figure 3. Transpiration and canopy cover, and the water content in the root zone.

2.6 Water Productivity

Water productivity indicates the efficiency of water management to maximize the net production yield per net unit of water use in current environmental conditions **(Accounting for Water Use and Productivity, 1997; Tubiello et al., 2000; Steduto and Food and Agriculture Organization of the United Nations., 2012b)**. Estimating water productivity in several ways using different water use values depending on the area of interest **(Kaware et al., 2004)**. The Aqua-Crop model simulates the evapotranspiration water productivity WP_{ET} to represent the capacity of unit water transpired from plants and soil to produce a unit quantity of yield Eq. (8) **(Raes et al., 2018)**. In addition, this work used water applied to take into account the prediction effects of water regimes on the yield to maximize it by using the output data of yield and water from the model simulation to evaluate the WP_I in Eq. (9). **(Accounting for Water Use and Productivity, 1997)**

$$WP_{ET} = \frac{YIELD \quad kg}{Water\ evapotransperd \quad m3} \tag{8}$$

$$WP_{I} = \frac{Yield \quad kg}{water\ applied \quad m3} \tag{9}$$

3. RESULTS AND DISCUSSION

The results revealed in the validation test to conclude the calibration and verification periods and the future simulation of winter wheat crop parameters to respond to the potential impact are presented as follows:

3.1The Simulation of Climate Parameters

The project maximum and minimum temperature given in **Table 4**. tend to increase in all GCMs models. The ensemble change is anticipated to increase by 0.17˚C and 0.66˚C for the maximum temperature in the near (2021-2040) and mid-term (2041-2060), respectively. An increase in minimum temperature of 0.5˚C and 0.85˚C in the near and mid-term related to the reference period (1995-2014). A frequent precipitation change is noticed in the growing seasons of projected periods, where the ensemble precipitation change tends to increase in the near term at 19.75 mm/year and decrease in the mid-term at 27.86 mm/year. This frequency is presented in **Fig. 4**.

Table 4. Simulation temperature and rainfall changes during the growing season for 6 GCMs models and the ensemble over near and midterm.

Model	Maximum temperature change (˚C)		Minimum temperature change (˚C)		Rainfall (mm/year)	
Horizons	2021-2040	2041-2060	2021-2040	2041-2060	2021-2040	2041-2060
CMCC	+0.3	+0.82	+0.53	+1.2	-33.85	+5.7
CNRM	+0.1	+0.69	+0.34	+0.96	+52.57	-25.4
EC-EARTH	+0.14	+0.58	+0.39	+0.95	+97.21	-12.2
MPI	+0.27	+0.49	+0.3	+0.96	-75.14	-35.7
MRI	-0.15	+0.69	+0.35	+0.67	+103.35	-21.95
NOR	+0.38	+0.71	+0.5	+0.85	-25.67	-77.6
Ensemble	+0.17	+0.66	+0.4	+0.93	+19.75	-27.86

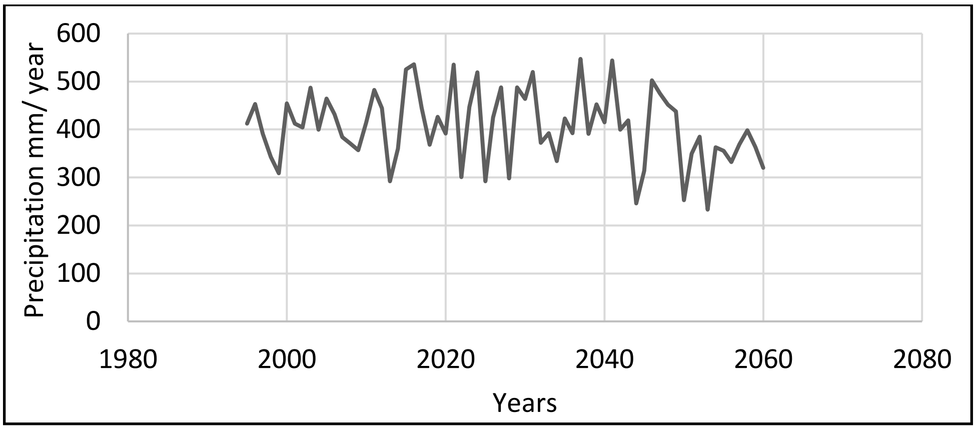


Figure 4. Predicted precipitation ensemble (mm/year) during the growing seasons (1995-2060).

3.2 Model Validity

The Aqua-Crop model was calibrated in seasons (2019-2020), depending on the non-conservation crop data, as phenology periods were measured on Growing Degree Day (GDD) and observed in the season of 2022. And different parameters of CC_o initial canopy cover, HI harvesting index, and relative biomass B to propose the best concurrence through group C (3.5, 30, 90%) of CC_o, HI, and B, respectively, as presented in **Fig. 5**. To achieve excellent correlation in simulated and observed yield data by RRMSE was 7.1, d equal 1, R^2 equal 1. And using the same parameters to verify its performance in the two observed seasons (2021-2022), as shown in **Figs. 6**. And achieved RRMSE is 4.1, d was one, and R^2 was 1. And these results indicated good model performance **(Jamieson, 1991; Loague and Green, 1991).**

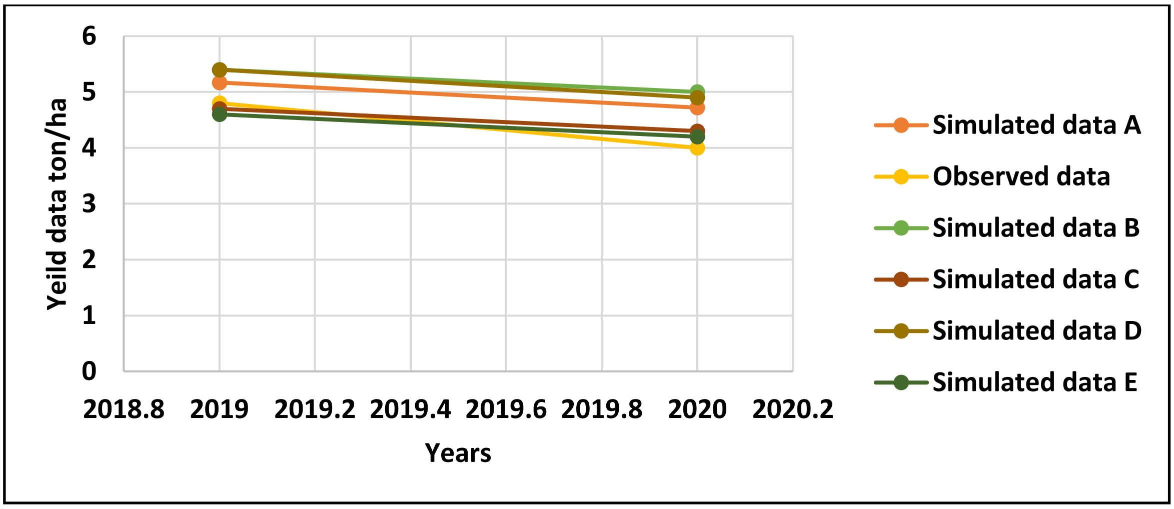


Figure 5. The simulated and observed yield data in the calibration period (2019-2020).

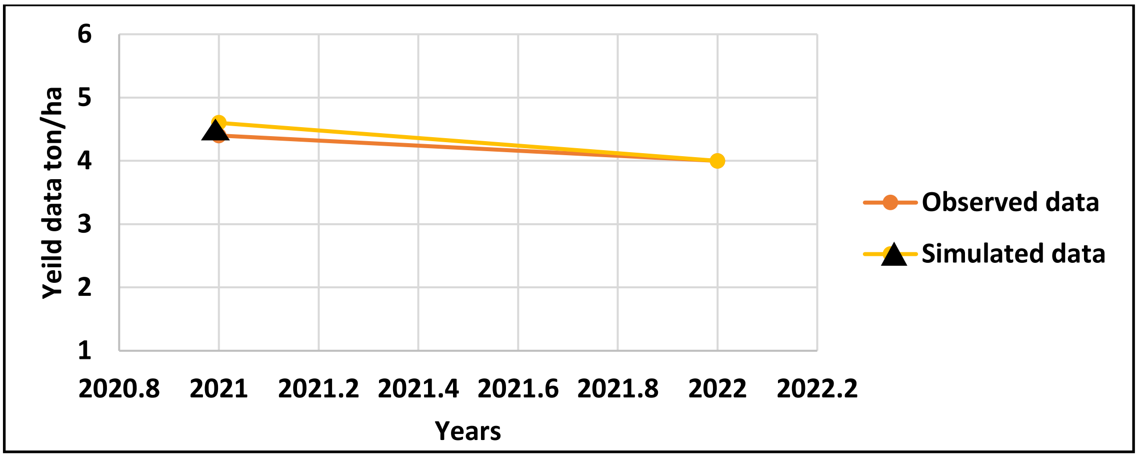


Figure 6. The simulated and observed yield data in the verification period (2021, 2022).

3.3 Predicted Growing Cycle Length And Transpiration Depth

With the associated increase of temperature degrees in the projected future periods, the growing season tends to reduce to reach three days in the near term and eight days in the mid-term related to the reference as presented in **Fig. 7**, on the line of the study **(Azad et al., 2018).** This physiological strategy for the plant was interpreted by **(Sabella et al., 2020)** as escaping the high temperature that occurred through advances in ripening kernels. The expected result of annual transpiration depth tends to reduce in the two irrigation regimes and under both CO_2 concentration scenarios due to the projected shortening in the growing season, as presented in **Fig. 8,** especially in the state of changing CO_2. The predicted reduction can reach 7% and 8% in the mid-term related to the reference period under conditions of traditional and developed water schedules, respectively, since the CO_2 contribution effect. The study's results **(Jones and Singels, 2018)** found that CO_2 elevating increased the yield of rain-fed sugarcane to 7% and 6% through transpiration, reducing and improving the water status of the crop.

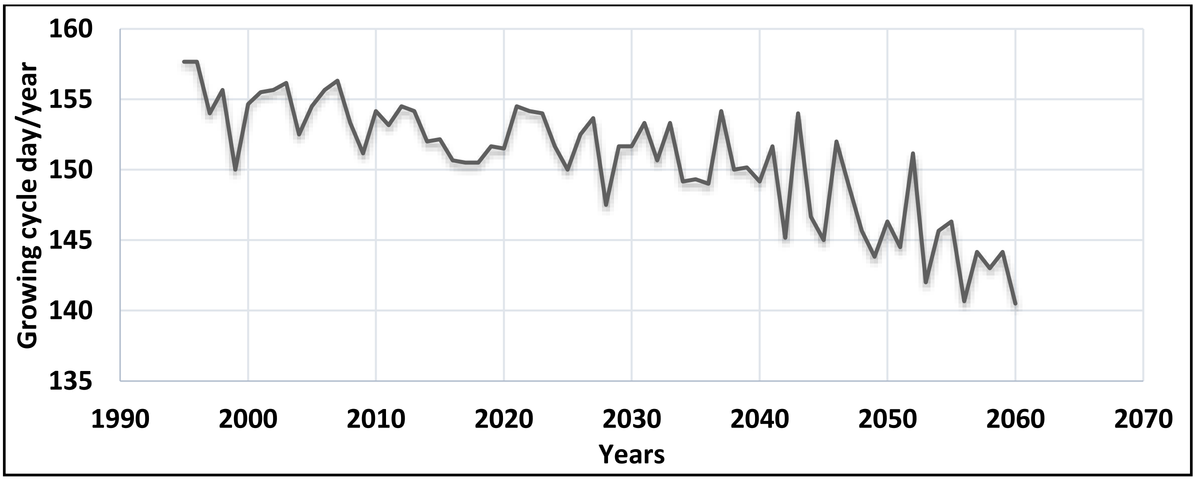


Figure 7. Simulated length of the growing cycle in (day/year) over the duration (1995-2060).

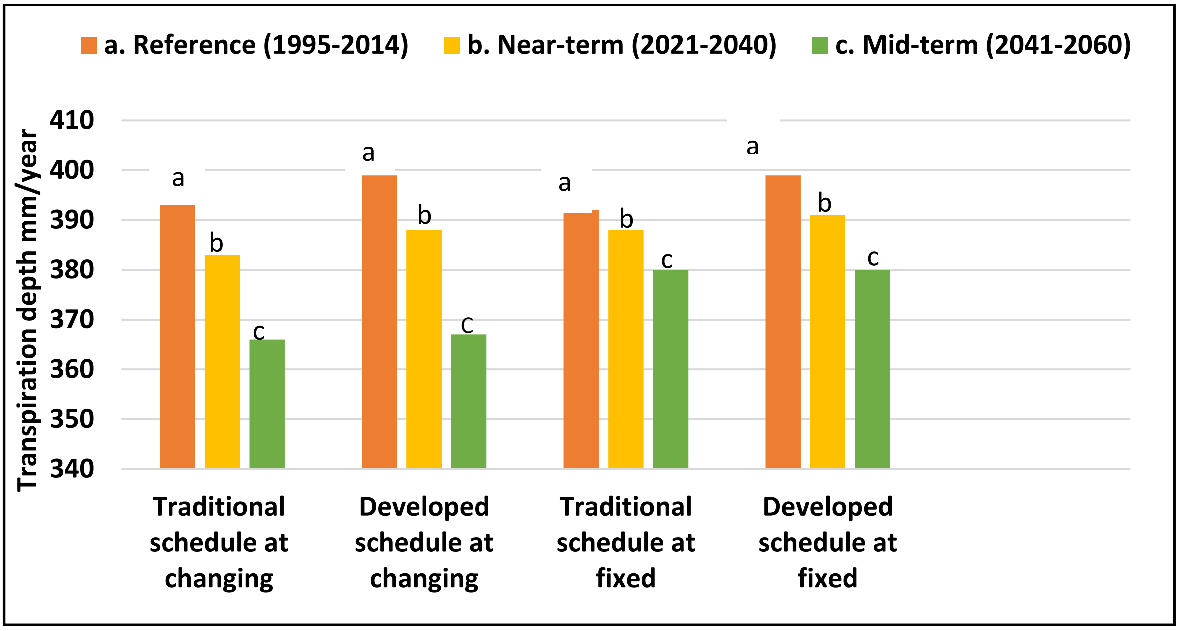


Figure 8. The Simulated annual transpiration depth in (mm/year) under the scenario of changing and fixed CO_2 concentration over the projected periods.

3.4 Predicted Yield

The simulation of yield production experienced an increase under two conditions of water regime in both states of CO_2 concentration, as presented in **Fig. 9**. The significant change in the case of changing CO_2 concentration was 17% and 30% for the near and mid-term, respectively related to the reference period, as a result, has revealed in the study **(Jones and Singels, 2018)**. And a slight increase in the fixed state of CO_2 concentration was 12% and 13% for the near and mid-term, respectively, related to the reference period. There are no important differences between the yield simulations in both conditions of water regimes. However, the net crop water requirement in the developed schedule was supplied by rainfall most time. In contrast, the traditional schedule depended on irrigation water most during the growing season.

3.5 Predicted Evapotranspiration Water Productivity

The evapotranspiration water productivity is anticipated to rise in the two conditions of water regimes without any differences. A significant increase was noticed in the case of changing CO_2 to reach 22% and 44% in the near and mid-term related to the reference period. And a slight increase in the case of fixed CO_2 concentration to reach 15% and 21% in the near and mid-term related to the reference period **Fig. 10**. Due to the CO_2 elevated effect on the transpiration reduction in the two cases, as said in previous sections.

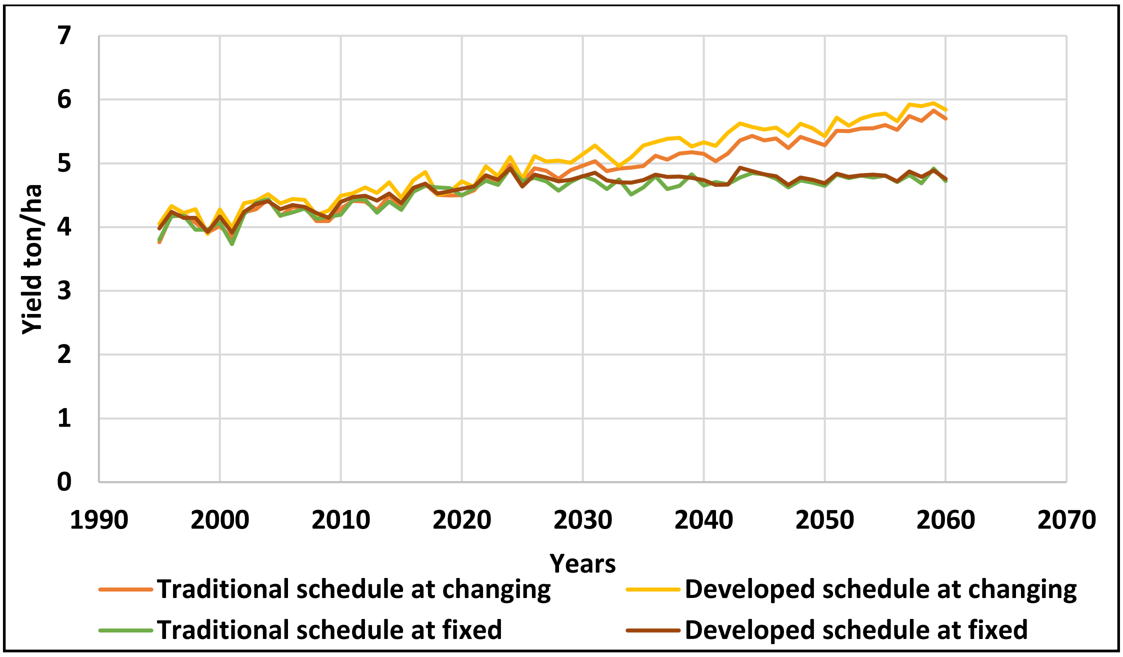


Figure 9. Simulated yield production under the cases of changing and fixed CO_2 concentration over the period (1995-2060).

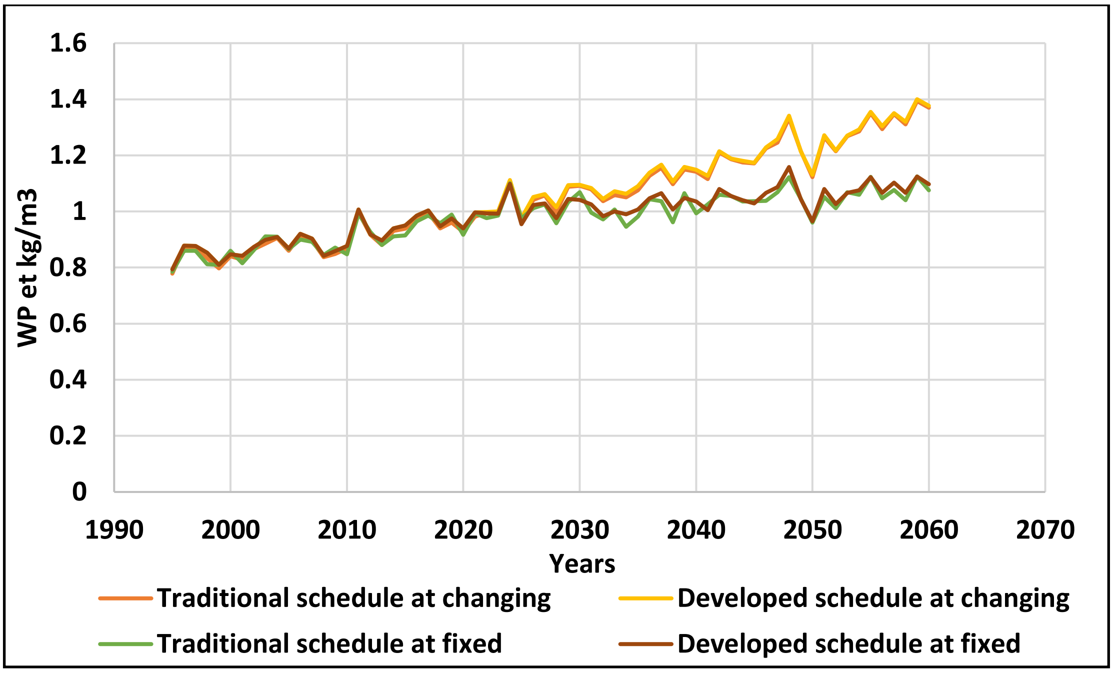


Figure 10. Simulated evapotranspiration water productivity under the scenario of changing CO_2 concentration and changing CO_2 concentration over the period (1995-2060).

3.6 Predicted Irrigation Water Productivity

The simulation of the irrigation water productivity examines a high difference between the two conditions of water regimes as presented in **Fig. 11**, where the average water productivity in the developed schedule increases by 2.4 and 2.5 kg/m^3 in the near and mid-term from the traditional schedule in the case of changing CO_2. An increase of 2.2 and 1.8 kg/m^3 in the near and mid-term under the traditional schedule and case of fixed CO_2 concentration. And noticed a continuous rise in the average water productivity in the developed schedule under the case of changing CO_2 to reach 23% and 28% in near and Mid-term, respectively, related to the reference period. While in the case of fixed CO_2, there is an increase in the average water productivity of 17% in the near term related to the reference period and noticed reduction of 13% in the mid-term related to the near term. Coinciding, another indicator, is influenced by elevated CO_2.

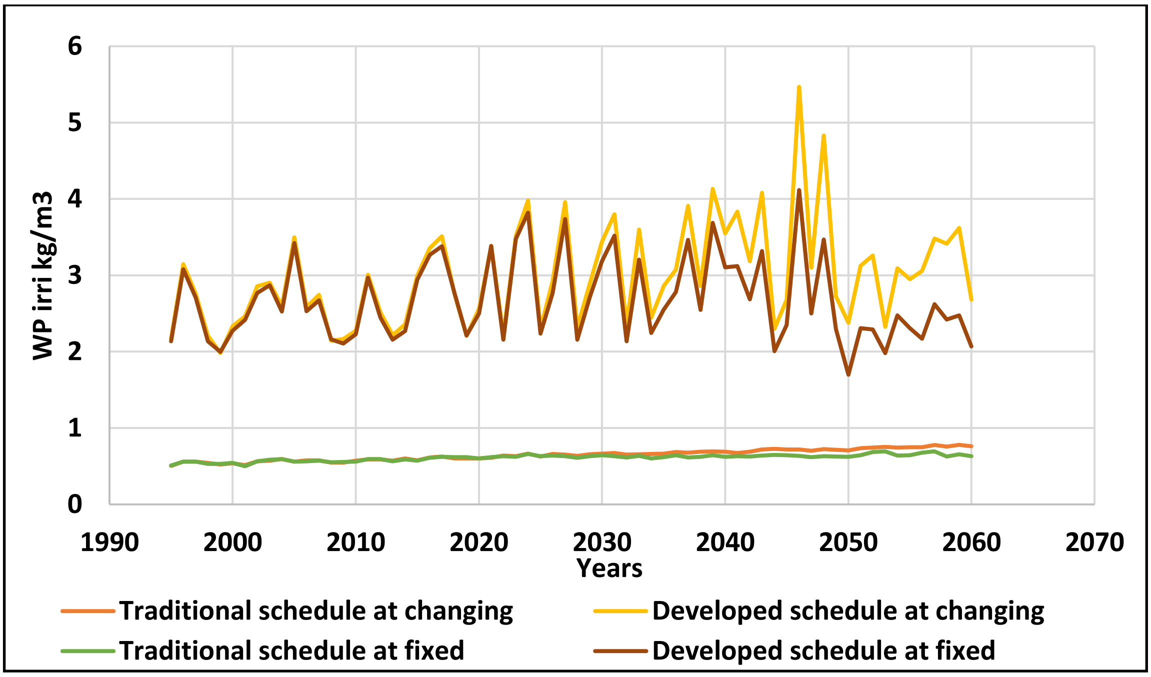


Figure 11. Simulated irrigation water productivity under the cases of changing and fixed CO_2 concentration over the period (1995-2060).

4. CONCLUSIONS

The associated change increase in the maximum and minimum temperatures and the frequent change in rainfall rates are driven by different scenarios of CO_2 concentration and water regimes. In this region where the agricultural practices for winter wheat, depending on the supplemental irrigation method, have affected the biological response of the crop parameters as follows:

- Noticed continuous increase toward the near and mid-term under the changing CO_2 concentration (emission scenario SSP5-8.5) in all simulation trends of yield and evapotranspiration and irrigation water productivity.

- Stable or slight increase trends have been explored toward the projected periods under the scenario of fixed CO_2 concentration. That interpreted the influence of CO_2 elevated and temperature increase to have advantages the crop growth and water productivity.
- Growth period shortening caused a reduction of transpiration depth and increased water productivity and yield production.
- In comparison between both water regimes examined, the findings revealed higher irrigation water productivity projected under a developed schedule than traditional ones in both cases of CO_2 concentration. To demonstrate that improving water management is an efficient adaptation approach to benefit from the climate change opportunities or reduce the challenges.
- Aqua-Crop examined good validity in this region to provide an overall future vision of water productivity and yield production response to the potential impact of climate change. Facilitate the annual followed schedules assessment and develop an appropriate deficit schedule under current field conditions for enhancing water productivity.

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