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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

Tsegaye Getachew Mengistu[1], Tewodros Assefa Nigussie[2], Ashebire Haile[3,*], Awel Seid[2]

[1]Debre Birhan Agricultural Research Center, Debre Birhan, Ethiopia.
[2]Department of Water Resources and Irrigation Engineering, Hawassa University Institute of Technology, Hawassa, Sidama, Ethiopia.
[3]Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia.

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***Corresponding author:** Ashebire Haile, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia.
Email: ashu_haile@yahoo.com

Abstract

In the future, the agricultural sector in many parts of the world is to produce more with less water. In this regard, this experimental study was carried out to evaluate the performance of AquaCrop model in simulating potato crop growth parameters under various water levels at Debre Birhan, Ethiopia (2019-2020). The simulated crop yield parameters were compared to experimental results for this purpose. The experiment was arranged in Randomized Complete Block Design, with four replications and under five water levels (115%, 100%, 85%, 70% and 55 %). The 100% water level was determined to be 377.2 mm of water depth in the growing season. The growth parameter and tuber yield were significant differences among the water levels at $p < 0.05$. The fresh potato tuber yield and water productivity ranges from 36.09 ton/ha to 43.13 ton/ha and 12.67 kg/m^3 to 10.5 kg/m^3 were obtained in 55% and 115% water levels respectively. The AquaCrop model performance in the canopy cover, dry aboveground and tuber biomass and soil water content of the potato crop. The statistical indicators; Nash-Sutcliffe efficiency (NSE), Normalized Root mean square error (NRMSE) index of agreement (d) and Coefficient of determination (R^2) showed very well to excellent efficiency, there value is in ranges on aboveground and tuber biomass ranges 0.78 to 0.99, 14.1 to 35.5, 0.96 to 0.99 and 0.96 to 0.98 was observed respectively. However, the results of soil water content before irrigation were found to be poor efficiency ranges -0.96 to 0.00, 10.2 to 10.7, 0.5 to 0.78 0.081 to 0.45 respectively in the above order. From the results of the study, we can conclude in two scenarios: First, in case of water scarce area, it may be more profitable for a farmer to maximize crop water productivity instead of maximizing the harvest per unit of land. The saved water can be used to irrigate extra units of land. Second, in case of no water scarce area, it may be more profitable to maximize the yield harvest than crop water productivity. Under the first scenario, farmers should adopt 70% of crop water requirement with a 10-days interval, which 16.65% saved water with 10.1% yield penalty over 100%. On the other hand, they should adopt 100% of crop water requirement within 10-days interval in the case of no water scarce area.

Keywords

AquaCrop, Water Scarcity, Water Levels, Water Productivity, Potato

1. Introduction

Ethiopia is said to be rich in land and water resources, with a total land area of about 1.13 million km^2 and annual surface water flow of 124 BMC. Despite this, however, the country is also known as one of the poorest countries in the world. Most of the problems in Ethiopia such as low agricultural productivity, low economic development, food insecurity and poverty are related to under and/or miss-utilization of water resources [1], stated that the economy of Ethiopia, which is heavily dependent on rain-fed subsistent agriculture, is extremely affected as a result of the erratic nature of the rainfall, frequent drought occurrence and little development of the available water resources. In Amhara Region of Ethiopia (the second most populous Region in the Country), the variability of the precipitation is manifested with an extended dry spell, erratic and highly variable in space and time [2]. The problem of food security has been intensifying as a result of rapid population growth and the consequent increase in demand for food and Region is one of the regions in Ethiopia suffering from food shortage every year [3].

Provided it is economically viable, irrigation could become a key source of agricultural growth as well as poverty relief for farmers, who otherwise would unjustifiably depend on low and erratic rainfall. This would help increase the productivity of the land, although to a limited extent, the need for extending the cultivated area for feeding the rapidly growing population [4]. Irrigation development is viewed as one of the strategies as means to reduce poverty and promote economic growth by the Ethiopian Government [5]. As stated by [6], irrigation development has been viewed as one of the main strategies to free the economy from rain fed-based agriculture and enable sustainable growth and development in Ethiopia through enhancing public and private investment. This is because irrigation increases productivity and production, reduces risk of crop failure due to drought, enables farmers to diversify the crops they grow, and produce high-value market-oriented crops and employs farmers in various income generating schemes [1].

Nonetheless, the traditional irrigation is an old age practice in Ethiopia, the irrigation practice under such schemes is considered as poor as these schemes consist of elementary structures like diversion weirs that are made of local material which tend to be washed away by floods nearly every year and unlined canals. Moreover, particularly in Amhara Region, there exists poor management of the existing limited amount of water resources, and there is a limitation of knowledge about how much and when to irrigate various crops. Therefore, there is a need to improve the water use efficiency to obtain more crop production per drop of water with declining irrigation resources and the uncertainty in the temporal and spatial distribution of rainfall. Among many, one of the mechanisms or strategies to improve crop productivity per unit of water under rain-fed, full irrigation and deficit irrigation is the employment of the aid of models to fill the gaps during dry spells [7]. In addition, knowing the response of crops to soil moisture stress is crucial for irrigation water management [8].

The solution to the above-mentioned issues and improve productivity at the farm level is better irrigation water management. This can be accomplished by determining water productivity under different irrigation regimes or deficit irrigation approach [9], based on experimental results or by using appropriate prediction tools. However, determining irrigation scheduling merely based on field research is expensive and time-consuming and, thus, the application of models in such studies is crucial. Some physical-based models developed for such purpose include the Crop System model (CropSyst) [10], the Decision Support System of Agro-Technology Transfer (DSSAT) [11], the World Food Studies crop growth model (WOFOST) [12] and the AquaCrop model.

Among the above-mentioned models, AquaCrop is known to provide a valid alternative for herbaceous crops, as incorporation of advanced knowledge of crop-water relationships allowing a more accurate modeling of actual crop growth and yield formation processes under various soil water availability, climate and soil fertility conditions [13]. It is water-driven model used as decision support tool in planning and scenario analysis in different seasons and location at farm level. It also elaborates the fundamental process involved in crop productivity and the response to water deficits [14]. It is widely applicable due to the only use the relatively small number of explicit parameters and mostly-intuitive input-variables that can be determined by simple methods. Besides, the calculation procedures are based on the basic biophysical processes to guarantee an accurate simulation of the crop response in the plant-soil system [15, 16].

Potato (*Solanum tuberosum L.*) is selected in this study as it is by far the most important tuber crop in terms of quantities produced and consumed worldwide [17]. This crop is considered as a high-potential food security crop due to its ability to provide high yield and quality product per unit input [18]. It is also because Ethiopia has possibly the greatest potential for potato production as 70% of its arable land mainly in the highlands with an altitude greater than 1,500 m above sea level is considered suitable for potato [19]. The objective of the study was, therefore, to evaluate the performance of AquaCrop model in simulating potato crop growth parameters under various water levels at Debre Birhan, Amhara Region, Ethiopia as such a study has not been carried out in the study area.

2. Materials and methods

2.1 Description of the study area

This study was conducted at Debre Birhan Agricultural Research Centre (DBARC) experimental site located in North Shewa Administrative Zone, Amhara National Regional State, Ethiopia (Figure 1). The location is 09º 36' 30.5" North, 39 º 30' 29.8'' East and it has a mean elevation of 2,815 m above mean sea level. It is at about 121 km north of Addis Ababa and 9 km far from Debre Birhan Town in the South direction.

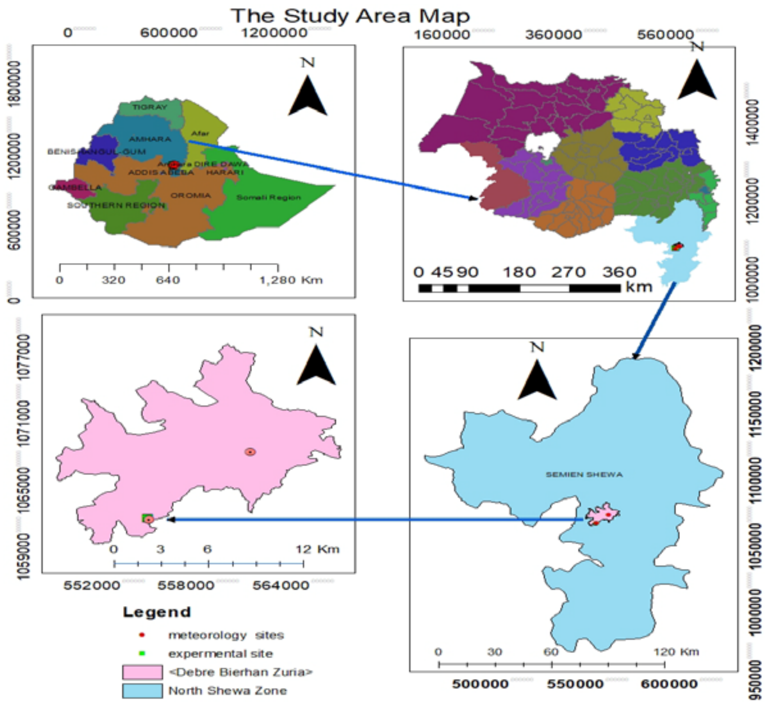

Figure 1. Location of the experimental site.

2.2 Acuacrop Model Description

AquaCrop is a crop water productivity model developed by the Land and Water Division of FAO. It simulates yield response to water of herbaceous crops, and is particularly suited to address conditions where water is a key limiting factor in crop production. It is designed to balance simplicity, accuracy and robustness, and is particularly suited to address conditions where water is a key limiting factor in crop production. AquaCrop is a companion tool for a wide range of users and applications including yield prediction under climate change scenarios.

As in other models, AquaCrop model structures its soil-crop-atmosphere continuum by including: (1) the soil, with its water balance; (2) the plant, with its growth, development, and yield processes; and (3) the atmosphere, with its thermal regime, rainfall, evaporative demand, and carbon dioxide concentration. Additionally, some management aspects are explicit, with emphasis on irrigation, but also the levels of soil fertility as they affect crop development, water productivity, and crop adjustments to stresses, and therefore final yield.

2.3 Performance evaluation of AquaCrop model

Model performance evaluation is an important step of model verification and involves a comparison between independent field measurements (data) and output created by the model. Soil water content over the root depth, above-ground dry biomass and tuber yield were considered in this study for model evaluation (Table 1).

2.4 Experimental design

Field experiment is an important task to validate the model result with the observed data in order to obtain accurate prediction versus observed data. In this regard, the experiment was arranged in Randomized Complete Block Design (RCBD) within five irrigation treatments. The plot size was 3 m x 3.75 m = 11.25 m^2 area and total experimental area 19.5m*19 m = 370.5 m^2. And 1 m and 1.5 m apart between plots and blocks respectively was as shown in Figure 2.

2.5 Data input parameters

On basic and complex biophysical processes, AquaCrop uses a relatively small number of explicit parameters and largely-intuitive input variables, either widely used or requiring simple methods for their determination. The inputs are stored in climate, crop, soil and management files and can be easily changed through the user-interface.

Table 1. Statistical performance indictors

No	Statistical indictors	Formulas	Agreements
1	Coefficient of determination (R^2)	$R^2 = [\frac{\sum(O_i - \bar{O}_i)(P_i - \bar{P}_i)}{\sqrt{\sum(O_i - \bar{O}_i)^2 (P_i - \bar{P}_i)^2}}]^2$	0 to 1, with values close to 1 indicating a good agreement
2	Root Mean Square Error (RMSE)	$RMSE = \frac{\sqrt{\sum(p_i - o_i)^2}}{N}$	It ranges from 0 to 1 the value 0 indicating good and the value 1 indicating poor model performance.
3	Normalized Root Mean Square Error (NRMSE)	$NRMSE = \frac{1}{Q_i} X \frac{\sqrt{\sum(p_i - o_i)^2}}{N} \otimes 100$	A model can be considered excellent if NRMSE is <10%, good if between 10 and 20%, fair if between 20 and 30% and poor if >30
4	Nash-Sutcliffe Efficiency (NSE)	$NSE = 1 - \frac{\sum(Oi - Pi)^2}{\sum(Oi - \overline{Oi})^2}$	data are that to fits the 1:1 line indicates a perfect match between the model and the observations.
5	Willmott's index of agreement (d)	$d = 1 - \frac{\sum(Pi - Oi)^2}{\sum(/Pi - \overline{Oi}/ + /Oi - \overline{Oi})^2}$	It ranges between 0 and 1, with 0 indicating no agreement and 1 indicating a perfect agreement between the predicted and observed data:

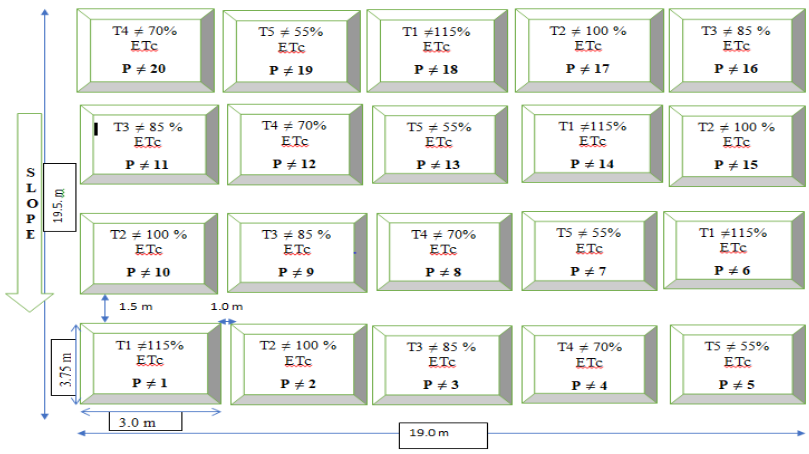

Figure 2. Experimental lay out.

2.5.1 Climate file

Historical climate data such as rainfall, minimum and maximum temperature, relative humidity, wind run at 2 meter and sunshine hour duration of 40 year (1979-2018) obtained from two principal stations that 9 km far apart to each other (located at DBARC and Debre Birhan Town) were used for simulating the test crop growth parameters using the AquaCrop model. For the CO_2 file was determined automatically adjusted by AquaCrop software by using the reference of the 2000-year 369.55 ppm and increment about 2 ppm (y=1.8034x-3234.9 with R^2 = 0.9905) every year. This CO_2 concentration data from international rice research institute (IRRI) the model was IPCC: RCP 8.5. After inputted the above climatic data and the geo-referenced data then the model created an ETo, rain, temperature and CO_2 file.

2.5.2 Created crop file

For created crop file first marked the file name and described the crop type that was potato crop under root and tuber crop, and then specified parameters. The AquaCrop generated the complete set of required crop parameters from the agronomic perspective of the crop nature in that specific location. As presented in Appendix Table 1, Appendix Table 2, the parameters were displayed and the values of non-conservative parameters and generated the model for conservative parameters respectively.

2.5.3 Created soil file

In creating a soil file, the user has to specify only a few characteristics like soil type, depth of soil, texture, etc. With the assistance of this information, AquaCrop generated the complete set of soil parameters. The parameters were displayed and the values adjusted or modified in the soil profile characteristics menu. The soil physical characteristics such as field capacity, permanent wilting point bulk density and a textural class of the experimental sites was presented as follows.

2.5.4 Created management file (irrigation schedule)

For created an irrigation schedule, the user specifies the time and application depth of the irrigation events. The volume of water applied for 100% ETc irrigation treatments were determined after several simulation of the AquaCrop model run by running several times (by trial and error) during simulating time, then accordingly for other water level treatments was determined as per their percentages.

The Values of crop coefficients (Ks) were used from FAO, Irrigation and Drainage Paper no 24 paper [20]. The coefficient of each irrigation treatment was Ks (1) = 100% of ETc no stress, Ks (0.85) = 85% of ETc, Ks (0.70) = 70% of Etc, Ks (0.55) = 55% of ETc, and Ks (1.15) = 115% of ETc. The irrigation water was applied for all treatments on the same day as that of fully irrigated plot (T2). while the irrigation depths were varied as their percentage 115%, 85%, 70%, and 55%, of the full irrigation for T_1, T_3, T_4, T_5 treatments respectively.

The seasonal amount of irrigation water from each treatment was recorded. In full irrigation, treatment (100%) the AquaCrop model was adjusted at 35% root zone depletion and refill to the field capacity. Before starting, the treatment there was applied equally for all treatment every 5-day interval. The irrigation method was used with a garden hose from water tanker on the average the rate of 0.20833 lit/sec. During rainfall, the irrigation water was applied after calculating the effective rainfall using the AquaCrop model.

2.6 Statistical analyses

The results were subjected to the analysis of variance (ANOVA) procedure, using SAS 9.0 statistical software to investigate whether there are statistical differences in the parameter studied (canopy cover, water content, and water productivity, and yield and yield components) or not. The mean comparisons were done using LSD test due to small number of treatments involved and comparison was done between the control treatment (100%) of water level at a probability level of $p < 0.05$ for separation of means [21].

3. Results and discussion

3.1 Performance of AquaCrop on dry-aboveground and tuber biomass yield in year 2019& 2020 G.C.

As presented in Table 2 and Table 3, the dry aboveground and tuber biomass yield had excellent in the Nash-Sutcliffe Efficiency (NSE) (0.96, 0.94, 0.90, 0.84 & 0.78 in year 2019 G.C. and 93, 93, 90, 95 & 98 in year 2020 G.C.) was obtained for the water levels 115%, 100%, 85%, 70% and 55%, respectively. For normalized root mean square error (NRMSE) had fair to poor values (14.1%, 16.3%, 21.6%, 28.1% & 35.5% in year 2019 G.C and 17.1%, 17.8%, 21.30%, 15.50% & 10.0% in year 2020 G.C.) was observed for the water levels 115%, 100%, 855, 70% and 55%, respectively. As well for index of agreement (d) had excellent value (0.99, 0.99, 0.98, 0.97 & 0.96) for the water levels 115%, 100%, 85%, 70% and 55% respectively. The simulated result on coefficient of determination (R^2) had excellent value (0.96, 0.96, 0.96, 0.98 and 0.98 in year 2019 G.C. and 98, 98, 98, 99 & 99 in year 2020 G.C.) for the water levels 115%, 1,005, 85%, 70% and 55% respectively. The results show that the well to excellent correlated as simulated value. The results in line with the study of the AquaCrop model performance in Tigray on potato were found a satisfactory result on the NRMSE [22].

3.2 Performance of AquaCrop on simulating canopy cover in year 2019 & 2020 G.C.

As presented in Table 4 and Table 5, the canopy covers as indicated by excellent to good model efficiency NSE (0.96, 0.82, 0.76, 0.0.68 & 0.54 in year 2019 and 94, 93, 85, 78 & 73 in year 2020 G.C.) for the water levels 115%, 100%, 85%, 70% and 55%, respectively. For normalized root mean square error NRMSE very good to good (fair) (12.9%, 15%, 18.7%, 20.5% and 25% in year 2019 and 10.1, 11.2, 16.9, 20.4 & 23.0 in year 2020 G.C.) for the water levels 115%, 100%, 85%, 70% and 55% of water level, respectively. As well for the index of agreement (d) was excellent (0.97, 0.96, 0.95, 0.93 and 0.91 in year 2019 and 99, 98, 97, 95 & 94 in year 2020 G.C.) for the water levels 115%, 100%, 85%, 70% and 55%, respectively. The simulated result on the coefficient of determination R^2 was excellent (0.96, 0.94, 0.94, 0.94 and 0.92 in year 2019 and 98, 98, 96, 96 & 94 in year 2020 G.C.) for the water levels 115%, 100%, 85%, 70% and 55%, respectively. The results showed that the AquaCrop model very well simulated value observed on in all water levels. This result agreed with [22], in Tigray, Ethiopia. Another result shows index of agreement (d) and coefficient of determination (R^2) was found > 90% in Spain [23].

Table 2. Observed and simulated dry aboveground biomass and dry tuber weight 2019 G.C.

DaP	115% DAGB t/ha OBS	115% DAGB t/ha SIM	100% DAGB t/ha OBS	100% DAGB t/ha SIM	85% DAGB t/ha OBS	85% DAGB t/ha SIM	70% DAGB t/ha OBS	70% DAGB t/ha SIM	55% DAGB t/ha OBS	55% DAGB t/ha SIM
34	0.083	0.092	0.077	0.092	0.073	0.092	0.065	0.092	0.054	0.092
44	0.693	0.941	0.628	0.941	0.586	0.941	0.535	0.941	0.517	0.941
54	2.486	2.891	2.326	2.891	2.138	2.891	2.045	2.89	1.906	2.89
64	5.36	4.965	4.618	4.965	4.121	4.965	3.663	4.964	3.277	4.963
74	8.326	7.028	7.781	7.028	7.059	7.028	6.175	7.027	5.925	7.027
86	10.265	9.471	9.641	9.47	8.711	9.47	8.326	9.469	7.764	9.467
95	11.717	11.265	11.495	11.264	11.474	11.264	10.409	11.263	9.762	11.082
106	12.401	13.372	11.856	13.372	11.491	13.372	10.553	13.267	10.044	12.72
117	12.742	15.015	12.301	15.015	11.6255	15.015	11.169	14.628	10.032	13.671
R	0.98***		0.98***		0.98***		0.99***		99***	
RMSE	1.00*		1.10*		1.40*		1.70^{+}		1.8^{+}	
NRMSE	14.10**		16.30*		21.60*		28.10^{+}		33.5^{+}	
NSE	0.96***		0.94***		0.90***		0.84***		0.78***	
D	0.99***		0.99***		0.98***		0.97***		0.96***	
R^2	0.96***		0.96***		0.96***		0.98***		0.98***	

Notes. (Field experiment, 2019) DaP is day after planting DAGB is dry aboveground biomass OBS is observed, SIM is simulated * good, ** very well, *** excellent, and + poor.

Table 3. Observed and simulated dry aboveground biomass and dry tuber weight 2020 G.C.

DaP	115% DAGB t/ha OBS	115% DAGB t/ha SIM	100% DAGB t/ha OBS	100% DAGB t/ha SIM	85% DAGB t/ha OBS	85% DAGB t/ha SIM	70% DAGB t/ha OBS	70% DAGB t/ha SIM	55% DAGB t/ha OBS	55% DAGB t/ha SIM
31	0.076	0.063	0.074	0.063	0.064	0.063	0.065	0.063	0.051	0.063
41	0.664	0.365	0.582	0.365	0.589	0.365	0.569	0.362	0.547	0.354
52	2.496	1.647	2.288	1.646	2.136	1.646	2.056	1.615	1.871	1.523
61	4.411	3.332	4.178	3.332	3.960	3.331	3.805	3.278	3.755	3.104
71	6.126	5.334	5.795	5.334	5.114	5.332	4.871	5.263	4.683	4.942
81	8.309	7.357	8.153	7.356	7.552	7.354	6.843	7.283	6.515	6.732
91	10.429	9.361	10.223	9.361	9.176	9.359	9.008	9.206	8.184	8.221
102	11.598	11.537	11.633	11.536	10.966	11.534	10.757	10.955	9.550	9.525
112	12.156	13.465	12.017	13.465	11.278	13.364	10.864	12.254	9.792	10.483
122	12.605	15.344	12.277	15.344	11.475	14.965	11.022	13.417	9.970	11.334
R	0.98***		0.98***		0.99***		0.99***		0.99***	
RMSE	1.2*		1.2*		1.3*		0.9*		0.6**	
NRMSE	17.1*		17.8*		21.3*		15.5*		10**	
NSE	0.93***		0.93***		0.90***		0.95***		0.98***	
D	0.99***		0.98***		0.98***		0.99***		0.98***	
R^2	0.98***		0.98***		0.99***		0.99***		0.99***	

Notes. (Field experiment, 2020) DaP is day after planting DAGB is dry aboveground biomass OBS is observed, SIM is simulated * good, ** very well, *** excellent, and + poor.

Table 4. Observed and simulated canopy cover (%) 2019 G.C.

DaP	115 % OBS	115 % SIM	100 % OBS	100 % SIM	85% OBS	85 % SIM	70 % OBS	70 % SIM	55% OBS	55 % SIM
34	7.125	5.8	6.8	5.8	6.3	5.8	5.792	5.8	5.667	5.8
44	55.05	62.7	52.35	62.7	50.308	62.7	49.683	62.7	48.933	62.7
54	84.842	89.6	85.008	89.6	83.158	89.5	81.475	89.5	77.375	89.4
64	85.55	91.8	84.633	91.8	81.692	91.8	81.608	91.8	81.35	91.8
74	88.892	92	88.375	92	85.267	92	84.108	92	82.967	92
86	86.991	92	84.108	92	83.558	92	81.1	92	79.45	92
96	85.208	90.9	84.975	90.9	81.967	90.9	81.267	90.9	74.658	90.9
106	72.725	89.2	71.067	89.2	68.825	89.2	67.675	89.2	65.325	89.2
115	70.833	87.2	68.067	87.2	64.883	87.2	61.983	87.2	57.508	87.2
R	0.98***		0.97***		0.97***		0.97***		0.96***	
RMSE	9.1**		10.4*		12.4*		13.6*		16*	
NRMSE	12.9*		15*		18.7*		20.5*		25*	
NSE	0.86***		0.82***		0.76***		0.68**		0.54	
D	0.97***		0.96***		0.95***		0.93***		0.91***	
R^2	0.96***		0.94***		0.94***		0.94***		0.92***	

Notes. (Field experiment, 2020) DaP is day after planting, CC is canopy cover, OBS is observed, SIM is simulated, * good, ** very well, and *** excellent.

Table 5. Observed and simulated canopy cover (%) 2020 G.C.

DaP	115 % OBS	115 % SIM	100 % OBS	100 % SIM	85% OBS	85 % SIM	70 % OBS	70 % SIM	55% OBS	55 % SIM
31	3.86	3.2	3.34	3.2	3.19	3.2	2.88	3.2	2.40	3.2
41	24.39	16.2	22.58	16.2	17.87	16.2	16.72	16.2	14.29	15.4
52	76.52	65	73.48	65	71.26	65	68.07	65	64.82	58.8
61	85.48	82.6	83.81	82.6	80.10	82.6	77.69	82.6	74.52	76
71	88.72	86.9	86.84	86.9	83.27	86.9	81.64	86.9	77.69	81.2
81	85.93	87.7	83.28	87.7	80.81	87.7	80.22	87.7	76.67	84.2
91	86.99	87.9	87.43	87.9	84.76	87.9	82.30	87.9	76.60	85.2
102	79.87	87.6	78.14	87.6	71.09	87.6	67.91	87.6	65.07	84.9
112	77.94	86.9	75.10	86.9	68.84	86.9	65.62	86.9	61.26	84.2
122	75.12	86.1	72.27	86.1	66.02	86.1	62.79	86.1	58.43	83.4
R	**0.98^{***}**		**0.98^{***}**		**0.96^{***}**		**0.96^{***}**		**0.94^{***}**	
RMSE t/ha	**6.9^{**}**		**7.4^{**}**		**10.6^{*}**		**12.4^{*}**		**13.1^{*}**	
(RMSE) %	**10.1^{**}**		**11.2^{**}**		**16.9^{*}**		**20.4^{*}**		**23^{*}**	
NSE	**0.94^{***}**		**0.93^{***}**		**0.85*****		**0.78^{**}**		**0.73^{**}**	
d	**0.99^{***}**		**0.98^{***}**		**0.97^{***}**		**0.95^{***}**		**0.94^{***}**	

Notes. (Field experiment, 2020) DaP is day after planting, CC is canopy cover, OBS is observed, SIM is simulated, * good, ** very well, and *** excellent.

3.3 Performance of AquaCrop in simulating soil water content after irrigation in year 2019 & 2020 G.C.

As presented in Table 6 and Table 7 and Figures 3-7, the soil water after irrigation had poor to excellent model efficiency NSE (0.09, 0.43, 0.96, 0.97 and 0.98 in year 2019 and 0.48, 0.73, 0.89, 0.93 & 0.89 in year 2020 G.C.) for the water levels 115%, 100%, 85%, 70% and 55% respectively. For normalized root mean square error, NRMSE excellent simulated as (1.3%, 0.8%, 0.75, 1.1% and 2.2% in year 2019 and 2.5, 1.5, 1.5, 1.6, & 2.5 in year 2020 G.C.) for the water levels 115%, 100%, 85%, 70% and 55% respectively. As well for the index of agreement (d) was from very well to excellent values were observed (0.86, 0.85, 0.99, 0.99 and 0.98 in year 2019 and 0.89, 0.94, 0.97, 0.98 & 0.98 in year 2020 G.C.) for the water levels 115%, 100%, 85%, 70% and 55% respectively. The simulated result on the coefficient of determination R^2 was very well to excellent simulated (0.72, 0.69, 0.96, 0.98 and 0.96 in year 2019 and 0.88, 0.91, 0.99, 0.98 & 0.86 in year 2020 G.C.) for the water levels 115%, 100%, 85%, 70% and 55% respectively. The results show that the well correlated as simulated values, however, the value of lower water levels better simulated than highest water level treatments. Generally, the soil water content after each irrigation for the simulation result was observed very well to excellent result validation results obtained.

Table 6. Observed and simulated SWC on Different water level after irrigation 2019 G.C.

DaP	115% AI OBS	115% AI SIM	100% AI OBS	100% AI SIM	855%AI OBS	85% AI SIM	70% AI OBS	70% AI SIM	55% AI OBS	55% AI SIM
2	372.2	376.4	373.8	376.4	374.4	376.4	371.2	376.4	372.2	376.4
8	369.4	366.6	369.9	366.6	370.3	366.6	371.5	366.6	369.0	366.6
13	373.1	365.9	370.0	365.9	368.2	365.9	367.3	365.9	365.0	365.9
20	369.5	364.7	367.2	364.7	369.4	364.7	372.4	364.7	369.0	364.7
25	370.5	368.0	369.1	368.0	366.8	368.0	366.8	368.0	361.3	368.0
35	366.7	368.5	366.5	365.5	360.4	363.5	364.0	360.5	349.3	357.5
45	376.9	376.2	373.4	371.9	367.0	369.3	365.5	364.8	357.8	361.7
55	378.5	384.0	374.8	372.7	365.6	363.1	352.3	352.0	336.5	342.3
66	375.5	382.5	370.2	371.0	357.0	355.5	338.8	338.4	324.9	323.7
75	381.3	386.7	378.0	371.9	351.5	351.4	324.6	329.3	314.9	310.6
85	363.6	368.3	358.5	361.4	342.5	341.1	321.0	319.1	312.2	300.4
87	376.6	376.6	370.2	368.0	348.0	345.7	322.6	320.7	304.9	300.0
96	378.0	382.2	367.6	368.7	343.0	341.5	314.5	311.4	308.3	289.0
106	380.1	388.7	373.9	370.4	338.0	336.1	308.5	301.3	285.5	281.1
R	0.85^{**}		0.83^{**}		0.98^{***}		0.99^{***}		0.98^{***}	
RMSE	4.90^{***}		2.80^{***}		2.40^{***}		4.00^{***}		7.5^{***}	
CV(NRMSE)	1.30^{***}		0.80^{***}		0.70^{***}		1.10^{***}		2.2^{***}	
NSF	0.09^{+}		0.43^{*}		0.96^{***}		0.97^{***}		0.93^{***}	
D	0.86^{**}		0.85^{**}		0.99^{***}		0.99^{***}		0.98^{***}	
R^2	0.72^{**}		0.69^{**}		0.96^{***}		0.98^{***}		0.96^{***}	

Table 7. Observed and simulated SWC on Different water level after irrigation 2020 G.C.

DaP	115% obs	115% sim	100% obs	100% sim	85% obs	85% sim	70% obs	70% sim	55% obs	55% sim
11	384.23	378.9	380.69	378.4	373.66	378.4	368.45	378.4	371.87	378.4
21	405.06	386.1	402.75	386.1	383.65	386.1	382.75	386.1	380.27	386.1
31	418.94	421.4	415.22	416.5	408.78	411.4	396.21	406.4	393.41	402.4
41	424.92	424	419.09	419.7	404.50	412.5	395.40	402.4	391.76	394.1
52	422.05	418.5	411.45	413	403.03	405.4	388.70	390.1	384.77	377.5
61	439.05	417.9	406.09	410.6	386.12	398.3	377.06	377.2	367.50	360.8
71	434.82	421.6	406.84	411.4	384.99	394.1	363.85	369.9	358.89	348.2
81	424.96	417.7	404.40	408.8	383.85	387.5	366.12	356.4	349.63	335.7
91	426.48	419.8	409.78	407.7	376.69	380.4	345.72	344.2	338.27	324.9
102	413.82	413.7	404.22	399.6	362.33	366.3	335.33	336.2	328.28	321.0
112	409.00	401.2	384.18	382.3	344.12	346.6	328.34	324.2	304.23	312.1
R	0.88**		0.91***		0.99***		0.98***		0.86***	
RMSE t/ha	10.4***		5.9***		5.9***		6****		8.9***	
CV(RMSE) %	2.5***		1.5***		1.5***		1.6***		2.5***	
NSE	0.48*		0.73**		0.89***		0.93***		0.89***	
D	0.87**		0.94***		0.97***		0.98***		0.98***	

observed vs simulated 115% water level

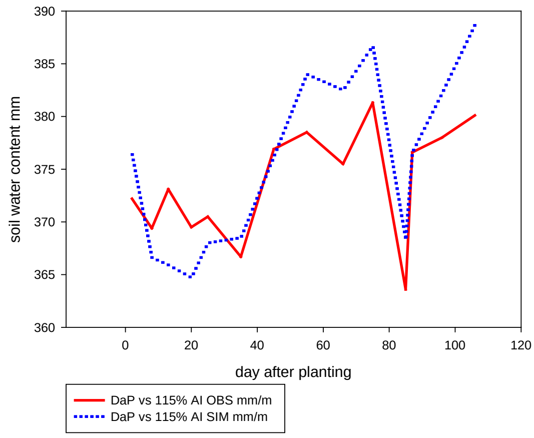

Figure 3. Observed Vs. Simulated at 115% water level 2019 G.C.

Observed vs. simulated 100% water level

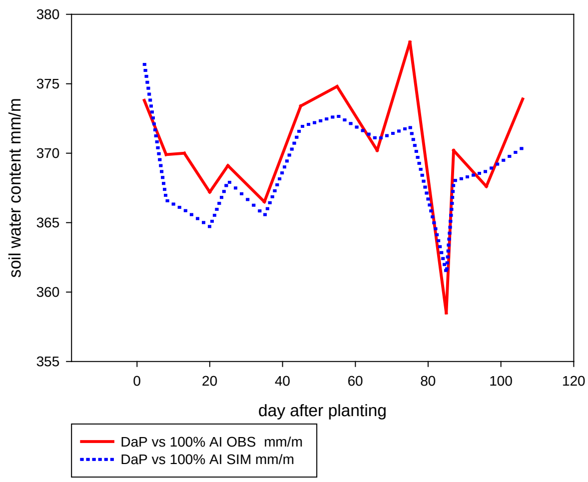

Figure 4. Observed Vs. Simulated at 100% water level 2019 G.C.

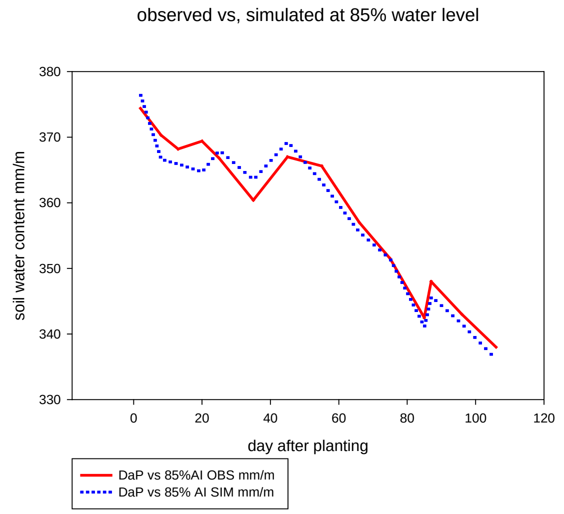

Figure 5. Observed Vs. Simulated at 85 % water level 2019 G.C.

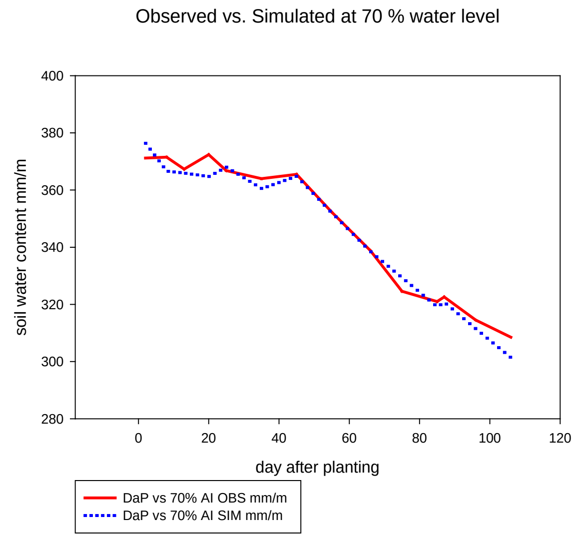

Figure 6. Observed Vs. Simulated at 70 % water level 2019 G.C.

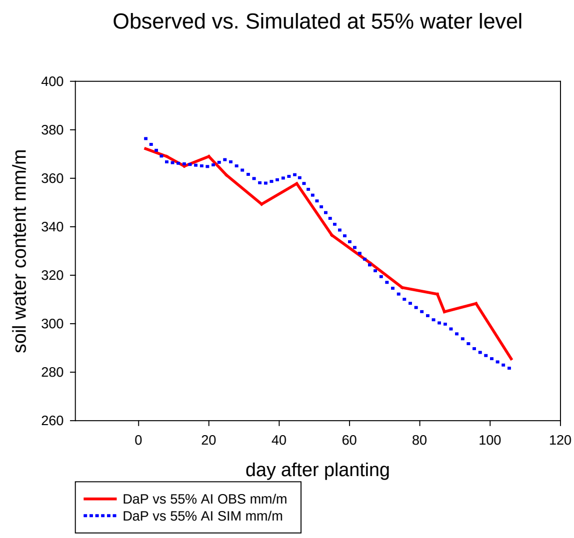

Figure 7. Observed Vs. Simulated at 55 % water level 2019 G.C.

3.4 Effect of water level on, tuber yield and crop water productivity (combined 2019 and 2020)

As presented in Table 8, the effect of different irrigation water levels on the mean marketable fresh tuber, weight ranges from 36.09 ton/ha to 43.13 ton/ha observed in combined year (2019 and 2020 G.C). There was highly significant difference among treatments at ($p < 0.05$). The water levels 115% and 100% water levels had significantly highest value of 43.13 ton/ha and 42.07 ton/ha respectively followed by 85% and 70 % water level had 38.77 ton/ha and 38.27 ton/ha respectively, but 55% water level had the least value (36.09 ton/ha) recorded. The results are on the line of FAO, I & D paper 66 document 40 ton/ha to 50 ton /ha [13]. This result agree with on fresh tuber yield was obtained in Iraq 35.23 ton/ha in furrow irrigation [24]. And also, Birhanu [25] reported 56.85 ton/ha and 39.08 ton/ha fresh potato tuber yield observed in Hirna and Haramaya respectively in 2013, during the main season.

As presented in Table 8, the water productivity on fresh potato tuber ranges 14.12 kg/m^3 to 9.75 kg/m^3 were observed. There was highly significant difference among treatments at ($p < 0.05$). The water levels 55% water levels had the highest value 14.12 kg/m^3 followed by 70% and 85% water level had 11.50 kg/m^3 and 10.63 kg/m^3 respectively. The least water productivity had 9.75 and 10.47 kg/m^3 was obtained in 115 % and 100% of water level. This result little higher value than FAO I & D paper 66 document recorded in the range of 4 kg/m3 to 11 kg/m^3 [13]. Another research was found the water productivity on potato crop in Iraq ranges 5.129 kg/m^3 to 7.379 kg/m^3 [24].

Table 8. Combined results in yield and water productivity (2019 and 2020 G.C)

Parameters	*Treatments*					Grand Means	LSD	CV (%)	r2	P value <0.05
	115%	100%	85%	70%	55%					
Fresh unmarketable yield ton/ha	0.88	0.76	0.95	0.94	0.87	0.880	ns	21.3	0.70	<0.0001
Fresh marketable yield ton/ha	43.13^a	42.07^a	38.77^b	38.27^b	36.09^c	39.66	1.802	4.135	0.80	<0.0001
Total yield ton/ha	43.65^a	43.15^a	39.83^b	38.92^b	37.67^c	40.24	1.458	3.298	0.89	<0.0001
Crop water productivity kg/m^3	9.75^c	10.47^c	10.63^{bc}	11.50^b	14.12^a	11.29	0.918	7.395	0.91	<0.0001
Irrigation mm	374.9^a	336.8^b	298.7^c	260.7^d	183.7^e	290.9	12.3	3.834	0.989	<0.0001
Irrigation + rainfall mm	455.9^a	417.8^b	379.7^c	341.7^d	264.7^e	371.9	12.3	2.999	0.986	<0.0001

3.5 Yield and water productivity advantages on potato crop

As presented in Figure 8, the 115% of water level had 8.33% of extra water used over 100% of water level, while the 85%, 70% and 55% of water level had 8.33%, 16.65%, and 24.98% of water save respectively as compared to 100%. The 55% of water level had extra 25% of hectare of land opportunity observed while 55% water level, punished by 18% of yield as compared to a 100% of water level. However, the 115% water level had 8.3% of hectare of land punished as compared to 100% water level and 3% of yield advantages was recorded.

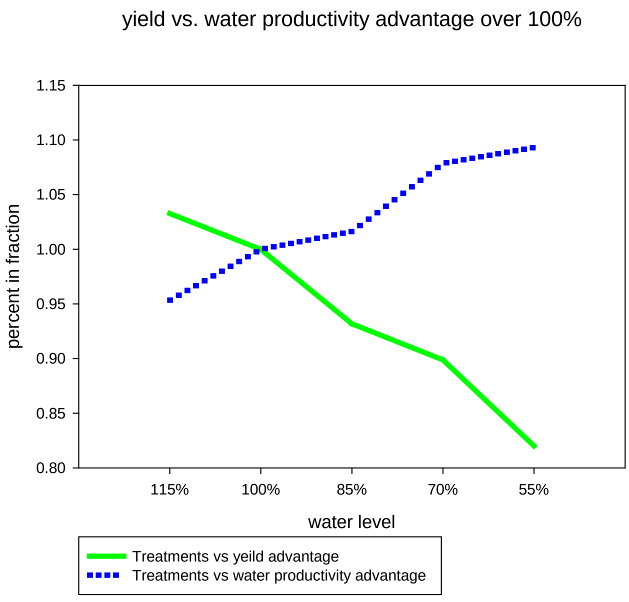

Figure 8. Yield vs water productivity opportunities.

3.6 Evapotranspiration water productivity

As presented in Figure 9, the evapotranspiration water productivity obtained from actual field experiment at 100 % water level was found to be 11.59 kg/m^3 and 12.86 kg/m^{3}in the year 2019 G.C and 2020G.C respectively. The results show that the AquaCrop model a little bit over estimated that was 13.36 kg/m^3 as compared to the actual experimental yield.

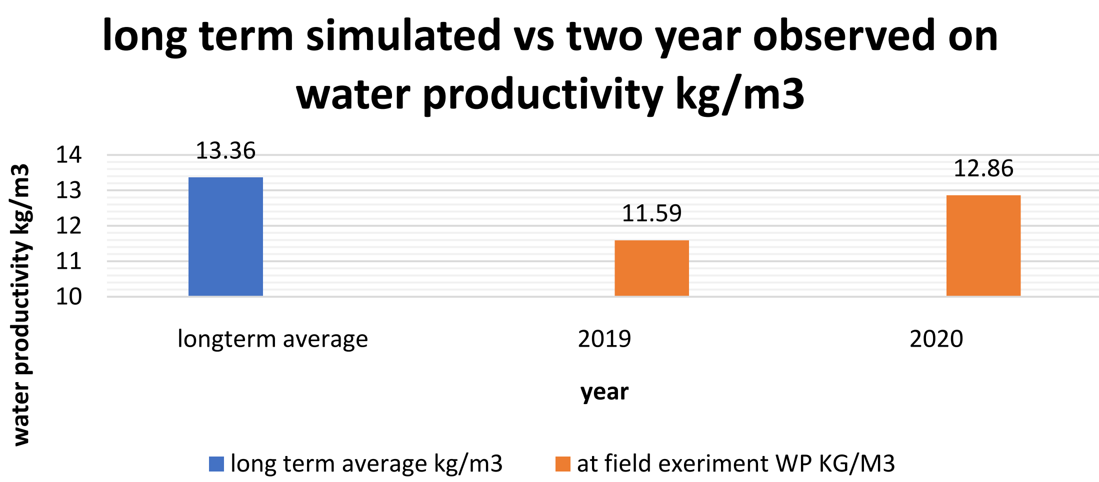

Figure 9. Water productivity on fresh potato tuber.

3.7 Partial Budget Analyses

As presented in Table 9, high marginal rates of returns (MRR, 26.1% and 22.5%) and in Table 10 in combined year (MRR, 16.17% and 25%) were also observed under 70% and 100% water levels, respectively. Meanwhile, the marginal rate of return under both the 115% and 85% water levels was found to be 10.3 in combined year. Thus, 70% and 100% water levels resulted in better results and in line with a study conducted in Spain that higher yields were obtained under 100% and 80% water level [23].

Table 9. Total variable cost, net benefit and marginal rate of return (MRR) 2019

Treatment	AY kg/ha	ADY kg/ha	FP/KG (ETB)	GFB/KG (ETB)	TVC (ETB/ha)	NB (ETB/ha)	MC	MB	MRR
55%	35,850	32,265	20.00	645,300	8,374.6	6,369,254			
70%	39,290	35,361	20.00	707,220	10,658.5	696,562	2,284	59,636	26.1
85%	40,730	36,657	20.00	733,140	12,942.5	720,198	2,284	23,636	10.3
100%	43,710	39,339	20.00	786,780	15,226.5	771,554	2,284	51,356	22.5
115%	45,140	40,626	20.00	812,520	17,510.4	795,010	2,284	23,456	10.3

Notes. AY is average yield kg/ha, ADY is (-10%) adjusted yield kg/ha, FP is field price per kg, GFB is gross filed benefit kg/ha, TVC is total variable cost (Birr/ha), NB is net benefit (Birr/ha) MC is marginal cost, MB is marginal benefit and MRR is marginal rate of return.

Table 10. Total variable cost, net benefit and marginal rate of return (MRR) combined year

Treatment	AY kg/ha	ADY kg/ha	FP/KG (ETB)	GFB/KG (ETB)	TVC (ETB/ha)	NB (ETB/ha)	MC	MB	MRR
55%	36,087.9	32,479.11	20	649,582.2	8,374.6	641,207.6			
70%	38,266.6	34,439.94	20	688,798.8	10,658.5	678,140.3	2,283.9	36,932.7	16.17089
85%	38,768.6	34,891.74	20	697,834.8	12,942.5	684,892.3	2,284	6,752	2.956217
100%	42,068.1	37,861.29	20	757,225.8	15,226.5	741,999.3	2,284	57,107	25.00306
115%	43,128.2	38,815.38	20	776,307.6	17,510.4	758,797.2	2,283.9	16,797.9	7.354919

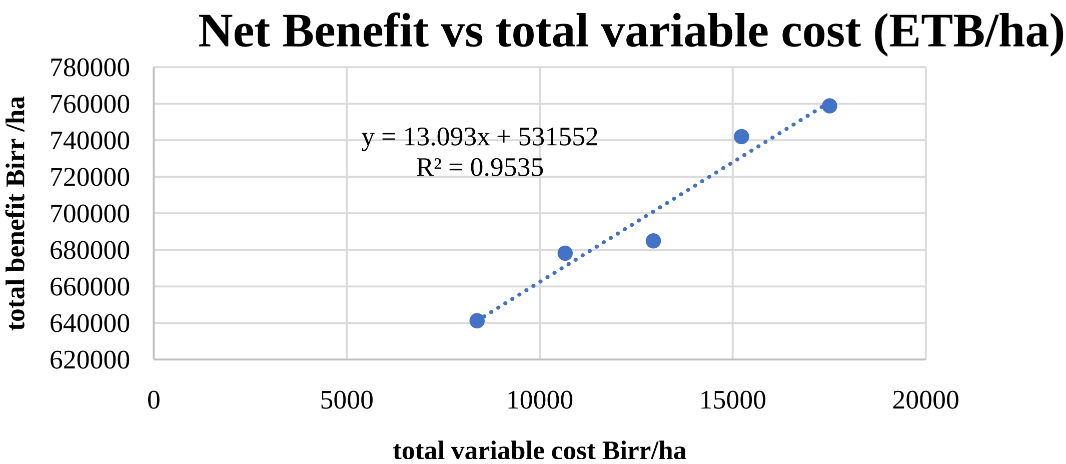

Figure 10. Net Benefit Vs total variable cost in combined year.

As presented in Figure 10 in 70 % and 100 % water level showed that above the fitted line while 50%, 85% and 115% had on and below the line This R^2 value (0.9535) was indicated that 95.35% of variation comes from treatment variation. The highest marginal rate of return (25.00% and 16.17%) was also observed for 70% and 100% water level respectively. While, the water level 115% and 85% was 7.35% and 2.95% respectively, while the water level 55% as control (least cost). Results in the line with as reported in Spain, the higher yield in 100% and 80% [23].

4. Conclusion and recommendations

The following points are given as concluding remarks based on the results of this study.

- ✓ The AquaCrop model simulated results showed that for 100% was 3,772.0 m^3/ha used in growing season. For the rest of other water levels used as corresponding of their percentage of the 100% water level (4,086.1 m^3/ha, 3,457.9 m^3/ha, 3,143.8 m^3/ha and 2,829.8 m^3/ha of water used for 115%, 85%, 70% and 55% of water level respectively.
- ✓ Based on the results of the model performance indictors used in this study, the AquaCrop model was found to well simulate all considered crop parameters. The AquaCrop model performance in the canopy cover, dry aboveground and tuber biomass and soil water content of the potato crop. The statistical indicators; Nash-Sutcliffe efficiency (NSE), Normalized Root mean square error (NRMSE) index of agreement (d) and Coefficient of determination (R^2) showed very well to excellent efficiency, there value is in ranges on aboveground and tuber biomass ranges 0.78 to 0.99, 14.1 to 35.5, 0.96 to 0.99 and 0.96 to 0.98 was observed respectively. However, the result of soil water content before irrigation was found to be poor efficiency ranges -0.96 to 0.00, 10.2 to 10.7, 0.5 to 0.78 0.081 to 0.45 respectively in the above order.
- ✓ The statistical analysis had highly significantly affected on growth parameters and yield of potato crop on different water level. The fresh potato yield ranges from 36.09 ton/ha to 43.13 ton/ha was obtained in 55% and 115% water levels respectively. The water levels 115% and 100% water levels had significantly highest value of 43.13 ton/ha and 42.07 ton/ha respectively followed by 85% and 70 % water level had 38.77 ton/ha and 38.27 ton/ha respectively, but 55% water level had the least value (36.09 ton/ha) recorded. The water productivity ranges from 11.59 kg/m^3 to 12.67 kg/m^3 was obtained in 55% and 115% water level respectively. The best combination among the treatment was found to be on the water level of 100 % for no water scarce area and 70% under water scarce area.
- ✓ The results of partial budget analyses showed that 70% and 100% water levels best fitted the net benefit with the total variable cost being above the trend line. The highest marginal rates of return (26.1% and 22.5%) were obtained under for 70% and 100% water levels, respectively. Therefore, I recommended in the study area and similar area with two scenarios. The first one is under “water scarce” condition, farmers should apply 70% of the irrigation water requirement with 10-days irrigation interval. On the other hand, under “no water scarce” condition”, farmers should apply 100% irrigation water requirement with 10-days irrigation interval.

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Appendix

Appendix Table 1. Non-conservative parameters used for AquaCrop Potato Model

Non-conservative (crop specific) parameters	Values
Plant density (plants ha−1)	44,444.44
Initial canopy cover CCo (%)	0.67
Maximum canopy cover CCx (%)	88
Time to maximum canopy cover (d)	60
Time to flowering (d)	51
Length of the flowering stage (d)	27
Time to senescence (d)	95
Time to maturity (d)	115
Maximum rooting depth (m)	0.70
Minimum effective rooting depth (m)	0.50
Reference harvest index HIo (%)	75

Appendix Table 2. Conservative parameters used for AquaCrop Potato Model

Conservative parameters	Values
Base temperature (°C)	2
Upper temperature (°C)	26
Cover per seedling (cm2 plant−1)	0.4
Canopy growth coefficient CGC (% d−1)	0.14
Canopy decline coefficient CDC (% d−1)	0.08
Soil water depletion factor for canopy expansion, upper limit	0.25
Soil water depletion factor for canopy expansion, lower limit	0.55
Shape factor for Water stress coefficient for canopy expansion	0
Soil water depletion factor for stomata closure	0
Shape factor for Water stress coefficient for stomata closure	0
Soil water depletion factor for early canopy senescence	0
Shape factor for Water stress coefficient for canopy senescence	0
Normalized water productivity WP* (g m^{-2})	18
Normalized water productivity during yield formation WP* (g m^{-2})	18

Appendix Table 3. Results yield and yield parameters and water productivity 2019G.C

Parameters	*Treatments*					Grand Means	LSD	CV (%)	r2	P value <0.05
	115%	100%	85%	70%	55%					
Fresh unmarketable yield ton/ha	0.77[a]	0.69[ab]	0.67[ab]	0.66[b]	0.61[b]	0.681	0.102	9.704	0.73	0.0096
Fresh marketable yield ton/ha	44.37[a]	43.02[a]	40.06[b]	38.63[b]	35.25[c]	40.27	1.742	2.808	0.94	<0.0001
Total yield ton/ha	45.14[a]	43.71[a]	40.73[b]	39.29[b]	35.85[c]	40.95	1.758	2.787	0.94	<0.0001
Crop water productivity kg/m^3	11.05[c]	11.59[b]	11.78[b]	12.5[a]	12.67[a]	11.92	0.509	2.599	0.98	<0.0001
Irrigation mm	311.8[a]	280.4[b]	249[c]	217.6[d]	186.1[e]	235.4	0	0	1	<0.0001
Irrigation + rainfall mm	408.6[a]	377.2[b]	345.8[c]	314.4[d]	282.9[e]	332.2	0	0	1	<0.0001