

Research Article

Optimization of Wheat (*Triticum aestivum* L.) Water Productivity Under Deficit Furrow Irrigation Using AquaCrop Model

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Abstract

Crop growth models like AquaCrop maximize crop output and water use efficiency by forecasting agricultural indicators including crop yield, dry biomass, and water productivity. This study not only validated and calibrated the AquaCrop model, but also investigated the effects of deficit irrigation on wheat yield and water productivity. The experiment was conducted for calibration in 2022-2023 and for validation in 2023-2024. Five irrigation treatments were utilized in this study: 100% ET_c, 80% ET_c, 80% ET_c at development and mid-stage, 60% ET_c, and 60% ET_c at development and mid-stage. The test variety was the Kingbird local wheat variety. Applying 100% ET_c produced the maximum plant height, biomass, yield, and thousand seed weight (66.97cm, 36.43g, 3.47t ha⁻¹, 9.53t ha⁻¹), while 60% ET_c produced the lowest values (63.1cm, 30.4g, 1.94t ha⁻¹, and 7.74t ha⁻¹). The best water productivity of 0.92kg m⁻³ was seen throughout the development and mid-stages when 80% ET_c was applied. The AquaCrop model's root mean square error ranged from 0.002 to 0.25 t ha⁻¹, its model efficiency ranged from 0.81 to 0.95, and its coefficient of determination for grain yield, dry biomass, and water productivity ranged from 0.84 to 0.98. Model efficiency was 0.83, 0.85, and 0.77, yield, biomass, and water productivity had coefficients of determination of 0.96, 0.93, and 0.73, and the AquaCrop model's root mean square error was 0.244, 0.413t ha⁻¹, and 0.03kg m⁻³, respectively. When 60% ET_c was used, the largest prediction error of 17.36 was observed under yield, while when 100% crop water requirement was applied, the lowest prediction error of 0.26 was obtained under biomass. Therefore, it can be concluded that the AquaCrop model can reliably forecast crop metrics that are impacted by different watering schedules.

Keywords

AquaCrop Model, Calibration, Validation, Wheat, Yield

1. Introduction

Today's population growth also raises the demand for food, but climate change and irregular rainfall throughout the year cause a shortage of fresh water for agriculture, increasing the need for freshwater. Methods that can boost crop water yield are therefore more important in arid and semi-arid areas.

Simulation models are becoming increasingly significant in agriculture water management these days since they can forecast how irrigation will affect crop development [1].

Crop growth models, which forecast crop metrics like total biomass, total grain yield, and water productivity, are a crucial

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tool for farm-level water management since they replicate crop behavior throughout the growing season. Additionally, it forecasts canopy cover and transpiration [2]. In order to maximize irrigation under limited available water for improved sustainability and economic production, crop growth models are crucial tools for evaluating the effects of water shortages on crop yield or productivity and forecasting yields [3].

The AquaCrop model was created by the Food and Agricultural Organization (FAO) to improve food security and investigate the effects of crop management and environmental change on crop yield [4]. Herbaceous crop yields under various soil types, weather conditions, and water management techniques are predicted by the AquaCrop model. When water is a constraint, AquaCrop is a very helpful tool. Although the crop model is crucial for explaining crop growth, it is quite complicated and requires a lot of computations, making it challenging to utilize [2]. FAO created the AquaCrop model to simulate crop growth in a straightforward and precise way in order to remove the limitations [5]. AquaCrop must undergo a number of tests under diverse crop, soil, irrigation, and climate conditions in order to be considered worldwide relevant [6].

The AquaCrop model for cotton was evaluated by [5] in Northern Syria under various irrigation schedules and environmental conditions. AquaCrop simulates crop parameters with an inaccuracy of 10-32%, according to the results. The AquaCrop model for barley in northern Ethiopia was assessed by [7]. According to their findings, the crop parameters are predicted by AquaCrop with a model effectiveness of 0.5 to 0.95. During the 2009 and 2010 kharif seasons in Northern India, [8] assessed AquaCrop for maize crops under various irrigation and nitrogen regimes. When simulating water productivity (WP), the model prediction error ranged from 2.35 to 27.5%.

Therefore, the goal of this study was to use the AquaCrop model to maximize wheat water productivity under deficit furrow irrigation.

2. Materials and Methods

2.1. Description of Study Area

The study was carried out in the Oromia national regional state's West Shoa zone, specifically in the Toke Kutaye woreda. Guder town, the administrative hub of Toke Kutaye woreda, is 12 kilometers west of Ambo town. The location of the site is 8°52'27" N and 37°48'23" E. The average yearly temperature falls between 10 °C to 29 °C. The region experiences bi-modal rainfall, with the first season beginning in March and ending in April, and the second, or main, season beginning in June and lasting until September. The place receives 800-1000mm of precipitation on average each year.

2.2. Experimental Design and Treatments

Five irrigation treatments were used in the experiment. 15 experimental plots, each measuring 20m² (4m x 5m), were used to test the five irrigation treatments in a randomized full block design experiment with three replications. The following treatments were used: (i) 100% ET_c; (ii) 80% ET_c deficit irrigation at all crop growth stages; (iii) 80% ET_c deficit irrigation at development and mid-stages; (iv) 60% ET_c deficit irrigation at all crop growth stages; and (v) 60% ET_c deficit irrigation at development and mid-crop stages only.

2.3. Crop Management Practice

The kingbird variety of wheat (*Triticum aestivum* L.) was planted in the experimental plot and given adequate watering to ensure proper germination and a healthy plant stand. The experimental plot measured 5m in length and 4 m in width. The wheat was planted in double rows with a 0.2m row spacing, and each ridge was separated by 0.4m. Plots and replications were separated by 1 m and 1.5m, respectively. In order to ensure a consistent seed rate, the right and left sides of the furrow were drilled by hand. The approved rate of 150kg/ha DAP was administered to the wheat at planting, and 100kg/ha of urea was applied, half during planting and the other half during the tillering stage. The Parshall flume was used to measure the amount of water applied during the furrow irrigation process.

2.4. Data Collected

The Ethiopian National Meteorological Agency (ENMA) provided weather data, such as average wind speed [m/s] at a height of 2 m above soil surface, maximum and minimum relative humidity [%] (RH max. and RH min.), and daily maximum and minimum air temperature [°C] (T_{max}. and T_{min}.). The estimation of "evapotranspiration crop (ET_c)," which is the product of reference evapotranspiration (ET_o) and crop coefficient factor (K_c), is used to determine irrigation water requirements throughout the seasons. Using "ET_o Calculator" software, the daily ET_o was computed from daily meteorological data using the conventional FAO-Penman approach outlined in [9]. The growing period and K_c variables will be the same as those given for wheat crops in [9].

2.5. Input Data for AquaCrop Model

Climate factors, soil, crop, and irrigation management data are among the input variables needed for the Aqua Crop model.

Climate data: Rainfall, mean annual carbon dioxide concentration (CO₂), reference crop evapotranspiration (ET_o), and daily values of minimum and maximum air temperatures (T_{min}. and T_{max}.) are among the meteorological variables needed by the AquaCrop model.

Crop data: The range of ambient temperatures where plants

can thrive is indicated by the base temperature and cutoff temperature. The ranges of water percentages for improved plant growth are indicated by the senescence stress coefficient, stomatal conductance threshold, and leaf growth thresholds. Row spacing, time to emergence, time to start flowering (or at seed formation), duration of flowering, time to start canopy senescence, time to physiological maturity, and maximum effective rooting depth (Z_x) were all measured during both crop seasons, but the non-conservative crop parameters needed by the AquaCrop model have different values for different wheat varieties.

Soil data: The AquaCrop model requires the following soil data: hydraulic conductivity, field capacity, saturation (SAT), and soil water content (vol%) at the permanent wilting point (PWP). Table 1 displays the parameters of the soil needed for the AquaCrop model.

2.6. Physicochemical Properties of Soil

In order to ascertain the physicochemical characteristics of soil, samples of various soil layers from 0-20 and 20-40cm soil depth are collected. Using USDA's Soil Water Characteristics Model Software (Version 6.02.74), the soil moisture retention properties were determined based on soil texture.

2.7. Irrigation and Field Management

An irrigation schedule was created using the generation of irrigation schedule mode as the irrigation input. Each irrigation event's time (days after sowing) and application depth (mm) must be specified when using the irrigation schedule option. The AquaCrop model's field management components included bunds to reduce runoff, mulch to reduce evaporation, and relative biomass.

Leaf area index (LAI): An irrigation schedule was created using the generation of irrigation schedule mode as the irrigation input. Each irrigation event's time (days after sowing) and application depth (mm) must be specified when using the irrigation schedule option. The AquaCrop model's field management components included bunds to reduce runoff, mulch to reduce evaporation, and relative biomass.

$$LA = L * W * A \quad (1)$$

Where, L= Length of leaf, W = Width of Leaf, A = constant (0.754), LA = Leaf area (m^2)

LAI is dimensionless quantity that characterize plant canopy and calculated by the equation as below:

$$LAI = \frac{\text{Leaf Area } (m^2)}{\text{Ground Area } (m^2)} \quad (2)$$

According to [10], equation (3) illustrates the relationship between crop canopy and leaf area index (LAI):

$$CC = 1.005(1 - \exp(-0.6 * LAI))^{1.2} \quad (3)$$

Where, CC = Canopy cover

2.8. Water Productivity

The yield per unit of water utilized was used to calculate wheat water productivity. The water productivity function assesses water productivity based on yield. The following formula will be used to calculate water productivity based on wheat yield:

$$WP = \frac{Y_t}{I_w} \quad (4)$$

Wp = Water productivity (kg/m^3)

Y_t = Total yield (t)

I_w = Irrigation water used (m^3/ha)

2.9. Calibration and Validation of AquaCrop Model

Grain yield, dry biomass, and water productivity were among the output data that were predicted by simulating the AquaCrop model after it was calibrated using the observed data from the field experiment conducted in 2022-2023. The observed yield and biomass of the experimental plots were then contrasted with the expected values. The development of canopy cover is determined by three parameters: maximum canopy cover, canopy growth coefficient (CGC), and canopy decline coefficient (CDC). By fitting the canopy cover, those parameter values were repeatedly found through a trial-and-error process. The harvest index was then modified to correspond with the measured yields after biomass and the measured values were compared using the water productivity (g/m^2). For every treatment combination, the process is repeated until the model simulated value and the experiment's observed value match as closely as possible.

The AquaCrop model for the kingbird wheat variety was validated using crop season 2023-2024 input data. For the kingbird wheat variety, the AquaCrop model was verified under various watering conditions. The prediction error statistics were used to confirm the integrity of fit between the simulated and observed data. The AquaCrop model's calibration and validation outcomes were assessed using the following error statistics: prediction error (Pe), coefficient of determination (R^2), root mean square error (RMSE), and model efficiency (ME). The statistical parameters used to assess the model's performance are provided in equations (5) through 8 as follows:

$$Pe = \frac{(S_i - O_i)}{O_i} \times 100 \quad (5)$$

$$ME = 1 - \frac{\sum_{i=1}^N (O_i - S_i)^2}{\sum_{i=1}^N (O_i - \bar{O})^2} \quad (6)$$

$$R^2 = \left[\frac{(\sum (O_i - \bar{O})(S_i - \bar{S}))}{\sqrt{\sum (O_i - \bar{O})^2 \sum (S_i - \bar{S})^2}} \right]^2 \quad (7)$$

$$RMSE = \sqrt{\frac{\sum (O_i - S_i)^2}{n}} \quad (8)$$

Where, S_i and O_i = Simulated and observed data

$\bar{O}$ = Mean value of O_i

$\bar{S}$ = Mean value of S_i

N = The number of observations

2.10. Data Analysis

Statistical analysis was performed on the gathered data using R software (version 4.1.0 for Windows). The contrasts between the treatment means were compared using a mean separation test with least significant difference (LSD) at a 5% probability level.

3. Results and Discussion

3.1. Soil Physico-chemical Properties

According to the experimental site's chosen soil physical characteristics, the proportional percentages of sand, silt, and clay in the soil were 33, 19, and 48%, respectively. Clay was identified as the predominant textural class at the experimental location based on the USDA soil textural categorization. The average soil saturation, hydraulic conductivity, permanent wilting point, field capacity, and bulk density were 1.42g/cm³, 41%, 28.9%, 0.86mm/hr, and 48.05%, respectively. Additionally, the study area's soil had mean pH, EC, OC, OM, and TN values of 7.01, 0.325 ds/m, 1.1, 1.895, and 0.095%, respectively. According to [11], the electrical conductivity measurement indicates that the soil in this study location is below the yield reduction threshold of 1.2 dSm⁻¹. Additionally, the soil's organic matter and organic carbon concentration show that it is fertile (OC > 1%) and excellent for growing crops [12]. It was discovered that the pH of the soil in the testing field was almost neutral and quite narrow, ranging from 7.0 to 7.01. An essential metric for determining the pH of soil is the concentration of hydrogen ions, which shows how acidic or alkaline the soil is. A pH range of 6.0 to 8.0 is ideal for wheat growth [13].

Table 1. Chemical and physical properties of soil of study area.

Soil parameters	Soil depth (cm)		Mean
	0-20	20-40	
Sand (%)	36	30	33
Silt (%)	18	20	19
Clay (%)	46	50	48
Textural class	Clay	Clay	Clay
Bulk density (g/cm ³)	1.37	1.47	1.42
PH-water (1: 2.5)	7.14	6.88	7.01
EC (ds/m)	0.353	0.296	0.325
OC (%)	1.06	1.14	1.1
OM (%)	1.83	1.96	1.895
TN (%)	0.09	0.1	0.095
FC (%)	40	42	41
PWP (%)	27.9	29.9	28.9
Hydraulic conductivity (mm/hr)	0.94	0.78	0.86
Saturation (%)	47.3	48.8	48.05

3.2. Effect of Deficit Irrigation on Yield and Water Productivity of Wheat

The different levels of soil moisture stress had a significant effect on plant height ($p < 0.05$) (Table 2). Under 100% ETc, the plant reached its maximum height of 66.97cm, while under 60% ETc, it reached its lowest height of 63.1cm across all stages. This result is consistent with what [14] found. This is due to the fact that moisture stress affected plant height by decreasing photosynthesis and the plant's total biomass production [14].

Deficit irrigation had a significant ($p < 0.05$) impact on the weight of the thousand seeds (Table 2). The weight of the thousand seeds was greater under full irrigation (36.43g), and it was 80% ETc at development and mid-stages (35.15g). Higher deficit irrigations of 60% ETc during all stages resulted in a noticeably lower thousand seed weight (30.4g). Grain shriveling may be the cause of the lower thousand seed weight reached at lower irrigation levels, which has an impact on weight. According to earlier research findings, this conclusion is supported [15-17].

Grain yield was significantly impacted by the degree of soil moisture stress ($p < 0.05$) (Table 2). With an average output of 3.47 t ha^{-1} throughout the two seasons, the complete irrigation treatment yielded the most grain. The yield rapidly decreased as less water was supplied due to the irrigation deficit, reaching its lowest value under the 60% ETc treatment, with an average of 1.94 t ha^{-1} . The findings demonstrated that the

total yield at the development and mid-stages did not change significantly between 100% ETc and 80% ETc.

The result highlights the significance of optimal water availability for maximizing wheat output and is in line with the findings of earlier studies [15, 16, 18, 19].

The aboveground biomass of wheat was significantly ($p < 0.05$) impacted by the different levels of soil moisture stress. At every stage, the biomass was at its lowest of 7.74 t ha^{-1} under 60% ETc and at its peak of 9.53 t ha^{-1} under 100% ETc (Table 2). The amount of water provided is insufficient to produce increased biomass as the degree of moisture stress increases. According to [20], the yield of every wheat cultivar under study declined as the degree of soil moisture depletion increased.

The water productivity of irrigated wheat has been found to be significantly ($p < 0.05$) impacted by the various levels of soil moisture stress (Table 2). The range of water productivity values, as reported by [21], was 0.80 to 0.92 kg m^{-3} . Due in part to lower evapotranspiration losses in relation to yield, it was shown that water deficit treatments of 80% ETc during development and mid-stage produced higher water productivity [22]. With less crop decline than full-season deficit practice, this method could achieve the necessary balance between irrigation application and water production.

Determining the ideal water productivity level is crucial in water-limited situations in order to maintain the equilibrium between maximizing crop yield and conserving water at ideal levels.

Table 2. Effect of deficit irrigation on yield, yield related and water productivity.

Treatments	PH (cm)	TSW (g)	Yield (t ha^{-1})	BY (t ha^{-1})	WP (kg m^{-3})
100% ETc	66.97 ^a	36.43 ^a	3.47 ^a	9.53 ^a	0.86 ^b
80% ETc	65.9 ^{ab}	33.43 ^b	2.73 ^b	8.63 ^b	0.85 ^{bc}
80% ETc DM	66.47 ^{ab}	35.15 ^a	3.32 ^a	9.17 ^a	0.92 ^a
60% ETc	63.10 ^c	30.40 ^c	1.94 ^c	7.74 ^c	0.80 ^c
60% ETc DM	65.40 ^b	33.32 ^b	2.59 ^b	8.26 ^b	0.82 ^{bc}
LSD (0.05)	1.2122	1.361	0.16	0.44	0.05
CV (%)	0.98	2.14	3.08	2.72	3.44

Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at $p < 0.05$ level of significance, PH = Plant height, TSW = Thousands seed weight, BY = Biomass yield, WP = Water productivity, LSD (0.05) = Least significant Difference at 5% of significance and CV (%) = Coefficient of variation

3.3. Calibration of AquaCrop Model

Table 3 displays the calibrated values of the crop parameters. The Canopy drop Coefficient (CDC) and Canopy Growth

Coefficient (CGC) were modified by "average decline canopy cover" and "reduction of canopy expansion," respectively. The CGC and CDC are 9.4% and 10.3% per day, respectively. The reference harvest index was 31%, and the maximum canopy cover was 66%.

Table 3. Calibrated of crop parameters for kingbird wheat variety.

Description	Calibrated Values
Canopy Growth Coefficient (CGC) (%/day)	9.4
Canopy Decline Coefficient (CDC) (%/day)	10.3
Maximum canopy cover (%)	66
Reference Harvest Index (HIO) (%)	31

3.4. Grain Yield, Dry Biomass and Water Productivity (WP)

Table 4 displayed the final aboveground biomass, water productivity, and observed and simulated grain yield figures. The outcome demonstrated a discrepancy between the simulated biomass (0.53 to 4.25%) and grain yield (0.18% to 15.66%) and their respective observed values. Grain yield and

biomass showed the most positive deviation when 60% ETc was applied across all growth phases. This could perhaps be attributed to the fact that; the senescence of the canopy increases under extreme water stress at the field settings. The findings of [7] are comparable. For many crops that the model simulated, they reported significantly higher deviation under rainfed or severe water stress treatments than under full irrigation treatments.

Table 4. Relative error of observed and predicted yield, biomass and water productivity of wheat crop for calibration of AquaCrop model.

Treatment	Yield			WP			Biomass		
	Obs	Sim	PE (±%)	Obs	Sim	PE (±%)	Obs	Sim	PE (±%)
100% ETc	3.36	3.05	9.23	0.83	0.88	5.63	9.54	9.44	1.01
80% ETc	2.60	2.59	0.20	0.81	0.82	1.63	8.61	8.71	1.22
80% ETc DM	3.21	2.86	11.03	0.89	0.90	0.64	9.31	8.94	3.92
60% ETc	1.91	2.21	15.66	0.79	0.79	0.08	7.79	7.46	4.25
60% ETc DM	2.54	2.53	0.18	0.80	0.82	1.93	8.23	8.19	0.53

Obs = Observed; Sim = Simulated; DM = Development and mid stages, PE = prediction error

Table 5. Statistical indices for calibration AquaCrop model for wheat crop.

Model output parameters	Observed	Simulated	RMSE	ME	R ²
Grain yield (t ha ⁻¹)	2.73	2.53	0.25	0.81	0.98
Dry biomass (t ha ⁻¹)	8.69	8.27	0.23	0.94	0.93
WP (kg m ⁻³)	0.83	0.82	0.02	0.95	0.84

RMSE = Root Mean Square Error, ME = Model Efficiency, R² = Coefficient of determination

Table 5 displayed the AquaCrop model's calibration statistics for the 2022-2023 wheat crop. The findings demonstrate a strong correlation between the observed and anticipated grain yield, with a coefficient of determination (R²) of 0.98 and a

model efficiency (ME) of 0.81. Grain yields were 2.73 and 2.53 t ha⁻¹ on average, with a root mean square error (RMSE) of 0.25 t ha⁻¹. The correlation and model efficiency values for dry biomass were 0.93 and 0.94, respectively. 8.69 and 8.27 t

ha⁻¹, respectively, were the average values of the observed and anticipated biomass, with an RMSE of 0.23t ha⁻¹.

This result is consistent with lower RMSE values of 0.32 and 0.34 t ha⁻¹ found by [23]. For water productivity, the model's efficiency and correlation were 0.95 and 0.77%, respectively. With an RMSE of 0.02kg m⁻³, AquaCrop's projected and observed average water productivity is 0.82 and 0.83kg m⁻³, respectively. The outcome demonstrated how well the AquaCrop model replicates grain production, biomass, and water productivity. In terms of ME and R2 values, which are very close to one another, the predicted parameter values exhibit the same general behavior as the actual parameters. Furthermore, in semi-arid conditions, the AquaCrop model could accurately forecast wheat's grain production, water productivity, and ultimate aboveground biomass.

3.5. Validation of AquaCrop Model

Data from a 2023-2024 field trial for the kingbird wheat variety was used to validate the AquaCrop model (Table 6). For 60% ETc during development and mid-stage and 60%

ETc throughout growth stages, the minimum and greatest prediction errors between simulated and projected yield were 0.53% and 17.36%, respectively (Table 6). According to the results, the minimum and greatest errors in dry biomass prediction were found to be 0.26% and 11.74%, respectively, for complete irrigation application and 60% ETc throughout growth stage treatments. The 80% ETc at development and mid-stages and 100% ETc treatments showed the lowest and largest water productivity prediction errors, respectively, of 0.87% and 7.12%.

The statistical performance findings of the AquaCrop model indicate that the observed and predicted grain yields accord well, with a coefficient of determination (R2) of 0.96 and a model efficiency of 0.83. With an RMSE of 0.244t ha⁻¹, the average grain yields of the observed and anticipated seasons are 2.89 and 2.82t ha⁻¹, respectively (Table 7). For biomass, the corresponding model efficiency (ME), coefficient of determination, and RMSE were 0.85, 0.93, and 0.41t ha⁻¹. Additionally, WP had an RMSE of 0.03kg m⁻³, a coefficient of determination of 0.77, and a ME of 0.73.

Table 6. Relative error of observed and predicted yield, biomass and water productivity of wheat crop for calibration of AquaCrop model.

Treatment	Yield			WP			Biomass		
	Obs	Sim	PE (±%)	Obs	Sim	PE (±%)	Obs	Sim	PE (±%)
100% ETc	3.58	3.21	10.20	0.89	0.95	7.12	9.51	9.49	0.26
80% ETc	2.85	2.70	5.30	0.88	0.86	2.75	8.66	8.91	2.84
80% ETc DM	3.42	3.26	4.68	0.95	0.96	0.87	9.02	9.16	1.51
60% ETc	1.97	2.38	17.36	0.81	0.83	2.13	7.45	6.58	11.74
60% ETc DM	2.63	2.62	0.53	0.83	0.85	1.91	8.29	8.37	0.89

Table 7. Model statistics of validation of AquaCrop model for wheat crop.

Model output parameters	Obs	Sim	RMSE	ME	R ²
Grain yield (t ha ⁻¹)	2.89	2.82	0.24	0.83	0.96
Dry biomass (t ha ⁻¹)	8.59	8.50	0.41	0.85	0.93
WP (kg m ⁻³)	0.87	0.89	0.03	0.77	0.73

4. Conclusions and Recommendations

Deficit irrigation maintains an ideal yield near maximal watering while conserving water and increasing water output. This study sought to test the AquaCrop model for wheat

production and assess the impact of water scarcity on wheat yield and water usage efficiency. The highest plant height, thousand seed weight, yield, and biomass (66.97cm, 36.43g, 3.47t ha⁻¹, 9.53t ha⁻¹) were obtained by applying 100% ETc, whereas the lowest were obtained by applying 60% ETc (63.1cm, 30.4g, 1.94t ha⁻¹, and 7.74t ha⁻¹). But when 80% ETc was applied during the development and mid-stages, the

highest water productivity of 0.92kg m⁻³ was discovered.

The AquaCrop model's grain yield efficiency was 0.81 when it was calibrated, but it was within an acceptable range of 0.70 when it was validated. Thus, it demonstrates that the AquaCrop model can successfully stimulate crop characteristics under various conditions. By boosting crop yields and water usage efficiency, especially in regions with limited water resources, this discovery may contribute to greater food security. In this agroclimatic situation, it is advised to use this model to study other crops that are irrigated.

Conflicts of Interest

The authors declare no conflicts of interest.

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