Prevision of biomass, yield and water productivity for soft and durum wheat in Setif region using Aquacrop under SSPscenarios

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Abstract

Algeria's food security in the upcoming years is threatened by the anticipated climate change, so the study aims to employing the AquaCrop crop model under SSP1.9, SSP4.5, and SSP8.5 of the experimental site situated in the Eastern High Plains of Algeria Setif to examine the effects of climate change on the rainfed durum and soft wheat cultivar known as Oued el bard and El Wifek sucssively. The model also has been calibrated using meteorological, pedological, phenological paramètres, and yield, biomass, canopy cover and soil water content data observed over a period spanning three cycles, from 2021–2022 to 2023–2024. The model has been calibrated, validated, and parametrized for the prediction of wheat grain yields and was then used to simulate, biomasse, water productivity and yield wheat at the study site for short-term (2020–2039) and medium-term (2040–2059) periods in comparison to a reference period (1995–2014). AquaCrop was confirmed to replicate the yields of the Oued el lberd and El Wifek cultivars with a high degree of accuracy (RMSE = 0.34 et RMSE = 0.60). For both cultivars of durum and soft wheat, it is anticipated that the average wheat grain yield will increase by+136.67%; +161.33 % and 176.67%; +28.38%, +62..16%, +89.19 % under SSP1.9, SSP4.5, and SSP8.5, respectively in 2020–2039 and by 153.33%; +269.17%, +369.76% ; +41.89% , +75.68 % and +109.46% in 2040-2059 under SSP1.9, SSP4.5, and SSP8.5, succsively compared to the average yield of the baseline period (1995–2014), which was estimated to be 6 t/ha and 7.4 t/ha for durum and soft wheat succsively. The increase in CO_2 concentrations fertilizes the production of rainfed wheat. This effect offsets the adverse effects of rising temperatures and falling precipitation. Under three SSPs scenarios, an increase in wheat water productivity and biomass is anticipated. Overall, the simulation results demonstrated that the AquaCrop model is suitable for simulating the effects of climatic stress on the productivity of cultures in the zones pluvial agriculture, which could benefit in making decisions on water productivity and cultural adaptation to future climatic trends in semi-arid conditions.
Keywords : Aquacrop, SSPs, durum wheat, soft wheat, yield crop

1. Introduction

Increased, high temperatures and rainfall, fewer rainy days, extended dry spells, and other effects of climate change have an impact on crop yield in Semi-Arid regions. (Mahmood et al., 2015). The findings show notable drops in precipitation and rises in warmth. The most negative forecast is provided by SSP5-5.8, which predicts the greatest drops in precipitation (65.9% to 60.94%) and the highest temperature elevations (24.52 to 27.18°C, 31.83 to 34.43°C, and 17.30

to 20°C for average, maximum, and lowest temperatures).(Chetioui & Bouregaa, 2024) Further-more, research shows that North African agriculture is vulnerable to being among the most impacted, not just because of its heavy reliance on pluviometry, but also and primarily due to its limited ability to adjust to climate change (Mertz et al., 2009). The surface area used for agriculture (SAU) in Algeria is just about 3.6 percent of the country's total land area, and only 30% of this SAU is required to be at least 400 mm of rain in the year.Cereal cultivation, which is dominated by durum wheat and accounts for 85% of the SAU, is found in semi-arid zones and is characterized by unpredictable, erratic, and efficient rainfall (Bessaoud, 2019).Particularly in areas with scarce water supplies, durum wheat is a crucial cereal crop ((Xynias et al., 2020 ; Martínez-Moreno et al., 2022). Water scarcity and other biotic and abiotic factors make it difficult for Algeria to cultivate durum wheat (Hannachi & Fellahi, 2023). Algeria's driest regions are growing while its rainiest ones are decreasing. Therefore, the rainfed crop is extremely susceptible to climate change in the future. It was expected that crop yields in Algeria would drop by 10 to 30 percent by 2030 as a result of the CC mentioned above (Kourat et al., 2022) . Accurate crop yield predictions contribute to regional and/or national food security. In certain ways, the crop yield forecast model (Zhao et al., 2022). The modeling approach is transparent since AquaCrop mimics final crop yield in four simple steps. The procedures include simulating the growth of the canopy cover of green crops, crop transpiration, above-ground biomass, and crop production, regarding the utilization of water production by presenting novel ideas and model equations (Vanuytrecht et al., 2014).

Using the FAO AquaCrop model, the primary goal of this study is to simulate wheat productivity under various future climate scenarios and models in a rainfed agriculture site called "Setif , biomass and water productivity simulation for the short-term (2020–2039) and medium-term (2040–2059) periods by taking into account three common socioeconomic Pathway scenarios (SSP 1.9, SSP 4.5, and SSP 8.5) in order to obtain average model outputs, with an emphasis on crop yield, biomass, and water productivity and other goals such as using experimental field data, we concentrated on AquaCrop calibration and validation in rainy conditions, all this in order to support the farmers in their efforts to prevent climate change induced losses in wheat yields in order to prepare a national strategy to adapt rainfed wheat against the expected negative impacts of climate change.

2. Methodology

2.1 Study Area

The study area, which is situated in northeastern Algeria, includes the high plaines of Sétif, which stretch from latitude 36°10′ N to longitude 5°21′ E and are about 980 meters above sea level (Figure 1). The climate of the area is semi-arid, with hot, dry summers and cool, rainy winters. Rainfall varies greatly in both space and time, from 900 mm per year in the north to only 200 mm in the south. With a pH of about 8, the calcareous earth soil is categorized as a steppic brown soil.
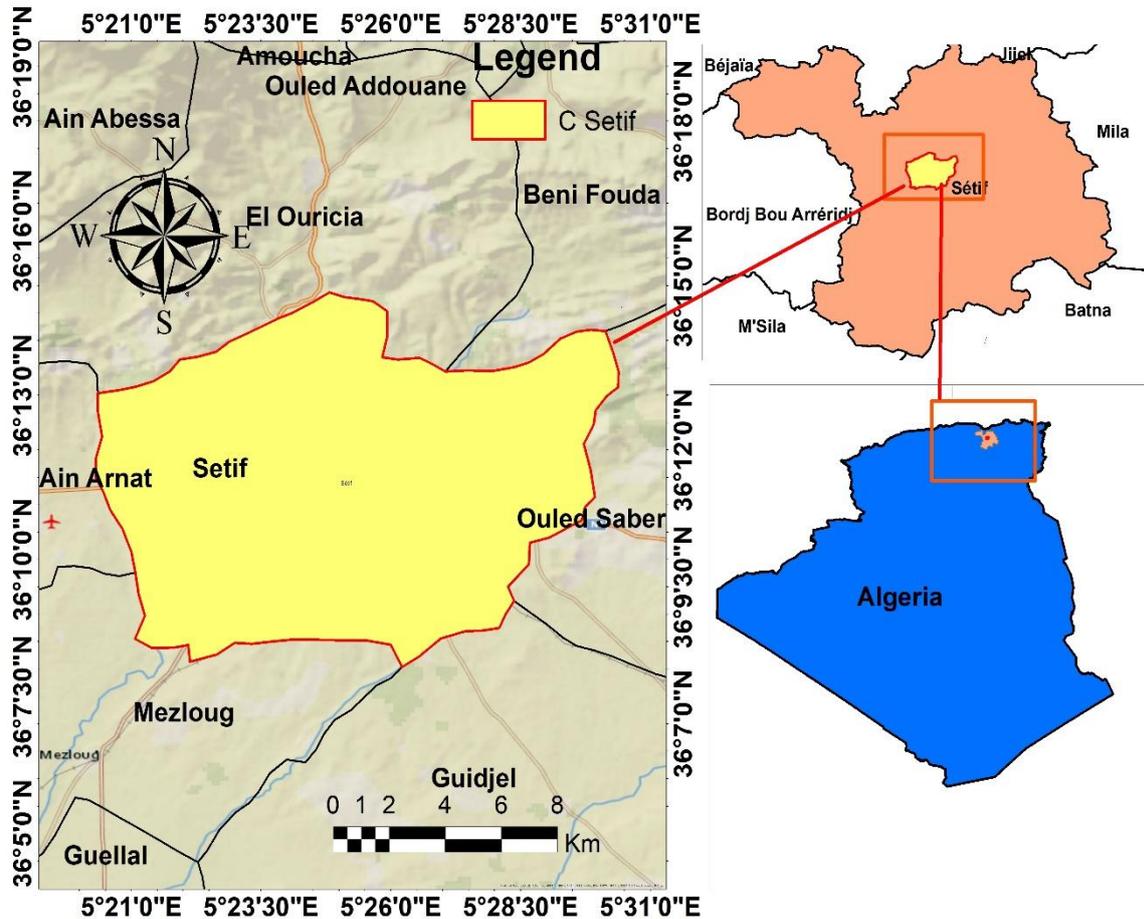
Fig.1 The experimental site's geographic location.

2.2 Climate Data
2.2.1 Calibration period (2021-2024)
Climate data for the experimental site (ITGC): Monthly rainfall (mm), maximum, minimum temperatures (C°) were all obtained from the site: https://www.ogimet.com: For the growth season of 2021–2024. For the daily reference evapotranspiration (ETo), the FAO Penman-Monteith method was used to determine the reference crop's evapotranspiration (ET0). (Surendran et al., 2015), To estimate reference crop evapotranspiration, the FAO's Land and Water Development division created a decision support tool called CROPWAT 8. (Balan & Joseph, 2021). The Aquacrop model, which was based on observed field performance, was calibrated and validated using this data.

2.2.2 Reference Period (1995-2014)
Long-term climate data from 1995 to 2014 were used for the baseline simulation , The historical data comes from https://climateknowledgeportal.worldbank.org :maximum, minimum temperature (C°) and precipitation (mm) and the ET0 (mm) calculeted by CROPWAT 8, either the CO_2 concentration originate from ongoing measurements made at the Mauna Loa Observatory in Hawaii and have been added to this data base.

2.2.3 Future projections under SSPs (2020-2039 and 2040-2059)

General climate model results under three Shared Socioeconomic paths (or "SSPs") :SSP1-1.9 (low emissions), SSP4.5 (mid emissions), and SSP8.5 (high emissions) were used to create future climate scenarios for the two projections 2030 (2020-2039) and 2050 (2040-2059) : the maximum and minimum of air temperature (∘C), precipitation (mm), were taken from https://climateknowledgeportal.worldbank.org, the CO_2 concentration was added to this data-base based on continuous measurements taken at Hawaii's Mauna Loa Observatory. the ET0 calculeted by CROPWAT 8,to reflect générale conditions in the Setif region.To assess the impact of climate change on durum and soft yields, mensuelly meteorological files were created and entered into Aquacrop.

2.2.4 Soil Data

Laboratory studies showed that the soil texture was categorized as silty clay, consisting of 47% silt, 48% clay, and 15% sand. Electrical conductivity (EC) was low at 0.15 ms/cm and the pH was somewhat alkaline (7.80), suggesting non-saline conditions. To ascertain the physical and chemical characteristics pertinent to crop modeling, a soil investigation was carried out at the ITGC experimental site in Sétif. With a calcareous content of 37%, With an estimated organic carbon content of 1.45%, the results indicate moderate fertility. At 1.32 g/cm³, the bulk density was within the ideal range for water flow and root growth. In terms of water retention properties, the soil displayed a Permanent Wilting Point (PWP) of 14.56% and a Field Capacity (FC) of 33.9% (Table1).

Table 1. Physical and chimical caracteristics of the ITGC site experimental, Setif.

Station	Depth	sand (%)	Clay (%)	Silt (%)	calcareous (%)	Ph	organic matter (%)	Electric conductivity	Bulk density	FC (%)	PWP	PWP (%)
ITGC Sétif	(0-20cm)	15	48	47	37	7.80	2.5	0.15	1.32	33.9	14.56	33.9

2.2.5 Crop Data :

The research area's most common crops, Oeud el bard durum wheat and soft wheat ELWifek, were the subject of the crop data. 300 and 250 seeds m-2 were successfully seeded on average. Applications of fertiliser prior to seeding and during the stage of stem elongation were adequate to fulfil dietary needs. The main methods of controlling weeds and diseases were herbicides and a preventative fungicide. There were no signs of pests or disease infections.

Aboveground biomass (ton /ha) was measured five to six times from a 0.25 m² area in 2021/2022,2022/2023, and 20232024 by randomly chopping four representative plants from Each plot. Every plant sample was heated to 105 degrees Celsius, then oven-dried to a consistent Weight at 70 degrees Celsius. The final dry weight (DW) was then noted (Jin et al., 2014).

Over time, the technique for measuring soil moisture content (SWC) has evolved to use the gravimetric method for the three seasons Using a tarriere that is 0.2 meters deep (Belkhiri et al., 2019). However canopy cover (%) was estimated by the Canopeo application wich was created as a quick, easy, accurate, and cost-free tool to determine the ground cover fraction (GCF) from field-captured red-green-blue (RGB) photos and videos. (Hale et al., 2024).

3. AquaCrop model (Version 7.0)

The Division of Lands and Water of the Organisation of Nations for Agriculture and Food (FAO) created the AquaCrop model of water-based cultural productivity (Dubey et Sharma, 2018).In addition to predicting green canopy cover (CC), AquaCrop divides evapotranspiration (ET) into biomasse, evaporation (E), and transpiration (T) based on the daily flow of water into and out of a system (Araya et al., 2010; Toumi et al., 2016).

AquaCrop uses climate files as input data, which include ETo, minimum-maximum air temperature,crop file (emergence date, flowering start and duration, maximum canopy cover, canopy senescence, and physiological maturity), soil file (field capacity, permanent wilting points, saturated hydraulic conductivity), management file (irrigation, field management practices), and initial condition file (initial soil water content) .(Steduto et al., 2012).

3.1 Model calibration and validation

Aquacrop is calibrated to grow Oued el berd and Wifek for the two succeeding seasons 2021/2022 and 2022/2023 at the Institute Technique des grandes cultures (ITGC) in Sétif. It has also been validated for 2023-2024 based on the yield, water productivity, biomass, and canopée cover values observed during the three agricultural seasons that followed: 2021-2022, 2022-2023, and 2023-2024 within the experimental farm of Sétif. The prediction error statistics were then used to evaluate the quality of fit between the expected output and observed values.

3..2 Data analysis

To assess the dependability of the model, measured and simulated variables, such as soil water content, dry biomass, canopy cover and grain yield, were statistically compared. The Calculating the coefficient of determination, the root mean square error (RMSE), the normalised root mean square error (NRMSE) (Jacovides & Kontoyiannis 1995), the Nash-Sutcliffe efficiency (EF) (Nash & Sutcliffe 1970), and the index of Willmott (d) (Willmott 1982) allowed for the definition of agreement between predicted and measured values. Equation 1-4 provided the statistical parameters.

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

$$\text{NRMSE} = \frac{1}{O} \times \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Si - O_i)^2} \times 100 \qquad (2)$$

$$d = 1 - \frac{\sum_{i=1}^{n}(S_i - Oi)^2}{\sum_{i=1}^{n}(|S_i - \overline{O_i}| + |Oi - \overline{O_i}|)^2} \qquad (3)$$

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \Sigma(y_i - \bar{y})^2}} \tag{4}$$

A model adjustment is made when the RMSE is close to zero. The RMSE unit is the same as Si and Oi's (Abedinpour, 2014). Using $\bar{O}$ as the average of observations.According to Amiri (2016), the model's accuracy is outstanding if the NRMSE is less than 10%, satisfactory if it is between 10% and 20%, acceptable if it is between 20% and 30%, and moderate if it is greater than 30%.According to (Andarzian et al 2011 ; Tavakoli et al 2015; Mohammadi et al 2016), the value of the index of agreement (d) ranges from 0 to +1.The proximity with a indicates that the estimated and observed values are the same based on the values of d. They vary as follows in the Pearson test: -1 from 0 to 1. Positive values of r indicate a positive linear correlation, whereas negative values indicate a negative linear correlation. If r is negative, it means that there is no linear connection; if r is close to 1 or -1, the linear correlation is strong (Grey et Kinnear, 2012).

3.3 Simulation of climate change

Following calibration, the model was used to simulate the productivity of wheat, the duration of culture growth, canopy cover, biomass, evapotranspiration and water productivity for three time periods: reference period (1995-2014), short-term (2020-2039), and medium-term (2040-2059) using the climate data related to each period. We used 11 general circulation models within the framework of the three SSP scenarios (SSP1.9, SSP4.5, and SSP8.5) to assess the impact of climate change on the study site and on the crop. The cultural management and fertility strategies have remained the same as they were during the étalonnage.

4 Results and discussion
4.1 Calibrated Aquacrop Model
4.1.1 Canopy cover

Five statistical indices were used to assess the model AquaCrop's performance in simulating the canopy cover (canopy cover) of durum wheat and soft wheat : the correlation coefficient (R), the racine of quadratique mean error (RMSE), the quadratique mean error normalised (NRMSE), the model's effectiveness coefficient (EF), and the agreement index (d). The outcomes for the agricultural campaigns in 2021–2022, 2022–2023, and 2023–2024 show a remarkable predictive ability of the model.

Indeed, there is a very strong correlation between the simulated data and the field measurements, as indicated by the coefficient of correlation R, which ranges from 0.90 to 1 with an average of 0.96. The maximum value (R = 1) attained in 2023–2024 highlights perfect fit. Regarding RMSE, it shows a declining trend from 5.4 in 2021–2022 to 2.1 in 2023–2024, indicating a continuous improvement in simulation accuracy. According to agronomic standards, the average NRMSE is 15.83%, with a substantial improvement in 2022–2023 and 2023–2024 (≈ 14.7%–14.8%). With respective averages of 0.96 and 0.99, the EF (model efficiency) and d (accord) indices are exceptionally high, demonstrating both the overall robustness of the Aqua-Crop model to dynamically reproduce the wheat cover plant under the conditions under study as well as the quality of adjustment (Table 4).

Additionally, for the blé tendre, the overall coefficient of correlation (R) is high, ranging from 0.95 to 0.99 with a mean of 0.97, indicating a strong correlation between the measured and simulated values. With a mean RMSE of 4.73 and a notable interannual variability (3.4 in 2021–2022, against 6.8 in 2022–2023), the simulations' accuracy is generally satisfactory, however there are some variations that are likely related to climatic or cultural factors.The average NRMSE is higher than that found for the wheat dur (21.23%), reaching a peak of 24.2% in 2021–2022. These values demonstrate a greater degree of variability in the model's predictive ability regarding this particular culture. The model is marginally less effective than the results obtained on the blé dur, as indicated by the coefficient of effectiveness (EF), which ranges from 0.73 to 0.92 with an average of 0.83.Finally, the agreement index (d) shows a mean of 0.88, indicating a good overall agreement between the predictions and the observations (Table 5).

Figure 2 shows the correlation between the actual data for durum wheat across three seasons (2021–2024) and the simulated canopy cover (CC) by the AquaCrop model. This graphic comparison makes it possible to see how accurate the model is in reproducing the dynamics of foliar development.The close proximity of the measured and simulated curves suggests that the model has a very good ability to depict the cultural growth in the air. This is important since CC directly affects photosynthetic processes, evapotranspiration, and ultimately biomass and yield. The stability of the model's performances is confirmed by the two temporally aligned profiles over a number of years.

The correlation between the measured and simulated values over the three years under study is depicted in the Figure 3. The distribution of points around the regression's right side shows the general trend towards a high correlation as well as a more noticeable dispersion in some campaigns, such as 2022–2023 for soft wheat.

Table 4 The AquaCrop model's performance in forecasting canopy cover was measured using statistical indices of durum wheat .

parametres	R	RMSE	NRMSE	EF	d
2021-2022	0.98	5.4	18	0.94	0.99
2022-2023	0.90	4.9	14.8	0.96	0.99
2023-2024	1	2.1	14.7	0.97	0.99
Average	0.96	4.13	15.83	0.96	0.99

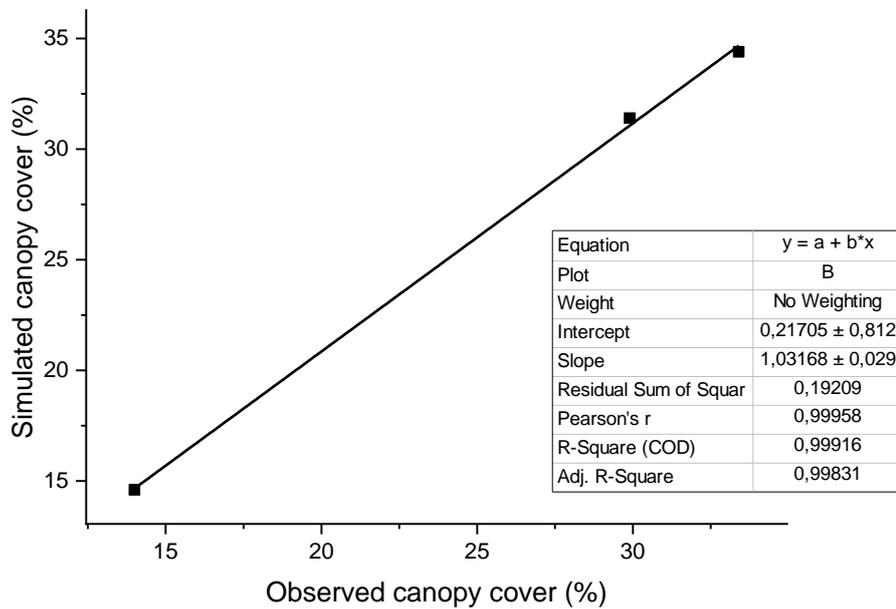| Equation	y = a + b*x
Plot	B
Weight	No Weighting
Intercept	0,21705 ± 0,812
Slope	1,03168 ± 0,029
Residual Sum of Squar	0,19209
Pearson's r	0,99958
R-Square (COD)	0,99916
Adj. R-Square	0,99831

Fig .2correlation over three years between the simulated and measured canopy cover (CC) of durum wheat.

Table 5 The AquaCrop model's performance in forecasting canopy cover was measured using statistical indices of soft wheat.

parametres	R	RMSE	NRMSE	EF	d
2021-2022	0.99	3.4	24.2	0.85	0.96
2022-2023	0.95	6.8	21.3	0.73	0.69
2023-2024	0.97	4	18.2	0.92	0.98
Average	0.97	4.73	21.23	0.83	0.88

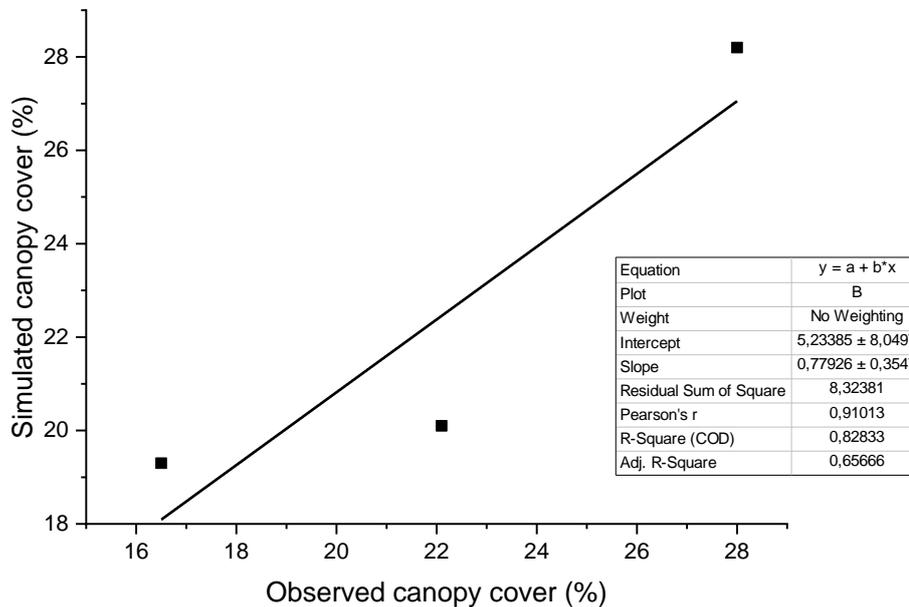| Equation	y = a + b*x
Plot	B
Weight	No Weighting
Intercept	5,23385 ± 8,0497
Slope	0,77926 ± 0,3547
Residual Sum of Square	8,32381
Pearson's r	0,91013
R-Square (COD)	0,82833
Adj. R-Square	0,65666

Fig.3 correlation over three years between the simulated and measured canopy cover (CC) of soft wheat.

4.1.2 Soil water content

The model's durum wheat performances vary according on the agricultural campaigns: The results for 2021–2022 are very satisfactory, with a R = 0.96, an RMSE of 6.8%, an NRMSE of 24.2%, an EF of 0.86, and a d of 0.71. These values indicate a strong correlation between the observed and simulated values as well as the model's overall good performance. In 2022–2023, despite a slightly lower RMSE (6.3%), the performances decline significantly (R = 0.53, EF = 0.07). Although the predictive effectiveness is essentially zero, the NRMSE is still acceptable at 19.6%.Performances improve in 2023–2024 (R = 0.77, EF = 0.43, NRMSE = 15.4%), indicating a return to simulation quality.The three-year average yields a R mean of 0.75, an NRMSE of 19.73%, and an EF of 0.45. This indicates that, despite certain years being less representative, the model is moderately viable for simulating the humidity of the wheat soil. The relationship between the water teneurs of the simulated and observed sol on the first 0.9 meters of the profile is shown in (figure 4). In contrast to the strong correlation in 2021–2022, the strong dispersion in 2022–2023 is evident due to the sinistré in this year.

The model also displays the following performance characteristics for the soft wheat: In 2021–2022, the indices show a good simulation of the soil's humidity (R = 0.92, RMSE = 3.4, NRMSE = 16.4%, EF = 0.44, d = 0.96).The performance is worse in 2022–2023 (R = 0.48, EF = 0.10, NRMSE = 21.3%), while these numbers are still reasonable in a semi-advanced difficult to model.The results for 2023–2024 are good (R = 0.91, NRMSE = 16.3%, EF = 0.42), indicating a strong correlation between the observed and simulated data.The average of the three campaigns yields a R = 0.77, an NRMSE = 18%, and an EF = 0.32, indicating a somewhat good performance with some years more dependable than others.

Overall, the AquaCrop model performs marginally better for durum wheat (EF mean = 0.45) than for soft wheat (EF mean = 0.32).Simulation quality is strongly influenced by interannual conditions, which are likely related to climatic fluctuations (temperature, precipitation), as well as soil variability.In most cases, values with an NRMSE of less than 25% indicate a simulation quality that satisfies performance criteria in agro-environmental modelling.The distribution of simulated and observed values over the three seasons is depicted in (figure 5).It visually validates the highest concordance achieved in 2021–2022 and 2023–2024.

Table 6. The AquaCrop model's performance in forecasting soil water content was measured using statistical indices of durum wheat .

Parametres	R	RMSE	NRMSE	EF	d
2021-2022	0.96	6.8	24.2	0.86	0.71
2022-2023	0.53	6.3	19.6	0.07	0.73
2023-2024	0.77	7	15.4	0.43	0.70
Average	0.75	6.7	19.73	0.45	0.71

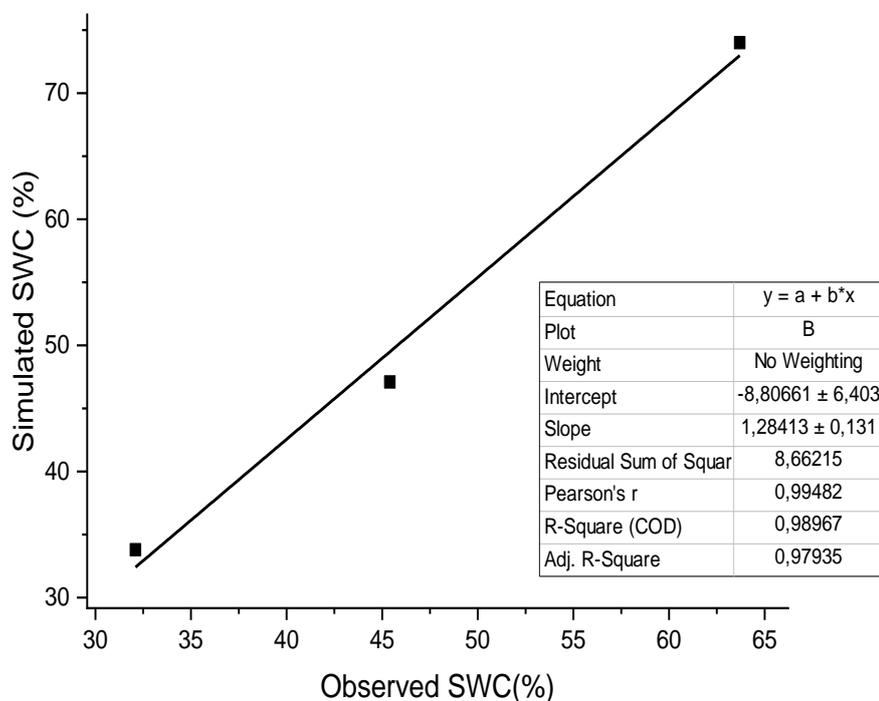| Equation	y = a + b*x
Plot	B
Weight	No Weighting
Intercept	-8,80661 ± 6,403
Slope	1,28413 ± 0,131
Residual Sum of Squar	8,66215
Pearson's r	0,99482
R-Square (COD)	0,98967
Adj. R-Square	0,97935

Fig 4. The three-season crop's top 0.90-meter soil profile's correlation actual and simulated soil water content for durum wheat .

Table 7. The AquaCrop model's performance in forecasting soil water content was measured using statistical indices of soft wheat.

parametres	R	RMSE	NRMSE	EF	d
2021-2022	0.92	3.4	16.4	0.44	0.96
2022-2023	0.48	6.8	21.3	0.10	0.69
2023-2024	0.91	6.7	16.3	0.42	0.72
Average	0.77	5.63	18	0.32	0.79

Equation	y = a + b*x
Plot	B
Weight	No Weighting
Intercept	7,72782 ± 12,941
Slope	0,81987 ± 0,3130
Residual Sum of Squar	11,30485
Pearson's r	0,9342
R-Square (COD)	0,87273
Adj. R-Square	0,74546
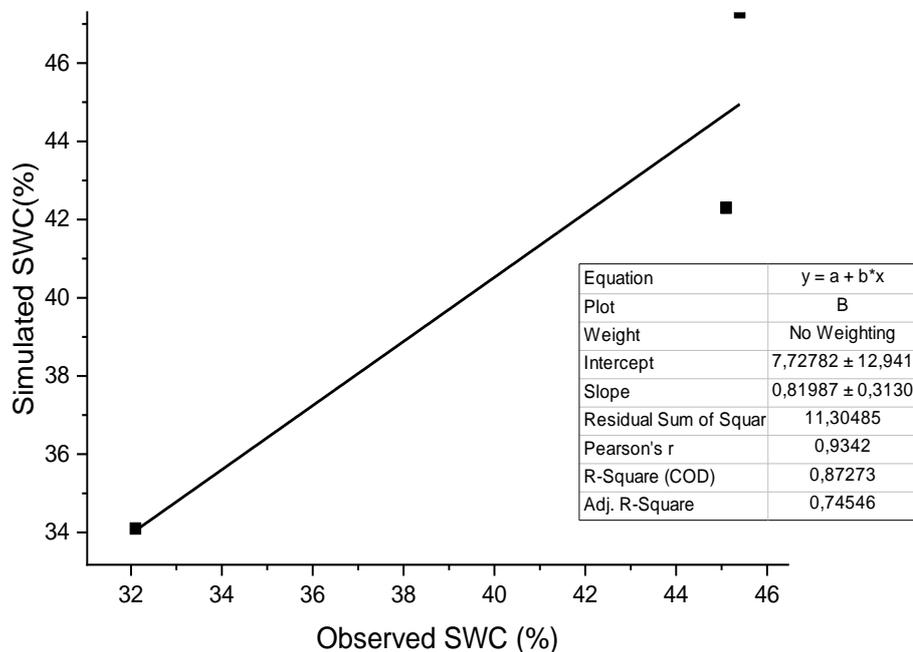
Fig.5 The three-season crop's top 0.90-meter soil profile's correlation actual and simulated water content for soft wheat.

4.1.3 Biomass and yield

The simulation results for the durum wheat biomass are largely satisfactory : In 2021–2022, the model shows a good correlation between measured and simulated values (R = 0.92), with an RMSE of 0.83 t/ha, an NRMSE of 17.81%, and a concordance index of d = 0.91. However, Nash-Sutcliffe's effectiveness is low (EF = 0.18), indicating a surestimation or a dispersion of the simulated values in comparison to the data.

- Performance holds steady in 2022–2023 (R = 0.91), but a more significant simulation error is shown by the NRMSE of 39.89%. L'EF = 0.43 is moderate. The simulation performs better in 2023–2024 in terms of relative precision (NRMSE = 8.62%, RMSE = 0.37 t/ha), with a good d = 0.94 and an EF = 0.43.On average, R = 0.87, NRMSE = 22.10%, EF = 0.35, and d = 0.91 are

obtained, indicating that the model performs globally correctly for the biomass of durum wheat, particularly in terms of correlation and agreement.

(Figure 6) shows these trends, including in 2021–2022 and 2023–2024, with a good global distribution of points around the diagonal.

The results of the soft wheat vary depending on the campaigns:Between 2021 and 2022, the model's correlation (R = 0.95) is great, but its predictive effectiveness (EF = 0.05) and RMSE (13.2 t/ha) are quite poor, which may indicate a high absolute error.

The simulation is more coherent in 2022–2023 (R = 0.92, RMSE = 6.3, NRMSE = 19.6%, EF = 0.47), which translates into a noticeable improvement in the model's performance.The simulation quality in 2023–2024 is accurate (R = 0.73, NRMSE = 15.4%, EF = 0.43, d = 0.70. - The model's average performance for predicting the biomass of the blé tendre is moderate, with R = 0.87, NRMSE = 18.57%, and EF = 0.32.

Although the dispersion is greater in 2021–2022, (Figure 7)shows a strong visual correlation in 2022–2023 and 2023–2024.

For durum wheat (EF mean = 0.35) as opposed to soft wheat (EF mean = 0.32), the AquaCrop model appears to be somewhat more viable, in part because of improved accord index stability.The high R values for the two cultures show that the model accurately reproduces the overall trend, even though the absolute values may be less accurate.

The relative errors (NRMSE < 25%) are within acceptable bounds for modelling biomass in semi-arid climates.

Table 8. The AquaCrop model's performance in forecasting biomasse was measured using statistical indices of durum wheat.

parametres	R	RMSE	NRMSE	EF	d
2021-2022	0.92	0.83	17.81	0.18	0.91
2022-2023	0.91	0.84	39.89	0.43	0.87
2023-2024	0.77	0.37	8.62	0.43	0.94
Average	0.87	0.68	22.10	0.35	0.91

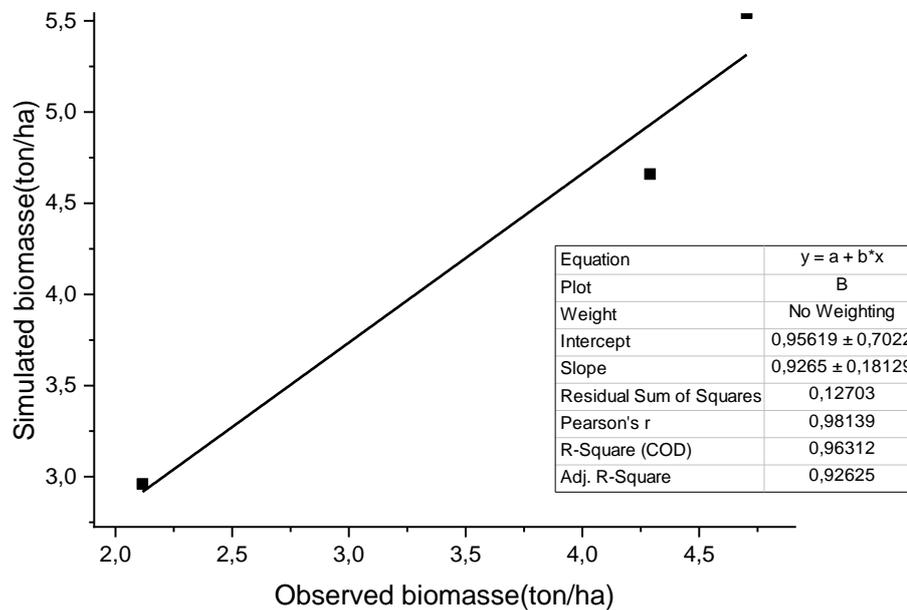| Equation	y = a + b*x
Plot	B
Weight	No Weighting
Intercept	0,95619 ± 0,7022
Slope	0,9265 ± 0,18129
Residual Sum of Squares	0,12703
Pearson's r	0,98139
R-Square (COD)	0,96312
Adj. R-Square	0,92625

Fig .6 correlation between the three-year cycle of measured and simulated durum wheat bio-mass.

Table 9. The AquaCrop model's performance in forecasting biomasse was measured using statistical indices of soft wheat .

parametres	R	RMSE	NRMSE	EF	d
2021-2022	0.95	13.2	20.7	0.05	0.77
2022-2023	0.92	6.3	19.6	0.47	0.83
2023-2024	0.73	7	15.4	0.43	0.70
Average	0.87	8.83	18.57	0.32	0.77

Equation	y = a + b*x
Plot	B
Weight	No Weighting
Intercept	-4,43851 ± 0,8492
Slope	1,75539 ± 0,19428
Residual Sum of Squares	0,10017
Pearson's r	0,99393
R-Square (COD)	0,9879
Adj. R-Square	0,9758
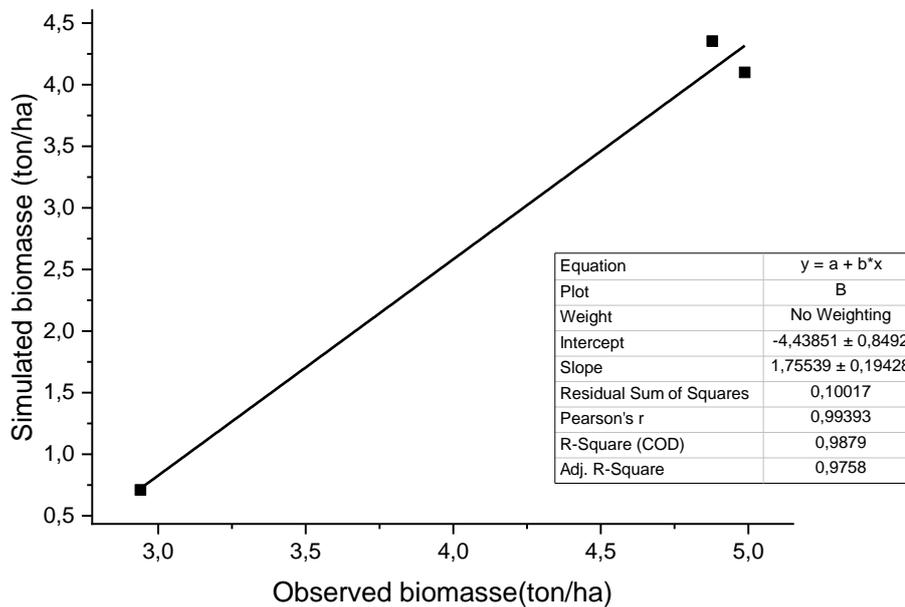
Fig .7 correlation between the three-year cycle of measured and simulated soft wheat biomass. The statistical indicators shown in Table 10 enable the evaluation of the quality of the soft wheat yielding simulations:D = 0.83: this high result indicates good overall model precision. RMSE = 0.60 and NRMSE = 34.7%: although if the absolute error is still moderate, the NRMSE shows that there is still significant variability around the observations.R = 0.94: this indicates a strong linear correlation between the measured and simulated values.EF (Efficiency Coefficient) = 0.74: this indicates that the model is reasonably reliable, even though there is still room for improvement.Table 12's results, which are related to the durum wheat, are generally better: D = 0.92, RMSE = 0.34, NRMSE = 22.1%, R = 0.99, and EF = 0.94. These values indicate a high level of simulation accuracy.These values indicate great simulation accuracy.The model can reproduce the results with a very low relative error and a nearly perfect correlation with the observed data. The tool's high effectiveness coefficient attests to its applicability to future research on durum wheat .These results show that the AquaCrop model performs satisfactorily for soft wheat, albeit slightly less robustly than for durum wheat.

Table 10. The AquaCrop model's performance in forecasting yield was measured using statistical indices of soft wheat for average three seasons 2021 to 2024.

parametres	Value
D	0.83
RMSE	0.60
NRMSE	34.7
R	0.94
EF	0.74

Table 11. The AquaCrop model's performance in forecasting yield was measured using statistical indices of durum wheat for average three seasons 2021 to 2024.

parametres	Value
D	0.92
RMSE	0.34
NRMSE	22.1
R	0.99
EF	0.94

4.1.4 Simulation biomass, yield and water prodictivity under three scenarios
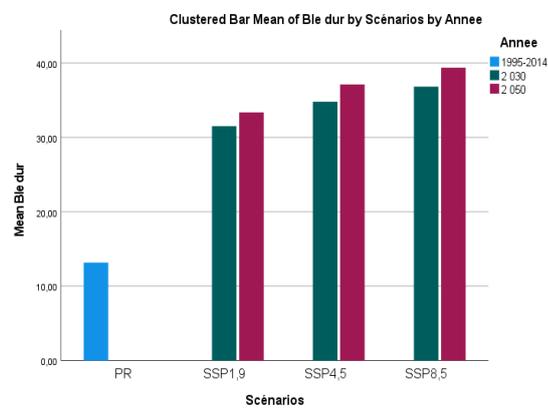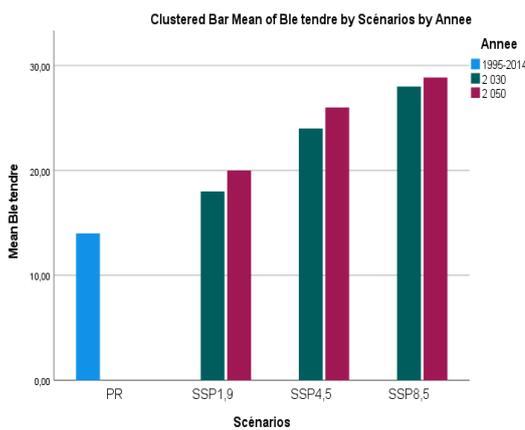
Fig.8 Comparison of PR (1995-2014) averages for biomass of soft wheat between the PR and the SSP1.9, SSP4.5, and SSP8.5 scenarios for projections futures (2030 – 2050).
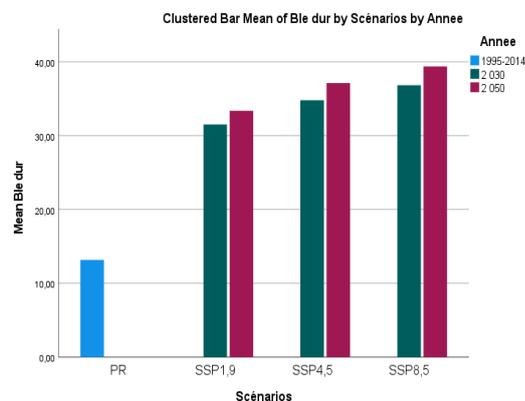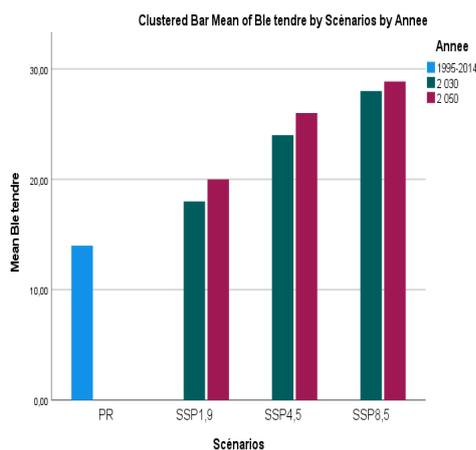

Fig.10 Comparison of PR (1995-2014) averages for water productivity of soft wheat between the PR and the SSP1.9, SSP4.5, and SSP8.5 scenarios for projections futures (2030 – 2050).

Figure 8,9 and 10 compares the average yield, biomass, and water productivity (WP) values for wheat over the reference period (PR: 1995–2014) with the future climate projections for 2030 and 2050 based on three SSP climate scenarios (SSP1-1.9, SSP4-4.5, and SSP5-8.5).

By 2030, the yield will have increased from 6 ; 7.4 t/ha in PR to 14.20 ; 9.5 t/ha (SSP1.9), 15.68 ;12 t/ha (SSP4.5), and 16.60 ; 14 t/ha (SSP8.5). In 2050, it will be 15.20 ,10.5 t/ha ;22.15, 13t/ha ; 28.75 t/ha and 15.5 t/ha for durum and sof wheat, respectively. The biomass increases in a parallel fashion, rising from 13.17 ; 14 q/ha for (PR) to 39.38 q/ha ;29.86 q/ha SSP8.5 in 2050.Water productivity (WP) also increased significantly, rising from 0.15 kg/m³ in PR to a maximum of 0.84 kg/m³ ;0.53 kg/m³ (SSP8.5, 2050) for both cultuvars succsively . These findings indicate a potential net increase in productivity under the projected future climate, especially under the most pessimistic scenarios (SSP5-8.5). This is likely due to both an increase in atmospheric CO_2 (which has a fertilising effect) and an improvement in water efficiency under hotter and drier climate conditions. The intermediate SSP4.5 scenario also shows significant improvements, highlighting the accuracy of the gains forecasts

This evolution made it clear that wheat appears to benefit from a positive response to simulated climate changes, much like wheat does, especially when combined with an adjustment of the growing season, a boost to photosynthetic activity (from CO_2), and possibly an optimisation of water use.

Table 14 compares the yields predicted by the AquaCrop model with the yields measured on the ground at the ITGC installation for both durum and soft wheat in three consecutive agricultural seasons: 2021–2022, 2022–2023, and 2023–2024.There is a very good agreement between the measured and simulated yields for the durum wheat . The model's ability to accurately replicate this culture's performances under varied situations is confirmed by the relatively small mean écart.Conversely, a significant discrepancy is shown for the blé tendre during the 2022–2023 campaign, where the simulated yield (0.360 t/ha) is significantly lower than the observed value (1.470 t/ha). This could be caused by a partial model calibration or by local factors (i.e., illnesses, temporary hydraulic stress, etc.) not accurately captured by the simulation.

The relationship between the measured and simulated yields of wheat during the three seasons is depicted in (figure 8). The points are visually aligned close to the diagonal, indicating a strong correlation between the values.This correspondence confirms the effectiveness of the AquaCrop model's calibration for hard wheat, indicating that it is well-suited to replicate the dynamics of yield in agroclimatic settings.The corresponding relationship for the soft wheat is shown in figure 9. The slightly more marked point distribution reflects the more significant differences between the simulated and observed results, particularly in 2022–2023.Despite this, two of the three points remain close to the ideal line, indicating that the model is still relevant for the soft wheat but needs more refinement to better represent some particular instances.

The analysis of three agricultural campaigns demonstrates that the AquaCrop model accurately simulates the long-term yields of wheat with high robustness and regularity. Although the results are generally satisfactory, the blé tendre exhibits a greater sensitivity to annual conditions, necessitating a strengthened calibration or the integration of additional factors. The 2021–2022

and 2023–2024 campaigns show a much stronger coherence between the two types of wheat ,
which increases the model's overall long-term reliability.

Table 14. Durum and soft wheat production at the ITGC facility was measured and simulated.

Cropping season	Simulated durum yield (ton/ha)	Observed durum yield (ton/ha)	Simulated soft yield (ton/ha)	Observed soft yield (ton/ha)
2021-2022	2.771	2.352	2.05	2.499
2022-2023	1.480	1.058	0.360	1.470
2023-2024	2.330	2.145	2.177	2.439
Average	2.194	1.852	1.529	2.136

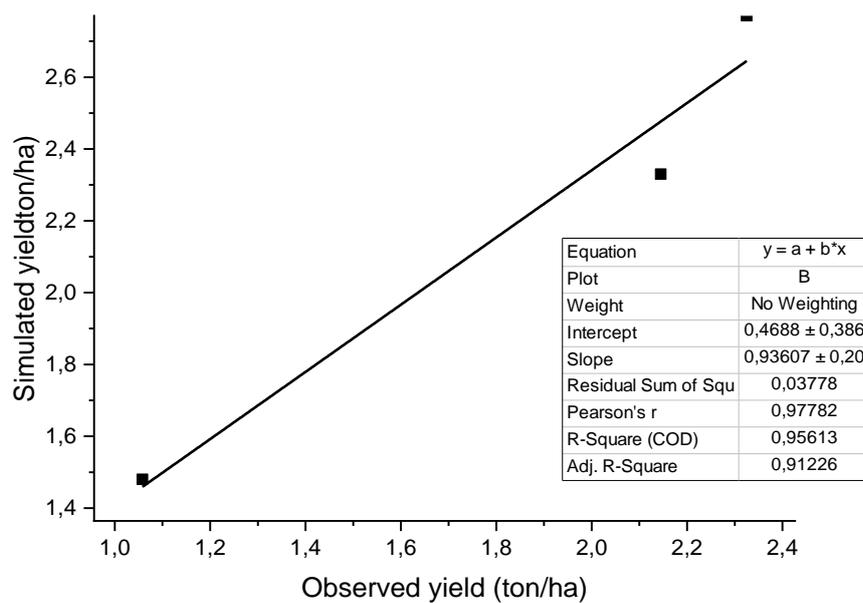| Equation	y = a + b*x
Plot	B
Weight	No Weighting
Intercept	0,4688 ± 0,386
Slope	0,93607 ± 0,20
Residual Sum of Squ	0,03778
Pearson's r	0,97782
R-Square (COD)	0,95613
Adj. R-Square	0,91226

Fig. 8 Relationship between three cropping seasons' worth of simulated and observed wheat
grain durum yield (t ha-1).

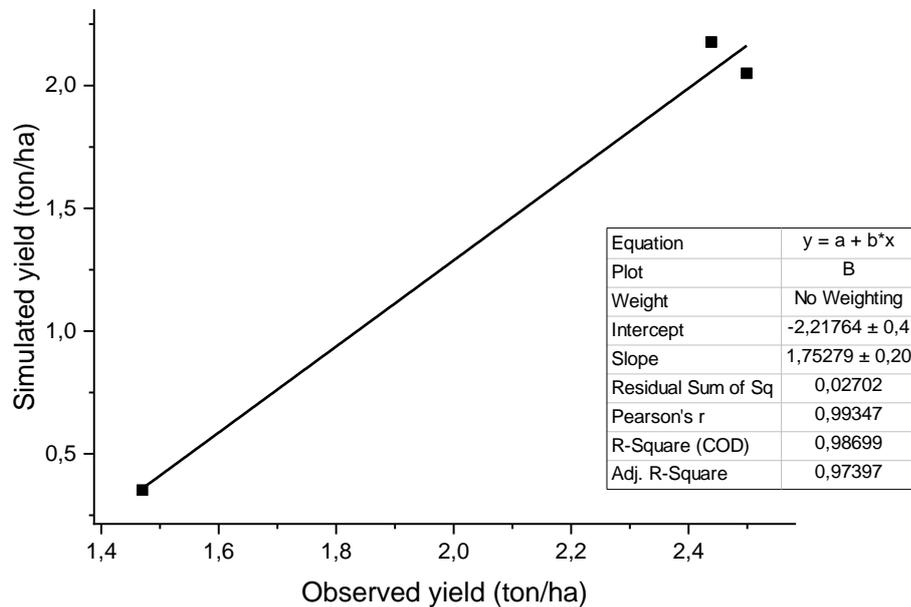| Equation	y = a + b*x
Plot	B
Weight	No Weighting
Intercept	-2,21764 ± 0,4
Slope	1,75279 ± 0,20
Residual Sum of Sq	0,02702
Pearson's r	0,99347
R-Square (COD)	0,98699
Adj. R-Square	0,97397

Fig. 9 Relationship between three cropping seasons' worth of simulated and observed wheat grain soft yield (t ha-1) .

5. Discussion

The FAO's AquaCrop model is intended to help better understand how cultures will respond to climate change and management scenarios in Mediterranean environments. It is used to calibrate the model based on parameters such as soil water content (SWC), biomass (B), and canopy cover (CC) of wheat in algal conditions. The results for the SWC and CC parameters showed respective nRMSEs of 8.0% and 11.3% in the first campaign and 3.7% and 1.8% in the second. Over the course of two campaigns, the values of the index d, which is close to the unit, varied between 0.86 and 0.97 and 0.96 and 0.98 for the same parameters.

In terms of forecasting, AquaCrop has demonstrated a suitable response to the hydraulic stress that occurred in the spring of the second campaign, resulting in a 2.9% decrease in grain yield per hectare in comparison to the first campaign, which was marked by better rainfall distribution.(Belkhiri et al., 2019). The results of the model simulation shown that the model accurately represents the soil water content in the root zone (SWC), canopy cover (CC), grain yield (GY), and aboveground biomass (BM) of wheat. The simulated and observed SWC, CC, GY, and BM had average root mean square errors (RMSEs) of 21.1 mm, 7.1%, 0.32 t ha-1, and 0.34 t ha-1, respectively. Additionally, Nash-Sutcliffe efficiency (EF) and the Willmott index (d) were 0.89 and 0.98 for CC, 0.74 and 0.93 for SWC, 0.98 and 0.92 for BM, and 0.95 and 0.82 for GY. The model estimated the soil water content at a depth of 90 cm with a reasonable level of precision, whereas it predicted biomass, canopy cover, and grain yields with high accuracy under irrigation in semi arid region Antalia (Turkey) : According to the results, the AquaCrop model can

be recommended as a practical model for determining whether or not irrigating wheat is a priority in places with limited water resources.(Kale & Madenoğlu, 2018). According to the results, the simulated canopy cover (CC), biomass yield (BY), and grain yield (GY) had corresponding coefficients of determination (R2) of 0.93, 0.91, and 0.93, respectively, and were similar with the measured CC, BY, and GY in North China Plain(Jin et al., 2014).In otherhund, The model has been calibrated, validated, and parametrised to predict wheat grain yields. It has then been used to simulate wheat productivity at the study site for short-term (2020–2030) and medium-term (2040–2050) periods in comparison to a reference period (1985–2005). Three general circulation models (CNRM, EC-EARTH, and GFDL) were taken into consideration for the two CO2 concentration evolution scenarios (the mean scenario, RCP 4.5, and the pessimistic scenario, RCP 8.5) in order to derive the software's outputs with a focus on cultural performance. The calibration results show an R2 correlation coefficient of 0.84, a Nash-Sutcliffe indicator of 0.71, and a Willmott index of 0.94. The simulation showed a short-term drop in performance of 5.94 percent for the RCP 4.5 scenario. Regarding RCP 8.5, the model predicts a 12.9% decline in performance. Overall, the simulation results have demonstrated that the AquaCrop model is suitable for simulating the effects of hydric and climate stress on the productivity of cultures in agricultural pluvial zones. This could aid in decision-making regarding water productivity and cultural adaptation to future climate trends under semi-arid conditions (Halima et al., 2021). As the cumulative temperature rose, the grain yield and WP increased steadily.The AquaCrop model offers a technological means of application for creating the best irrigation schedules in arid and semi-arid regions and has a dependable accuracy for revealing crop development and output under water deficit conditions.(Zhang et al., 2022). For the purpose of simulating grain production and water productivity across all treatment levels, the AquaCrop model was calibrated, and the prediction error statistics were $0.54 < E < 0.95$ percent, $0.06 <$ RMSE< 0.12 t ha, $0.59 <$ MAE< 0.82 t ha 1 and. The Aquacrop model's validation performed admirably, with model efficiency for grain yield and water productivity of 91% and 73%, respectively, falling within acceptable bounds. In light of fluctuating rainfall and air temperatures, 50 mm of additional irrigation can sustain maize grain yield under rainfed conditions. From the near century (2025) to the end of the century (2090), maize yield is predicted to increase by 28.39–74.79 percent in RCP 4.5 and 34.81–85.27 percent in RCP 8.5. in semi- arid region (Umesh et al., 2022). AquaCrop's ability to replicate Mexicali cultivar yields was validated with a high degree of accuracy (RMSE = 0.41 tha−1). At both locations Borj Bou Arreridj and Setif , it is anticipated that the average wheat grain yield will increase by +49% and +105% under RCP 4.5 and RCP 8.5 in 2035–2064 in comparison to the baseline production of the 1981–2010 period, which was predicted to be 29 qha−1. The increase in CO2 concentrations has a fertilizing effect on the yield of rainfed wheat in both locations over 2035–2064 under RCP 4.5 and RCP 8.5. This effect offsets the adverse effects of rising temperatures and falling precipitation and net solar radiation. Under both RCP scenarios, wheat water productivity is expected to rise. WP is the ratio of water lost through evapotranspiration throughout the growing cycle of durum wheat to the amount of biomass produced (in kilogrammes). The AquaCropmodel simulations

thus show that the WP enhancement under both Sc1 and Sc2 scenarios is the result of the ferti-lising impact of the CO2 enrichment of the atmosphere, which raises the above-ground biomass of the Mexicali cultivar. Due to stomatal control under Sc2, this resulted in an acceleration of photosynthetic activity and a decrease in evapotranspiration-induced water loss, while the TS increase under Sc1 caused the GSL of the Mexicali cultivar to shorten (Kourat et al., 2022) .

6. Conclusion

In this work, wheat yield, biomass, and water productivity in rainfed conditions at the Setif site in northeastern Algeria were simulated using the AquaCrop model under three different future climatic scenarios SSP1.9 ; SSP4.5 and SSP8.5 . Three crop growing seasons (2021–2024) were used in a field experiment to calibrate AquaCrop model. The simulation results for biomass and durum ,soft wheat yield agreed with the values recorded during the calibration period. The im-pact of the three socio-economic scenarios on the future wheat water productivity, biomass and yield was studied. The prediction by AquaCrop revealed positive impacts of climate change on wheat yields , biomasse and water productivity in the short 2020-2039 and medium term period 2040-2059. However, the highest increase was predicted by the SSP 8.5 (39 .38 q/ha, 29.86 q/ha and 0.84 et 0.53kg/m³ compared to 6 q/ha , 7.4 q/ ha and 0.15q/ m³ during reference pe-riod for soft and durum wheat respectively) in the long -term period. In addition, For three scenarios, we can assumpt that water productivity increase due to positive effects of climatic variability water productivity also improves from 0.15 kg/m³ (reference) to 0.39–0.46 kg/m³ for durum wheat and 0.41–0.84 kg/m³ for soft wheat over 2020-2039; and for 2040-2059, it reaches 0.41–0.84 kg/m³ (durum) and 0.13–0.53 kg/m³ (soft) . The model's examination of the root zone's soil water content, seasonal canopy cover, grain yield, and ultimate harvested biomass revealed that the model's simulation and observed values were sufficiently accurate. The ob-served and simulated CC, SWC, BM, and GY had average root mean square error (RMSE) values of 4.13% and 4.73%, respectively. 0.67 t ha-1, 8.83 t ha-1, 0.60 t ha-1, 0.34 t ha-1, 6.7 mm, and 5.63 mm. For durum and soft wheat, the corresponding Nash-Sutcliffe efficiency (EF) and index of Willmott (d) were 0.96, 0.83, and 0.99,0.88 for CC, 0.45 and 0.32, 0.71, 0.79 for SWC, 0.35, 0.32, and 0.91, 0.77 for BM, and 0.74 and 0.94 and 0.60, 0.34 for GY.

Data avaibility
During the current investigation, no datasets were created or examined.
Declarations
Conflict of interest The authors have nothing to report about their relevant financial or non-financial interests.

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