Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1247795

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2023, 4(1), 26-45

Research Article

AquaCrop Model Validation for Simulating Biomass and Water Productivity Under Climate Change for Potatoes

AbdelGawad SAAD[a*]ID, Hani Abdelghani MANSOUR[b]ID, Elsayed ALI[a]ID, Mostafa Mohamed AZAM[c&d]ID

[a] Department of Biosystem Engineering, Agricultural Engineering Research Institute (AEnRI), Agricultural Research Center (ARC), Dokki, Giza, EGYPT*
[b] Department of Water Relations and Field Irrigation, Agriculture and Biological Division, National Research Centre, Cairo, EGYPT
[c] Department of Agricultural Engineering, Faculty of Agriculture, Menofia University, Shibin El-Kom, EGYPT
[d] Department of Agricultural Systems Engineering, College of Agriculture & Food Sciences, King Faisal University, Al-Ahsa, SAUDI ARABIA

(*) Corresponding Author: en_gawad2000@yahoo.com

Article Info

Received: 05.02.2023 **Accepted:** 16.05.2023 **Published:** 30.06.2023

ABSTRACT

Effective crop development modelling is essential for crop management, water resource planning, assessing climate change's influence on agricultural production, and yield prediction. Validation and simulation of the measured data indicated that AquaCrop software is an effective and reliable program for designing pressurized irrigation systems to increase water application efficiency, system performance and the future prediction. The AquaCrop model was evaluated through a solid-set sprinkler and surface drip irrigation systems at 100%, 80%, and 60% of evapotranspiration (ETo) for the potato crop. The AquaCrop model has shown better performance to simulate potato growth and predicting crop variables under various water systems. The surface drip-irrigation system's at 80% of ETo (48.00, 8.05 ton ha^{-1}) Yield had a substantial impact on the yield of potato and water productivity (WP), matching the yield of potatoes that was irrigated with solid-set sprinklers at 100% of ETo (37.39, 7.19 ton ha^{-1}), with 20% water savings. Attributes of potatoes (canopy cover, biomass, potato crop factor (Kc), and water productivity) were affected by increasing water deficit. The simulated of AquaCrop model was a little higher than observed at 80% of ETo treatment, but still has a similar deviation, and it was slightly lower than seen for 60% of ETo treatment at the mid-season. The AquaCrop model predicted the yield of potatoes and biomass correctly when irrigation is adequate. The results indicated that there may be some changes in AquaCrop model simulation operations over future years based on the climate and irrigation method.

Keywords: *AquaCrop model, Drip irrigation, Sprinkler irrigation, Potato yield, Water productivity*

To cite: Saad A, Mansour HA, Elsayed A and Azam MM (2023). AquaCrop Model Validation For Simulating Biomass And Water Productivity Under Climate Change For Potatoes. Turkish Journal of Agricultural Engineering Research (TURKAGER), 4(1), 26-45. *https://doi.org/10.46592/turkager.1247795*

INTRODUCTION

The impact of current agricultural climate change depends on climatic and weather conditions, as well as crop production and agricultural production are affected by climatic conditions. Precipitation and carbon dioxide concentration both have a direct effect on the production of potatoes. The environment is impacted by climate change, either directly or indirectly. According to Malhi *et al.* (2021), climate change will have an effect on agriculture and mitigation strategies. Because of the climate change effect caused by greenhouses, which is actually rising, food security is a global concern. It has been reported that about 1.5-1.8 ppm of carbon dioxide is added to the atmosphere every year. It is crucial to point out that precipitation will fall by 0.7% and 3.0% in 2050, by 5.0% and 7.6% in 2100, and that temperatures will increase by 3-4°C by the end of the 21st century. Crop response to water deficit remains to be one of the most reactions to be described by crop models since the water deficit varies in duration, timing, and intensity (Molden *et al.*, 2001). The competitive demand for the limited supply of water is now becoming critically important. The agricultural sector is facing a major difficulty in using less water and produce more food because there are limited opportunities to increase the availability of high water quality. Developing methods to increase the effectiveness of water application in agriculture is therefore required. One of the most effective irrigation techniques for use in agriculture with advanced water-saving technology is pressurised irrigation (Kemanian *et al.*, 2007). Simulation models of crop growth are essential tools for analyzing the consequences of water shortages and for optimizing water use in constrained situations to increase crop production. There is a need to take into consideration about the effectiveness of the use of the available water given the undesirable climate change's effects on current agricultural practices followed by reducing water availability. This is especially important for high-value plants that can be grown in irrigation conditions (Hsiao, 2000; Hsiao, 2007). The potato crop's yield and biomass were simulated using the AquaCrop model in response to different water application rates. It is also required to calibrate the Aquacrop model for potatoes under limited climatic conditions, as doing so would make it simpler to simulate and predict crop's performance and yield using all of the AquaCrop model's input data parameters (Steduto, 2003). In recent years, the potato has taken on a significant role in Egypt's crop rotation as a winter crop in both rich and poor fertile soils, alkaline, saline, and calcareous soils. Farmers could then make prior plans for their returns based on every parameter supplied for the model's input data.

A drip irrigation system uses less water than a sprinkler irrigation system. For total and marketable yield, surface drip and subsurface drip were among the most effective techniques. In addition, nitrate leaching under potatoes was reduced by drip irrigation or sprinkler irrigation (at fairly dry soil criteria). Potato yield was unaffected by reducing nitrogen rates when irrigated with a subsurface drip system (Kaur *et al.*, 2022). Ibrahim *et al.* (2018) explored the impact of tape depth and emitter spacing on Texas potato (Norgold Russet) yield and quality. Potato yield was unaffected by tape depth or emitter spacing, Nevertheless, when the tape was buried at 0.2 m as opposed to shallower placement, the percentage of tubers that were misshaped was greater. The soil temperature was higher at the tape of 0.2 m, than at 0.1 m or 0.025 m. In comparison to intermediate and greater depths, the drip tape performed best at depths of 0.08 m (above tubers) and 0.46 m (below tubers), according to DeTar *et al.* (1996)'s study. Ten drip irrigation treatments were used by Fabeiro *et al.* (2001) to investigate the effect of irrigation deficit timing on tuber productivity and water use efficiency in Spain. Deficits in irrigation that occurred during the mid and late season bulking of tubers were mostly harmful to tuber yield. When irrigation shortfalls are limited to early in the season, good yields are associated with high water usage efficiency. The growth of "Umatilla Russet" in silt loam with drip irrigation. The variables that were investigated included four levels of soil water tension and tape placement (1 tape/ single row or 1 tape/ double row) for automatically beginning irrigation (15, 30 45, and 60 kPa) (King *et al.*, 2020); (Mansour *et al.*, 2015a; Mansour *et al.*, 2015b; Mansour *et al.*, 2019a; Mansour *et al.*, 2019b). They found that drip tape placement significantly affected every measure, with the exception of total yield and bud-end fry colour, where associations between irrigation criterion and tape quantity were significant. Total yield, total marketable yield, and US No. 2 yield were all influenced by the interaction between the tape placement and irrigation criterion. The results revealed that set the silt loam soil and 2.5 mm water applied during each irrigation episode, potatoes should be irrigated at 30.0 kPa. The whole US No. 1 and over 340.0 g tuber size categories were the only ones affected by the irrigation criterion taken into account alone. Different potato cultivars performed considerably differently when subjected to drip irrigation (Eldredge *et al.*, 2002); (Mansour *et al.*, 2016). The AquaCrop model uses a semi-quantitative method to characterize the impact of biomass production but does not predict nutrient cycles and balances (Rahimikhoob *et al.*, 2021). Mengistu *et al.* (2021) discovered that the AquaCrop model accurately simulates all observed crop variables. The performance of the AquaCrop model for the potato crop's canopy cover, biomass from dried aboveground and tubers, as well as soil moisture levels.

This study was envisaged to estimate the yield response factor under deficit irrigation in various stressed irrigation systems and validate the AquaCrop model using irrigated potatoes under full and deficit irrigation levels for future prediction.

MATERIALS and METHODS

Area of Study and Crop Management

The potato Spunta variety was planted in an area of 2000 m^2 with split-plot design at the Experimental Farm of National Research Centre, El Nubaria, Egypt, (latitude 30.87 N, longitude 30.17 E) with an altitude of 20 m above sea level. All plots received the normal and recommended care steps for potato growing indicated in the instructions of the official agricultural bulletins. The potato was planted manually to each line at a 15 cm distance between tuber seeds. The potato was cultivated for the growing season on 15th Oct. 2021 and harvested on 31st Jan 2022. Before cultivation, the soil was plowed three perpendicular times at 20 cm depth, and leveled 100 cm distance apart to extend the lateral tubes of surface irrigation in each experimental plot.

Table 1. *Some physical properties of the soil.*

	Particle Size distribution, %					θS % on weight basis					
Depth, cm	C. Sand	F. Sand	Silt	Clay	Texture class	F.C.	W.P.	AW	HC (cmh^{-1})	BD (g/cm^3)	“P (cm^3 voids /cm^3 soil)
0-15	8.4	77.6	8.5	5.5	Sandy	14.0	6.0	8.0	6.68	1.69	0.36
15-30	8.6	77.7	8.3	5.4	Sandy	14.0	6.0	8.0	6.84	1.69	0.36
30-45	8.5	77.5	8.8	5.2	Sandy	14.0	6.0	8.0	6.91	1.69	0.36
45-60	8.8	76.7	8.6	5.9	Sandy	14.0	6.0	8.0	6.17	1.67	0.37

Particle Size Distribution according to (Gee and Bauder, 1986) and Moisture retention according to (Klute, 1986), F.C.: Field Capacity, W.P.: Wilting Point, AW: Available Water, HC: Hydraulic conductivity (cm h^{-1}), BD: Bulck density (g cm^{-3}) and P: Porosity (cm^3 voids/cm^3 soil).

Table 2. *Some chemical properties of the soil.*

Depth, cm	pH 1:2.5	EC dS/m	Soluble Cations, meq/L				Soluble Anions, meq/L			
			Ca^{++}	Mg^{++}	Na^+	K^+	CO_3^{--}	HCO_3^-	SO_4^{--}	Cl^-
0-15	8.3	0.35	0.50	0.39	1.02	0.23	0	0.11	0.82	1.27
15-30	8.2	0.36	0.51	0.44	1.04	0.24	0	0.13	0.86	1.23
30-45	8.3	0.34	0.56	0.41	1.05	0.23	0	0.12	0.81	1.23
45-60	8.4	0.73	0.67	1.46	1.06	0.25	0	0.14	0.86	1.22

Chemical properties according to Rebecca (2004).

Table 3. *Potato crop factor (Kc) in the semi-arid area.*

Stage of growth	Initial	Crop development	Mid-season	Late-season
Periods	1 - 20	21-55	56.0-70	71-110
Total days	35	60	70	45
Kc	0.35	1.2	1.2 > Kc > 0.7	0.5

Irrigation Systems and Experimental Layout

Standard methods were used to analyze the irrigation water to identify its chemical characteristics. To evaluate the chemical and physical properties of soil, as shown in (Tables 1 and 2) the samples were withdrawn from the soil profile at various layer thicknesses (0, 15, 30, 45, and 60 cm). Every main plot was split into three subplots, each of which contained three treatments and represented three water treatments used to calculate the crop's evapotranspiration (ETo) (100, 80, and 60%). The irrigation plan was designed on a two-day interval and applied using pressurized irrigation methods to meet crop water requirements (WR) (solid-set sprinkler and surface drip irrigation). The rotation depends on a shocking stick (kind of sprinkler that can control its rotation and it has a nail to deflect the rush of the water path).
The following equation provided by Wu and Gitlin (1975) was used to determine how much irrigation water was used.

ETc=ETo×Kc.ETc is evapotranspiration (mm/day), ETo is reference evapotranspiration (mm day^{-1}) and Kc is a crop factor.

Agronomic Data

All agronomic measurements were started after one month from the date of potato planting. Every month, three representative plants were randomly chosen from every plot and measured for height (cm), leaf length (cm), number of leaf $plant^{-1}$, tuber diameter (cm), fresh weight of the top (leaves) /plant (g), dry weight of the top (leaves) /plant (g), total fresh tuber weight (g $plant^{-1}$) and total fresh dry weight (g $plant^{-1}$). At 70°C, plant samples were over-dried until their weight remained constant. A random sample was selected (5 plants) from each plot at harvest to assess the productivity and quality characteristics of the potatoes.

Leaf area index (LAI)=Total area of leaf / Occupied land area (Fang *et al.*, 2019) (1)

By the CC-LAI relationship for canopy cover (CC) of potato was calculated using LAI (García-Vila and Fereres, 2012).

$$CC=1.005 \times [1-\exp(-1.2LAI)]1.7\times100 \quad (2)$$

$$WP= \text{Yield/ Total applied water amount} \quad (3)$$

Where: WP is productivity of water, (kg m^{-3}); Y is total tuber yield, (kg ha^{-1}); and total applied by (m^3 ha^{-1}), (Howell, 2001).

Models of the potato plant's reaction to water stress take into account changes in harvest index, canopy cover, and leaf expansion. The model then simulates the yield and biomass using the values of the daily transpiration (Equations 4 and 5).

$$Y=HI\times B \quad (4)$$

$$B=WP\times\sum Tr \quad (5)$$

Where: B = biomass (g m^{-2}), Tr = potato plant transpiration (m^3 ha^{-1}), and HI = harvest index.

Climatic Data

The monthly meteorological data for the area of study during the growth period was displayed in Table 4, based on the official data collected by the Central Laboratory for Agricultural Climate. Climatic elements of air temperature (°C), dew point temperature (°C), wind speed (m s^{-1}), and rainfall (mm). The evapotranspiration (ETo) was calculated with the use of the ETo calculator program depending on the Penman-Monteith equation (Version 3.2, September 2012; Raes *et al.*, 2009).

Representative Concentration Pathways (RCPs) 8.5 were chosen for the impact assessment of the climate scenarios 2030, 2050, and 2100. The International Panel on Climate Change adopted the RCPs as greenhouse gas concentration pathways for future climate (Attia and Gobin, 2020).

***Table 4.** Average climate data in the study area.*

Month	T_{max} °C	T_{mean} °C	T_{min} °C	T_{dew} °C	Wind speed, m s^{-1}	Rain, mm
October 2021	28.35	21.88	16.44	5.72	0.45	0.00
November 2021	23.90	17.22	12.14	0.48	0.22	1.89
December 2021	18.45	11.49	6.25	0.64	0.35	2.12
January 2022	17.83	11.36	6.33	0.00	0.45	2.79

AquaCrop Model

The AquaCrop flow chart for calibration and validation is shown in Figure 1. In order to get the most favourable understanding between the simulated and measured system variables, the model's input parameters must be calibrated (Shaw *et al.*, 2002).

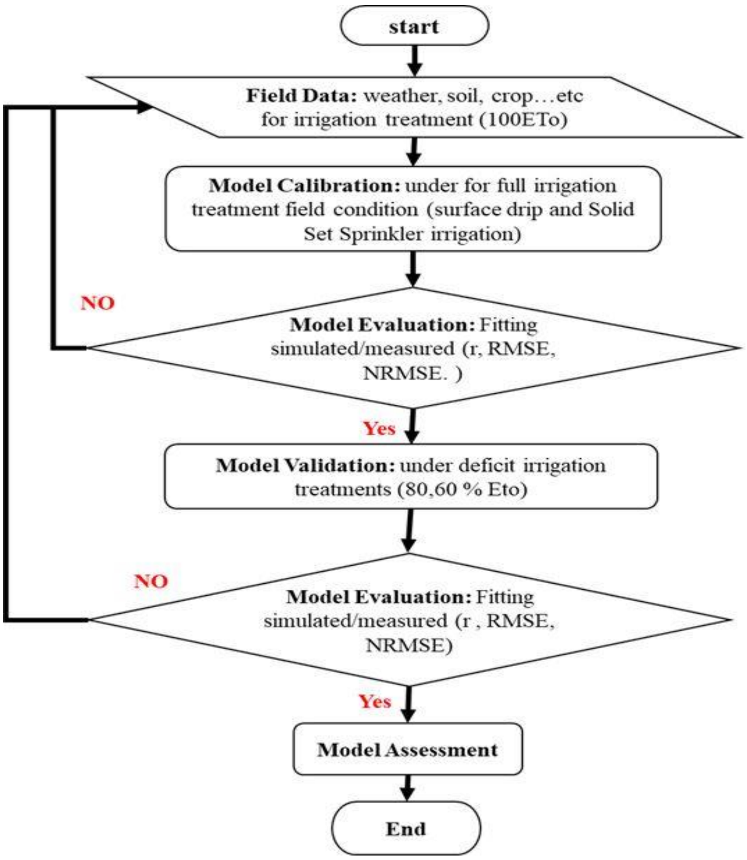

***Figure 1.** AquaCrop model flow chart processing.*

An essential component of model verification is model performance evaluation, which entails contrasting the output produced by the model with independent field measurements. It was calibrated for potatoes using the AquaCrop model (version 6.1).

The Model Performance Criteria

The performance of the model was then assessed by statistical tools, like Pearson correlation coefficient (r), normalized root mean square error (NRMSE), and root mean square error (RMSE).

The Pearson correlation coefficient (r), which runs from -1 to 1, indicates strong agreement when values are close to 1 and are normally deemed acceptable in watershed modelling when values are more than 0.5. (Moriasi *et al.*, 2007). If the measured and simulated values are completely independent, ie they are not correlated or will be zero (Loague and Green, 1991).

$$r = \frac{\sum O_i P_i - n\bar{O}.\bar{P}}{\sqrt{\sum O_i^2 - n\bar{O}^2} \cdot \sqrt{\sum P_i^2 - n\bar{P}^2}} \tag{6}$$

Where *Pi* is the simulated values, *Oi* is the observed values, $\bar{O}$ is the mean of observed values and n is the number of observations.

The testing of models with various scales is made easier by RMSE and NRMSE. RMSE has a range of zero to positive infinity, with zero signifying excellent model performance and positive infinity, bad model performance. Since RMSE is scale-dependent, it should be used to compare prediction errors of several models of a specific set of data rather than between data sets (Pontius *et al.*, 2008). The variable's observed range and the RMSE are connected by the normalised RMSE (NRMSE). The NRMSE can be seen as a part of the total range that the model normally resolves as a consequence.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}} \tag{7}$$

$$NRMSE = \frac{\sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}}}{\bar{O}} \tag{8}$$

Where *Pi* is the simulated values, *Oi* is the observed values, $\bar{O}$ is the mean of observed values and is the number of observations.

RESULTS and DISCUSSION

Reference Evapotranspiration (ETo)

The data shown in Figure 2 shows the daily of (Reference evapotranspiration) ETo. It was calculated by the Penman-Monteith eq., for daily weather data for irrigated potatoes from October 15, 2021, to January 31, 2022. The average of ETo was about 2 mm day^{-1} season.

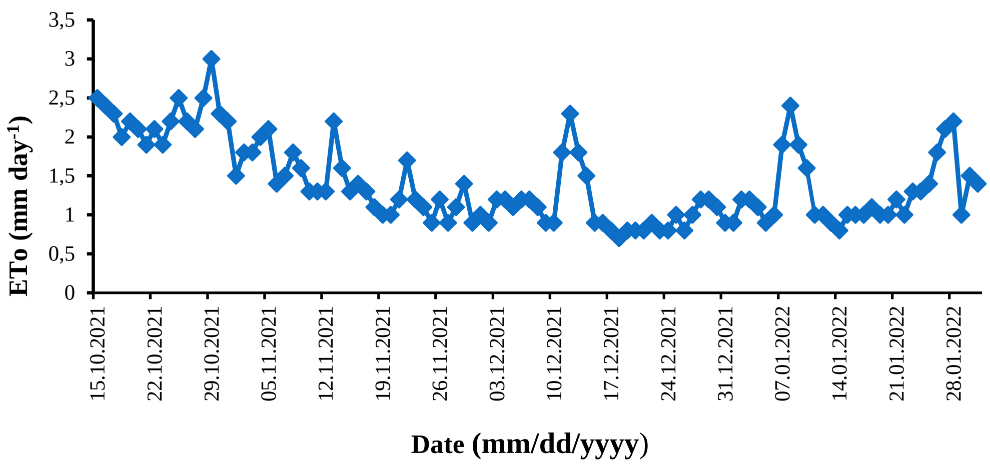

Figure 2. *The daily reference evapotranspiration (ETo).*

Applied Water Requirements

The data in Table 5 show the water requirements for irrigated potatoes grown under surface drip and solid-set sprinkler irrigation systems at various water application rates (100, 80, and 60% of ETo) throughout each growth stage. These values were calculated using ETo and Kc. It is evident that due to the high evapotranspiration, the largest amount of water applied was (617 mm) under solid-set sprinkler irrigation and more than (11%) under surface drip irrigation. The irrigation schedule was timed to coincide with the WR applied via surface drip irrigation systems and metered solid-set sprinklers, and it was based on a two-day interval.

Table 5. *Applied water requirements (WR) under the surface drip and solid-set sprinkler irrigation.*

Days from planting	Growing stage	Applied water due to ETo					
		100%		80%		60%	
		Solid-sed sprinkler	Surface drip	Solid-sed sprinkler	Surface drip	Solid-sed sprinkler	Surface drip
1 20	Initial	68.71	60.63	54.97	47.50	41.23	36.38
21 55	Development	273.60	244.85	218.88	191.13	164.16	144.85
56 70	Mid-season	176.26	155.52	141.01	124.52	105.75	93.31
71 110	Late-season	98.40	86.82	78.72	68.66	59.04	52.09
Total on the season		616.97	547.82	493.58	431.81	370.18	326.63
% of the saved water		0.00	0.00	11.21	20.00	30.01	40.00

AquaCrop Calibration

The AquaCrop calibration was performed based on measurements of the green canopy cover and data on observed crop growth for the irrigated potato crop under both irrigation systems. The data collected under 80% and 60% of ETo were used to validate the model, while the observed field data under the full irrigation method were used to calibrate the model. The meteorological information, soil properties, CC growth, date of sowing, planting density, CC, biomass (B), and total yield (Y) were used as input for each simulation run. For model calibration, plant density, maximum measured tuber depth, crop development period, and crop water productivity were used. The relationship between the biomass of potato crop, which was determined from samples obtained periodically throughout the growing season, and ETo is given in Figure 3.

According to the data, the WP for surface drip irrigation and solid-set sprinkler irrigation was around 14.1 and 15.1 g m^{-2} respectively with an average of about 14.6 g m^{-2}. The simulation results for CC, biomass (B), and total yield (Y) were compared to the measured data to evaluate the model's performance.

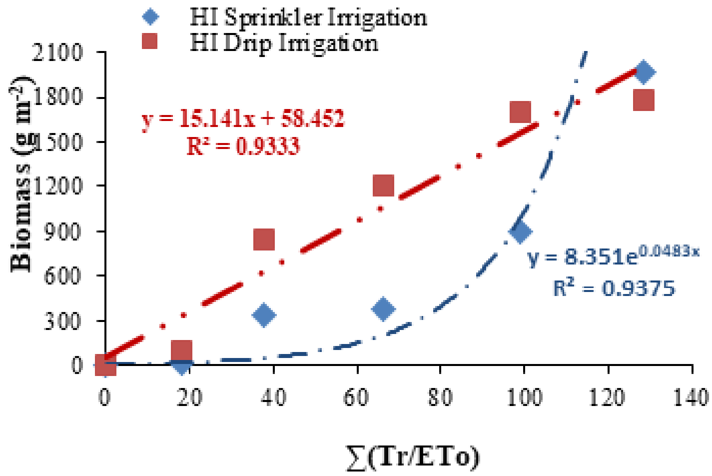

Figure 3. *Determination of potato crop biomass.*

Green Canopy Cover (CC)

In Figure 4, with the full irrigation requirement (100% of ETo), the CC analysis results for both irrigation systems are shown. Although there was some variation in the CC between measured (observed) and simulated in the two irrigation systems, it was obvious that surface drip irrigation (S100) had a maximum measured CC of about 80%, while solid-set sprinkler irrigation (S100) had a maximum measured CC of about 75% (D100).

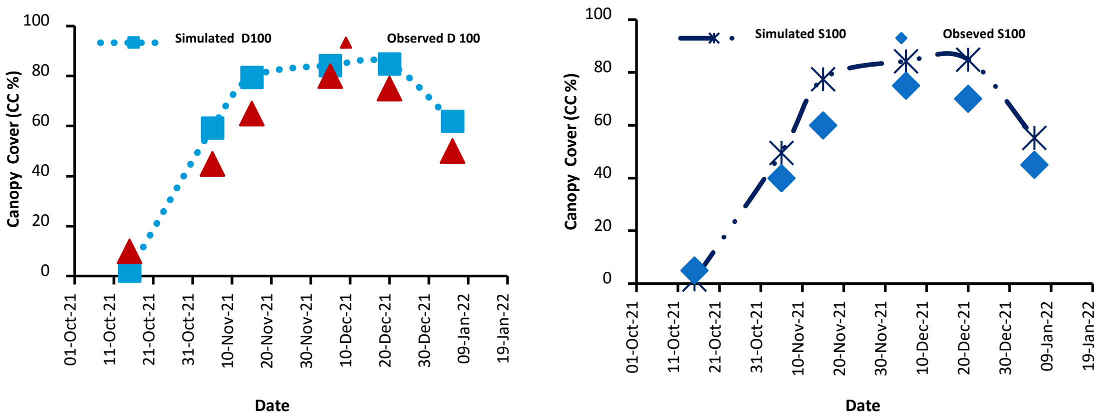

Figure 4. *Measured and simulated CC under full irrigation a) surface drip irrigation system b) a solid-set sprinklers irrigation system.*

Dry Biomass (B) and Yield (Y)

Figure 5 shows the results of the dry biomass (B) analysis for both irrigation systems under the full irrigation requirement (100% of ETo). The measured dry biomass and the simulated dry biomass under the surface drip irrigation system differed slightly, as indicated, with the simulated dry biomass being higher than the measured, while there was no difference under the solid-set sprinkler irrigation. Additionally, the maximum measured and simulated dry biomass production of potatoes under surface drip irrigation at harvest was approximately 19.35, 19.23 ton ha^{-1}, whereas it was approximately 14.56, 17.33 ton ha^{-1} with solid-set sprinkler irrigation. Figure 6 shows the dry yield response to applied water during the growing season. According to the data, both irrigation systems' water applications increased along with the dry yield. The data obtained calculated that there was no significant difference in the model performances, and the statistical indicators validated the good calibration and performance of AquaCrop in simulating the potato growth and crop water productivity (WP) planted under drip and solid-set sprinkler irrigation systems. The best simulation results were achieved for CC and biomass, with the Pearson correlation coefficient (r) being high above 0.99 for both irrigation systems, although it varied for other statistical indicators presented in Table 4. The irrigation treatment had an impact on the simulated values. For two irrigation treatments, the biomass simulation values followed the same trend. On the other hand, the simulated was a little higher than observed at 80% of ETo, but continues to deviate similarly, and it was slightly lower than seen at 60% of ETo treatment at the mid-season. These results agree with those of Razzaghi *et al.* (2017), who indicated that a variety of simulated biomass from the observed biomass of less than 10% is acceptable.

Table 6. *Statistical indicators for CC and biomass for full irrigation.*

Statistical Indicator	CC, S100	Biomass S100	CC, D100	Biomass D100
r	0.99***	0.99***	0.98***	0.99***
RMSE	11.70*	1.30*	11.10*	1.45*
NRMSE	23.80*	20.20*	20.50*	20.30*

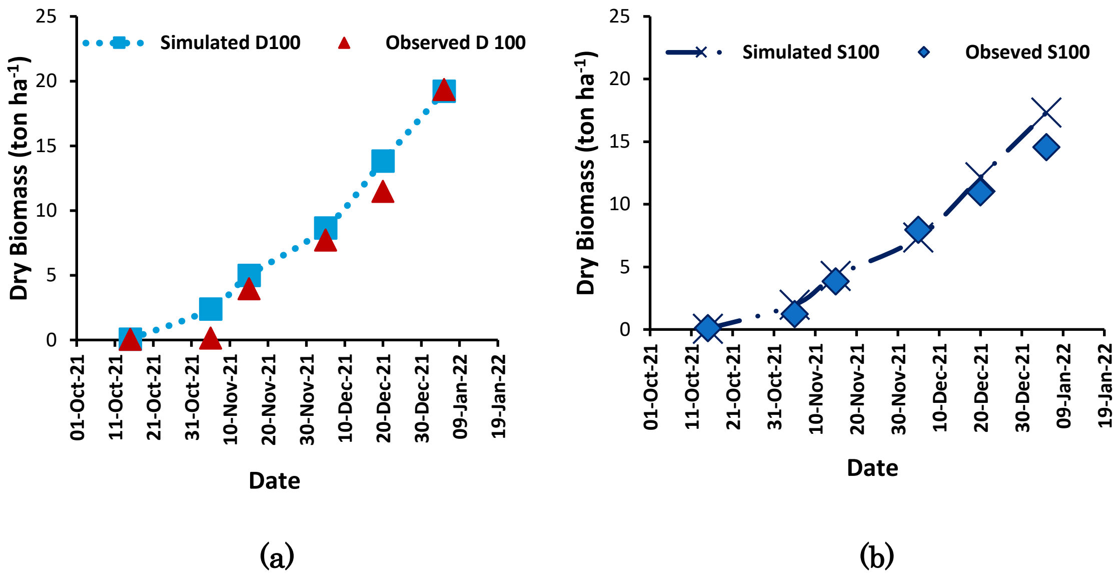

Figure 5. *Measured and simulated dry biomass under full irrigation a) surface drip irrigation system b) a solid-set sprinklers irrigation system.*

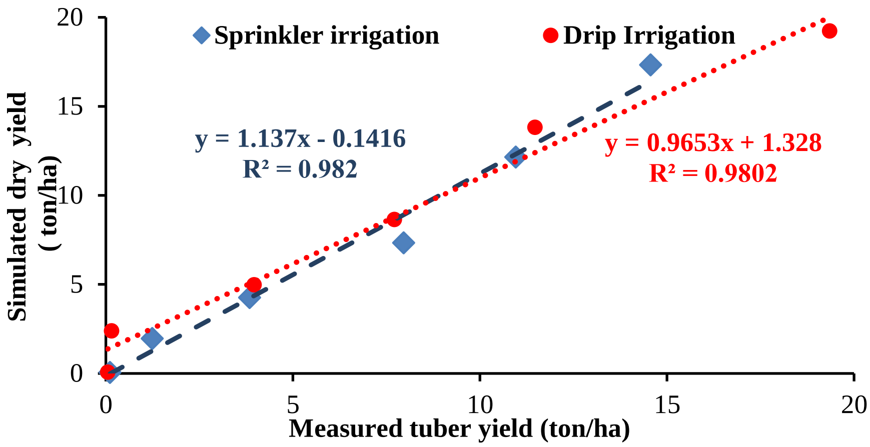

Figure 6. Measured and simulated dry yield under full irrigation.

AquaCrop Validation

The green yield, biomass, WP, and CC were simulated for different water regimes under both irrigation systems using the calibrated model. Validation of the model was done by contrasting the simulated vs. with measured parameters which included CC and biomass to evaluate the AquaCrop model against the field measured data.

Comparison of Measured and Simulated CC

The results of the comparison between measured and simulated CC under both irrigation water regimes (80 and 60% of ETo) are shown in Figure 7. The results displayed a significant difference in the CC due to the water stress effect. The crop's increased water transpiration and greater vegetative growth were the causes of this result. The results showed that the model overstimulated CC in all the treatments, especially under 60% of ETo treatment, and the prediction improved with a decline in the water rate application. When compared to the simulated CC, the deficit-irrigated at 60% of ETo yielded lower CC values. As the potato plants developed during growth, the need for water increased, but the supply was insufficient to satisfy crop WR, so the model did not predict properly. However, 80% of ETo treatment of the AquaCrop model had a good prediction of crop growth, especially in the mid and late season. The results of CC model validation are acceptable according to the statistical indicators as shown in Table 7, but the modelling of 60% of ETo treatments was less satisfactory compared to 80% of ETo treatments, which showed the model high performance.

Table 7. Statistical indicators for canopy cover (CC) under deficit irrigation.

Statistical Indicator	CC S80	CC, S60	CC,D80	CC, D60
r	0.98***	0.86**	0.93***	0.80*
RMSE	9.80*	16.00***	12.20*	20.40**
NRMSE	18.10*	45.70***	22.60*	58.30**

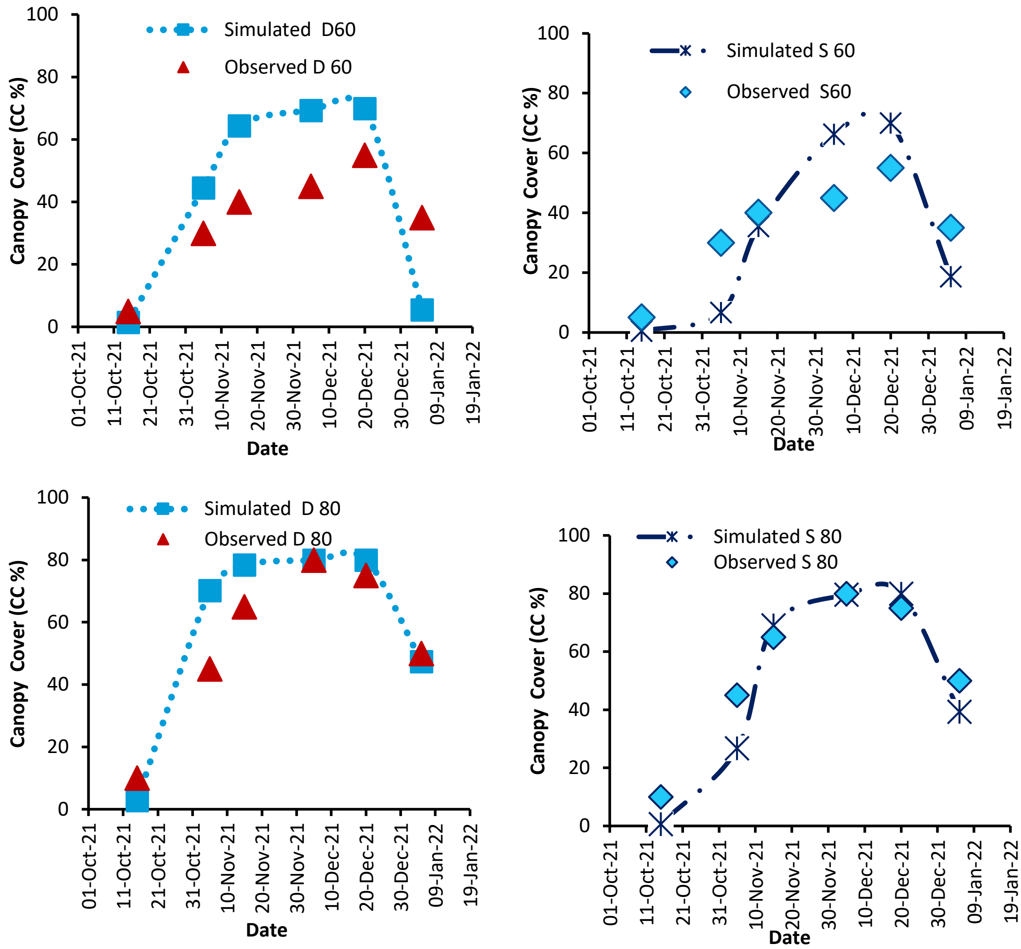

Figure 7. *Measured and simulated CC with 80% and 60% regimes.*

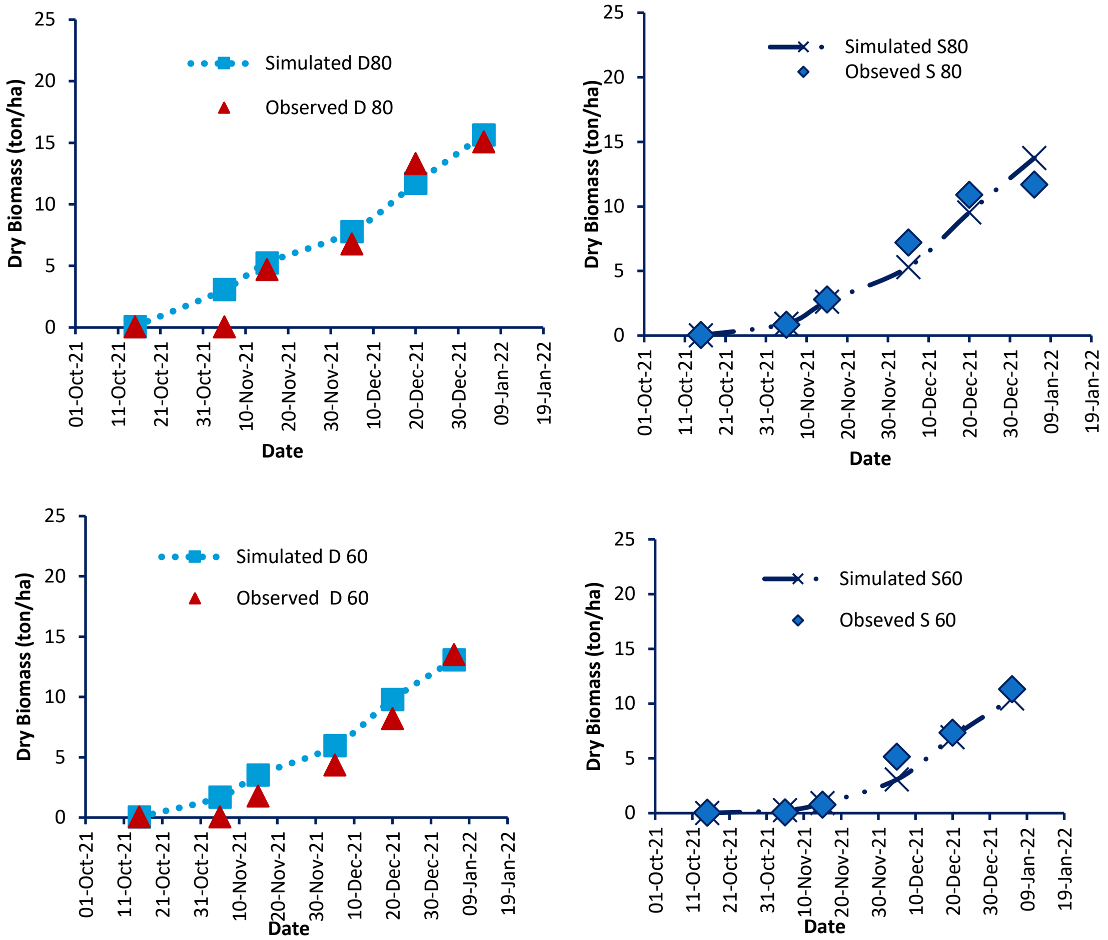

Figure 8. Measured and simulated dry biomass with 80% and 60% of Eto.

Also, the data simulated and measured showed that the dry yield of drip-irrigated potato at 80% of ETo closely matched with the yield of solid-set sprinkler-irrigated potato at 100% of ETo. They was no variation between measured and simulated data under full and deficit irrigation for both irrigation systems. The statistical indicators for different water regimes (80% and 60% of ETo) are presented in Table 8 clarified the results obtained from the model showed that the validation of AquaCrop is acceptable according to the statistical indicators for 80% treatment under both irrigation systems as the simulated dry biomass was slightly the same of the measured and the r-value was about 0.97 and 0.98 for solid-set sprinkler and surface drip irrigation, respectively showing highly significant with the other indicators.

The modelling of the 60% treatment was less successful; the simulated dry biomass was higher than the measured dry biomass in the 60% of ETo solid-set sprinkler irrigation treatment, while it was the opposite in the surface drip irrigation treatment, despite the r value for the sprinkler and surface drip irrigation treatments being approximately 0.99 and 0.98, respectively. This might be because neither 80% of the treatments experienced the acute water stress that would have affected biomass accumulation. Moreover, 60% of ETo experienced water stress through the developing season. Additionally, the AquaCrop model's estimated potato water productivity (WP) for dry yield was significantly higher than the actual value for all irrigation treatments, particularly when deficit irrigation was used, with WP values rising as the water deficit increased. The highest WP was obtained using surface drip irrigation, particularly when 80% treatment was recorded (11.02 kg m^{-3}). In contrast, solid-set sprinkler irrigation had a lower productivity of 7.68, 6.89, and 7.44 at 100%, 80%, and 60% of under water regimens, respectively.

Table 8. *Statistics for dry biomass under shortage irrigation.*

Statistical Indicator	Dry biomass S80	Dry biomass S60	Dry biomass D80	Dry biomass D60
r	0.97***	0.99***	0.98***	0.98***
RMSE	1.30*	0.94*	1.50*	1.35*
NRMSE	22.80*	22.80*	22.50*	29.10*

Water Stress's Impact on a Potato Yield Component

The results demonstrated how water shortages during the winter of 2021–2022 affected some potato characteristics and yield under surface drip and solid-set sprinkler irrigation methods. Including the mean tuber weight, sucrose, impurities purity percentages, and white sugar yield. According to the measurements, raising the water deficit from 100 to 60% of ETo crop water requirement under two irrigation systems had a substantial impact on potato productivity and white sugar production.

Averaged data over the season revealed at 100% of ETo produced the highest value of tuber yield (54.36, 47.38 ton ha^{-1}) under surface drip and solid-set sprinkler irrigation, respectively. Surface drip-irrigated potato plants by 80% of ETo gave the highest percentages of sucrose (19.90%) and purity (84.66%). Additionally, there was no significant variance in the crop ETo at 60% and 80%. The highest WP for white potato yield obtained was under 80% of ETo with about 1.85 kg m^{-3} with comparing with all treatment irrigation as shown in Figure 9. Contrarily, when the water deficit grew from 100 to 60% of ETo, the WP raise under both irrigation methods with a few water amount. Additionally, that means there is a big chance to increase the production of white sugar by cultivating a larger area while using the same amount of water (617 mm) under solid-set sprinkle full irrigation, as shown in Table 9. Under surface drip and solid-set sprinkler irrigation systems, the reduction in white sugar yield was 37% and 42.05%, respectively.

Our results were in agreement with those of Salemi *et al.* (2011), who recommended that the climate, variety of plants planted, and irrigation method might cause some variations in model simulations over dissimilar years. When irrigation is adequate, the AquaCrop model accurately predicts biomass and yield, as shown by Heng *et al.* (2009), and this result was supported by the results of the current study. Additionally, the measured biomass under various irrigation methods and the simulated Biomass (B) were both consistent (Tables 7 and 8). During this investigation, the CC results were comparable to those found in Salemi *et al.* (2011). The study found that the AquaCrop model could simulate CC of potato, B, and Tuber Yield (T) under various irrigation methods.

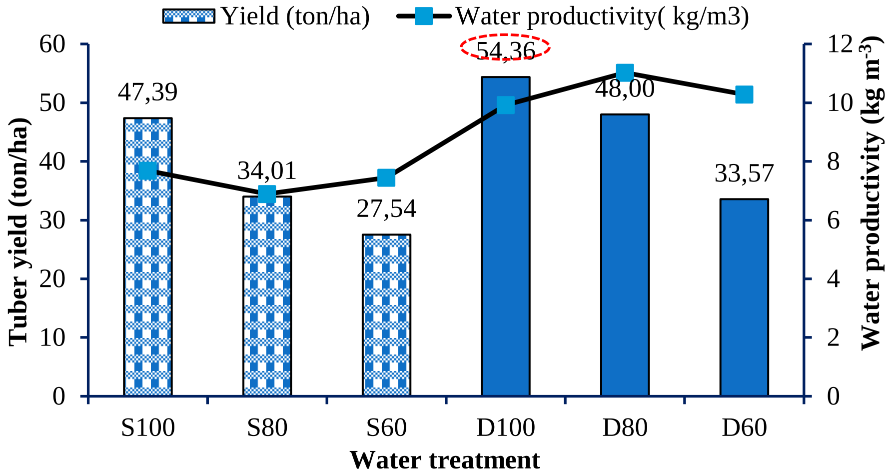

Figure 9. *Tuber yield and WP under different irrigation systems regimes.*

Table 9. *Total area cultivated and total tuber yield using different mean water amounts of solid-set sprinkle full irrigation.*

Water applied treatments	S100	S80	S60	D100	D80	D60
Water applied amounts (m^3 ha^{-1})	336.33	269.07	201.79	319.49	235.41	168.15
Total area cultivated (ha)	1.00	1.25	1.76	1.13	1.42	1.89
Total tuber yield (ton)	7.19	6.96	6.96	10.25	11.43	10.79

The expected scenarios 2030, 2050 and 2100 for WR and WP for winter potato

The expected scenarios for the WR of the winter potato crop in the study area are displayed in Table 10 and Figure 10 with values of 2544 m^3 ha^{-1} in 2030, 2035 m^3 ha^{-1} in 2050, and 1527 m^3 ha^{-1} in 2100 at 100% of ETo. These values were estimated for the comparative treatment and without water stress. The potato will require 2597 m^3 ha^{-1} of water in the year 2030, 2077 m^3 ha^{-1} in the year 2050, and 1558 m^3 ha^{-1} in the year 2100 if the same treatment was applied in the future, which results in water stress using 80% of ETo. Additionally, if 60% of ETo is adopted, the water quantity needed in 2030, 2050, and 2100 will be 2851, 2281, and 1711 m^3 ha^{-1}, respectively.

Table 10 and Figure 11 showed the expected scenarios for the WP of the winter potato crop in the study area were estimated for the comparative treatment and without water stress with the value of WP 129.4 kg m^{-3} in the year 2030, the value of 102.9 kg m^{-3} in the year 2050, and the value of 77.64 kg m^{-3} in the year 2100. In the future, if the treatment is used, water stress 80% of ETo, the crop will be the value of 114.24 kg m^{-3} in the year 2030, the value of 91.39 kg m^{-3} in the year 2050, and the value of 68.54 kg m^{-3} in the year 2100. Also, if a water stress treatment of 60% is used, the value of WP will be 79.89 kg m^{-3} in the year 2030, the value will be 63.93 kg m^{-3} in the year 2050, and the value will be 47.93 kg m^{-3} in the year 2100.

The study found that all of the study regions' potato yield is negatively impacted by climate change, particularly the rise in temperature, average monthly evapotranspiration, and CO_2 rate (Nourani *et al.*, 2020; Stričević *et al.*, 2017). The results of our study, which assessed how several climate change scenarios would affect biomass and potato yield, remain consistent with those of this study. Since the current potato cultivars in Egypt require a period of the chilly climate for tuber start, it is necessary to change potato planting dates in order to minimize adverse temperature impacts on production of potato and decrease yield losses (Dewedar *et al.*, 2021). Climate change is probable to have an impact on crop yield and quality in relation to temperature, carbon dioxide concentrations, precipitation, the availability of water resources, and climate uncertainty (Luck *et al.*, 2012). As a result of the physiological effects of these expected climatic changes, increasing temperatures during the growing season and shorter times of crop development will result in lower yields in this situation. Due to the detrimental effects of increasing temperatures, it is predicted that potato productivity, growth, and duration will decline (Borus, 2017). In a different study, future climate change scenarios were applied to evaluate the worldwide tuber yield of potatoes, and the results showed that, depending on Representative Concentration Pathways scenarios, the yield will be reduced in 2055 and 2085 by 2 to 6% and 2 to 26%, respectively (El-Shaer *et al.*, 1997).

Table 10. *WR and WP under scenarios years 2030, 2050 and 2100.*

	WR (m^3 ha^{-1})			WP (kg m^{-3})		
Years scenarios	100 %	80 %	60 %	100 %	80 %	60 %
2030	2544.22	2596.58	2851.24	129.38	114.24	79.89
2050	2035.38	2077.26	2280.99	102.89	91.39	63.93
2100	1526.53	1557.95	1710.74	77.64	68.54	47.93

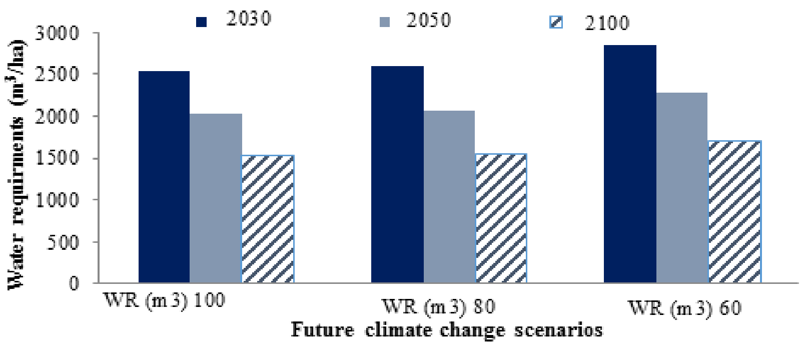

Figure 10. *WR of winter potato under climate change scenarios of years 2030, 2050 and 2100.*

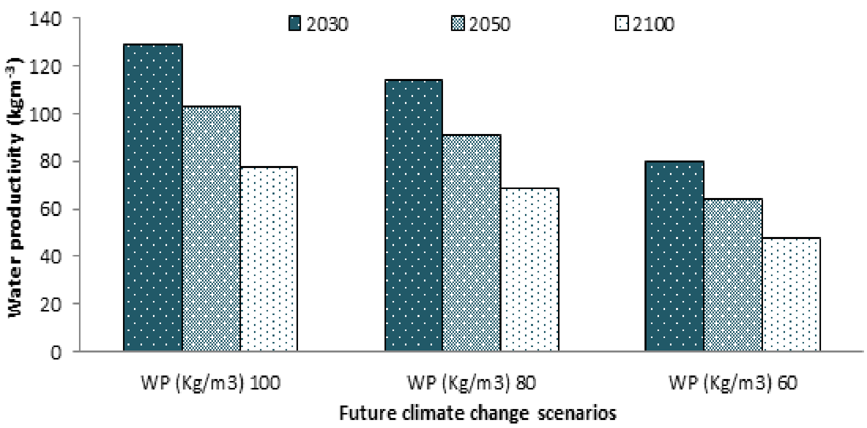

Figure 11. *WP of winter potato under climate change scenarios of years 2030, 2050 and 2100.*

CONCLUSION

Under conditions of water shortage, the calibrated AquaCrop model successfully simulated the selected potato crop. As well as, under different irrigation regimes and climatic changes, it is possible to simulate well potato tuber yield, water productivity (WP), and total biomass, but it is unsatisfactory under extreme water stress (intensive water stress). The effects of water management on potato yield and water productivity under deficit irrigation and climate change scenarios can be predicted using this model. Additionally, the potatoe yield cultivated with a surface drip irrigation system using 80% of (Reference evapotranspiration) ETo (48.00, 8.05 ton ha^{-1}) was significant compared to the potato yield grown with a solid-set sprinkler irrigation system using 100% of ETo (37.39, 7.19 ton ha^{-1}). The AquaCrop model can be dependably applied to predict crop variables and evaluate climate change scenarios for the effectiveness of planning irrigation management strategies for potato crop variables. When describing the results under extreme water stress conditions, the constraints should be taken into consideration.

ACKNOWLEDGMENTS

The Agricultural Engineering Research Institute (AEnRI) and National Research Centre, which provided the laboratory equipment and chemicals as well as financial support for the achievement of this research work, are sincerely appreciated by the authors.

APPENDIX

Symbols and abbreviations.

Symbol	Detail	Symbol	Detail
ETo	Evapotranspiration	**LAI**	Leaf area index
WP	Water productivity	**CC**	Canopy cover
Kc	Potato crop factor	**Y**	Total tuber yield
WR	Water requirements	**B**	Biomass
RMSE	Root mean square error	**HI**	Harvest index
r	Pearson correlation coefficient	**Tr**	Potato plant transpiration
NRMSE	Normalized root mean square error		

DECLARATION OF COMPETING INTEREST

There is no conflict of interest between authors.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declare the contributions to the manuscript such as the following sections:

AbdelGawad Saad: Conceptualization, visualization, ınvestigation and review of relevant literatures, methodology, data curation, validation, formal analysis, writing-original draft, review, and editing,

Hani Abdelghani Mansour: Visualization, data curation, conceptualization, ınvestigation methodology, formal analysis, validation, writing-original draft, review, and editing,

Elsayed Ali: Conceptualization, ınvestigation, methodology, data curation, formal analysis, review, and editing,

Mostafa Mohamed Azam: Investigation methodology, formal analysis, data curation, validation, review, and editing.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

REFERENCES

Attia S and Gobin C (2020). Climate change effects on Belgian households: a case study of a nearly zero energy building. *Energies, 13(20): 5357.*

Borus DJ (2017). *Impacts of climate change on the potato (Solanum tuberosum L.) productivity in Tasmania, Australia and Kenya*. PhD Thesis. University of Sydney pp. 206.

DeTar WR, Browne GT, Phene CJ and Sanden BL (1996). *Real-time irrigation scheduling of potatoes with sprinkler and subsurface drip systems.* In Proceeding International Conference on Evapotranspiration and Irrigation Scheduling, eds. CR Camp, EJ Sadler, and RE Yoder (pp. 812-824).

Dewedar O, Plauborg F, El-Shafie A and Marwa A (2021) Response of potato biomass and tuber yield under future climate change scenarios in Egypt. *Journal of Water and Land Development. 49(IV-VI): 139-150.*

Eldredge EP, Shock CC and Saunders LD (2002). *Early and late harvest potato cultivar response to drip irrigation.* In XXVI International Horticultural Congress: Potatoes, Healthy Food for Humanity: International Developments in Breeding, 619 (pp. 233-239).

El-Shaer HM, Rosenzweig C, Iglesias A, Eid MH and Hillel D (1997). Impact of climate change on possible scenarios for Egyptian agriculture in the future. *Mitigation and Adaptation Strategies for Global Change, 1(3): 233-250.*

Fabeiro CM, de Santa Olalla FM and De Juan JA (2001). Yield and size of deficit irrigated potatoes. *Agricultural Water Management, 48(3): 255-266.*

Fang H, Baret F, Plummer S and Schaepman-Strub G (2019). An overview of global leaf area index (LAI): Methods, products, validation, and applications. *Reviews of Geophysics, 57(3): 739-799.*

García-Vila M and Fereres E (2012). Combining the simulation crop model AquaCrop with an economic model for the optimization of irrigation management at farm level. *European Journal of Agronomy, 36(1): 21-31.*

Gee GN and Bauder JW (1986) Particle Size Distribution. In: Klute, A., Ed., Methods of Soil Analysis Part 1. Physical and Mineralogical Methods, 2nd Edition, *Agronomy Society of America/Soil Science Society of America, Madison, Wisconsin, 383-411.*

Heng LK, Hsiao TC, Evett S, Howell T and Steduto P (2009). Validating the FAO AquaCrop model for irrigated and water deficient field maize. *Agronomy Journal, 101: 488-498.*

Howell TA (2001). Enhancing water uses efficiency in irrigated agriculture. *Agronomy Journal, 93: 281-289.*

Hsiao TC (2000). Sensitivity of growth of tubers vs. leaves to water stress: Biophysical analysis and relation to water transport. *Journal of Experimental Botany, 51: 1595-1616.*

Hsiao TC (2007). *AquaCrop–Model parameterization and testing for maize. In ASA-CSSA-SSSA International Annual Meetings (November 4-8, 2007). ASA-CSSA-SSSA.*

Ibrahim A, Csúr-Varga A, Jolánkai M, Mansour H and Hamed A (2018). Monitoring some quality attributes of different wheat varieties by infrared technology. *Agricultural Engineering International CIGR Journal, 20: 201-210.*

IP and Gitlin HM (1975). *Irrigation efficiencies of surface, sprinkler and drip irrigation*. Proceedings Second World Congress, International Water Resources Association, New Delhi: 191-199.

Kaur A, Singh KB, Gupta RK, Alataway A, Dewidar AZ and Mattar MA (2022). Interactive effects of nitrogen application and irrigation on water use, growth and tuber yield of potato under subsurface drip irrigation. *Agronomy, 13(1): 11.*

Kemanian AR, Stockle CO, Huggins DR and Viega LM (2007). A simple method to estimate harvest index in grain crops. *Field Crops Research, 103: 208-216.*

King BA, Stark JC and Neibling H (2020). Potato irrigation management. In Potato Production Systems (pp. 417-446). *Springer, Cham.*

Klute A (1986). Water Retention: Laboratory Methods, in Klute, A. (ed.): Methods of Soil Analysis. *Part 1. Physical and Mineralogical Methods. ASA and SSSA, Madison, WI, USA, pp. 635-662.*

Loague K and Green RE (1991). Statistical and graphical methods for evaluating solute transport models: overview and application. *Journal of Contaminat Hydrology, 7: 51-73.*

Luck J, Asaduzzaman M, Banerjee S, Bhattacharya I, Coughland K, Chakraborty A, Debnath G C, De Boer R F, Dhutta S, Griffiths W, Hossain D, Huda S, Jagannathan R, Khan S , O'leary G, Miah M G, Shana A, Spooner-Hart R (2012). The effects of climate change on potato production and potato late blight in the Asia-Pacific Region. *APN Science Bulletin, 2: 28-33.*

Malhi GS, Kaur M and Kaushik P (2021). Impact of climate change on agriculture and its mitigation strategies: review. *Sustainability, 13(3): 1318.*

Mansour HA, Abdallah EF, Gaballah MS and Gyuricza C (2015a). Impact of bubbler discharge and irrigation water quantity on 1-hydraulic performance evaluation and maize biomass yield. *International Journal Geomate, 9, 1538-1544.*

Mansour HA, Abdel-Hady M, Eldardiry EI and Bralts VF (2015b). Performance of automatic control different localized irrigation systems and lateral lengths for emitters clogging and maize (*Zea mays* L.) growth and yield. *Intenational Journal Geomate, 9, 1545-1552.*

Mansour HA, Abd-Elmabod SK and Engel BA (2019a). Adaptation of modeling to the irrigation system and water management for corn growth and yield. *Plant Archives, 19 (Suppl. S1), 644-651.*

Mansour HA, El-Hady MA, Bralts VF and Engel BA (2016). Performance automation controller of drip irrigation system and saline water for wheat yield and water productivity in Egypt. *Journal of Irrigation and Drainage Engineering, 142, 05016005.*

Mansour HA, Hu J, Ren H, Kheiry AN and Abd-Elmabod SK (2019b). Influence of using automatic irrigation system and organicfertilizer treatments on faba bean water productivity. *Intenational Journal Geomate, 17: 256-265.*

Mengistu TG, Nigussie TA, Haile A and Seid A (2021). Evaluating the performance of aquacrop model in simulating the productivity of potato (*Solanum tuberosum* L.) crop under various water levels at Debre Birhan, *Amhara Regional State, Ethiopia. Culture, 5(4), 674-687.*

Molden DJ, Sakthivadivel R and Habib Z (2001). Basin-level use and productivity of water: Examples from South Asia. *Research Report 49, International Water Management Institute, Colombo, Sri Lanka.*

Moriasi DN, Arnold JG, Liew MWV, Bingner RL, Harmel RD and Veith TL (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE, 50: 885-900.*

Nourani V, Rouzegari N, Molajou A and Baghanam AH (2020). An integrated simulation-optimization framework to optimize the reservoir operation adapted to climate change scenarios. *Journal of Hydrology. 587: 125018, 1-19.*

Pontius R, Thontteh O and Chen H (2008). Components of information for multiple resolution comparisons between maps that share a real variable. *Environmental Ecological Statistics, 15: 111-142.*

Raes D, Steduto P, Hsiao TC and Fereres E (2009). AquaCrop-The FAO crop model to simulate yield response to water: II. Main algorithms and software description. *Agronomy Journal, 101: 438-447.*

Rahimikhoob H, Sohrabi T and Delshad M (2021). Simulating crop response to nitrogen-deficiency stress using the critical Nitrogen concentration concept and the AquaCrop semi-quantitative approach. Scientia Horticulturae, 285, 110194.

Razzaghi F, Zhou Z, Andersen MN and Plauborg F (2017). Simulation of potato yield in temperate condition by the AquaCrop model. *Agricultural Water Management, 191: 113-123.*

Rebecca B (2004). Soil Survey Methods Manual. Soil Survey Investigations *Report. No 42 Natural Resources Conservation Services.*

Salemi H, Mohd-Soom MA, Lee TS, Mousavi SF and Ganji A (2011) Application of AquaCrop model in deficit irrigation management of winter wheat in arid region. *African Journal of Agricultural Research. 610: 2204-2215.*

Shaw B, Thomas TH and Cooke DT (2002). Responses of potato (*Beta vulgaris* L.) to drought and nutrient deficiency stress. *Plant Growth Regulation, 37: 77-83.*

Steduto P (2003). Biomass water-productivity. Comparing the growth engines of crop models. *FAO expert consultation on crop water productivity under deficient water supply, Rome.*

Stričević R, Trbić G, Vujadinović M, Cupać, R, Đurović, N and Ćosić M 2017. *Impact of climate change on potato yield grown in different climatic zone in Bosnia and Herzegovina*. In VIII International Scientific Agriculture Symposium, Agrosym (pp. 596-601).