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Response of potato biomass and tuber yield under future climate change scenarios in Egypt

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Abstract

FAO AquaCrop model ver. 6.1 was calibrated and validated by means of an independent data sets during the harvesting seasons of 2016/2017 and 2017/2018, at El Noubaria site in western north of Egypt. To assess the impact of the increase in temperature and CO_2 concentration on potato biomass and tuber yield simulations, experiments were carried out with four downscaled and bias-corrected of General Circulation Models (GCMs) data sets based on the fifth phase of the Coupled Model Intercomparison Project (CMIP5) scenarios under demonstrative Concentration Trails (RCPs) 4.5 and 8.5, selected for 2021–2040 and 2041–2060. The study showed that the model could satisfactorily simulate potato canopy cover, biomass, harvest and soil water content under various irrigation treatments. The biomass and yield decreased for all GCMs in both future series 2030s and 2050s. Biomass reduction varied between 5.60 and 9.95%, while the reduction of the simulated yield varied between 3.53 and 7.96% for 2030. The lowest values of biomass and yield were achieved by HadGEM2-ES under RCP 8.5 with 27.213 and 20.409 Mg·ha^{-1}, respectively corresponding to –9.95 and –7.96% reduction. The lowest reductions were 5.60 and 3.53% for biomass and yield, respectively, obtained with MIROC5 under RCP 8.5 for 2030. Reductions in biomass and yield in 2050 were higher than in 2030. The results are showing that higher temperatures shortened the growing period based on calculated growing degree days (GDD). Therefore, it is very important to study changing sowing dates to alleviate the impact of climate change by using field trials, simulation and deep learning models.

Key words: *AquaCrop model, biomass, climate change, CMIP5 scenarios, potato, yield*

INTRODUCTION

The worldwide crop production is generally effected by climate factors which makes it susceptible to climate change so far. Climate change plays a very vital role in the production, growth and development of crops through which any variation in climate parameter possibly threaten the global food production and security. Agriculture is known as the most vulnerable economic factor fluctuation of precipitation and temperature.

Agricultural sector in developing countries is one of the sectors that have been negatively affected by climate change. Climate change has negatively effects on the productivity of agricultural land, predominantly, arid and semi-arid area [FAO 2016]. Crop production is affected by climate variability, climate change related to temperature increases, and increases in carbon dioxide. For these reasons and with increasing population pressure, 14% of people do not have enough food, and further, a billion people suffer from protein and energy deficiency in their diets [GODFRAY *et al.* 2010]. For studying future global food security, it is very vital to comprehend the expected impacts of climate change over the production of different crops [KUMAR 2016; LIPOVAC *et al.* 2018; MALL *et al.* 2017]. In developing countries, agriculture is severely affected by the climate change, carbondioxide emission, precipitations, temperature and industrialization that negatively effects on the agricultural process. Climate is changing globally which eventually result an increase in atmospheric carbondioxide (CO_2)

concentration, because, it is a foremost driver of greenhouse effects [IPCC 2014].

Potatoes are considered to be a very important crop all over the world and are likely to be affected as other crops due to climate change. Potatoes are considered to be the fourth most important crop after rice, wheat and maize and measured as one of the most important crops grown in Egypt [EL-SHAFIE *et al.* 2017]. The total production in Egypt is 432.5 thous. Mg produced from 164 thous. ha [FAOSTAT 2019].

There are numerous studies describe the effect of climate change on a production of particular crops [AGESA *et al.* 2019; FODOR *et al.* 2017; VAN OORT, ZWART 2018; OZTURK *et al.* 2017; RAYMUNDO *et al.* 2018].

Climate change, especially with increasing temperature and CO_2 level, has a harmful impact on potato production in all study regions [STRIČEVIĆ *et al.* 2017]. Potato reacted with physiological changes as an effect of climate change [LUCK *et al.* 2012]. Other studies showed the reducing effect of increasing temperature and carbon-dioxide on potato harvest [EL-SHAER *et al.* 1997; RAYMUNDO *et al.* 2018].

Egyptian farming is particularly very subtle to climate change, the expected rise in temperature and change in the seasonal rainfall schedule will most likely to reduce the agricultural productivity of some crops [MEDANY, HASSANEIN 2006; RADHOUANE 2013].

There is a need to change in potato planting dates, to avoid the negative temperature effects on potato production to reduce yield losses as the present potato cultivars in Egypt need a time of chilly climate for tuber initiation [EL-NOEMANI *et al.* 2015a]. Egypt suffers from water shortage and low rainfall, which is about 12 mm a year and occurs only in the winter season [ABDEL-SHAFY *et al.* 2010; EL-NOEMANI *et al.* 2015b; MARWA *et al.* 2017; WAHBA *et al.* 2016]. The farming sector has long been the major consumer of water, therefore, faces the extreme challenge in its efforts to minimize the usage of water [DEWEDAR *et al.* 2019; EL-SHAFIE *et al.* 2018; RAES *et al.* 2009; YOUSSEF *et al.* 2018].

AquaCrop is a model that is dominating the usage of water in great amount, it is a model for pretending crop water efficiency established by FAO and can be used extensively in any place and time by regularizing a water-productivity parameter for climate (evaporative demand and concentration of atmospheric carbon-dioxide) [FARAHANI *et al.* 2009; STEDUTO *et al.* 2009]. A number of studies verified that AquaCrop gave a precise forecast of crop biomass and harvest [ABEDINPOUR *et al.* 2014; MBANGIWAA *et al.* 2019; RAZZAGHI *et al.* 2017]. Therefore, the model is relevant to apply in studying scenarios of climate change [KET *et al.* 2018; MONTERROSO-RIVAS *et al.* 2018; SEMENOV, BARROW 2002; SHRESTHA, SHRESTHA 2017].

The novel Coupled Model Intercomparison Project Phase 5 (CMIP5) emission scenarios in The Intergovernmental Panel on Climate Change (IPCC) AR5 have been extensively used for the future climate status assessments, and the combined application of LARS-WG, there was a great concern in recent studies with AR5 scenarios [FENTA MEKONNEN, DISSE 2018; SEMENOV, STRATONOVITCH 2015]. LARS-WG model is used for downscaling daily rainfall, daily minimum and maximum temperatures [ARAJI *et al.* 2018].

Still, there is a lack of research using GCMs data based on CMIP5 scenarios for agricultural purposes. Therefore, the goal of this study is to measure the outcome of climate change on the potato biomass and yield according to the IPCC RCP 4.5 and 8.5 scenarios by using the AquaCrop after calibration and validation.

In present day, there are only few of the experimental data that are available over the effects of higher concentration of biomass distribution of potatoes. In order to identify and recognize the possible future results on above ground biomass manufacture and tuber yield, potatoes were presented to three CO_2 levels (380, 550 and 680 $\mu mol \cdot mol^{-1}$ CO_2) under near fields experimental circumstances in OTCs. In order to examine the effects of CO_2 enhancement as the most significant global change constituent and as absolute biomass production and tuber yield.

This study aims to assess the impact of the increase in temperature and CO_2 concentration on potato biomass and tuber yield simulations.

MATERIALS AND METHODS

SITE AND CROP MANAGEMENT

Potato (*Solanum tuberosum* L.) 'Cara' cultivar was grown during two consecutive seasons (2016/2017 and 2017/2018) in sandy soil at Agrarian Research Station, National Research Centre, El-Nubaria, Egypt (latitude of 30°30' N and longitude 30°20' E) in North West of the Nile delta of Egypt. The crop was planted on 1st of November 2016 in the primary season and 2nd November 2017 in the subsequent season. The row spacing of plants was 0.75 m, and the space between every plant was 0.25 m. The soil where the experiment take place is sandy soil. The participating soil samples from the various parts of experimental area were occupied from the depths 0–15, 15–30, 30–45 and 45–60 cm. The parallel depths of the soil models were assorted thoroughly and a compound sample was taken from every depth for several examinations. Few of the physical and chemical properties of the experimental soil are obtainable in Tables 1 and 2, correspondingly. Irrigation water was achieved from an irrigation channel (Nile water) going towards the experimental area, with pH 7.3, and electrical conductivity of 0.37 $dS \cdot m^{-1}$, containing a very suitable amount of cations (Ca^{2+} 0.76, Mg^{2+} 0.24, Na^+ 2.6, K^+ 0.13), anions (CO_3^- 0, HCO_3^- 0.9, SO_4^{2-} 0.32, Cl^- 2.51) and *SAR* 4.61.

Soil particle size, circulation had carried out with respect to pipette method, enumerated by GEE and BAUDER [1986]. Soil moisture content at field capacity (*FC*) and permanent wilting point (*PWP*) were calculated with respect to the method provided by GARDNER [1986]. Soil hydraulic conductivity (*K*) was resolute under a constant head technique [KLUTE, DIRKSEN 1986].

Table 1. Some physical properties of the soil

Depth (cm)	Particle size distribution (%)				Texture class	θS % on volume basis			K (cm·h^{-1})	ρ (g·cm^{-3})	Φ (cm^3·cm^{-3})
	coarse sand	fine sand	silt	clay		*FC*	*PWP*	*A.W*			
0–15	8.4	77.6	8.5	5.5	sandy	12.0	4.1	7.9	6.68	1.69	0.36
15–30	8.6	77.7	8.3	5.4	sandy	12.0	4.1	7.9	6.84	1.69	0.36
30–45	8.5	77.5	8.8	5.2	sandy	12.0	4.1	7.9	6.91	1.69	0.36
45–60	8.8	76.7	8.6	5.9	sandy	12.0	4.1	7.9	6.17	1.67	0.37

Explanations: *FC* = field capacity, *PWP* = permanent wilting point, *AW* = available water, *K* = saturated hydraulic conductivity (cm·h^{-1}), ρ = bulk density (g cm^{-3}), φ = porosity (cm³ cm^{-3}), θS = the volumetric soil moisture content.
Source: own study.

Table 2. Some chemical properties of the soil

Depth (cm)	pH 1:2.5	*EC* (dS·m^{-1})	Soluble cations (meq·dm^{-3})				Soluble anions (meq·dm^{-3})			
			Ca^{2+}	Mg^{2+}	Na^+	K^+	CO^{3-}	HCO_3^-	SO_4^{2-}	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

Explanations: *EC* = electric conductivity.
Source: own study.

EXPERIMENTAL DESIGN

The experiment was supported with two irrigation treatments: T1 (irrigation at 50% of field capacity) and T2 (irrigation at 80% of field capacity), and three replications (R1, R2 and R3).

Water requirements at 50 and 80% of field capacity determined with a Soil Moisture Device (WaterScout SM 100 Soil Moisture Device, FieldScout Soil Sensor Reader, Spectmeter Technologies, Inc.) were calculated by measuring the amount of irrigation water applied with a flow meter. Before the start of the growing seasons a drip irrigation network was constructed and tested in the field with, PE laterals with 16 mm in-line drip emitters at a measurement of 30 cm among drippers and 75 cm between lines.

The canopy cover was estimated from leaf area index founded on Ritchie type of equation as the following equation [BELMANS *et al.* 1983; RITCHIE 1972; RITCHIE *et al.* 1985; SAADATI *et al.* 2011]:

$$CC = 1 - \exp^{(-K.LAI)} \qquad (1)$$

where: *CC* = canopy cover, *K* = extinction coefficient, *LAI* = leaf area index.

The value of extinction coefficient for potato is 0.77 [OLIVEIRA *et al.* 2016]. The plant leave area was measured using a laser leave area meter device.

AQUACROP MODEL THEORY

AquaCrop V6.1 model were verified against T1 and T2 season spell 2016/2017 and 2017/2018 data that used to evaluate biomass and harvest of potato under the IPCC RCP 4.5 and 8.5 scenarios. AquaCrop is a crop water output model advanced by the Land and Water Division of FAO. AquaCrop is a crop model that pretends harvest response to water developed by FAO, and it is suitable to contemplate effects where water is restraining factor for crop production [RAES *et al.* 2009; STEDUTO *et al.* 2009].

This simulates yield reaction to herbaceous crop water, and is specifically suitable to address situations where water is a key warning factor in crop production. The parameters of AquaCrop inputs include climatic, crop, soil, irrigation, and initial soil water circumstances, which were held for some, and for the others either measured or standardized during the growing period. The model provided excellent refuge yield simulation. AquaCrop tests a fair amount of variables related to the quality of crop water, crop growth and development of crop yields. The model was verified in this study by equating modelled productivity to crop production measures, canopy cover, soil water content, biomass during the crop development season and final tuber yield. AquaCrop is mainly dependent on water as a water – driven crop, whereby transpiration is first measured and converted into biomass using a conventional, crop – specific parameter.

Biomass, water productivity regulated itself as atmospheric evaporative demand and carbon dioxide concentration in air. The process of standardization continues to make AquaCrop suitable in different locations and seasons. Simulations are usually performed over a thermal time period but in daily routine time-lapse it can also be achieved over calendar cycles. Instead of the leaf area index (*LAI*), the model uses canopy ground cover to calculate transpiration and separate soil evaporation from transpiration; the crop yield can be calculated as the biomass and harvest index (*HI*) feature. Once yield development begins (*HI*) rises linearly with time after an interval stage, until the physiological maturity period. There is no partitioning of biomass into the various tissues for growth. Crop responses to water deficit repeated with Fourier transformers that are the aim of fractional soil water modulative through evaporative demand based on the differential sensitivity to water pressure of four major plant processes: canopy extensions, stomatal transpiration regulation, canopy senescence, and *HI*. Based on pressure level, time duration and canopy duration the *HI* can be expressed both negatively and positively. The AquaCrop model is intended to develop end-users of the practitioner category, such as those associated with extension facilities, links to infrastructure, government agencies, non-administrative organization, and several types of field organizations.

Table 3. Monthly weather data at experimental site during growing seasons

Period	Precipitation (mm day^{-1})	Wind speed (m s^{-1})	Relative humidity (%)	Maximum temperature	Minimum temperature	Average temperature	Solar radiation (MJ·m^{-2}·day^{-1})
				°C			
November 2016	1.0	3.2	64.1	24.3	16.1	19.5	13.7
December 2016	1.6	3.6	67.5	18.2	11.3	14.2	11.9
January 2017	0.2	3.1	68.4	16.9	8.5	12.0	12.5
February 2017	0.5	2.7	67.4	18.7	9.0	13.1	15.7
March 2017	0.01	3.4	63.9	21.6	11.5	15.9	20.3
November 2017	0.7	2.7	66.2	23.0	14.7	18.2	14.1
December 2017	0.3	3.0	70.3	20.3	12.9	16.1	10.8
January 2018	1.3	3.8	69.1	18.1	10.2	13.7	12.5
February 2018	0.4	2.6	65.2	20.7	10.8	15.2	10.8
March 2018	0.04	2.9	55.6	24.9	12.4	17.9	20.3

Source: own elaboration acc. to data of the meteorological station data at experimental station of El-Nubaria, Egypt.

It also seeks to meet the essential needs of economists and policy analysts to use different methods for preparing and analysing the situation.

METEOROLOGICAL DATA

Data collection and calculations. Climate files for AquaCrop model were created from meteorological daily data (highest and lowest air temperatures, solar radiation, relative humidity, precipitation and wind speed at a height of 2 m) collected by the meteorological position at the investigational site. Further, the daily meteorological data were used for climate scenario developments, LARS-WG model section below. Table 3 gives an overview of the data shown as averages for the months in the growing seasons.

LARS-WG model. There is a technique termed as "downscaling tecniques" which calculate the daily reliable hours of rainfall and temperature due to climate situations from the GCMs output, the downscaling models are used to produce the probable future values of local meteorological variables such as, precipitation and temperature in selected areas. Models are termed as statistical downscaling model (SDSM) that utilized the stochastic weather producers and the other one is Long Ashton research station weather generators (LARS-WG) which only operated the stochastic weather generators. The LARS-WG is definitely an achievable technique to be used as instruments in enumerating the effects of climate change condition in local scale.

Long Ashton Research Station Weather Generator (LARS-WG) version 6 was established to used for the trimming and generating of the climatic variables [ARAJI *et al.* 2018]. Initially, the certainty of statistical features was generated, which is generally termed as model calibration (site analysis) using to observe every day's weather data as a starting point period. The other step is authentication of model (QTEST), which elucidates the presentation of the model. In addition, the climatic variables used in the model calibration process have also been used to generate artificial weather data since statistical features are used to determine whether there are substantial differences between observed and artificial weather data. Some arithmetic tests such as the Kolmogorov–Smirnov test and the *t*-test to evaluate the differences between the distributions and mean values of the parameters derived from observed weather data and synthetic data. The final stage is the production of regular climatic variables, including lower temperature, higher temperature, and rainfall based on scenario records previously made by regulating the likelihood changes for the next period.

The new Coupled Model Intercomparison Project Phase 5 (CMIP5) emission scenarios in IPCC AR5 have been widely used for future climate status estimations and the integrated application of LARS-WG with AR5 scenarios in recent studies [FENTA MEKONNEN, DISSE 2018; SEMENOV, STRATONOVITCH 2015].

For the upcoming scenarios, Representative Concentration Pathways (RCPs) 4.5 and 8.5 were selected for 2021–2040 and 2041–2060 impact evaluation. The RCPs are greenhouse gas concentration routes for future climate adopted by the International Panel on Climate Change [IPCC 2013; NASH, SUTCLIFFE 1970]. Table 4 shows the four downscaled and bias-corrected GCMs data based on CMIP5 scenarios.

Table 4. Global climate models for climate scenario simulations provided daily data on maximum and minimum temperature, rainfall, and solar radiation

Model acronym	Centre(s)	Climate model
EC-EARTH	EC-EARTH consortium published at Irish Centre for High-End Computing, Netherlands/ Ireland	EC-Earth – A European community Earth-System Model
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	Model for Interdisciplinary Research on Climate
MPI-ESM-MR	Max Planck Institute for Meteorology, Germany	The traditional Max Planck Institute Earth system model
HadGEM2-ES	Met Office Hadley Centre, UK	climate configurations of the Met Office Unified Model

Source: IPCC [2013].

FUTURE YIELD, BIOMASS, AND ASSESSMENT OF TREATMENTS

The climatic variables obtained from LARS-WG6 for emission situations were applied to the AquaCrop model to predict the final tuber yield and biomass and to compare to the corresponding values of the two growing seasons (2016/2017–2017/2018).

CALIBRATION AND VALIDATION OF AQUACROP

Soil water content (SWC), green canopy cover (CC), dry biomass (B) and final tuber yield calculated by AquaCrop were calibrated using the measured data sets from the T1 and T2 treatment of 2016/2017 season, and the model was validated using the measured data T1 and T2 of 2017/2018 season.

In regards to check the correctness of the model for predicting dissimilar parameters, the arithmetical pointers such as normalised root mean square error (*NRMSE*), Willmott agreement index (*d*) [WILLMOTT *et al.* 1985] and the coefficient of efficiency (*E*) [NASH, SUTCLIFFE 1970] were calculated as follows:

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

$$d = 1 - \frac{\sum_{i=1}^{n}(O_i-P_i)^2}{\sum_{i=1}^{n}(|P_i-\bar{O}|+|O_i-\bar{O}|)^2} \qquad (3)$$

$$E = 1 - \frac{\sum_{i=1}^{n}(O_i-P_i)^2}{\sum_{i=1}^{n}(O_i-\bar{O})^2} \qquad (4)$$

where: P_i = the simulated value, O_i = the observed value, $\bar{O}$ = mean of observed value, n = the number of observations.

The coefficient of efficiency (*E*) varies from –∞ to 1. A value approaching 1 indicates a better agreement between observed and simulated data. The closer the model efficiency is to 1, the more accurate the model is. An efficiency of 0 ($E = 0$) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($E < 0$) occurs when the observed mean is a better predictor than the model.

When making a soil file, the maker need to specify only a few features (soil type, depth of soil, etc.). With the assistance of this material evidences, AquaCrop produces the complete set of soil parameters. The parameters and values can be accustomed in the soil outline features menu. Other crop parameters were supposed to be traditional (i.e., their values do not change) while the user-specific parameters were projected from the first experiment (Tab. 5).

RESULTS

AQUACROP CALIBRATION

Calibration of the AquaCrop model was carried out based on T1 and T2 season 2016/2017 data, by comparing simulated and measured data of soil water content, canopy cover, yield and biomass with crop development.

Table 5. Parameter values for the simulation of a potato crop (‘Cara’ variety) using the AquaCrop model

Parameter	Type	Value	Source
Crop phenology			
Time (days) to emergence	GDDNC	390	M
Time to maximum effective rooting depth	GDDNC	1420	M
Time to start tuber formation	GDDNC	840	M
Time to start senescence	GDDNC	1300	M
Time to harvest	GDDNC	1643	M
Time to maximum canopy cover	GDDC	884	M
Time for tuber formation	GDDC	1748	M
Crop growth and development			
Plant density (plants m^{-2})	NC	5.3	M
Depth of sowing (m)	NC	0.20	M
Initial canopy cover (%)	NC	0.80	E
Maximum effective rooting depth (m)	NC	0.60	M
Maximum canopy cover (%)	C	92.0	M
Base temperature (°C)	C	2.0	B
Upper temperature (°C)	C	26.0	B
Canopy size of transplanted seedling (cm^2 $plant^{-1}$)	C	15	E
Water productivity ($g \cdot m^{-2}$)	C	35	Cv
Yield formation			
Reference harvest index (%)	NC	75.0	Cv
Possible increase of *HI* caused by water stress before starting yield formation (%)	C	3	E
Positive impact of restricted vegetative growth during yield formation on *HI*	C	none	B
Negative impact of stomata closure during yieldformation on *HI*	C	small	C
Allowable maximum increase of specified *HI* (%)	C	5	B
Soil water stress			
Upper threshold for canopy expansion	C	0.20	B
Lower threshold for canopy expansion	C	0.60	B
Upper threshold for stomata closure	C	0.60	B
Upper threshold for early canopy senescence	C	0.70	B
Shape factor for canopy expansion	C	3	B
Shape factor for stomata closure	C	3	B
Shape factor for early canopy senescence	C	3	B
Air temperature stress measurement (°C)	C		
Minimum growing degrees required for full biomass production (°C day^{-1})	C	7	B

Explanations: Cv = calibrated and validated using field data, C = conservative, NC = nonconservative, E = estimated from field data, M = measured in the experimental plots, GDD = growing-degree-days (°C) and *HI* = harvest index (%).
Source: own elaboration.

CANOPY COVER

Figure 1 shows the comparison between simulated and measured canopy cover (*CC*) for the well watered and water stressed crop (80% *FC* and 50% *FC*, respectively) during the 2016/2017 growing season. There is a decent relationship between the observed canopy cover and simulated ones for the irrigation treatments. The statistical indicators, shown in the Table 6 demonstrated that the coefficient of determination(R^2) was 0.99 and *RMSE* was ranged between 3.2% and 3.8%, *NRMSE* was 4% and 4.8%, *E* was 0.96, 0.94 and *d* was 0.99 and 0.98 for T1 and T2 respectively.

Table 6. Statistical indicators for simulated and measured canopy cover, biomass and soil water content for potato for AquaCrop model calibration and validation

Parameter	Irrigation treatment	Season 2016/2017 calibration					Season 2017/2018 validation				
		R^2	*RMSE*	*NRMSE*	*E*	*d*	R^2	*RMSE*	*NRMSE*	*E*	*d*
Canopy cover	T1	0.99	3.2	4	0.96	0.99	0.99	4.4	6.4	0.97	0.99
	T2	0.99	3.8	4.8	0.94	0.98	0.99	5.2	6.8	0.96	0.99
Biomass	T1	0.99	0.931	7.2	0.98	0.99	0.99	0.927	8.9	0.98	0.99
	T2	0.99	1.252	8.9	0.99	0.99	0.99	1.371	9.4	0.98	0.99
Soil water content	T1	0.81	7.3	13.8	0.52	0.89	0.91	5.9	11.0	0.80	0.95
	T2	0.85	2.3	3.5	0.70	0.92	0.72	4.3	6.7	0.30	0.82

Explanations: T1 and T2 as in Fig. 1, R^2, = coefficient of determination, *RMSE* = root mean square error, *NRMSE* = normalised root mean square error, *E* = coefficient of efficiency, *d* = Willmott agreement index.
Source: own study.

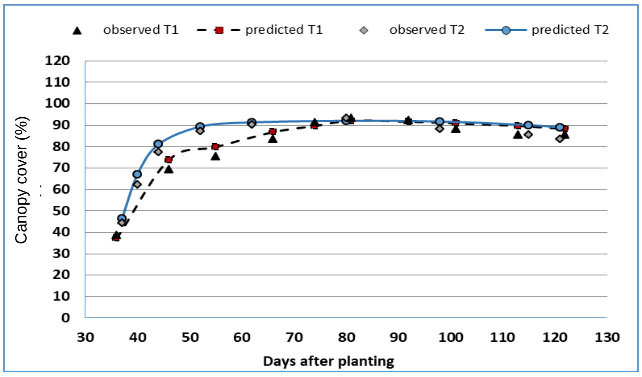

Fig. 1. Simulated and measured canopy cover against days of potato transplanting for AquaCrop model calibration (2016/2017); T1 = irrigation at 50% of field capacity, T2 = irrigation at 80% of field capacity; source: own study

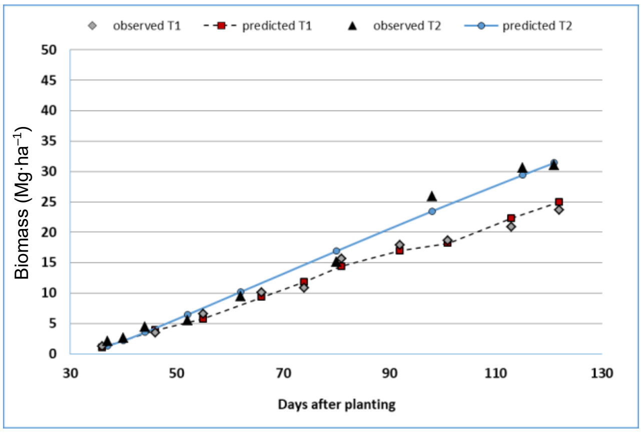

Fig. 2. Simulated and measured above ground biomass in potato against days after transplanting as a result of the AquaCrop model calibration (2016/2017); T1 and T2 as in Fig. 1; source: own study

ABOVE GROUND BIOMASS AND FINAL TUBER YIELD

The simulated and measured data of potato biomass are shown in Figure 2. According to the statistical analysis, there is a good fit for biomass between the observed and simulated values. Table 6 shows that 0.931 < *RMSE* < 1.252, 7.2 < *NRMSE* < 8.9 %, *E* was 0.98–0.99, *d* was 0.99 and R^2 was 0.99 for both irrigation treatments (T1 and T2). The results pointed out that the replicated values of biomass were closed to those measured in the field, but slightly higher than the observed data; the difference of the replicated biomass was acceptable as it was –7.48% and –3.15% for T1 and T2 respectively. The simulated values varied with respect to irrigation treatment. The simulated values of biomass had the same trend for two-irrigation treatments. However, the simulated was slightly lower than observed in the mid-season for T1 irrigation treatment on the contrary; it was slightly higher than observed for T2 treatment, but still has a similar deviation. Those results are in agreement with RAZZAGHI *et al.* [2017] who stated that the deviation of simulated biomass from observed is acceptable if it is ±10%.

For yield, the AquaCrop model predicted tuber yield with high accuracy. According to the Table 6 and Figure 3, the simulated values of tuber yield at harvest were comparable to those observed from the arena, with negative variances 9.78% and 6.03% for T1 and T2 respectively.

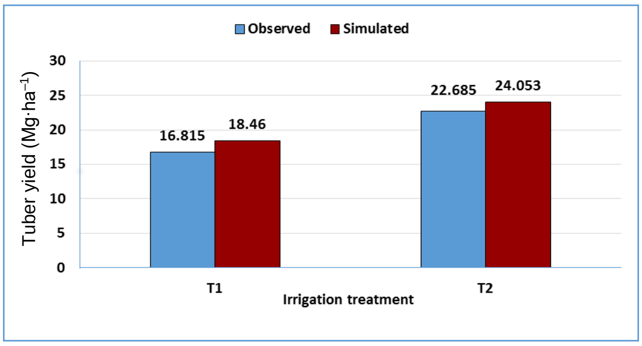

Fig. 3. Simulated and measured tuber yield of potato under both irrigation treatments for AquaCrop model calibration (2016/2017); T1 and T2 as in Fig. 1; source: own study

SOIL WATER CONTENT (*SWC*)

The soil and water content at the top 0.6 m soil depth was simulated with an acceptable result for both irrigation treatment T1 and T2 in the 2016/2017 season (Fig. 4). The statistical indicators R^2, *NRMSE*, normalized *NRMSE*, *E* and *d* were 0.81, 7.3 mm, 13.8%, 0.52 and 0.89 for T1 irrigation and 0.85, 2.3 mm, 3.5%, 0.70 and 0.92 for T2 irrigation, respectively (Tab. 6). The statistical indicators showed that the compliance of soil water content was not as high as that recorded for crop canopy and biomass, but similar trends were noted between the measured and simulated data.

Table 7. Statistical indicators for simulation and validation results from biomass and yield of potato for AquaCrop model (2016/2017–2017/2018)

Season	Irrigation treatment	Biomass			Yield		
		observed ($Mg \cdot ha^{-1}$)	simulated ($Mg \cdot ha^{-1}$)	deviation (%)	observed ($Mg \cdot ha^{-1}$)	simulated ($Mg \cdot ha^{-1}$)	deviation (%)
2016/2017 calibration	T1	23.856	25.640	–7.48	16.815	18.460	–9.78
	T2	31.090	32.070	–3.15	22.685	24.053	–6.03
2017/2018 validation	T1	20.682	21.283	–2.91	14.372	15.713	–9.33
	T2	29.359	30.859	–5.11	21.661	23.144	–6.85

Explanations: T1 and T2 as in Fig. 1.
Source: own study.

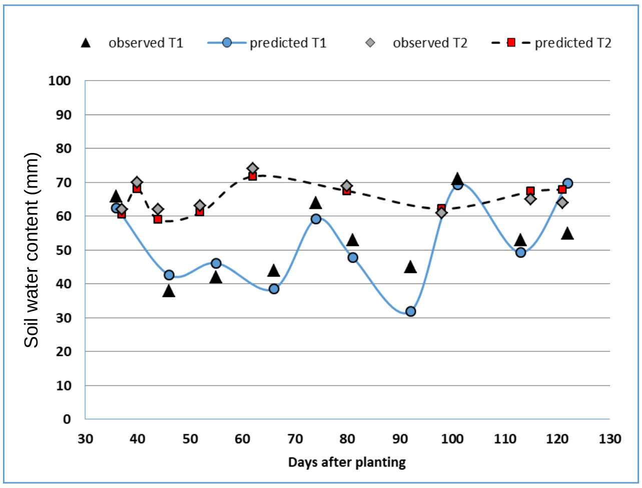

Fig. 4. Simulated and observed soil water content against days of potato transplanting for AquaCrop model calibration (2016/2017); T1 and T2 as in Fig. 1; source: own study

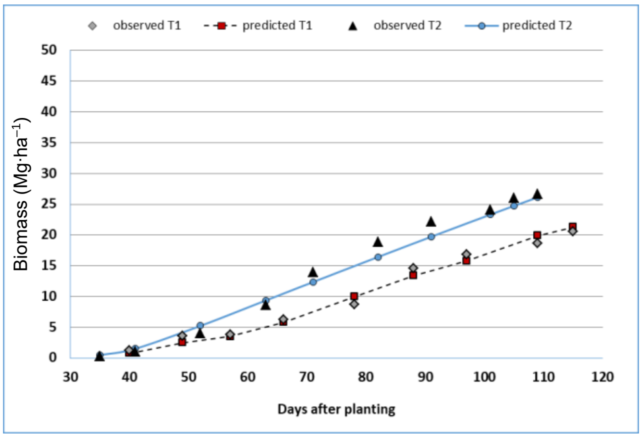

Fig. 5. Simulated and measured canopy cover against days of potato transplanting for AquaCrop model validation (2017/2018); T1 and T2 as in Fig. 1; source: own study

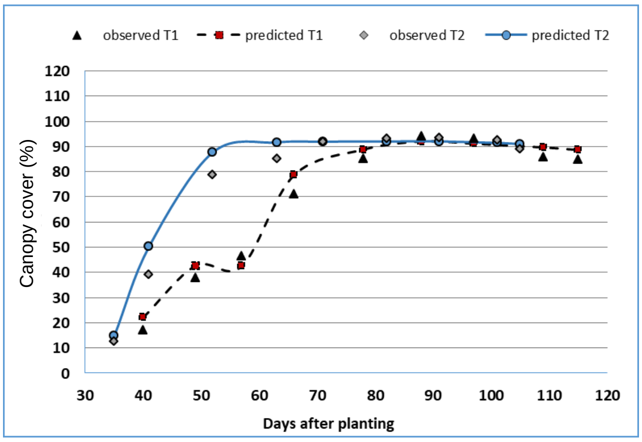

Fig. 6. Simulated and measured above ground biomass against days of potato transplanting for AquaCrop model validation (2017/2018); T1 and T2 as in Fig. 1; source: own study

MODEL VALIDATION

The same sets of parameter values assessed from the calibration of AquaCrop were used in the authentication to further estimate the presentation and accuracy of AquaCrop. Figures 5, 6, 7 and 8 display the difference of measured and replicated values of canopy cover, biomass and soil water content and tuber yield in both irrigation treatments for 2017/2018 season. The statistical indicators obtained from the comparison of the data showed a very good correlation and the degree of agreement of measured and simulated values ranged between good and very good (Tabs. 6, 7). The model simulated the seasonal trend for all selected data obtained from T1 and T2 from throughout the season 2017/2018 with good accuracy.

FUTURE YIELD, BIOMASS, AND COMPARISON OF TREATMENTS

The data in Table 8 shows the effect of GCMs under RCP (4.5, 8.5) on the 2030s and 2050s on biomass and yield for well irrigation conditions, irrigating at 80% of field capacity.

It is clear from the Table 8 that there are significant differences in biomass and yield between current and simulated data obtained from climate change scenarios GCMs. For the 2030s, it is obvious from data that simulated biomass is varied between 5.60 and 9.95% reduction, while the reduction of yield projection varied between 3.53 and 7.96% reduction. The lowest value of biomass and yield was achieved by HadGEM2-ES under RCP 8.5 with 27.213, 20.409 $Mg \cdot ha^{-1}$ and 9.95, 7.96% reduction (Fig. 9 a, b, c, d), respectively. The lowest reduction was 5.60, 3.53 % for biomass and yield with MIROC5 under RCP 8.5, respectively.

In addition, the biomass and yield decreased for all GCMs in the 2050 s with negative deviation, but the reduction was higher than that achieved in 2030s. The deviation of biomass ranged between –14.35 and –9.54 % with MPI-ESM-MR under RCP 4.5 and HadGEM2-ES under RCP 8.5, respectively.

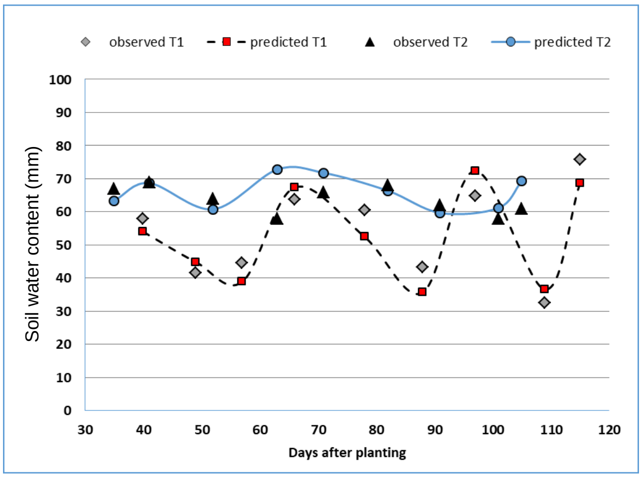

Fig. 7. Simulated and measured soil water content against days of potato transplanting for AquaCrop model validation (2017/2018); T1 and T2 as in Fig. 1; source: own study

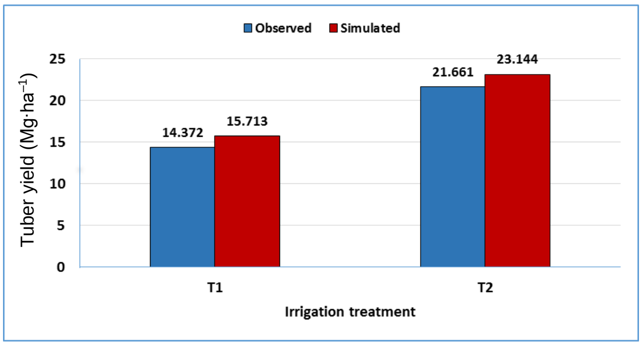

Fig. 8. Simulated and measured potato tuber yield for AquaCrop model validation (2017/2018); T1 and T2 as in Fig. 1; source: own study

Table 8. Predicted biomass and yield for future periods 2030s and 2050s under AR5 emission scenarios

Parameter	current (average)	RCP 4.5								RCP 8.5							
		EC-EARTH		HadGEM2-ES		MIROC5		MPI-ESM-MR		EC-EARTH		HadGEM2-ES		MIROC5		MPI-ESM-MR	
		estimated	deviation (%)	estimated	deviation (%)	est.	deviation (%)	estimated	deviation (%)	estimated	deviation (%)	estimated	deviation (%)	estimated	deviation (%)	estimated	deviation (%)
Period 2030s																	
Biomass	30.220	27.754	–8.16	27.756	–8.15	27.770	–8.11	28.008	–7.32	27.835	–7.89	27.213	–9.95	28.528	–5.60	27.742	–8.20
Yield	22.173	20.843	–6.00	20.824	–6.08	20.828	–6.07	21.006	–5.26	20.876	–5.85	20.409	–7.96	21.390	–3.53	20.806	–6.17
Period 2050s																	
Biomass	30.220	27.017	–10.60	26.455	–12.46	26.734	–11.54	27.338	–9.54	26.423	–12.56	25.884	–14.35	26.503	–12.30	26.431	–12.54
Yield	22.173	20.264	–8.61	19.841	–10.52	20.050	–9.57	20.504	–7.53	19.817	–10.63	19.413	–12.45	19.347	–12.75	19.823	–10.60

Explanations: EC-EARTH, HadGEM2-ES, MIROC5 and MPI-ESM-MR are global climate models as in Table 4.
Source: own study.

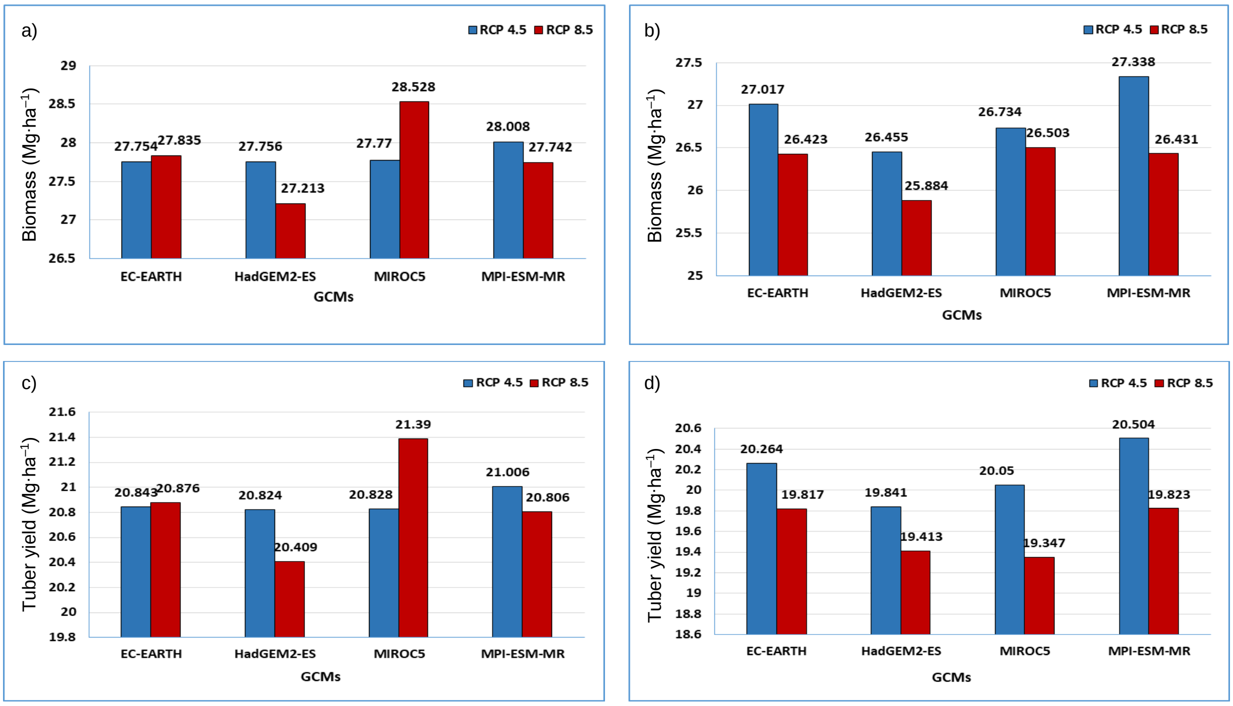

Fig. 9. Simulated parameters at harvest for a potato with global climate models under RCP 4.5 and 8.5: a) biomass 2030s, b) biomass 2050b, c) tuber yield 2030s, d) tuber yield 2050s; source: own study

For yield, MPI-ESM-MR under RCP 4.5 showed the lowest decrease with 20.504 Mg·ha^{-1} and –7.53 % deviation, and MIROC5 under RCP 8.5 showed the highest decrease with 19.347 Mg·ha^{-1} and –12.75% deviation. It is clear that changes in temperature and CO_2 rate in the 2030s and 2050s influenced potato biomass and yield. The possible reason for the decrease in production is the increasing temperature as it affects phenological growth of crop and as a result, the higher temperatures shortened the growing period based on calculated growing degree days (GDD).

DISCUSSION

FAO AquaCrop model versions 6.1 was calibrated and validated by using independent data sets throughout the harvesting seasons of 2016/2017 and 2017/2018, at El Noubaria place in western north of Egypt.

The results showed closed variation between simulated and observed data of Canopy cover, especially from the planting to 90 DAP beginning. The values of crop canopy for the two treatments showed the same trend, but with different magnitudes in both irrigation treatments. The peak value of the canopy cover was achieved after 90 DAP days from planting. In addition, there was not a big difference between experiential and simulated data. These indicators are in line some studies carried out on potato, cotton and wheat that indicated that R^2 for canopy cover was ranged between 0.98 and 0.99 [GOOSHEH *et al.* 2018; MBANGIWA *et al.* 2019; MONTOYA *et al.* 2016]. Also, another study was carried out experiments on the potato to evaluate AquaCrop model for potato under different irrigation conditions and stated that *RMSE* and d for canopy cover was outstanding goodness termed as ideal for most of the conducts, with durable lined relationships and higher coefficients of determination [JEFFERIES, BEEN 2015]. GOOSHEH *et al.* [2018] carried out an experiment on cotton and reported that the model acceptably simulated the seasonal trend in canopy cover for 14 irrigation treatment during the three seasons with R^2, *RMSE* and *d* of 0.92, 0.89, 10.6% and 0.92 respectively [GOOSHEH *et al.* 2018].

The results on biomass and yield from the present study coincided with those previously obtained by FENTA MEKONNEN and DISSE [2018] who demonstrated that the *NRMSE* values proved the good and excellent performance of the model for biomass and yield [FENTA MEKONNEN, DISSE 2018]. Similar decent match between replicated and calculated data was obtained in a field experiment in temperate conditions and results showed that AquaCrop simulated with high accuracy ground biomass in full and two different deficit irrigation conducts [MBANGIWA *et al.* 2019]. In alternative study on potato, the differences between replicated and observed biomass and yield were within ±10% for all treatments [JEFFERIES, BEEN 2015].

Similar results to those observed in the present study were observed in other studies on potato and cotton [FENTA MEKONNEN, DISSE 2018; GOOSHEH *et al.* 2018; JEFFERIES, BEEN 2015; MBANGIWA *et al.* 2019; MONTOYA *et al.* 2016; RAZZAGHI *et al.* 2017; TAN *et al.* 2018].

The data of soil water content fluctuated between moderate to good due to the non-homogeneity of the soil as soil varies from one location to another [HOZAYN *et al.* 2020]. While the AquaCrop model assumes that soil is homogeneous [ANDARZIAN *et al.* 2011].

GREGORY *et al*. [2005] pointed out that the AquaCrop simulated soil water content with very good performance, the *RMSE*, *NRMSE*, *d* and R^2 were 18 mm, 3.5%, 0.84 and 0.86 for full irrigation and 19 mm, 4%, 0.93 and 0.95 for water deficit irrigation, respectively. On the other hand, there is a study found that the *NRMSE* for of 80% of fully irrigated and not irrigated crop were 0.098 and 0.194, demonstrating that AquaCrop simulated the soil water content of 80% of full irrigation better than not irrigated potato [MBANGIWA *et al.* 2019].

Our findings concerning the effect of climate change scenarios on potato yield and biomass are in agreement with the study reported that climate change, especially the increase in temperature, average monthly evapotranspiration and CO_2 rate have a harmful impact on potato production in all study regions [NOURANI *et al.* 2020; STRIČEVIĆ *et al.* 2017]. There is a need to change potato planting dates, to avoid the negative temperature effects on potato production and reduce yield losses as the present potato cultivars in Egypt need a time of chilly climate for tuber initiation [EL-NOEMANI *et al.* 2015a]. Yield and quality of crops are predicted to be affected by climate change with temperature, carbon dioxide concentrations, precipitation, water resources availability, and climate uncertainty [LUCK *et al.* 2012]. In this case, yields will be reduced from increased temperatures during the growing season and shorter periods of crop development because of the physiological impact of these anticipated climatic changes. The crop productivity, growth and duration expected to decrease due to the negative impact of higher temperatures [BORUS 2017; MARWA *et al.* 2020]. In another study future climate change scenarios applied to assess potato global tuber yield, he found that reductions of the yield were (from 2% to 6%) and (from 2% to 26%), for 2055 and 2085 respectively depending on RCP [EL-SHAER *et al.* 1997].

In a similar study, the influence of climate change on potato production in India and Bangladesh presented a yield decline of 23–32% by 2050 due to increasing maximum and minimum temperature trend (form +0.2 to +0.6°C) for by 2050 [RAYMUNDO *et al.* 2018].

Despite yield decrease, there is a stable increase in the rate of growing degree-day (GDD) growth from planting to harvest for future periods the 2030s and 2050s. This increased rate in GDD accretion is projected to abbreviate the time to crop adulthood against the zeroline period by 12 days in 2035 and 20 days by 2050. There is a study stated that there is a stable increase in GDD accumulation from planting to harvest in the Tasmanian potato developing regions: 4.8% by 2050 and 12.3% by 2085 relative to the baseline period of 1981–2010 across the three sites. This increased rate in GDD accretion is predictable to shorten the time to crop maturity against the baseline period by 10 days in 2050 and 15 days by 2085 [BORUS 2017].

CONCLUSIONS

In the present examination, the investigational and AquaCrop demonstrating results pointed out that: The AquaCrop model had a good accuracy in simulation of soil and water content, canopy cover (%), biomass and final tuber yield of potato grown on sandy soil, for 50 and 80% of field capacity treatments under drip irrigation system in Egypt. The model, after being magnificently verified, was used to assess the impact of the increase in temperature and CO_2 concentration on potato biomass and tuber yield simulations were carried out with input of four downscaled and bias-corrected general circulation models GCMs data sets based on Coupled Model Intercomparison Project CMIP5 scenarios under demonstrative concentration trails (RCPs) 4.5 and 8.5 for 2030 and 2050.

It is showing that changes in temperature and carbon-dioxide rate in the 2030s and 2050s influenced potato biomass and yield. The possible reason for the decrease in production is the increasing temperature as it affects phenological growth of crop and as a result, the higher temperatures shortened the growing period based on calculated growing degree days (GDD). Consequently, it is very significant to study changing sowing dates to mitigate the influence of climate change.

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