Original Research Article

Modelling Wheat Productivity under Deficit Irrigation

Abstract

This research was carried out to simulate wheat growth under deficit irrigation across two cropping years (2020-21 and 2021-22) at Prayagraj, Uttar Pradesh India. Crop growth simulation models are useful for assessing the impact of water scarcity on crop productivity and crop yield. The AquaCrop model is one of these available options and this model is capable of simulating water productivity, grain yield, biomass yield, and canopy cover. Major inputs for the model in this investigation are climate, soil characteristics, plant attributes, and the management of crop cultivation. The results of the simulation revealed that the model accurately simulates grain yield, water productivity, biomass yield, and canopy cover at different amount of irrigation. Five treatments from the wheat influenced by deficit irrigation, field experiment that was conducted over two cropping years (2020–21 and 2021–22) were used in the AquaCrop validation procedures. The simulated and observed grain yield coefficients of determination (R^2) were 0.96 and 0.95, respectively. The model simulation performed well (RMSE=0.131, NRMSE=3.75) and model efficiency (EF) was 0.99. Simulated and observed water productivity is equivalent at different amount of irrigation regimes. The model simulation performed well (RMSE=0.106 and NRMSE=5.00). Simulated and observed water productivity had EF of 0.99 and R^2 of 0.96. The model simulation of biomass under different amount of irrigation varied between RMSE ranged from 0.492 to 0.857, NRMSE ranged from 9.239 to 17.513 and EF ranged from 0.97 to 0.99. Coefficients of determination (R^2) of simulated biomass yield and observed biomass of all treatments were 0.99. It was determined that the simulated canopy cover for all treatments at different amount of irrigation had successfully adapted to the observed canopy cover. Thus, the RMSE varied from 13.344 to 18.974, the NRMSE from 20.770 to 33.223, and the EF from 0.91 to 0.96 for model simulations treated to various interventions. Coefficients of determination (R^2) of simulated canopy cover for all treatments were 0.97, although R^2 of observed canopy cover for various treatments ranged from 0.88 to 0.92.

Keywords: Wheat, Treatment, Simulation, AquaCrop model.

1. Introduction

Wheat is considered one of the most important grain crops in the world due to its tolerance to many agroclimatic and soil conditions. Wheat ranks first among main cereals in terms of worldwide area and production, and it is the primary source of nutrition for around 35 percent of the world's population (Wang et al. 2018). One of the most important challenges in wheat production is limited factors of yield in wheat (Curtis & Halford, 2014). Wheat is the most common source of protein in human diet, containing more protein than maize, rice, and other main grains (Kaisa et al. 2021). The United Kingdom has the greatest average wheat yield (7.9 tonnes per hectare), followed by Germany (7.8 tonnes) and France (7.5 tonnes). It was cultivated on 29.9 million hectares in India, yielding 107 million metric tonnes with an average yield of 3,430 kg per hectare (Government of India. 2019-20). AquaCrop model simulates soil water balance and crop development processes based on crop, soil, climate, and management input data on a daily basis (Doorenbos and Kassam, 1979). The AquaCrop model explicitly simulates soil evaporation and plant transpiration as separate processes (Foster et al. 2017). The productive component of water consumption is used to estimate daily biomass accumulation using a crop-specific water productivity variable that is adjusted for reference evapotranspiration, making it relevant to a wide range of climates (Kukal and Irmark, 2020). The percentage of biomass that becomes harvestable yield is then computed using a harvest index parameter that grows over the growth season and reacts to water and temperature stressors. AquaCrop is intended to simulate the growth, biomass yield, and grain yield of herbaceous plant species (Steduto et al., 2007). In AquaCrop, the growth of the plant's leaves is measured by the green canopy cover (CC) and not by the Leaf Area Index (Nielsen et al., 2012). The production of above-ground biomass is related to the total quantity of crop transpiration. The proportionate factor is the productivity of biomass water (Mueller et al. 2005). In AquaCrop, biomass water productivity is normalised to account for the influence of climatic variables, making the normalised biomass water productivity applicable to various locations, seasons, and CO_2 concentrations (Raes et al. 2022). The simulated aboveground biomass (B) includes all photosynthetic products absorbed by the crop during the growing season. Crop yield (Y) is derived from aboveground biomass using a Harvest Index (HI), which represents the proportion of biomass that is the harvestable product (Steduto et al. 2012). During simulation, the actual harvest index is produced by changing the reference Harvest Index (HI_0) using a stress-effect adjustment factor.

2. Materials and Methods

AquaCrop was parameterized and tested using average data of wheat crop for two cropping years (2020-21 and 2021-22) at Prayagraj, Uttar Pradesh India. Experiments in the field were carried out at the Sam Higginbottom University of Agriculture, Technology, and Sciences Irrigation Research Farm in Prayagraj, Uttar Pradesh, India. Prayagraj is situated at 25.45 degrees North latitude and 81.84 degrees East longitude, and it is situated at the confluence of the Yamuna and Ganga rivers. The experimental design was a randomized complete block with three replication and five levels of irrigation included: however for the remaining treatment the irrigation amount to reduce by 0%, 20%, 40%, 60%, and 80% of 66 mm as designed depth of irrigation and irrigation was scheduled on the basis of limiting soil water conditions. The version of AquaCrop 6.1 used in this study. AquaCrop was parameterized using pooled data from the (2020-21 and2021-22) two cropping season that provided the most extensive in season plant measurements.

2.1 Irrigation scheduling based upon limiting soil water conditions

2.1.1 Soil moisture content: Irrigation was scheduled on the basis of limiting soil water conditions. This approach applies to the laboratory assessment of soil moisture content as a percentage of its oven-dried weight. The moisture content of the soil was calculated as a percentage of the dry soil weight using the following formula:

$$MC(\%) = \frac{(W2-W3)}{(W3-W1)} \times 100 \qquad \text{....eq. (1)}$$

Where, MC is the soil moisture content (%), W1 is the weight of tin (g), W2 is the weight of moist soil + tin (g), and W3 is the weight of dry soil + tin (g)

2.1.2 Total available water: Total available water refers to the quantity of water that may be used by plants. Actually, it's the soil moisture differential between the field capacity and the permanent wilting point. The total available water was determined using the formula below.

$$TAW = 1000\,[(\theta_{FC} - \theta_{PWP})] \times Zr \qquad \text{....eq. (2)}$$

Where, TAW is the total available water (mm), θ_{FC} is the moisture content at field capacity (%), θ_{PWP} is the moisture content at permanent wilting point (%), and Zr is the effective root zone depth, (m).

2.1.3 Readily available water: The readily available water is the fraction of TAW that a crop may take from the root zone without suffering from water stress (FAO- 56).

$$RAW = p\ TAW \qquad \text{....eq. (3)}$$

Where, RAW is the readily available soil water in the root zone (mm), p is the average fraction of total Available Water.

2.1.4 Calculate the net depth of irrigation: After the calculating of total available water (TAW), the maximum permissible depletion (p) in percentage was used in the following equation to determine the net depth of irrigation:

$$IW = p \text{ X } TAW \qquad \text{….eq. (4)}$$

Where, IW is the net depth of irrigation to be used for a single irrigation (mm), p is the maximum allowable depletion (%) and TAW is the total available water (mm). Using data from FAO-56, maximum allowable depletion (p) for wheat crop is equal to 0.55.

Table: 1 Irrigation details of deficit irrigation

Treatments	Level of irrigation	Depletion (%)	Depth of irrigation (mm)	No. of irrigation	Total applied of water (mm)
T_1	1	0	66	6	396
T_2	0.8	20	52.8	6	316.8
T_3	0.6	40	39.6	6	237.6
T_4	0.4	60	26.4	6	158.4
T_5	0.2	80	13.2	6	79.2

2.2 Model parameters and input data

2.2.1 Weather data

The weather data required by AquaCrop are the daily values of minimum and maximum air temperature, wind speed, relative humidity, rainfall and solar radiation (Raes et al., 2009, Steduto et al., 2009). The weather data, which prevailed during the two wheat crop growing seasons, November 2020 to April 2021 and November 2021 to April 2022, are presented in table: 2.

Table: 2 Average monthly weather data during crop growing season (2020-21 and 2021-22)

Weather data 2020-21						
Month	**T. max (^{0}C)**	**T. min (^{0}C)**	**Mean RH (%)**	**Sunshine (hour)**	**Wind speed (Km/h)**	**Rainfall (mm)**
November	32.21	13.59	74.35	8.41	1.11	0.80
December	26.76	9.56	80.90	7.91	1.01	18.40
January	22.29	9.15	78.90	2.99	0.98	7.00
February	30.13	11.26	67.70	8.18	1.03	5.20
March	36.21	19.52	60.40	9.21	1.17	2.80
April	41.99	20.08	52.30	9.15	1.53	0.00
Weather data 2021-22						
Month	**T. max (^{0}C)**	**T. min (^{0}C)**	**Mean RH (%)**	**Sunshine (hour)**	**Wind speed (Km/h)**	**Rainfall (mm)**
November	29.62	15.14	74.76	8.69	1.03	0.00
December	24.76	11.12	81.22	5.22	1.03	1.20
January	20.49	9.08	85.77	3.36	1.04	57.20
February	27.91	13.20	68.19	8.27	1.37	0.00
March	35.44	19.46	59.18	8.97	1.32	0.00
April	42.15	23.73	59.03	8.75	1.53	0.00

Source: Department of Forestry and Environment at Prayagraj, Uttar Pradesh

2.2.2 Wheat growth measurements

During the (2020-21 and 2021-22) season, canopy development was monitored in terms of growth stages and aboveground biomass. Before cutting the plants at the ground level, growth stage was recorded. AquaCrop requires identifying generic growth stages of time to emergence, maximum canopy cover, start of senescence, and maturity. For the purpose of AquaCrop simulation, time to emergence, maximum canopy cover, and start of senescence were based on field observations.

Table: 3 Wheat growth parameters used in AquaCrop 6.1 model

Parameter	Calibrated value
Number of plants per hectare	1000000
Time to reach maximum canopy cover	70 DAS
Initial canopy cover	1.50%
Maximum canopy cover	97%
Canopy growth coefficient	11.10%
Canopy decline coefficient	9.17%
Time to start senescence	90 DAS
Time to reach flowering	84 DAS
Length of flowering stage	15 days
Time from sowing to emergence	7 days
Time from sowing to reach maturity	130 days
Minimum effective rooting depth	0.30 m
Maximum effective rooting depth	1.0 m
Time from sowing to maximum root depth	40 days
Building up of harvest index	28 days
Reference harvest index	50%

2.3 Calibration of AquaCrop

For each of the simulation runs, weather data, soil characteristics, irrigation applications, sowing date, and sowing density were entered as observed. Crop data were obtained from the calibration fields and/or fine-tuned during the calibration runs. Calibrations were based on comparisons between observed biomass yield and seed yield biomass yield water productivity and canopy cover.

2.4 Model description

AquaCrop is intended to simulate the biomass and yield responses of field crops to various levels of water availability. Its applications include rain fed, supplementary, deficit, and full irrigation (Doorenbos and Kassam, 1979) provided an important source for determining the yield response to water of field, vegetable, and tree crops using the following equation.

$$(Y_x - Y_a)/Y_x = k_y(ET_x - ET_a)/ET_x \quad \text{....eq. (5)}$$

Where, Yx and Ya are the maximum and actual yields. ETx and ETa stand for maximum and actual evapotranspiration, respectively. Ky denotes the proportionality factor between relative yield decline and relative evapotranspiration reduction. The following processes are sequentially simulated by the model with a daily time step:

(A) Simulation of crop development: In crop growth simulations, canopy expansion is separated from root zone expansion. AquaCrop describes crop growth using canopy cover instead of leaf area index.

$$CC = 1 - exp^{(-065*LAI)} \qquad \text{….eq. (6)}$$

Where, CC represents the canopy cover (%) and LAI is the leaf area index.

(B) Simulation of crop transpiration: To calculate crop transpiration, first multiply the evaporating power of the atmosphere, which is denoted by ET_0, by a crop coefficient, which is denoted by K_{cb}, and then take into account water stresses, which are denoted by Ks.

$$Tr = Ks\left(Kcb_x\, CC^*\right)ET_o \qquad \text{….eq. (7)}$$

(C) Simulation of above ground biomass: The aboveground biomass production for each day of the crop cycle is calculated by multiplying the water productivity by the crop transpiration-to-reference evapotranspiration ratio (Tr/ET_0) for that day. Within AquaCrop, this is simulated by considering a temperature stress coefficient denoted by (Ks_b):

$$B = Ks_b\, WP^* \sum_i \frac{Tr_i}{ETo_i} \qquad \text{…. eq. (8)}$$

(D) Partitioning of biomass into yield: The yield (Y) is calculated by multiplying the simulated above-ground biomass (B) by the adjusted harvest index, which is as follows:

$$Y = f_{HI}\, HI_o\, B \qquad \text{....eq. (9)}$$

Where, HI is the harvest index and f_{HI} is a multiplier that takes into consideration the stresses that change the harvest index from its reference value.

(E) Water productivity: The correlation between crop yield and the quantity of water utilised in agricultural production is known as water productivity.

$$\text{WP (Kg m}^{-3}\text{)} = \frac{\text{Grain yield}}{\text{Total amount of water supplied}} \qquad \text{….eq. (10)}$$

2.5 Model validation

The experimental plot data will be used to run a simulation of the calibrated AquaCrop model; the simulated output in the form of grain yield, canopy cover, water productivity, and biomass will be compared to the observed value of the experimental plot; and the model validation performance statistics will be analysed.

2.6 Evaluation of model performance

Model performance must be evaluated in order to offer a resulting value of the model's capability to reproduce an observed variable, to assess the influence of calibrating model parameters, and to compare model results to earlier reports (Krause et al., 2005).

(I) Coefficient of determination (R^2): The coefficient of determination (R^2) is defined as the Pearson correlation coefficient squared. It has a value between 0 and 1, with values close to 1 indicating strong agreement.

$$R^2 = \left[\frac{\sum(O_i-\overline{O})\,(P_i-\bar{P})}{\sqrt{\sum(O_i-\bar{O}\,)^2\sum(P_i-\bar{P})^2}}\right]^2 \qquad \text{….eq. (11)}$$

In this equation, O_i and P_i are the observations and predictions, respectively; $\bar{O}$ and $\bar{P}$ are their means (Krause et al., 2005).

(II) Root mean square error (RMSE): The root mean square error (RMSE) is a popular statistical indicator that calculates the average magnitude of the discrepancy between predictions and observations (Krause et al., 2005).

$$RMSE = \sqrt{\frac{\sum(P_i-O_i)^2}{n}} \qquad \text{….eq. (12)}$$

Where, n is the number of observations, and Pi and Oi are the predicted and observed values, respectively.

(III) Normalized root mean square error (NRMSE): Several statistics methods were used to compare the simulated and observed results. Evaluated model performance using the root means square error normalized (Rinaldy et al., 2003).

$$NRMSE = \frac{1}{\bar{O}}\sqrt{\frac{\sum(P_i-O_i)^2}{n}} \times 100 \qquad \text{….eq. (13)}$$

The NRMSE of a simulation is deemed outstanding when it is less than 10%, acceptable when it is between 10% and 20%, fair when it is between 20% and 30%, and poor when it is more than 30%.

(IV) Nash-Sutcliffe model efficiency coefficient (EF): The Nash-Sutcliffe model efficiency coefficient (EF) is used to quantify the residual variance in relation to the variance of the observations (Nash and Sutcliffe, 1970). An EF of 1 denotes a perfect agreement between the model and the observations.

$$EF = 1 - \frac{\sum(P_i-O_i)^2}{\sum(O_i-\bar{O})^2} \qquad \text{….eq. (14)}$$

3. Result and Discussion

In this portion of the research, we attempt to determine how much water must be applied and at what intervals so that extra water does not drain but instead return to the root zone when deficit irrigation is administered. Thus, the irrigation leads along with maximum allowed depletion (MAD), percentage of thresholds, depth of irrigation (mm), irrigation frequency, and total quantity of water provide a standard for deficit irrigation in wheat. At the study site, the soil water availability for sandy loam was determined to be 120 millimetres. It was determined that the soil moisture content at field capacity was 35%. Wheat is considered to have a depletion fraction of 0.55, with a maximum rooting depth of 1.5 to 1.8 metres. In the 1st treatment, the depth of irrigation continues at 66 mm, however in the 2nd, 3rd, 4th, and 5th treatments, the depth of irrigation is 52.8 mm, 39.6 mm, 26.4 mm, and 13.0 mm, respectively. The highest total water applied to wheat was 396 mm in the 1st treatment, followed by 316.8 mm in the 2nd treatment, 237.6 mm in the 3rd treatment, 158.4 mm in the 4th treatment, and 79.2 mm in the 5th treatment.

3.1 Validation results

Five treatments from the wheat crop field experiment for the two crop years (2020–21 and 2021–22) were employed in the AquaCrop validation steps, adjusting for the calibration procedure's parameters. In the AquaCrop model's validation process, simulations of canopy cover and above-ground biomass at various days after sowing, grain yield, final above-ground biomass, and water productivity were run.

3.2 Simulation of grain yield

Five treatments from the wheat influenced by soil water limiting conditions, field experiment that was conducted over two cropping years (2020–21 and 2021–22) were used in the AquaCrop validation procedures. Table: 4 and Fig: 1 provides the findings of the model simulation for wheat grain yield.

Table: 4 Simulated grain yield and observed grain yield of wheat

Treatment	Observed grain yield (t/ha)			Simulated grain yield (t/ha)		
	2020-21	2021-22	pooled	2020-21	2021-22	Pooled
$T_{1(396mm)}$	4.60	4.26	4.43	4.86	4.28	4.57
$T_{2(316.8mm)}$	4.33	4.24	4.29	4.46	4.25	4.36
$T_{3(237.6mm)}$	3.13	3.43	3.28	3.23	3.62	3.43
$T_{4(158.4mm)}$	2.53	3.36	2.95	2.63	3.47	3.05
$T_{5(79.2mm)}$	2.13	2.84	2.49	2.38	2.93	2.66
RMSE		0.131				
NRMSE (%)		3.75				
EF		0.99				

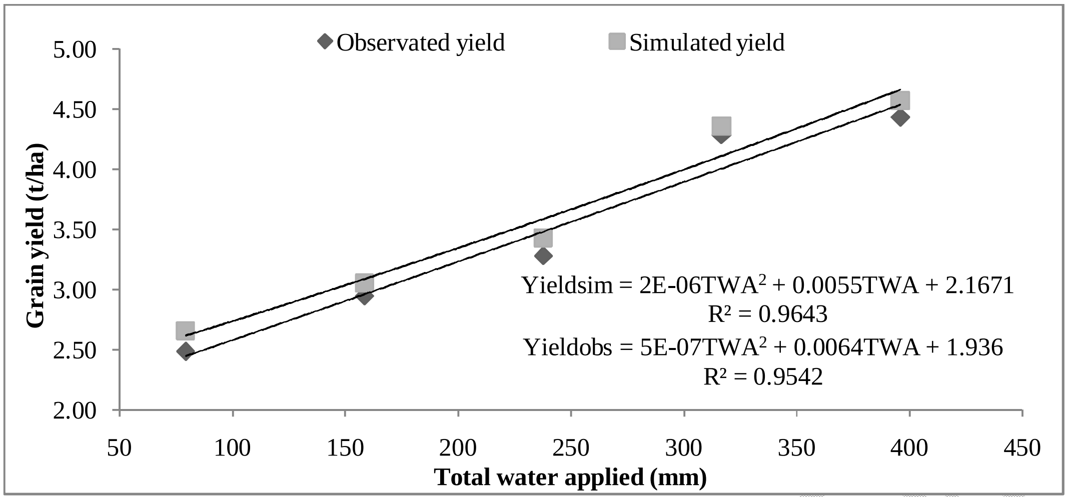

Fig: 1 Evaluation of Simulated grain yield and observed grain yield in wheat

Simulated grain yields in all treatments with various amount of irrigation depth had good agreement with observed grain yields. As a result, the model simulation performed very well (RMSE=0.131 and NRMSE=3.75). The model efficiency (EF) was 0.99 and coefficient of determination (R^2) of simulated and observed grain yield were 0.96 and 0.95.

3.3 Simulation of water productivity

Five treatments from the wheat influenced by soil water limiting conditions, field experiment that was conducted over two cropping years (2020–21 and 2021–22) were used in the AquaCrop validation procedures. Table: 5 and Fig: 2 exhibit the outcomes of the model simulation for the water productivity of wheat.

Table: 5. Simulated WP and observed WP of wheat

Treatment	**Observed WP (Kg/m^3)**			**Simulated WP (Kg/m^3)**		
	2020-21	**2021-22**	**pooled**	**2020-21**	**2021-22**	**Pooled**
$T_{1(396mm)}$	1.16	1.08	1.12	1.23	1.08	1.15
$T_{2(316.8mm)}$	1.37	1.34	1.35	1.41	1.34	1.37
$T_{3(237.6mm)}$	1.32	1.44	1.38	1.36	1.52	1.44
$T_{4(158.4mm)}$	1.60	2.12	1.86	1.66	2.19	1.93
$T_{5(79.2mm)}$	2.69	3.59	3.14	3.00	3.70	3.35
RMSE	0.106					
NRMSE	5.00					
EF	0.99					

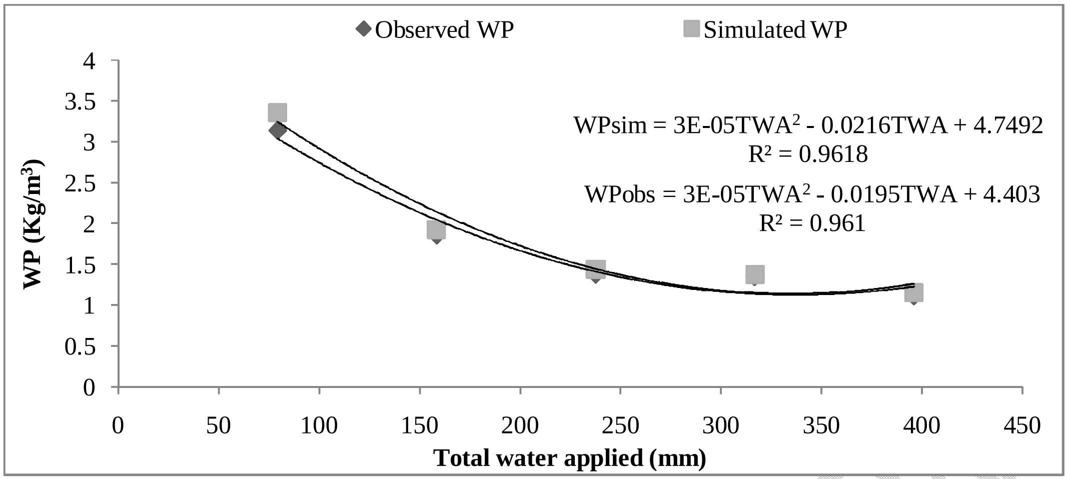

Fig: 2 Evaluation of Simulated WP and observed WP in wheat

Simulated water productivity matches observed water productivity well in all treatments with various amount of irrigation. The model simulation therefore performed quite well (RMSE=0.106 and NRMSE= 5.00). Between simulated and observed water productivity, the model efficiency (EF) was 0.99 and coefficient of determination (R^2) of simulated and observed water productivity were 0.96 and 0.96.

3.4 Simulation of biomass

Five treatments from the wheat influenced by soil water limiting conditions, field experiment that was conducted over two cropping years (2020–21 and 2021–22) were used in the AquaCrop validation procedures. Table: 6 and Fig: 3 to 7 show results of model simulation for wheat biomass.

Table: 6 Pooled data of simulated biomass and observed biomass (t/ha) of wheat

DAS	T_1(396mm)		T_2(316.8mm)		T_3(237.6mm)		T_4(158.4mm)		T_5(79.2mm)	
	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
20	0.57	0.40	0.55	0.39	0.53	0.39	0.51	0.39	0.49	0.39
30	1.23	1.05	1.23	1.04	1.21	1.04	1.18	1.04	1.16	1.04
40	1.77	1.87	1.76	1.87	1.73	1.86	1.69	1.86	1.65	1.86
50	2.95	2.67	2.93	2.66	2.88	2.65	2.82	2.64	2.75	2.64
60	3.56	3.75	3.51	3.74	3.46	3.72	3.38	3.71	3.31	3.71
70	4.81	4.65	4.68	4.63	4.61	4.60	4.51	4.59	4.41	4.59
80	5.93	5.89	5.85	5.86	5.76	5.83	5.63	5.81	5.51	5.81
90	7.12	7.73	7.02	7.69	6.91	7.65	6.55	7.62	6.42	7.63
100	8.42	9.57	8.19	9.52	8.05	9.46	7.84	9.44	7.63	9.44
110	10.25	11.12	9.95	11.05	9.76	10.99	9.51	10.95	9.33	10.95
120	11.96	12.05	11.86	11.97	11.22	11.89	10.95	11.85	11.17	11.76
RMSE	0.492		0.575		0.654		0.789		0.857	
NRMSE	9.239		11.01		12.833		15.9.3		17.513	
EF	0.99		0.99		0.98		0.982		0.97	

According to results was recognized that simulated biomass in all treatments influenced by soil water limiting conditions has adaptation well with observed biomass. So that model simulation under different treatments varied between RMSE ranged from 0.492 to 0.857, NRMSE ranged from 9.239 to 17.513 and EF ranged from 0.97 to 0.99. Coefficients of determination (R^2) of simulated biomass yield and observed biomass yield of all treatments were 0.99.

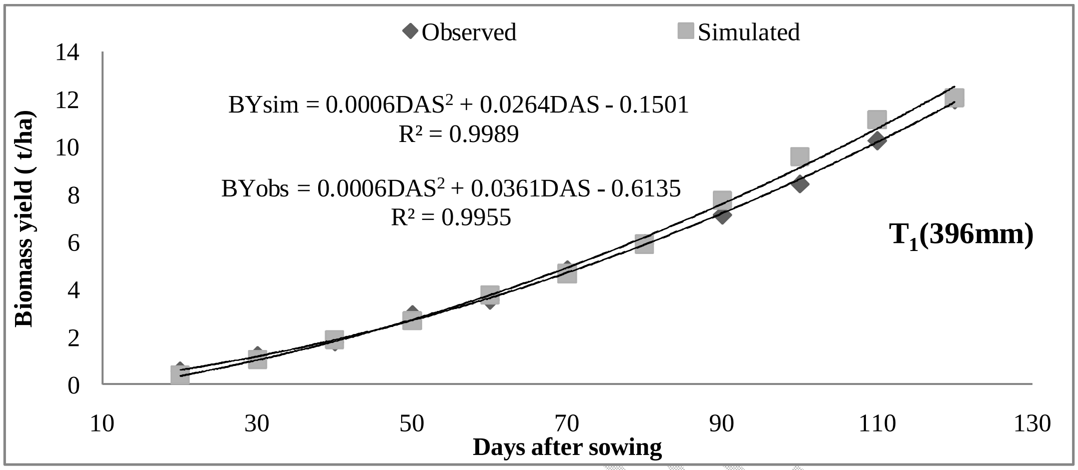

Fig: 3 Evaluation of Simulated and observed biomass yield in wheat of T_1 (396mm)

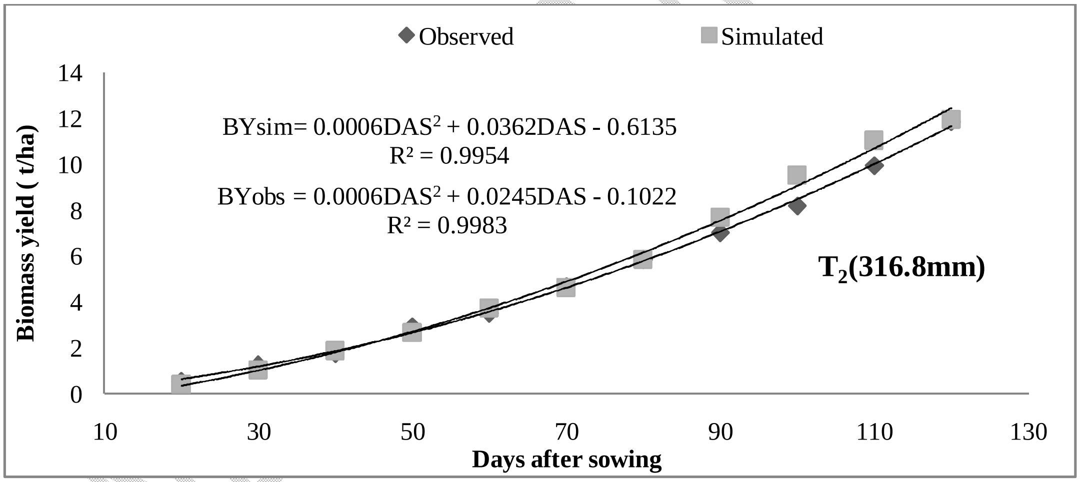

Fig: 4 Evaluation of Simulated and observed biomass yield in wheat of T_2 (316.8mm)

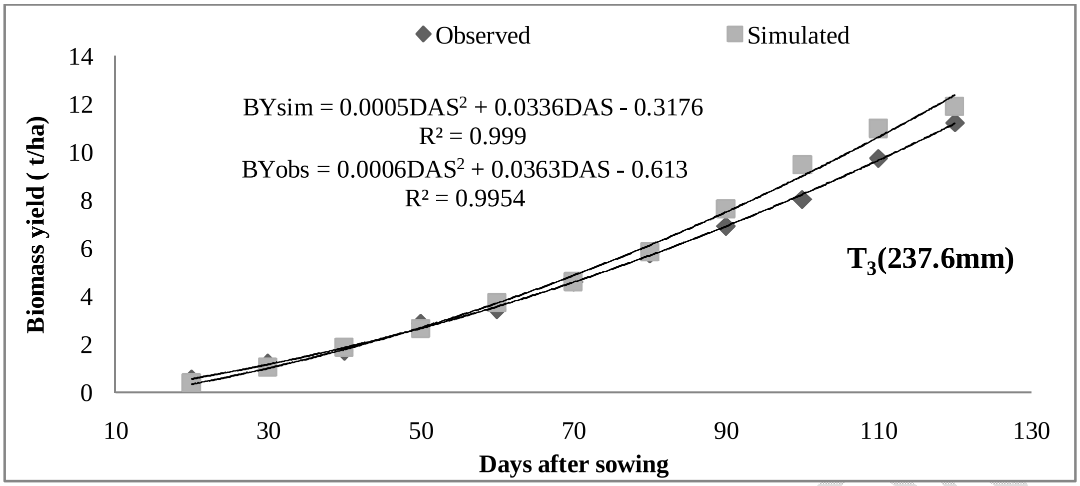

Fig: 5 Evaluation of Simulated and observed biomass yield in wheat of T_3 (237.6mm)

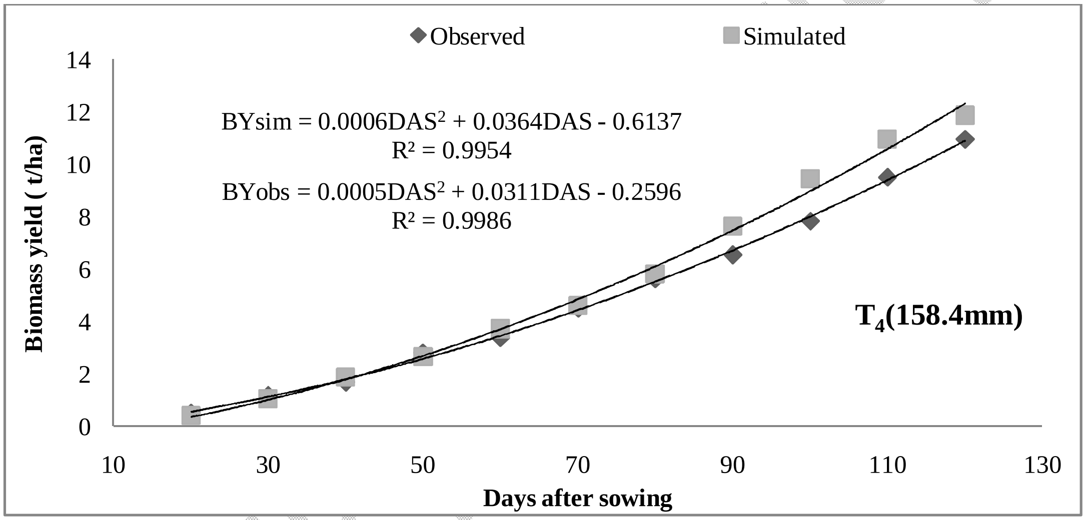

Fig: 6 Evaluation of Simulated and observed biomass yield in wheat of T_4 (158.4mm)

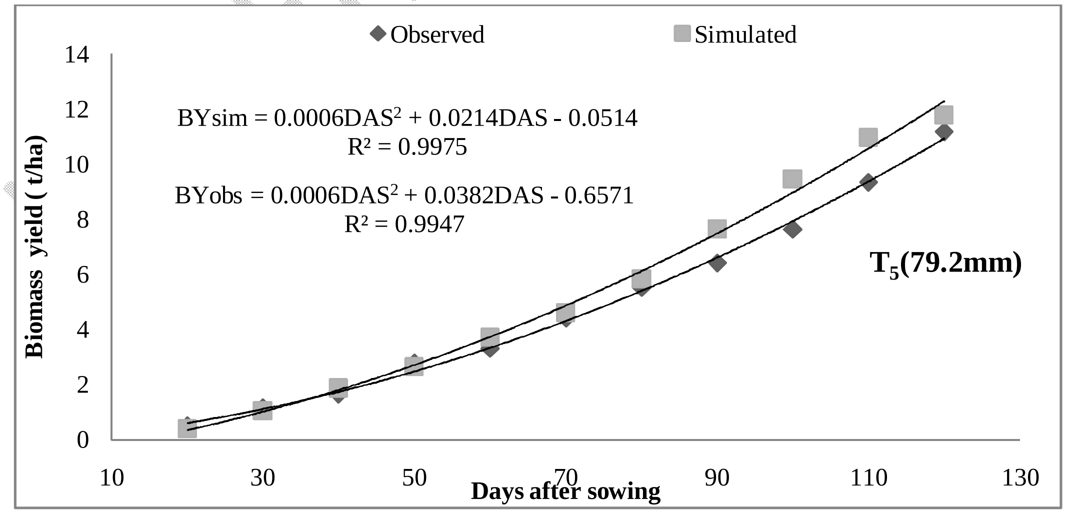

Fig: 7 Evaluation of Simulated and observed biomass yield in wheat of T_5 (79.2mm)

3.5 Simulation of canopy cover

Five treatments from the wheat influenced by soil water limiting conditions, field experiment that was conducted over two cropping years (2020–21 and 2021–22) were used in the AquaCrop validation procedures. Table: 6 and Fig: 8 to 12 show results of model simulation for wheat canopy cover. According to results was recognized that simulated canopy cover in all treatments influenced by soil water limiting conditions has adaptation well with observed canopy cover. So that model simulation under different treatments varied between RMSE ranged from 13.344 to 18.974, NRMSE ranged from 20.770 to 33.223 and EF ranged from 0.91 to 0.96. Coefficients of determination (R^2) of simulated canopy cover of all treatments were 0.97 and Coefficients of determination (R^2) of observed canopy cover of various treatments ranged from 0.88 to 0.92.

Table: 7 Pooled data of simulated canopy cover and observed canopy cover (%) of wheat

DAS	T_1(396mm)		T_2(316.8mm)		T_3(237.6mm)		T_4(158.4mm)		T_5(79.2mm)	
	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
20	8.64	15.50	7.98	15.50	7.38	15.50	8.82	15.45	9.23	15.45
30	24.97	37.10	23.29	37.00	20.45	36.80	21.27	36.75	18.94	36.75
40	43.71	70.30	40.82	69.70	35.05	69.10	35.01	68.80	33.77	68.80
50	87.66	85.60	85.19	84.80	85.01	84.00	81.72	83.55	81.46	83.55
60	94.57	92.00	93.75	91.10	93.06	90.20	91.77	89.70	90.93	89.70
70	97.21	94.70	97.21	93.70	96.62	92.80	96.24	92.30	95.18	92.30
80	93.47	96.20	92.66	95.20	91.34	94.20	90.78	93.70	89.02	93.70
90	82.90	96.70	81.63	95.70	79.00	94.70	77.94	94.20	74.45	94.20
100	72.91	90.20	67.43	89.30	64.38	88.30	62.72	87.85	58.36	87.85
110	53.29	76.50	47.73	75.50	46.52	74.60	42.41	74.15	42.41	74.15
120	47.39	45.20	42.39	44.40	37.42	43.50	34.46	43.05	34.46	43.05
RMSE	13.344		15.243		16.973		17.669		18.974	
NRMSE	20.77		24.656		28.45		30.22		33.223	
EF	0.964		0.95		0.936		0.927		0.913	

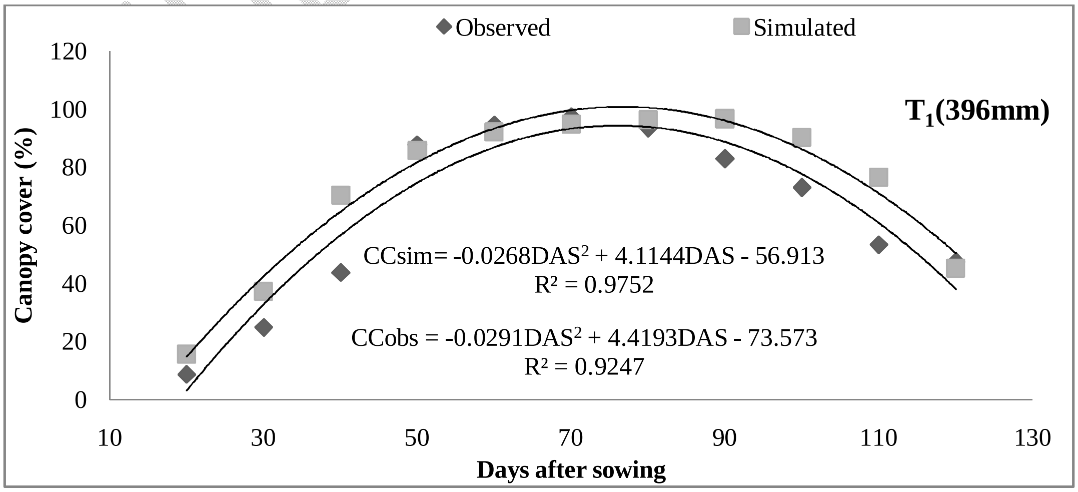

Fig: 8 Evaluation of Simulated and observed canopy cover in wheat of T_1 (396 mm)

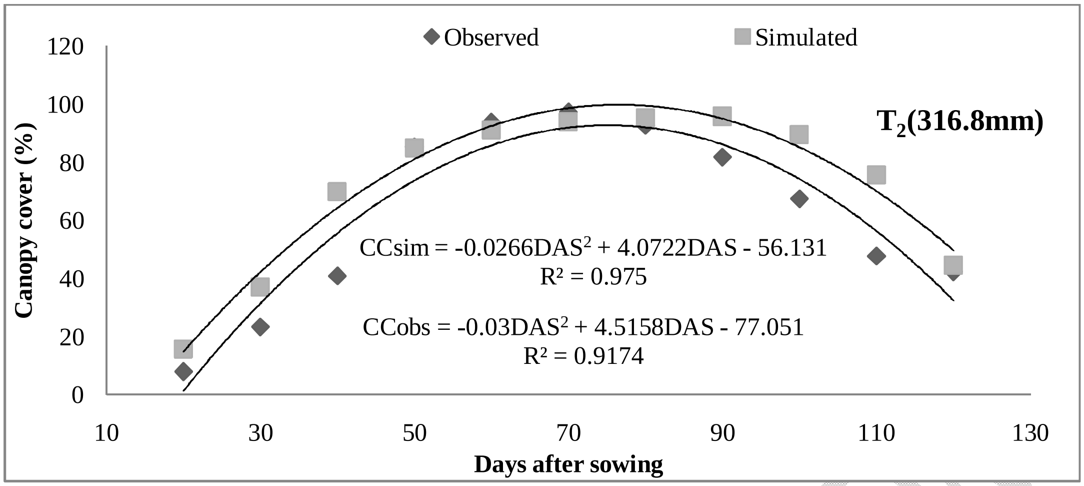

Fig: 9 Evaluation of Simulated and observed canopy cover in wheat of T_2 (316.8 mm)

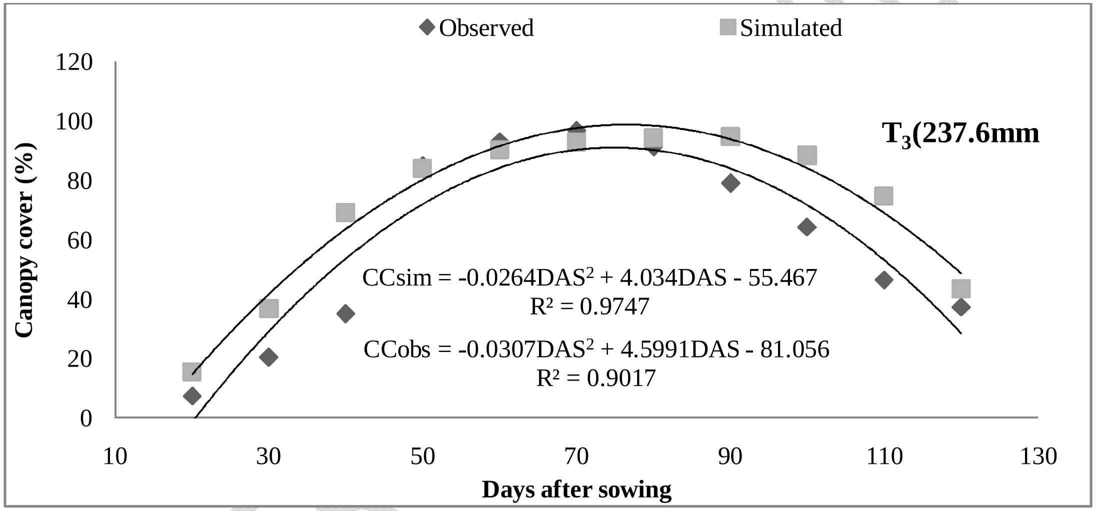

Fig: 10 Evaluation of Simulated and observed canopy cover in wheat of T_3 (237.6 mm)

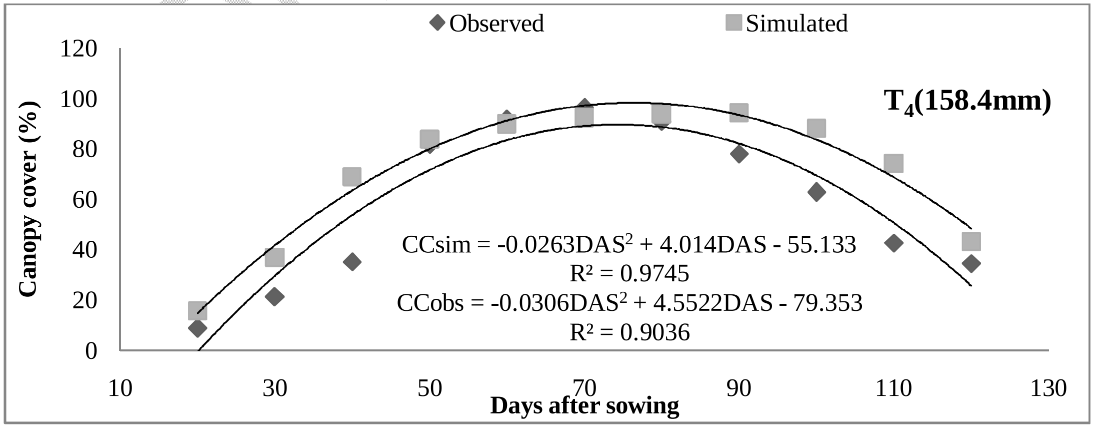

Fig: 11 Evaluation of Simulated and observed canopy cover in wheat of T_4 (158.4 mm)

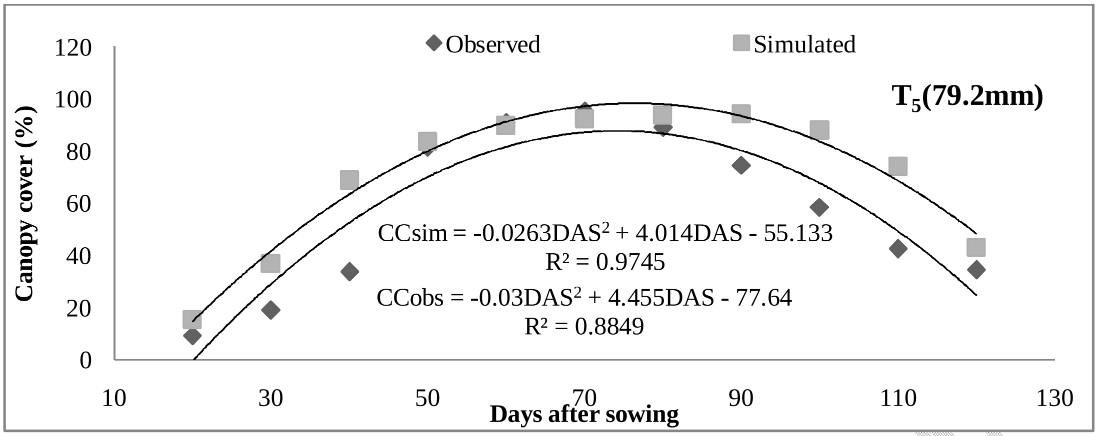

Fig: 12 Evaluation of Simulated and observed canopy cover in wheat of T_5 (79.2 mm)

Conclusion

The AquaCrop model was validated, and the results showed that it correctly simulated biomass production, water productivity, grain yield, and canopy cover. The ease of use of AquaCrop is mostly attributable to the fact that it only requires a minimal number of input data, all of which are either publicly accessible or can be quickly gathered. AquaCrop models are well suited for prospective research such as those examining the outcomes of future climate change. Aqua-crop models may be useful for determining what factors are restricting crop yield and water productivity by comparing potential yields with actual yields in a given field, farm, or area. It is suited for perspective studies such as those under future climate change scenarios.

References:

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998). Crop evapotranspiration. Guidelines for computing crop water requirements. Irrigation and Drainage Paper No. 56. United Nations and FAO, Rome.

Curtis, T. & Halford, N. G. (2014). Food security: the challenge of increasing wheat yield and the importance of not compromising food safety. *Annals of Applied Biology*, 164, pp. 354-372.

Doorenbos, J. and Kassam, A. H. (1979). Yield response to water. Irrigation and Drainage Paper no 33. FAO, Rome.

Foster, T., Brozovic, N., Butler, A. P., Neale, C. M. U., Raes, D., Steduto, P., Fereres, E. and Hsiao, T. C. (2017). AquaCrop-OS: An open source version of FAO’s crop water productivity model. *Agricultural Water Management* 181, pp. 18–22.

Kaisa S., Poutanen O. A., Gallego, C. G., and Johansson, D. P. (2021). Grains – a major source of sustainable protein for health. *Nutrition Reviews,* Vol. 80(6): pp. 1648–1663.

Krause, P., Boyle, D. P. and Base, F. (2005). Comparison of different efficiency criteria for hydrological model assessment. *Advances in Geosciences*, 5, pp. 89-97

Kukal, M. S. and Irmark, S. (2020). Characterization of water use and productivity dynamics across four C_3 and C_4 row crop under optimal growth conditions. *Agricultural Water Management,* Vol. 227, pp. 105840.

Mueller, L., Behrendt, A., Schalitz, G., Schindler, U. (2005). Above ground biomass and water use efficiency of crop at shallow water tables in a temperature climate. *Agronomy water Journal,* Volume 75, pp. 117-136.

Nash, J. E., and Sutcliffe, J. V. 1970. “River Flow Forecasting through Conceptual Models: Part I. A Discussion of Principles.” *Journal of Hydrology* 10 (3): pp. 282-90.

Nielsen, D., Garcia, J. J. M. and and Lyon, D. J. (2012). Canopy cover and leaf area index relationships for Wheat, Triticale, and Corn. *Agronomy water Journal,* Volume 104, pp. 1569-73.

Raes, D., Steduto, P., Hasiao, T. C., and Fereres, E. (2022). Manual, Chapter 1 – AquaCrop, Version 7.0, pp. 1-19.

Rinaldy, M., Losavio, N. and Flagella, Z. 2003. Evaluation of OILCROP-SUN model for sunflower in southern Italy. *Agricultural Systems*. 78: pp. 17-30.

Steduto, P., Hasiao, T. C., and Fereres, E. (2012). Crop yield response to water .FAO *Irrigation and Drainage paper 66*. Rome, Italy.

Steduto, P., Hsiao, T. C., Raes, D. and Fereres, E. (2009). AquaCrop. The FAO crop model to predict yield response to water. *Agron. J.* 101: pp. 426–437.

Wang, J., Vanga, S. K., Saxena, R., Orsat, V. and Raghavan, V. (2018). Effect of climate change on the yield of cereal crops. *Climate,* 6, 41, pp. 1-19.