OCL 2024, 31, 19
© H. Aboodeh *et al.*, Published by EDP Sciences, 2024
https://doi.org/10.1051/ocl/2024016

OCL
Oilseeds & fats Crops and Lipids

Available online at:
www.ocl-journal.org

RESEARCH ARTICLE OPEN ACCESS

Capacity of AquaCrop model in simulating performance variables and water use efficiency of spring rapeseed

Hana Aboodeh, Abdolmehdi Bakhshandeh, Mohammad Reza Moradi-Telavat*, Seyyed-Ataollah Siadat, Seyyed-Amir Moosavi and Khalil Alamisaeid

Department of Plant Production and Genetics, Agricultural Sciences and Natural Resources, University of Khuzestan, Ahwaz, Khuzestan, Islamic Republic of Iran

Received 12 February 2024 – Accepted 29 July 2024

Abstract – A study was conducted to simulate the performance of rapeseed using the AquaCrop model at Khuzestan University of Agricultural Sciences and Natural Resources (Iran), over two crop years, 2021–2022 and 2022–2023. The results of the first year were used to calibrate the model, while the results of the second year were used to validate it. The research showed that the highest grain yield (1.572–1.415 tons/hectare) and water use efficiency (0.50–0.45 kg/m^3) were obtained the first year from the control treatment, with a density of 110 plants m^{-2}, and the Hayola 4815 cultivar, and the second year, with a density of 140 plants m^{-2}. The normalized root mean square error (NRMSE) values were 1.82%, 15.36%, and 14.15% for grain yield, biomass, and water use efficiency, respectively, after the calibration phase and 15.4%, 19.99%, and 6.22%, after the validation phase. The model efficiency factor (EF) always resulted in values above 95%. According to the average relative error (RE), grain yield was overestimated both after calibration and validation steps, while biomass and water use efficiency were both underestimated. These results suggest that the simulations with AquaCrop model can be considered reliable for simulating spring rapeseed.

Keywords: Biomass / crop modeling / transpiration / vegetation / water use efficiency

Résumé – Capacité du modèle de simulation AquaCrop à représenter les variables de performance et d'efficience de l'eau pour le colza de printemps. Une étude a été menée pour simuler le rendement du colza à l'aide du modèle AquaCrop à l'Université des Sciences Agricoles et des Ressources Naturelles du Khuzestan (Iran) au cours de deux campagnes agricoles, 2021–2022 et 2022–2023. Les résultats de la première année ont été utilisés pour calibrer le modèle, et ceux de la deuxième année pour le valider. Cette recherche a montré que le rendement en grains le plus élevé (1,572–1,415 tonnes/hectare) et la meilleure efficience de l'eau (0,50–0,45 kg/m^3) ont été obtenus pour le traitement témoin, avec une densité de 110 plantes.m^{-2}, et le cultivar Hayola 4815. Lors de la deuxième année, ces mêmes variables ont été maximisées pour une densité de 140 plantes.m^{-2}. Les valeurs de l'erreur quadratique moyenne normalisée (NRMSE) pour le rendement en grains, la biomasse et l'efficience de l'eau étaient de 1,82%, 15,36% et 14,15% après calibration, et de 15,4%, 19,99% et 6,22 % à l'issue de la validation. Les valeurs d'efficience du modèle(EF) étaient supérieures à 95 %. L'erreur relative moyenne (ER) indiquait une surestimation du rendement en grains simulé aussi bien à l'issue de la calibration que de la validation. Pour la biomasse et l'efficience de l'eau, les valeurs simulées étaient sous-estimées aussi bien en phase de calibration que de validation. Ces résultats suggèrent que la précision du modèle AquaCrop peut être considérée comme acceptable pour la simulation du colza de printemps.

Mots clés : Biomasse / modélisation des plantes / transpiration / végétation / efficience d'utilisation de l'eau

*Corresponding author: moraditelavat@yahoo.com; moraditelavat@asnrukh.ac.ir

Highlights

- The model had appropriate accuracy in simulating water efficiency.
- The R2 statistic index showed that the model accurately estimated grain yield and water efficiency with higher accuracy than biomass characteristics.
- The index value (MBE) was obtained for calibration and evaluation of experimental, positive treatments.
- The AquaCrop model tends to overestimate the yield of rapeseed.
- Results further confirm the AquaCrop model's ability to simulate water consumption efficiency.

1 Introduction

Rapeseed is considered the most important oilseed crop in the temperate and subtropical regions of the world. This plant ranks second after soybean in terms of supply of edible oil in the world. In addition to providing edible oil, rapeseed is used to provide fodder for livestock and poultry by feeding domestic animals from the leaves and grain meal of this plant (Moradi-Telavat and Siadat, 2012). The study on the evaluation of the life cycle of biological energy obtained from oilseeds such as rapeseed, shows that the development of the cultivation of this plant with the aim of producing electricity, in addition to providing human edible oil and also its use in the preparation of animal and poultry fodder, can reduce the emission of greenhouse gases in Compare with electricity generation from fossil fuels (Cocco *et al.*, 2014). In the years leading to the first decade of the 21st century, the yield of rapeseed in some European countries has not increased and in some countries it has decreased. In addition, in arid and semi-arid regions of the world, rapeseed production faces various challenges, including water deficit and high temperatures during the flowering to ripening stage. This plant with three-carbon photosynthetic cycle is significantly affected by climate change. So that in the coming years, predicting the reaction of rapeseed yield under the influence of climate change will be a very important research topic. Different plant models such as *e.g.* DSSAT, Cropsyst, etc. have shown acceptable accuracy in describing the process of growth and yield formation of canola. These models describe the growth and yield formation of rapeseed based on light reception and efficiency of radiant energy consumption (Wang *et al.*, 2022). However, in many regions, increasing yield or maintaining current yields in rapeseed fields will face a significant limitation of water resources (Fathi *et al.*, 2010).The AquaCrop model describes the growth and yield of the crop based on the transpiration efficiency. Therefore, it may accurately describe the growth and yield of rapeseed in areas where water scarcity is considered the most important limiting factor.

Although the lack of irrigation can reduce agricultural production, it is a fundamental way to increase water consumption efficiency (Blum, 2009; Babalola and Ekinsaluna, 2016). The relationship between plant performance and water supply is based on empirical production functions (Doorenbos and Kassam (1979)), but these functions are not reliable in areas where they have not been developed. Therefore, recalibrated simulation models, such as the AquaCrop plant growth model developed by the World Food and Agriculture Organization (FAO), are increasingly used as an alternative solution for rapid assessment of plant performance in response to water limitation (Raes *et al.*, 2012; Foster *et al.*, 2014; Sayyahi *et al.*, 2020). The AquaCrop model is highly accurate in simulating grain and biomass yield under conditions of full irrigation and mild water stress (Heng *et al.*, 2009). Dirwai *et al.* (2021) investigated the AquaCrop plant growth model for rapeseed under different irrigation regimes and found that the calculated seed yield was respectively 1.32, 0.73 and 0.56 tons per hectare under the irrigation regimes of 100 %, 75 % and 50 %, while the simulated yield was estimated to be 1.48, 1.15 and 0.75 tons per hectare, respectively. Sayyahi *et al.*, 2020 also used the AquaCrop model to simulate the performance and efficiency of sugar beet water consumption, with the model estimating a yield of 1.79 and 0.99 tons per hectare, respectively. The AquaCrop model is also accurate in simulating plant density, planting date, and water requirement, and has an acceptable performance (Hsiao *et al.*, 2009). The inputs of the model are seed germination time, initial soil moisture, and depth. Irrigation water in full irrigation treatment does not have any sensitivity (Babazadeh and Mehdi, 2012). The model also performs well in simulating the growth of potato plants under different irrigation conditions in the southeast of Spain, with an index of agreement (d) and coefficient of explanation (R^2) above 0.9 (Montoya *et al.*, 2016). Although there has been limited research on rapeseed, Ebrahimi-Pak *et al.* (2018) calibrated and verified the AquaCrop model using data obtained from a rapeseed field in Qazvin. The results of this study were in good agreement with the actual data, indicating that the model can be used to simulate the efficiency of water consumption and yield of canola.

Researchers around the world have confirmed the validity of the AquaCrop model in simulating the performance of different plants in different environments (Huang *et al.*, 2017; Raes *et al.*, 2012; Zeleke *et al.*, 2011; Stricevic *et al.*, 2014 Ahmadi *et al.*, 2015; Akumuga *et al.*, 2017; Jovzi *et al.*, 2020). Although the AquaCrop model has been used in the simulation of many plants, there have been limited experiments conducted to evaluate the model's accuracy in simulating the performance of rapeseed plants under different irrigation management conditions. Therefore, this research aims to evaluate the accuracy of the AquaCrop model in predicting the seed yield, biomass, and water consumption efficiency of rapeseed.

2 Materials and methods

A research study was conducted at Khuzestan University of Agricultural Sciences and Natural Resources. This area is located at a distance of 35 kilometers north of Ahvaz, in Khuzestan province, Iran. The latitude and longitude of the area are 31°36' N and 48°53' E respectively, with an altitude of approximately 22 meters above sea level. The table below presents the amounts of water consumed during the first and

Table 1. Irrigation quantities during the growing season for two years 2021–2022 and 2022–2023.

	Irrigation quantities (mm)	Days
2021–2022	25	21 November
	18	30 November
	23	21 December
	24	8 January
	14	28 January
	12	24 February
	12	10 March
2022–2023	23	22 November
	14	30 November
	18	24 February

second year of the experiment, which was carried out over a period of two crop years – 2021–2022 and 2022–2023. The location of the experiment was classified as a dry region, based on Do Marten's classification (Ghasemifar and Naserpoor, 2014).

The water consumption data from the two-year experiment are presented in Table 1.

Tables 2 and 3 provide information on the meteorological parameters during the two crop years and the soil of the research field during the experiment period.

The experiment was designed using a split factorial research design based on randomized complete blocks, containing three replications. The experiment involved testing three levels of irrigation as the main plot, which included (1) Control (no interruption of irrigation), (2) Interruption of irrigation at the beginning of flowering (phenology code 60) until the formation of 50 % of the pods (phenology code 75), and (3) Interruption of irrigation at the stage of pod formation (phenology code 99) (Zavareh and Emam, 2008), until the stage of harvest (phenology code 99). The experiment also tested three levels of plant density (800000, 1100000, and 1400000 plants per square meter) and two cultivars (Hayola 4815 and Aram), which were arranged in subplots. Hayola 4815 cultivar, an early growth period cultivar, originated from Australia, while Aram, a mid-early growth period cultivar, originated from Iran. The spring cultivars were obtained from the Karaj Seed and Plant Breeding Research Institute.

The amount of irrigation water for each experimental plot was determined by calculating the area of the plot and measuring the water using a meter. It is important to note that the irrigation interruption at each stage was carried out based on the growth stage of each cultivar.

Nitrogen was supplied from a 46 % urea fertilizer source at a rate of 200 kg per hectare. The application was done twice: first during the four-leaf stage (phenology code 19) and then after thinning operations were completed and the second stage at the beginning of budding (phenology code 51). This information is based on a study conducted by Zavareh and Emam in 2008.

The AquaCrop plant growth model was used to analyze the results. The model covers a wide range of agricultural and horticultural products and uses climate information, plant management, and soil information. Some fixed parameters are specific to the plant, which were used from the default values of the model and calibrated with plant data. The model is based on Doorenbos and Kassam (1979) equation (Relation 1) and separates *ETa* into evaporation from the soil surface (*Es*) and transpiration (*Tr*). It also separates the final economic performance (*Y*) into biological performance (*B*) and harvest index (*HI*). Separating *Eta* into *Es* and *Tr* means that evaporation is not considered in product production (Raes *et al.*, 2009).

$$\left(1-\frac{Ya}{Ymax}\right)=Ky\left(1-\frac{ETa}{ETmax}\right), \quad (1)$$

$$\mathrm{CC}=\mathrm{CCO}\times \mathrm{e}^{\mathrm{CGC.t}}, \quad (2)$$

where $Y_{\max}$ is the maximum performance, *Ya* is the actual performance, $ET_{\max}$ is the maximum evaporation and transpiration, *ETa* is the actual evaporation and transpiration and *Ky* is the proportionality factor between the relative loss of performance and the relative reduction of evaporation and transpiration. CC is the crown cover in the plant development stage (percent), CC0 is the initial crown cover (percent), CGC is the growth factor of the crown cover (photo of the day) and *t* is the time (days). Therefore, the rate of plant transpiration based on crown coverage is obtained from equation (3):

$$Tr=K_s\times CC\times K_c\times ET_0 N, \quad (3)$$

where, *Ks* and *Kc* are coefficients of water stress and plant stress, respectively. The amount of grain yield is also calculated using equation (4) (Raes *et al.*, 2009).

$$\mathrm{Y}=\mathrm{f_{HI}}\times \mathrm{HI_0}\times \mathrm{BY}. \quad (4)$$

In the above relationship, HI_0 is the reference harvest index, *Y* is the grain yield, f_{HI} is the coefficient that adjusts the reference harvest index, and B is the biological performance obtained using the following relationship (Raes *et al.*, 2009).

$$\mathrm{B}=\mathrm{K_{Sb}WP}*\sum\frac{Tr}{ETo}. \quad (5)$$

In relation K_{sb}, temperature stress coefficient, WP* parameter is the normalized water productivity.

The Aquacrop plant growth model does not simulate the leaf area index, but instead represents foliage growth as canopy green cover (CC). CC is the fraction of the soil surface covered by the canopy and can vary from zero (before greening) to its maximum amount (CCx), which can be close to 100 % depending on the crop type and plant density. There are different ways of calculating CC, including: a) using digital images taken within a week of canopy development; b) measuring the leaf surface index and light extinction coefficient; and c) using the ratio of the measured values of photosynthetically active radiation (PAR) above and below the canopy. In this study, the third method of using equations (Farahani *et al.*, 2009) is used to estimate CC more accurately.

Table 2. Climate data of experimental were taken from of Ahvaz Metrological data.

	Month	Max temperature (°C)	Min temperature (°C)	Precipitation (mm)	Evaporation (mm)
2021–2022	November	31.3	15.2	8.7	152.7
	December	23.7	10.7	44.1	87.8
	January	18.2	6.8	65.1	55.3
	February	20.6	6.5	13.4	93.6
	March	25.1	11.7	4.3	147.4
	April	32.5	14.7	0	231
	May	36.3	20.1	9.8	302.6
2022–2023	November	31.4	3.27	41.7	90.6
	December	26.17	13.83	51.8	68.1
	January	20.01	10.83	36.91	34.2
	February	18.63	8.43	10.04	57.5
	March	27.53	13.50	15.52	95.5
	April	30.15	15.70	10.32	159.7
	May	38.45	21.2	2.0	271.8

Table 3. Physical and chemical propertice of.

Soil	pH	K mg/kg	P mg/kg	N mg/kg	EC ds/m	Depth of soil (cm)
ClaySilt	7.5	138	9.36	0.05	2.81	0–30

$$\mathrm{CC} = 1 - \frac{(PAR\,below)}{(PAR\,above)}, \tag{6}$$

In these equations, PAR_{above} and PAR_{below} are the photosynthetic active radiation above and below the canopy, respectively.

2.1 Evaluation of plant growth model

In order to evaluate and measure the validity of the model in estimating grain yield, biomass yield and water efficiency from root mean square (RMSE), root mean square normalized error (NRMSE), mean skew error (MBE), efficiency Model (EF), explanation coefficient (R^2) and relative error index (RE) were used:

$$\mathrm{RMSE} = \sqrt{\frac{\sum (Pi - Oi)2}{n}}, \tag{7}$$

$$\mathrm{NRMSE} = \frac{\sqrt{\frac{(Pi-Oi)2}{n}}}{\bar{\mathrm{O}}i} \times 100, \tag{8}$$

$$\mathrm{MBE} = \frac{\sum (Pi - Oi)}{n}, \tag{9}$$

$$\mathrm{EF} = 1 - \frac{\sum (Pi - Oi)2}{\sum \left(Oi - \bar{\mathrm{O}}\right)2}, \tag{10}$$

$$\frac{\mathrm{R}^2 = \left(\sum (Pi - \bar{P}\ )(Oi - \bar{\mathrm{O}})2\right)}{\sum (Pi -\ \bar{P}\ )2 \sum (Oi - \bar{\mathrm{O}})2}, \tag{11}$$

$$\mathrm{d} = 1 - \frac{\sum (Pi - Oi)2}{\sum \left(|Pi - \bar{\mathrm{O}}| + |Oi - \bar{\mathrm{O}}|\right)2}, \tag{12}$$

$$\mathrm{RE} = \sum \frac{(Pi - Oi)}{Oi}) \times 100. \tag{13}$$

In the equations presented above, Pi represents the simulated value, while Oi represents the measured value. P is the average of the simulated values, O is the average of the measured values, the average of the observed variable values $\bar{O}$ and n is the number of data. The RMSE statistic is always positive and the closer it is to zero, the more suitable it is. Values less than 0.1 for the NRMSE statistic indicate high accuracy of the model. Moreover, the mentioned statistic values in the range of 10–20 %, 20–30 %, and more than 30 % indicate good, medium, and poor accuracy, respectively.

The MBE statistic's positive value indicates that the aquacrop model has estimated the value of the desired

Table 4. Conservation inputs to the AquaCrop Model for rapeseed.

Description	Value	Unit
Base temperature	5.0	°C
Upper temperature	40	°C
Canopy growth coefficient	7	(%day^{-1})
Canopy decline coefficient	9.9	(%day^{-1})
Upper leaf growth threshold (Pupper)	0.20	–
Lower leaf growth threshold (Plower)	0.55	–
Upper stomata conductance threshold (Pupper)	0.50	–
Upper senescence stress conductance threshold (Pupper)	0.60	–
Shape factor for water stress coefficient for stomatal control	5.0	–
Shape factor for water stress coefficient for canopy expansion	3.5	–
Shape factor for water stress coefficient for canopy senescence	3.0	–
Water productivity normalized for ET0 and CO2	18.6	(g m^{-2})
($Kc_{Tr,x}$)Crop coefficient for transpiration	0.99	–

parameter more than the actual value, while the negative values indicate that the model has obtained a smaller number in the estimation of the desired parameter. The EF statistic indicates the correctness of the data fitting and varies from negative infinite values in the worst-case scenario to a value of one when the data is fully fitted. R^2's value changes from zero to one, and the closer it is to one, the better the fit of the data. A positive value of RE indicates an overestimation of the model, while its negative values indicate an underestimation of the model.

The "compatibility (*d*)" index, introduced by Milmot, is a measure of how closely the simulated data matches the observational data (Willmott, 1982). This index ranges from zero to one, with a value closer to one indicating a better model and more reliable simulated values. Ideally, this index should be equal to one. In practice, values greater than 0.5 are generally considered acceptable for simulations (Moriasi *et al.*, 2007).

3 Results and discussion

Calibration means estimating model parameters in such a way that the difference between the measured and simulated values estimated by the model is minimized.

The first year's results (2021–2022) were used to recalibrate the model and the second year's results (2022–2023) were used for Aquacrop model validation.

The AquaCrop model was implemented by entering measured plant data and other management factors into the model. The model already had some default plant growth factors, but based on the results obtained from the first year of the experiment, some of these factors required recalibration, which were presented in Tables 4 and 5.

Figures 1 and 2 illustrate the calibration and verification stages of the AquaCrop model for grain yield characteristics of experimental treatments. In the calibration stage, the highest and lowest yields of rapeseed were observed in two treatments. The first treatment was without interrupting irrigation (control) at a density of 1100,000 plants per hectare, using the Hayola 4815 cultivar. The second treatment was at the interruption of irrigation in the beginning of flowering until the formation of 50 % of the pods, using the Aram cultivar at the same density.

During the verification stage of the study, it was observed that the highest simulated and measured value was obtained when irrigation was not interrupted (control) at a density of 1400,000 plants per hectare and with the Hyola 4815 cultivar. On the other hand, the lowest value was observed when irrigation was interrupted during the beginning of flowering until the formation of 50 % of the pods, at a density of 1400,000 plants per hectare and with the Aram cultivar. Based on the results, it can be concluded that the interruption of irrigation during the flowering period has a significant impact on reducing the yield of canola. This conclusion is supported by the findings of Ghasemian (2020) and Zareei and Rezaeizad (2019).

The assessment and measurement of the reliability of the model used to estimate the grain yield of rapeseed cultivars have been carried out and the parameters used are listed in Table 6. During the calibration and evaluation stages of the model, the normalized error index (NRMSE) was used to measure the seed yield, and it was observed to be in the range of 10 % to 20 % and less than 10 %. A value of less than 10 % indicates that the modeling of rapeseed yield has been carried out in an appropriate and excellent manner. In Sandhu and Irmak's (2019) research on the simulation of corn seed yield, the model statistics during calibration and validation were observed, with NRMSE values of 7.7–12.1 and EF values of 0.8–0.7, respectively.

The model's efficiency index (EF) for the experimental treatments examined during both the calibration and evaluation stages was close to one, indicating that the model estimates grain yield with high accuracy. The index value (MBE) was obtained for calibration and evaluation of experimental, positive treatments. It shows that the AquaCrop model tends to overestimate the yield of rapeseed.

According to the research findings, it was observed that the maximum relative error of underestimation occurred during the calibration phase. This happened in the stage of irrigation interruption, specifically during the beginning of flowering until the formation of 50 % of the pods, and at a density of 1,400,000 plants per hectare for the Aram cultivar. Additionally, the cultivar

Table 5. Input variable parameters of aquacrop model in the calibration stage (year 1).

Irrigation	Density	Cultivar	Initial canopy cover time (day)	Maximum canopy cover (%)	Maximum canopy time (day)	Time to beginning of canopy senescence (dey)	Time to physiological maturity (day)	Flowering (day)	During of flowering (day)	Maximum root depth (m)	Time to reach maximum effective rooting depth (day)
Control	800000	Hayola4815	10	85	81	93	138	76	27	0.80	72
	800000	Aram	10	85	85	98	157	89	22	0.80	89
	1100000	Hayola4815	10	85	81	93	138	76	27	0.80	72
	1100000	Aram	10	92	81	98	157	89	22	0.80	89
	1400000	Hayola4815	10	90	81	93	138	76	25	0.80	72
	1400000	Aram	10	90	85	98	159	89	20	0.80	89
Interruption of irrigation in the beginning of flowering stage	800000	Hayola4815	10	85	81	93	135	74	25	0.80	72
	800000	Aram	10	89	82	98	154	84	22	0.80	89
	1100000	Hayola4815	10	85	81	93	134	72	26	0.80	72
	1100000	Aram	10	90	81	98	154	84	22	0.80	89
	1400000	Hayola4815	10	89	81	89	134	76	25	0.80	72
	1400000	Aram	10	92	81	92	155	84	20	0.80	89
Interruption of irrigation in the stage of formation of pods until harvest	800000	Hayola4815	10	81	81	93	134	76	25	0.80	72
	800000	Aram	10	92	85	98	154	84	20	0.80	89
	1100000	Hayola4815	10	81	81	93	134	76	27	0.80	72
	1100000	Aram	10	89	85	98	154	84	20	0.80	89
	1400000	Hayola4815	10	85	81	93	134	76	25	0.80	72
	1400000	Aram	10	91	81	98	154	84	20	0.80	89

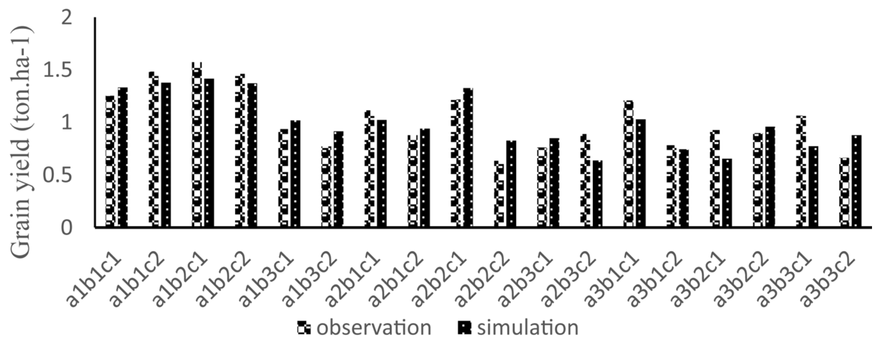

Fig. 1. Simulated and measured values of rapeseed grain yield (calibration stage).

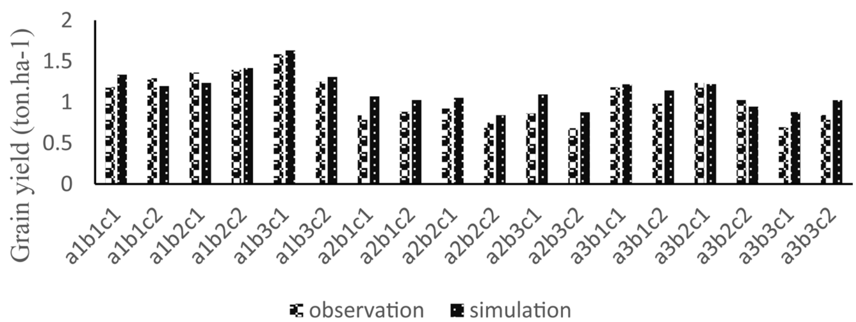

Fig. 2. Simulated and measured values of rapeseed grain yield (validation stage).

Table 6. Prediction error statistics of the calibration and validation AquaCrop model for all treatment.

	Model output Parameter	RMSE	NRMSE	MBE	EF	R^2	d
Calibration	Grain yield (ton.ha^{-1})	0.158	15.4	0.026	0.994	0.929	0.977
	Biomass (ton.ha^{-1})	1.233	19.99	0.727	0.954	0.893	0.990
	WP (kg/m^3)	0.018	6.22	0.038	0.959	0.908	0.991
Validation	Grain yield (ton.ha^{-1})	0.138	1.82	0.086	0.980	0.941	0.983
	Biomass (ton.ha^{-1})	0.950	15.36	0.651	0.973	0.904	0.994
	WP (kg/m^3)	0.074	14.15	–0.061	0.962	0.983	0.988

Hayola 4815 with a density of 1,100,000 plants per hectare showed the highest relative error of underestimation at the stage of irrigation interruption during the formation of pods until harvest. The details can be found in Table 7.

During the validation phase of the research, it was observed that the highest amount of relative error overestimation occurred in both stages of interruption of irrigation: the beginning of flowering until the formation of 50 % of the pods, and until harvest at a density of 1,400,000 plants per hectare. Furthermore, the research findings suggest that the percentage of relative error increased with the increase in plant density in most of the investigated treatments.

Overall, the AquaCrop model showed underestimation in the calibration stage and overestimation in the evaluation stage. The average relative error values for the calibration and validation stages were −0.29 and 10.51, respectively (Tab. 7).

It is observed that overestimation of model during validation the stage of interruption of irrigation in the beginning of flowering until the formation 50 % of the pods may be due to weather conditions during the experiment (Tab. 7). A similar finding was reported by Ebrahimi Ebrahimipak *et al.* (2018) where rapeseed yield was lower than the simulated value under water stress conditions. In another study by Zelki *et al.* (2011) on rapeseed calibration and evaluation, the yield error was obtained with the values of 4.7 and −2.1, respectively. Furthermore, in wheat plant simulation using the AquaCrop model, the accuracy of grain yield simulation was observed to be more accurate than biomass characteristics, as reported by Zhang *et al.* (2013).

The study aimed to measure the biomass values of rapeseed cultivars under different irrigation interruption treatments. To measure and predict the biomass, the AquaCrop model was employed during the calibration and validation stages. The treatment with a density of 1400000 plants per hectare and Hayola 4815 cultivar showed the highest amount of biomass during the calibration phase (as shown in Fig. 3). In the verification stage, the highest measured amount of biomass was observed in the control treatment with the same density of plants per hectare and Hayola 4815 cultivar. The highest simulated biomass was recorded in the control treatment and

Table 7. Relative error values of yield in calibration and validation stage.

Irrigation	Density	Cultivar	Calibration (year1)			Validation (year2)		
			Grain yield simulation (ton. ha^{-1})	Grain yield measure (ton.ha^{-1})	RE (%)	Grain yield measure (ton.ha^{-1})	Grain yield simulation (ton.ha^{-1})	RE (%)
Control	800000	Hayola4815	1.331	1.251	6.39	1.184	1.337	12.865
	800000	Aram	1.376	1.482	–7.15	1.293	1.198	–7.361
	1100000	Hayola4815	1.415	1.572	–9.98	1.361	1.236	–9.204
	1100000	Aram	1.37	1.46	–6.16	1.395	1.417	1.562
	1400000	Hayola4815	1.017	0.934	8.79	1.585	1.632	2.939
	1400000	Aram	0.913	0.770	18.52	1.251	1.31	4.657
Interruption of irrigation in the beginning of flowering stage	800000	Hayola4815	1.022	1.112	–8.09	0.840	1.072	27.543
	800000	Aram	0.939	0.877	7.06	0.884	1.027	16.071
	1100000	Hayola4815	1.325	1.216	8.96	0.923	1.053	14.035
	1100000	Aram	0.825	0.633	30.31	0.752	0.842	11.908
	1400000	Hayola4815	0.848	0.759	11.66	0.863	1.096	26.866
	1400000	Aram	0.635	0.887	–28.43	0.682	0.878	28.569
Interruption of irrigation in the stage of formation of pods until harvest	800000	Hayola4815	1.027	1.208	–14.98	1.182	1.219	3.060
	800000	Aram	0.742	0.779	–4.85	0.982	1.145	16.539
	1100000	Hayola4815	0.652	0.924	–29.49	1.235	1.221	–1.173
	1100000	Aram	0.957	0.896	6.8	1.026	0.945	–7.948
	1400000	Hayola4815	0.772	1.062	–27.3	0.694	0.88	26.728
	1400000	Aram	0.877	0.661	32.67	0.843	1.025	21.546
	Average		1.002	1.027	–0.29	1.054	1.140	10.51

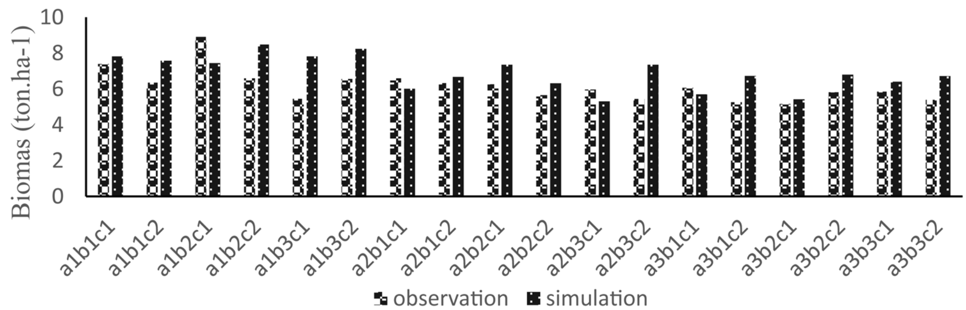

Fig. 3. Simulated and measured values of the biomass of rapeseed cultivars (calibration stage).

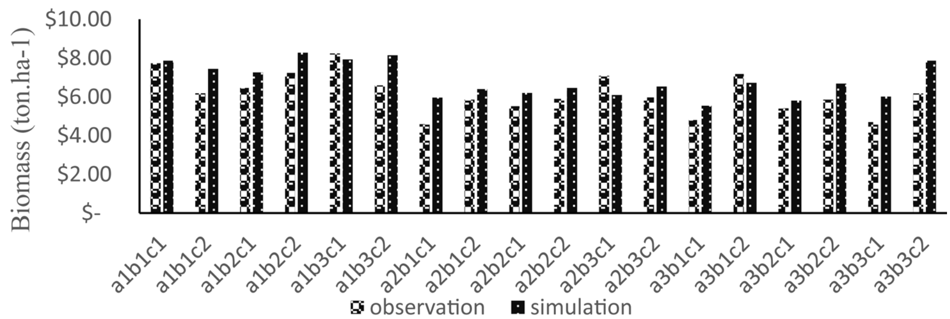

Fig. 4. Simulated and measured values of rapeseed biomass (validation stage).

the density of 1100000 plants per hectare and Aram cultivar (as shown in Fig. 4). Hayola 4815 and Aram cultivars showed the highest amount of biomass in both stages, respectively (as shown in Fig. 4).

At a density of 800,000 plants per hectare, the lowest biomass value was observed during the stage interruption of irrigation from the beginning of flowering until the formation of 50 % of the pods, and also during the simulated stage interruption of irrigation from the pod formation stage until harvest. These stages showed the lowest biomass values for the Hayola 4815 cultivar, as indicated in Figure 4.

According to the data presented in Table 6, the normalized root mean square error (NRMSE) for the biomass simulation was 19.99 % during the calibration stage and 15.36 % during the validation stage. This indicates that the biomass simulation has been done accurately, as the statistics fall within the medium range of 20 % to 30 %.

A study conducted by Ziaii *et al.* (2015) compared the performance of AquaCrop and CERES-Maize models in corn simulation. It was found that the normalized error rate for the AquaCrop model ranged from 20 % to 40 %, while the CERES-Maize model had a normalized error rate ranging from 20 % to 80 %. Similarly, in the research conducted by Sandhu and Irmak (2019), the AquaCrop model overestimated the final biomass in 2009 while the NRMSE value was 31 %. However, in 2010, the NRMSE value was 5.3 %.

The relative error (RE) values for biomass treatments are presented in the Table 8, showing that the stages of irrigation interruption had the lowest estimation error. Paredes *et al.* (2014) demonstrated the high ability of the AquaCrop model to accurately estimate the biomass and yield of corn in low irrigation conditions when simulating the effects of water stress on the performance of corn plants.

The treatment with the highest measured and simulated amount was observed when irrigation was interrupted during the stage of pod formation until harvest. This treatment had a density of 800000 plants per hectare and used the Hayola 4815 cultivar. The control treatment, which had a density of 1400000 plants per hectare and used the Hayola 4815 cultivar, also showed high results (see Fig. 6).

The minimum underestimation error of calibration was observed for the treatment was interruption of irrigation in the stage of formation of pods until harvest, with a density of 1400000 plants per hectare and the Hayola 4815 cultivar (Tab. 9). The reason for the reduction in model error in this treatment is the application of stress in the final periods of plant growth, which resulted in a significant decrease in plant water productivity, even in real conditions.

After verifying the water consumption efficiency, it was observed that the control treatment with a density of 800000 plants per hectare and the Hayola 4815 cultivar had the minimum relative error index of underestimation (as per Tab. 9). Additionally, most of the examined treatments showed higher efficiency of water consumption than the measured value, indicated by the positive MBE values in Table 6.

During the validation phase, all experimental treatments except for the control treatment, the Hayola 4815 cultivar at a density of 1400000 plants per hectare, and the Aram cultivar at 1100000 plants per hectare had lower water consumption efficiency than the measured value. This is confirmed by the negative MBE values. The measurements in Table 6 support this finding.

Table 8. Relative error values of biomass in calibration and validation stage.

Irrigation	Density	Cultivar	Calibration (year1)			Validation (year2)		
			Biomass simulation (ton. ha^{-1})	Biomass measure (ton.ha^{-1})	RE(%)	Biomass simulation (ton. ha^{-1})	Biomass measure (ton.ha^{-1})	RE (%)
Control	800000	Hayola4815	7.818	7.393	5.74	7.858	7.73	–1.65
	800000	Aram	7.578	6.347	19.39	7.439	6.18	–20.37
	1100000	Hayola4815	7.437	8.902	–16.45	7.26	6.453	–12.50
	1100000	Aram	8.478	6.594	28.57	8.276	7.231	–14.45
	1400000	Hayola4815	7.818	5.45	43.44	7.931	8.23	3.63
	1400000	Aram	8.232	6.558	25.52	8.141	6.585	–23.62
Interruption of irrigation in the beginning of flowering stage	800000	Hayola4815	6.013	6.594	–8.81	5.96	4.588	–29.90
	800000	Aram	6.673	6.322	5.55	6.394	5.854	–9.22
	1100000	Hayola4815	7.349	6.261	17.37	6.197	5.511	–12.44
	1100000	Aram	6.315	5.649	11.78	6.452	5.893	–9.48
	1400000	Hayola4815	5.301	5.967	–11.16	6.088	7.085	14.07
	1400000	Aram	7.353	5.438	35.21	6.529	5.963	–9.49
Interruption of irrigation in the stage of formation of pods until harvest	800000	Hayola4815	5.694	6.067	–6.14	5.538	4.804	–15.27
	800000	Aram	6.724	5.257	27.90	6.723	7.175	6.29
	1100000	Hayola4815	5.417	5.164	4.89	5.805	5.406	–7.38
	1100000	Aram	6.8	5.813	16.97	6.675	5.851	–14.08
	1400000	Hayola4815	6.4	5.848	9.43	6.011	4.695	–28.02
	1400000	Aram	6.712	5.395	24.41	7.858	6.176	–27.23
	Average		6.89	6.167	12.98	6.84	6.18	–11.73

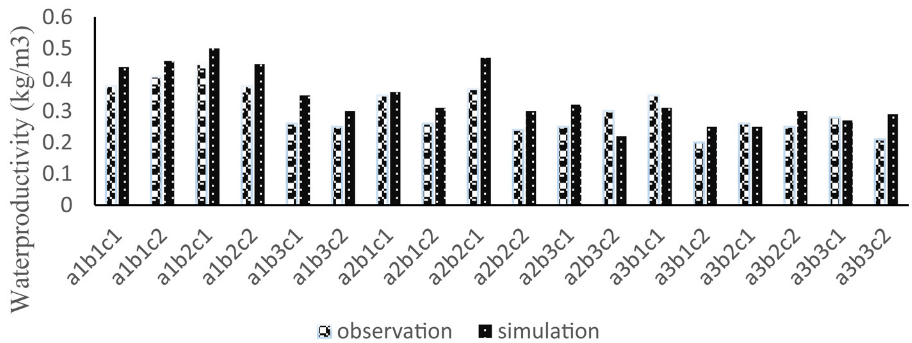

Fig. 5. Simulated and measured values of rapeseed water consumption efficiency (calibration stage).

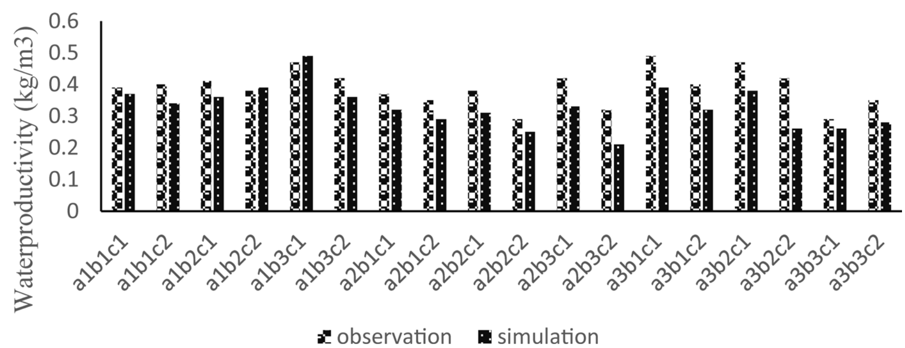

Fig. 6. Simulated and measured values of rapeseed water consumption efficiency (validation stage).

Table 9. Relative error values of waterpro ductivity in calibration and validation stage.

Irrigation	Density	Cultivar	Calibration (year1)			Validation (year 2)		
			Waterpro ductivity simulation (kg/m^3)	Waterpro ductivity measure (kg/m3)	RE (%)	Waterpro ductivity simulation (kg/m^3)	Waterpro ductivity measure (kg/m^3)	RE (%)
Control	800000	Hayola4815	0.44	0.38	15.78	0.37	0.39	–5.12
	800000	Aram	0.46	0.41	12.19	0.34	0.4	–15
	1100000	Hayola4815	0.5	0.45	11.11	0.36	0.41	–12.19
	1100000	Aram	0.45	0.38	18.42	0.39	0.38	2.63
	1400000	Hayola4815	0.35	0.26	34.61	0.49	0.47	4.25
	1400000	Aram	0.3	0.25	20	0.36	0.42	–14.28
Interruption of irrigation in the beginning of flowering stage	800000	Hayola4815	0.36	0.35	2.85	0.32	0.37	–13.51
	800000	Aram	0.31	0.26	19.23	0.29	0.35	–17.14
	1100000	Hayola4815	0.47	0.37	27.02	0.31	0.38	–18.42
	1100000	Aram	0.3	0.24	25	0.25	0.29	–13.79
	1400000	Hayola4815	0.32	0.25	28	0.33	0.42	–21.42
	1400000	Aram	0.22	0.30	–26.66	0.21	0.32	–34.37
Interruption of irrigation in the stage of formation of pods until harvest	800000	Hayola4815	0.31	0.35	–11.42	0.39	0.49	–20.40
	800000	Aram	0.25	0.2	25	0.32	0.4	–20
	1100000	Hayola4815	0.25	0.26	–3.84	0.38	0.47	–19.14
	1100000	Aram	0.3	0.25	20	0.26	0.42	–38.09
	1400000	Hayola4815	0.27	0.28	–3.57	0.26	0.29	–10.34
	1400000	Aram	0.29	0.21	38.09	0.28	0.35	–20
	Average		0.34	0.30	13.99	0.32	0.39	–15.91

The normalized squared error (NRMSE) for water efficiency simulation was 6.22 % during the calibration stage, and 14.15 % during the validation stage (Tab. 6). This indicates that the model had appropriate accuracy in simulating water efficiency. The coefficient of explanation (R^2) ranged from 0.90 to 0.98, while the efficiency coefficient (EF) ranged from 0.95 to 0.96 in the calibration and validation stages, respectively. These results further confirm the AquaCrop model's ability to simulate water consumption efficiency. Overall, Table 6 shows that there was a difference between the actual and simulated values of grain yield, biomass, and water use efficiency in the investigated treatments.

According to a study conducted by Kumar *et al.* 2014, the AquaCrop model performed better at simulating grain yield than it did at measuring water consumption efficiency and biomass. In another study by Zeleke *et al.* 2011, the RMSE statistic for the simulation of rapeseed yield with the Aquacrop model was between 1.75 and 2.58 tons per hectare. This research produced more accurate results for seed yield and water use efficiency, which aligns with the findings of Ebrahimi Pak *et al.* 2018 for rapeseed simulation.

4 Conclusion

The AquaCrop plant growth model was used in a recent research study to predict seed yield, biomass and water efficiency under different levels of irrigation interruption, plant density, and rapeseed cultivars. The R^2 statistic index showed that the model accurately estimated grain yield and water efficiency with higher accuracy than biomass characteristics. During the calibration stages, the normalized error value (NRMSE) of grain yield prediction, water efficiency efficiency, and rapeseed biomass were obtained, which showed that the model has good accuracy in predicting these parameters. However, the AquaCrop model showed overestimation and underestimation during the calibration and validation of biomas and waterproductivity respectively, while for grain yield, underestimation and overestimation were obtained. The relative error increased with an increase in plant density. Changes in irrigation management and different cultivars and densities resulted in changes in measured parameters during two crop years. Based on the results, the powerful AquaCrop model can be used to optimize water consumption and irrigation management for rapeseed.

Acknowledgments

Authors thanks grammarly AI for its help to improve overall English writing of manuscript.

Also, we would like to thank the vice-chancellor of education and graduate education and the vice-chancellor of research and technology of Agricultural Sciences and Natural Resources University of Khuzestan for supporting the implementation of this research.

Conflicts of interest

The authors declare that they have no conflicts of interest with regard to this article.

References

Ahmadi SH, Mosallaeepour E, Kamgar-Haghighi AA, Sepaskhah AR. 2015. Modeling maize yield and soil water content with AquaCrop under full and deficit irrigation managements. *Water Res Manag* 29: 2837–2853.

Akumaga U, Tarhule A, Yusuf AA. 2017. Validation and testing of the FAO AquaCrop model under different levels of nitrogen fertilizer on rain fed maize in Nigeria, West Africa. *Agric Forest Meteorol* 232: 225–234.

Babalola OS, Akinsanola AA. 2016. Change detection in land surface temperation and land use land cover over Lagos Metropolis, Nigeria. *J Remote Sen* 5: 2–19.

Babazadeh H, Mahdi ST. 2012. Assessment of aquacrop model under soybean deficit irrigation management condition. *J Water Soil* 26: 329–339.

Blum FA. 2009. Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. *Field Crops Res* 112: 119–123.

Cocco D, Deligios P, Ledda L, Sulas L, Virdis A, Carboni G. 2014. LCA study of oleaginous bioenergy chains in a Mediterranean environment. *Energies* 7: 6258–6281.

Dirwai TL, Senzanje A, Mabhaudhi T. 2021. Calibration and evaluation of the FAO AquaCrop model for Canola (*Brassica napus*) under varied moistube irrigation regimes. *J Agric* 11: 410.

Doorenbos J, Kassam A. 1979. Yield response to water. *FAO Irrigation and Drainage. Paper No*. 33: 257.

Ebrahimipak NA, Egdernezhad A, TaftehDavoud A, Dehkord KH. 2018. Evaluation of AquaCrop Model to Simulate Canola (Brassica napus) Yield under Deficit Irrigation Scenarios in Gazvin Plain. *Iran J Soil Water Res* 49: 1003–1015.

Farahani HJ, Izzi G, Oweis TY. 2009. Parameterization and evaluation of the AquaCrop model for full and deficit irrigated cotton. *Agron J*. 101: 469–476.

Fathi Gh, Moradi Telavat MR, Naderi Arefi A. 2010. Rapeseed Physiology. Publications of Shahid Chamran University.

Foster T, Brozovic N, Butler AP. 2014. Modeling irrigation behavior in groundwater systems. *Water Resources Res*. 50: 6370–6389.

Ghasemifar E, Naserpoor S. Zoning climate Zagros region. 2014. *Scientific-Research Quartery of Geographical Data* 23: 54–60.

Ghasemian Ardestani H, Jahan M, Shirani Rad AH. 2020. Evaluation of qualitative traits of selected cultivars of canola in autumn and winter crops affected by different irrigation regimes. *Environ Stresses Crop Sci* 12: 429–443.

Heng Lk, Hsiao TC, Evett S, Howell T, Steduto P. 2009. Validating the FAO AquaCrop model for irrigated and water deficient field maize. *Agron J*. 101: 488–498.

Hsiao TC, Heng LK, Stedut P, Raes D, Fereres E. 2009. AquaCrop-Model parameterization and testing for maize. *Agron J*.101: 448–459.

Huang X, Huang G, Yu Ch, Ni Sh, Yu L. 2017. A multiple crop model ensemble for improving broad scale yield prediction using Bayesian model averaging. *Field Crop Res*. 211: 114–124.

Kumar P, Sarangi A, Singh DK, Parihar SS. 2014. Evaluation of AquaCrop model in predicting wheat yield and water productivity under irrigated saline regimes. *Irrigat Drain* 63: 474–487.

Jovzi M, Ghorbani Z, Ghadami Firouzabadi A, Sepehri N, Zare Abyaneh H. 2020. Evaluation of AquaCrop model under deficit irrigation management of potato new clones in Hamedan. *Iran J Irrig Drain* 14: 230–240.

Montoya F, Camargo D, Ortega JF, Corcoles JI, Dominguez A. 2016. Evaluation of Aquacrop model for a potato crop under different irrigation conditions. *Agric Water Manag* 164: 267–280.

Moradi-Telavat MR, Siadat, SA. 2012. Introduction and Production of Oilseed Plants. Tehran: Education and Extention of Agriculture Press.

Moriasi DN, Arnold JG, Van liew MW, Bingener RL, Harmel RD, Veith TL. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Trans. ASABE*. 50.3: 885–900.

Paredes P, de Melo-Abreu JP, Alves I, Pereira LS. 2014. Assessing the performance of the FAO AquaCrop model to estimate maize yields and water use under full and deficit irrigation with focus on model parameterization. *Agric Water Manag* 114: 81–97.

Raes D, Steduto P, Hsiao TC, Fereres E. 2009. Reference manual AquaCrop. FAO, Land and Water Division, Rome, Italy.

Raes D, Steduto P, Hsiao TC, Freres E. 2012. Refrence manual AquaCrop, FAO, land and water division, Rome Italy.

Sandhu R, Irmak S. 2019. Performance of AquaCrop model in simulating maize growth, yield, and evapotranspiration under rainfed, limited and full irrigation. *Agric Water Manag* 223: 105687.

Sayyahi H, Egdernezhad A, Ebrahimipak N. 2020. Comparison of AquaCrop and SWAP for simulation of sugar beet yield and water use efficiency under different irrigation intervals. Iran *J Irrigat Drain* 14: 1311–1321.

Stricevic R, Dzeletovic Z, Djurovic N, Cosic M. 2014. Application of the AquaCrop model to simulate the biomass of *Miscanthus x giganteus* under different nutrient supply conditions. *Glob Change Biol Bioenergy* 7: 1203–1210.

Wang E, He D, Wang J, Lilley JM, Christy B, Hoffmann MP, O'Leary G. *et al.* 2022. How reliable are current crop models for simulating growth and seed yield of canola across global sites and under future climate change? *Climatic Change* 172. https://doi.org/10.1007/s10584-022-03375-2

Willmott CJ. 1982. Some comments on the evaluation of model performance. *Bull Am Meteorolog Soc*. 63: 1309–1313.

Zareei Siahbidi A, Rezaeizad A. 2019. Study on response of some oilseed rape genotypes to drought stress. Applied Res in Field Crop. 32(4): 75–59

Zavareh M, Emam E. 2008. A guide to identifying the life stage of canola. *Iran J Field Crop Sci* 1: 1–14.

Zeleke K, Luckett D, Cowley R. 2011. Calibration and testing of the FAO AquaCrop model for Canola. *Agron J.* 103: 1610–1618.

Zhang W, Liu W, Xue Q, Pei H, Chen J, Han X. 2013. Evaluation of the AquaCrop model for simulating yield response of winter wheat to water on the southern Loess Plateau of China. *Water Sci Technol* 68: 821–828.

Ziaii Gh, Babazadeh H, Abbasi F, Kaveh F. 2015. Evaluation of the AquaCrop and CERES-maize models in assessment of soil water balance and maize yield. *Iran J Soil Water Res* 45: 435–445.

Cite this article as: Aboodeh H, Bakhshandeh A, Moradi-Telavat MR, Siadat S-A, Moosavi S-A, Alamisaeid K. 2024. Capacity of AquaCrop model in simulating performance variables and water use efficiency of spring rapeseed *OCL* **31**: 19.