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Evaluation of Aquacrop model for potato crop in semiarid region

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Abstract
The analysis of experiment entitled "Evaluation of Aqua Crop model for potato crop" carried out using resulted data of field experiment for *rabi* season in 2020-21, 2021-22 and 2022-23 (Chavan, 2023 and Golande, 2024) [2, 7] at the Demonstration-cum-Research Farm of the Interfaculty Department of Irrigation Water Management, Mahatma Phule Krishi Vidyapeeth, Rahuri. This study aimed to calibrate and validate the FAO Aqua Crop model for potato crop using a factorial randomized block design with nine treatments and four replications. The Aqua Crop model was calibrated using data from 2020-21 and 2021-22, focusing on canopy cover, biomass, and yield, and validated with 2022-23 data. Calibration of AquaCrop model was done using three parameters *i.e* canopy cover, biomass and tuber yield. The calibration of the model for the *rabi* season of 2020-21 revealed a good fit for canopy cover (CC) with a coefficient of determination R^2 = 0.92, Root mean square error = 0.96, index of agreement = 0.96, and Mean Absolute error = 0.05, good prediction for biomass (R^2 =0 .90, RMSE = 0.25, d(IA) = 0.90, MAE = 0.01) and good prediction for yield (R^2 =0 .88, RMSE = 0.19, d(IA) = 0.99, MAE = 0.01). The calibration of the model for the *rabi* season of 2021-22 revealed a good fit for canopy cover (CC) with a coefficient of determination R^2 = 0.93, Root mean square error = 0.95, index of agreement = 0.96, and Mean Absolute error = 0.05, good prediction for biomass (R^2 =0.89, RMSE = 0.21, d(IA) = 0.89, MAE = 0.01) and good prediction for yield (R^2 =0 .84, RMSE = 0.25,d(IA) = 0.86, MAE = 0.01). The validation of the Model for rabi season of 2022-23 revealed a good fit for Biomass (R^2 = 0.89, (RMSE) = 0.21, d (IA) = 0.92, MAE = 0.01) good prediction for yield (R^2 =0 .81, RMSE = 0.24, d(IA) = 0.88, MAE = 0.01).The model slightly overestimated biomass and yield due to climatic influences but remained within acceptable limits. Aqua Crop model is considered a useful tool in predicting Canopy cover, biomass and yield.

Keywords: Potato, aqua crop, calibration, validation, yield, biomass, canopy cover

Introduction
Crop models based on different irrigation strategies and for specific edaphoclimatic conditions can be used to predict crop yields (Pereira *et al.*, 2002) [16]. Non-specific crop models as CropSyst (Stöckle *et al.*, 2003) [17] as well as potato simulator models as Substor-POTATO (Griffin *et al.*, 1993) [18] and LINTUL-POTATO (Kooman and Haverkort, 1995) [19], require the calibration of a great number of parameters for the simulation process. Moreover, the scientific approach of these models does not recommend their use by farmers and technicians. The Aquacrop model attempts to balance accuracy, simplicity and robustness to be useful for technicians and managers of irrigable areas (Raes *et al.*, 2009, Steduto *et al.*, 2009) [13, 9]. This model analyzes crop growth and development (canopy cover and accumulated biomass), soil water content and evapotranspiration from herbaceous crops. However, due to its simplicity the model is not able to simulate the soil erosion, the emission of CO_2 to atmosphere, or the balance of nutritional elements. The Aquacrop model was used to simulate the growth of several crops, including cotton (Farahani *et al.*, 2009) [4], maize (Hsiao *et al.*, 2009, Paredes *et al.*, 2014) [10, 11], wheat (Andarzian *et al.*, 2011), barley (Araya *et al.*, 2010) [20], quinoa (Geerts *et al.*, 2009) [6], sunflower (Todorovic *et al.*, 2009) [15], potato (García-Vila and Fereres, 2012). The Aquacrop manual defines a set of calibrated values for the most relevant crops. For the potato crop, Raes *et al.*, (2012) [21] stated that the goodness of fit for the calibrated parameters values was low. Other researchers (Domínguez *et al.*, 2011 [3], García-Vila and Fereres, 2012) [22] analyzed potato crop yield simulations, but the

Model Parameters were not calibrated by experimental field tests specifically designed to calibrate the model.

The FAO AquaCrop model is user friendly software that maintains an optimum balance between accuracy, robustness and simplicity with relatively less number of input data. The model works on the combined data input fed through user interface and the production potential can be generated by taking in to considerations of soil (per cent of sand, clay, loam), weather (air temperature, reference evapotranspiration and rainfall), crop (initial, final and rate of change in percent canopy cover, biomass water productivity, harvest index, typical management conditions such as irrigation dates and amounts, sowing and harvest dates, etc.) and field management practices. Algorithms and governing equations of various interfaces, generates the output in the form of spread sheets and graphical representations at the end of each time step. It is especially suitable for development of agricultural water management strategies for variety of objectives and applications under different climatic conditions. The AquaCrop model represents an effort to incorporate current knowledge of crop physiological responses into a tool that can predict the attainable yield of a crop based on the water supply available.

The potato (*Solanum tuberosum* L.) has become India's fourth most crucial food crop, following rice, wheat and maize. As a member of the *Solanaceae* family which also includes peppers, eggplant, tomato and tobacco it is highly sensitive to both water deficits and temperature fluctuations. Rich in vitamins and minerals essential for human health, potatoes are an indispensable part of the Indian vegetable repertoire. In the current shift from cereals toward horticultural crops, many farmers are finding that replacing wheat or barley with potatoes yields better economic returns. Moreover, potato farming is versatile across diverse agricultural systems: its rapid growth cycle producing high yields in around 100 days makes it ideal for double-cropping with rice and well-suited for intercropping alongside maize and soybeans.

Material and methods

Study Site: The analysis of experiment entitled "Evaluation of AquaCrop model for potato crop" carried out using resulted data of field experiment for *rabi* season in 2020-21, 2021-22 and 2022-23 (Chavan, 2023 and Golande, 2024) [2, 7] at Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra, India (19.85 °N, 74.63 °E, 513 m above mean sea level). The region has a semi-arid tropical climate with hot, dry summers and mild winters. Annual rainfall averages 700-800 mm, mostly during June-September.

Experimental Design and Treatments

A field experiment was set up in a factorial randomized block design with nine treatments and four replications. Treatments combined three mulching conditions: (1) silver-black plastic mulch (2) maize stover mulch, and (3) no mulch (control). These were crossed with three irrigation levels based on crop evapotranspiration (ETc): (1) 1.0 ETc, (2) 0.8 ETc, and (3) 0.6 ETc. Potato variety *Kufri Pukhraj* was planted at 60,000 plants ha^{-1}, with row spacing of 45 cm and plant spacing of 30 cm. Sowing dates varied slightly across years due to weather. Fertilizers were applied at 150:80:120 kg N:P:K ha^{-1}. Pests and diseases were managed with recommended practices.

Data Collection

Daily weather data (maximum/minimum temperature, rainfall, solar radiation, humidity, wind speed) were collected from an on-site weather station.

Climate Data

The Climate data for the crop period were collected from the Meteorological observatory of the All India Coordinated Research Project on Irrigation water Management, Mahatma Phule Krishi Vidyapeeth Rahuri. It comprised (maximum and minimum temperature (°C), mean daily relative humidity (%), daily sunshine hours (hr), wind speed (ms^{-1}), rainfall (mm) and evaporation (mm day^{-1}).

Crop Data

The potato crop was selected for the formulation of irrigation treatments and assessment of water use efficiency in the field. The AquaCrop model requires crop-specific parameters such as yield, biomass, harvest index, plant height, crop growth stages and green canopy cover (CC). In addition, user-defined parameters including crop cultivar, timing of the crop cycle, water management practices and agronomic inputs are also essential for accurate model simulation. The data collected was divided for calibration and validation was presented in Table 1.

Table 1: Division of data and input data preparation

Particulars	Calibration		Validation
	2020-21	2021-22	2022-23
Date of planting	30.11.2020	25.11.2021	22.11.2022
Date of Harvesting	08.03.2021	01.03.2022	27.02.2023
Days	99	96	97

(**Source:** Chavan, 2023 and Golande, 2024) [2, 7]

Water Resource Data

This includes irrigation methods, timing and frequency of irrigation events, net water application and water use efficiency parameters, all of which are crucial components of effective water management in the AquaCrop model.

Soil Data

The physical properties of the soil analyzed at the experimental field included soil texture, bulk density, field capacity and permanent wilting point. Additionally, the infiltration characteristics of the soil were determined.

Results and Discussion

Calibration and validation processes

AquaCrop version 6.0 was used in the study. The model was calibrated and validated by varying following parameters manually: a) Canopy cover i.e., initial canopy cover (CCo), mode of planting, canopy size of planted seedling, maximum canopy cover, plant density, canopy decline, day 1 to recovery, day 1 to maximum canopy, senescence, harvest, root system and maximum effective depth. b) Harvest index. The potato yield (Y) and biomass (B) were simulated for different treatments using the calibrated model.

Calibration of Aqua Crop Model

Aqua Crop model was calibrated for the two years *i.e.* 2020-21 and 2021-22. The field data collected for crop growth parameters i.e soil data and climate data were used as input models to simulate potato green canopy cover, tuber yield, biomass and water productivity and results obtained are presented and discussed in the following sections. The model was operated for all the selected treatments and prediction errors was calculated using observed and simulated results for tuber yield, biomass.

Canopy Cover

The observed and simulated canopy cover presented in Table 2. The observed canopy cover was determined by measuring crop shadow at regular intervals throughout the growth period (Casa *et al.*, 2013) [1]. Relationship between observed and simulated Canopy cover during calibration period presented in Fig. 1. The continuous line in the figure represents the values simulated by Aqua Crop, based on actual climate, soil and crop management conditions. It was observed that the close agreement between observed and simulated values throughout the season indicates that the model accurately represents canopy development. Hence, it can be inferred that a strong linear relationship exists between the observed and simulated canopy cover and there is close match between observed and simulated canopy cover. It is supported by high value of R^2 (0.92), as well as it is clearly indicated that canopy cover overestimated model particularly 32 to 95 days.

Biomass

The observed and simulated biomass presented in Table 3. The observed biomass ranged from 26.40 to 41.25 t ha^{-1}, the simulated biomass values ranged from 31.46 to 43.91 t ha^{-1}. The model overestimate biomass though the value of R^2 was as high as 0.90 due to increase vegetative growth under climatic conditions. It was showed that there was close agreement between observed and simulated values of biomass with the model predicted biomass values at harvest quite well with the calculated values of other statistical indices, i.e R^2 (0.90), RMSE (0.25), MAE (0.01) and d(IA) (0.90) respectively. Relationship between observed and simulated biomass during calibration period presented in Fig. 2.

Tuber Yield

In order to obtain a value of water productivity for environmental and technological conditions of Rahuri region, the final yield data of potato crop was collected from field experiment (Chavan 2023) [2]. Then a relationship was established between the observed tuber yield and yield estimated by Aqua Crop for different irrigation levels. Potato tuber yield was also adjusted by varying harvesting index manually (Pawar *et al.*, 2017) [12].

The model calibration was satisfactory as the observed and simulated values of potato yield matched well. All statistical parameters were in the acceptable range. Hence, the Aqua Crop model setup was considered as calibrated. Relationship between observed and simulated yield during calibration period presented in Fig. 3.

The observed and simulated yield presented in Table 4. It was showed that the observed potato yield varied between 24.66 and 39.29 t ha^{-1} for calibration period. For harvesting index of 70.52 per cent, the model predicted yield was varied between 27.89 t ha^{-1} to 40.25 t ha^{-1}. Coefficient of Determination (R^2) as 0.88 indicates that, Aqua Crop model was able to simulate the yield and Aqua Crop model overestimates the simulated yield than the observed throughout the crop growing period for all treatments. The model predicted yield values were quite well with the calculated values of other statistical indices, i.e RMSE (0.19), MAE (0.01) and d (IA) (0.99) respectively.

Calibration of Aqua Crop Model for potato crop during year 2021-22

Canopy cover

The results of observed and simulated Canopy cover presented in Table 5. The observed canopy cover was determined by measuring crop shadow at regular intervals throughout the growth period (Casa *et al.*, 2013) [1]. Relationship between observed and simulated Canopy cover during calibration period presented in Fig. 4. The continuous line in the figure represents the values simulated by Aqua Crop, based on actual climate, soil and crop management conditions. It was observed that the close agreement between observed and simulated values throughout the season indicates that the model accurately represents canopy development. Hence, it can be inferred that a strong linear relationship exists between the observed and simulated canopy cover and there is close match between observed and simulated canopy cover. It is supported by high value of R^2 (0.93), as well as it is clearly indicated that canopy cover overestimated model particularly 25 to 95 days.

Biomass

The observed and simulated biomass presented in Table 6. The observed biomass ranged from 25.30 to 39.50 t ha^{-1}, the simulated biomass values ranged from 29.31 to 42.08 t ha^{-1}. The model overestimate biomass though the value of R^2 was as high as 0.89. The model overestimates biomass because increase vegetative growth due to climatic conditions. It was showed that there was close agreement between observed and simulated values of biomass with the model predicted biomass values at harvest quite well with the calculated values of other statistical indices, i.e R^2 (89), RMSE (0.21), MAE (0.01) and d(IA) (0.89) respectively. Relationship between observed and simulated biomass during calibration period presented in Fig. 5.

Yield

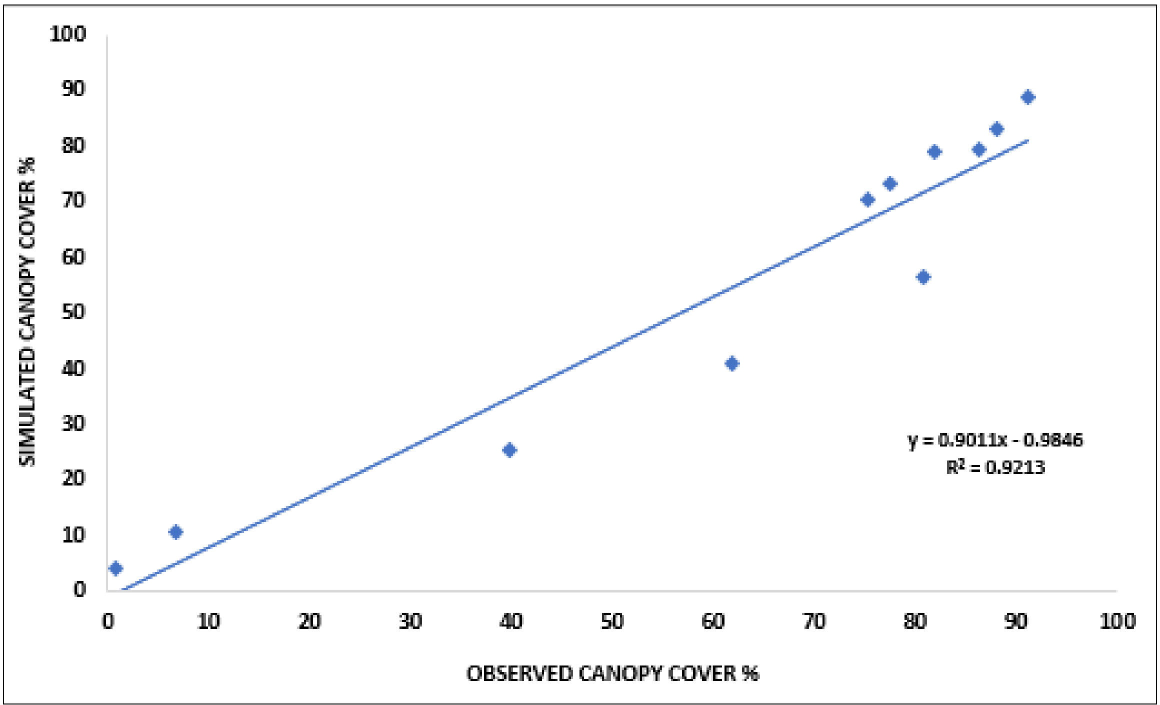
In order to obtain a value of water productivity for environmental and technological conditions of Rahuri region, the final yield data of potato crop was collected from field experiment (Golande 2024) [7]. Then a relationship was established between the observed tuber yield at field and yield estimated by Aqua Crop for different irrigation levels.

Potato tuber yield was also adjusted by varying harvesting index manually (Pawar *et al.*, 2017) [12].

The model calibration was satisfactory as the observed and simulated values of potato yield matched well. All statistical parameters were in the acceptable range. Hence, the Aqua Crop model setup was considered as calibrated for the year 2021-22. Relationship between observed and simulated yield during calibration period presented in Fig. 6. The observed and simulated yield presented in Table 7. It was showed that observed potato yield varied between 23.12 and 37.13 t ha^{-1} for calibration period. For harvesting index of 74.5%, the model predicted yield was varied between 27.93 to 40.43 t ha^{-1}. Coefficient of Determination (R^2) as 0.84 indicates that, Aqua Crop model was able to simulate the yield and Aqua Crop model overestimates the simulated yield than the observed throughout the crop growing period for all treatments. The model predicted yield values at harvest quite well with the calculated values of other statistical indices, i.e RMSE (0.25), MAE (0.01) and d (IA) (0.86) respectively.

Table 2: Observed and simulated Canopy cover during calibration of Aqua Crop Model for year 2020-21

Days after sowing	Canopy cover (%)	
	Observed	Simulated
20	4	0.8
25	10.7	6.8
32	25.4	39.8
39	40.8	61.9
46	56.3	80.8
53	79.5	86.2
60	88.7	91.2
67	83.2	88.1
74	78.8	81.8
81	73.1	77.4
95	70.4	75.2



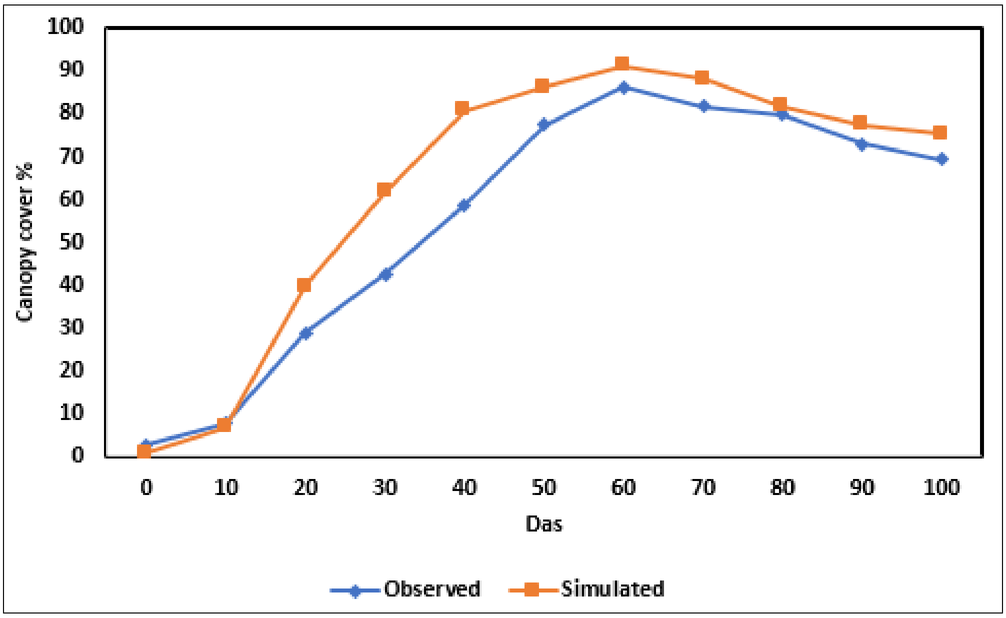
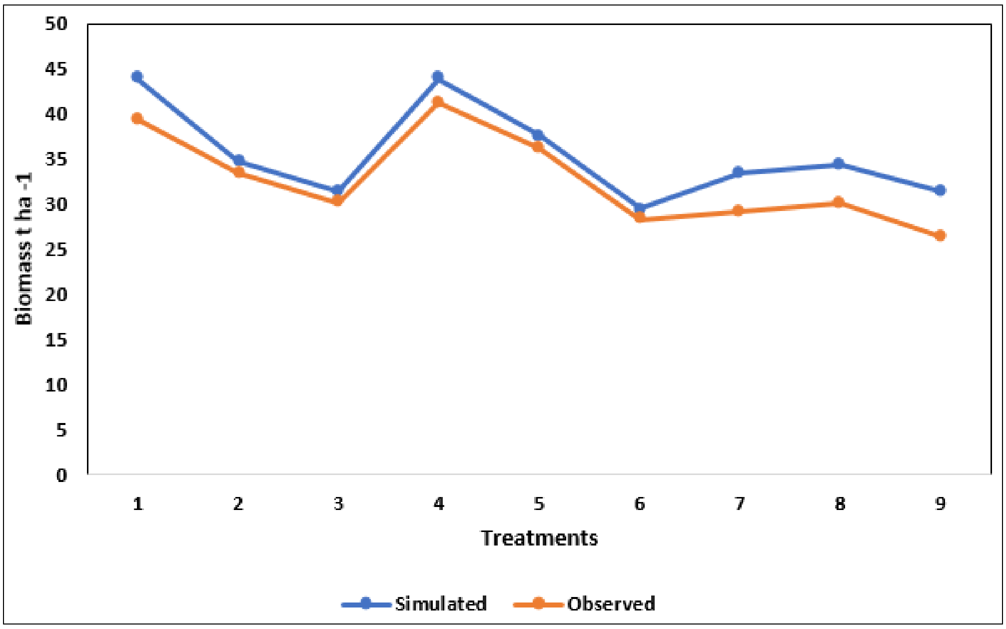


Fig 1: Relationship between observed and simulated Canopy cover for calibration during year 2020-21

Table 3: Observed and simulated biomass during calibration of Aqua Crop Model for year 2020-21

Treatments	Biomass (t ha^{-1})		
	Observed Biomass	**Simulated Biomass**	**Prediction error (%)**
T_1	39.30	43.87	10.4
T_2	33.40	34.74	3.85
T_3	30.15	31.36	3.88
T_4	41.25	43.91	6.05
T_5	36.20	37.65	3.85
T_6	28.30	29.43	3.83
T_7	29.18	33.35	12.50
T_8	30.10	34.34	12.34
T_9	26.40	31.46	16.03
RMSE		0.25	
MAE		0.01	
R^2		0.90	
d(IA)		0.90	



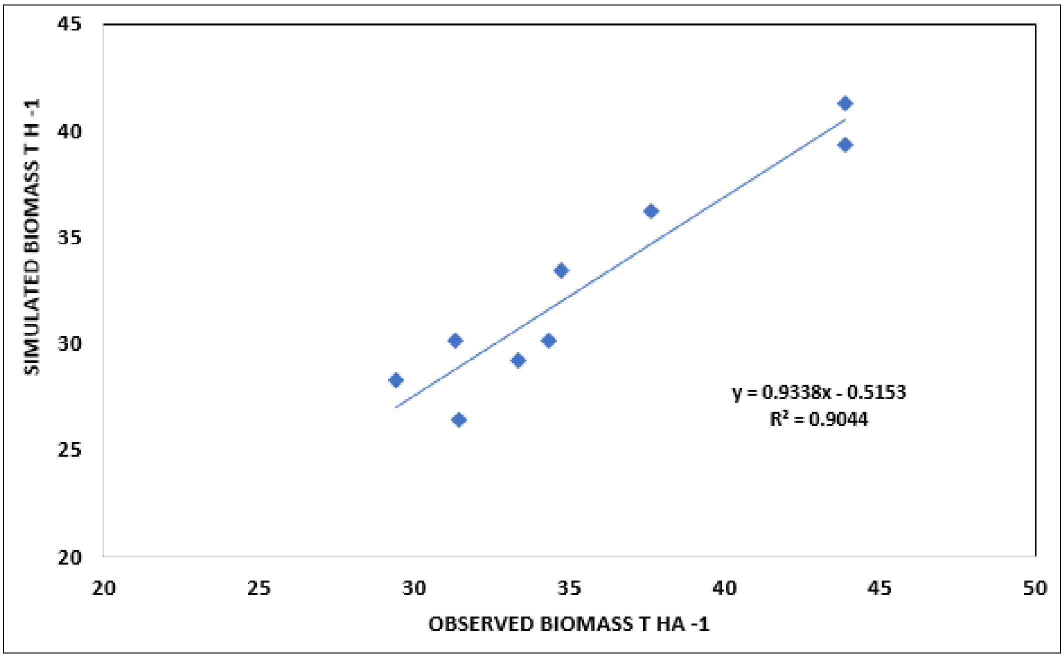
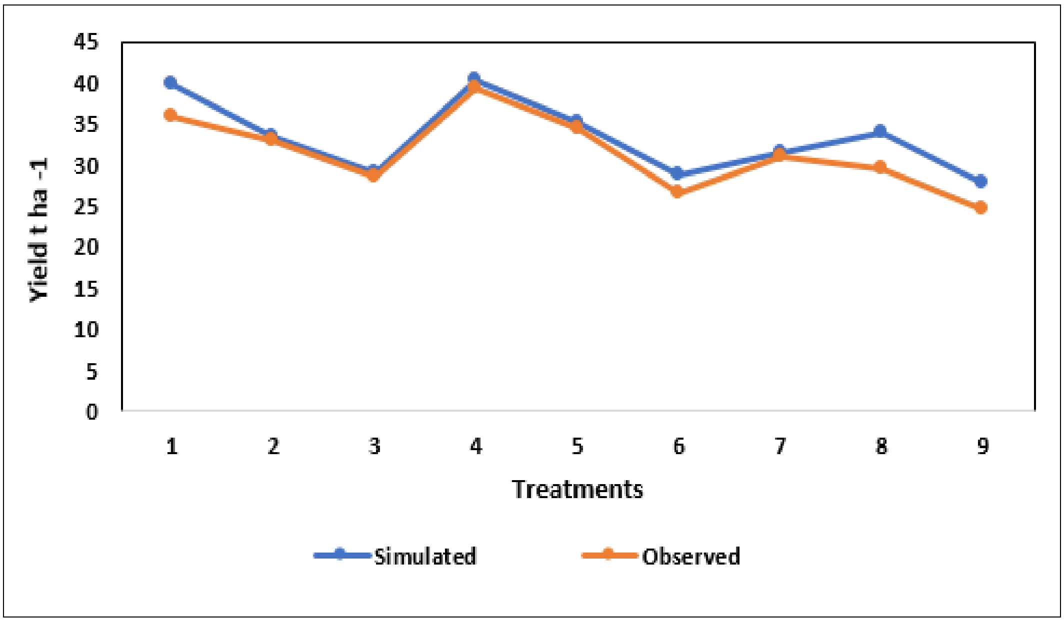


Fig 2: Relationship between observed and simulated biomass during calibration period for year 2020-21

Table 4: Observed and simulated yield during calibration of Aqua Crop Model for year 2020-21

Treatments	Yield (t ha^{-1})		
	Observed Yield	Simulated Yield	Prediction error (%)
T_1	35.96	39.76	9.55
T_2	32.88	33.52	1.90
T_3	28.59	29.02	1.48
T_4	39.29	40.25	2.38
T_5	34.41	35.13	2.04
T_6	26.49	28.81	8.05
T_7	30.94	31.49	1.74
T_8	29.41	33.88	13.18
T_9	24.66	27.89	11.58
RMSE		0.19	
MAE		0.01	
R^2		0.88	
d(IA)		0.99	



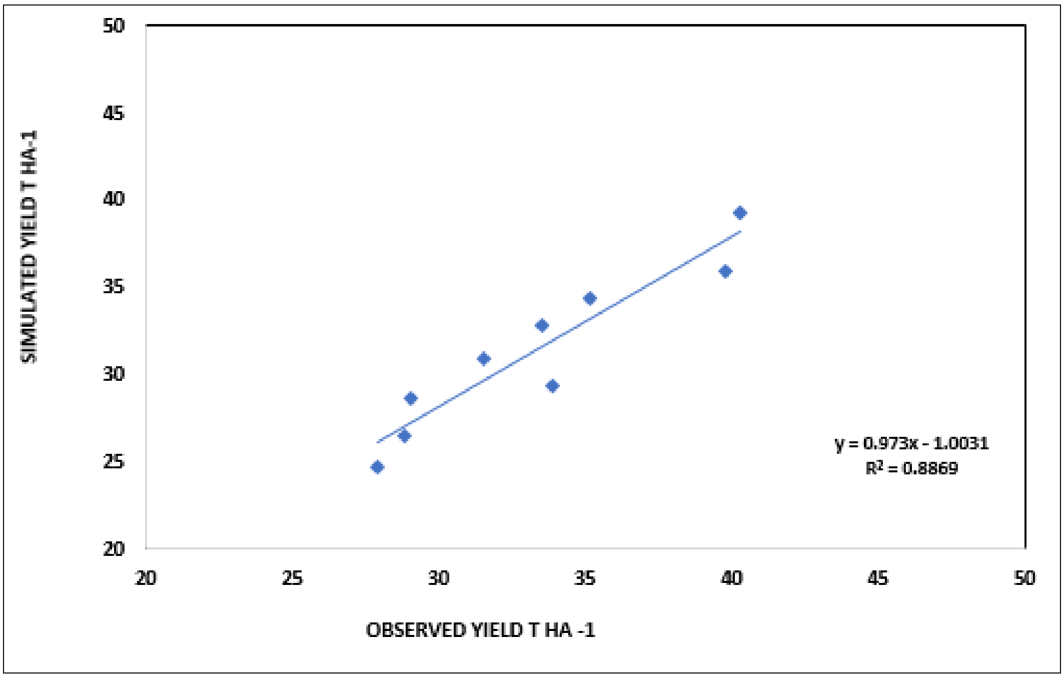
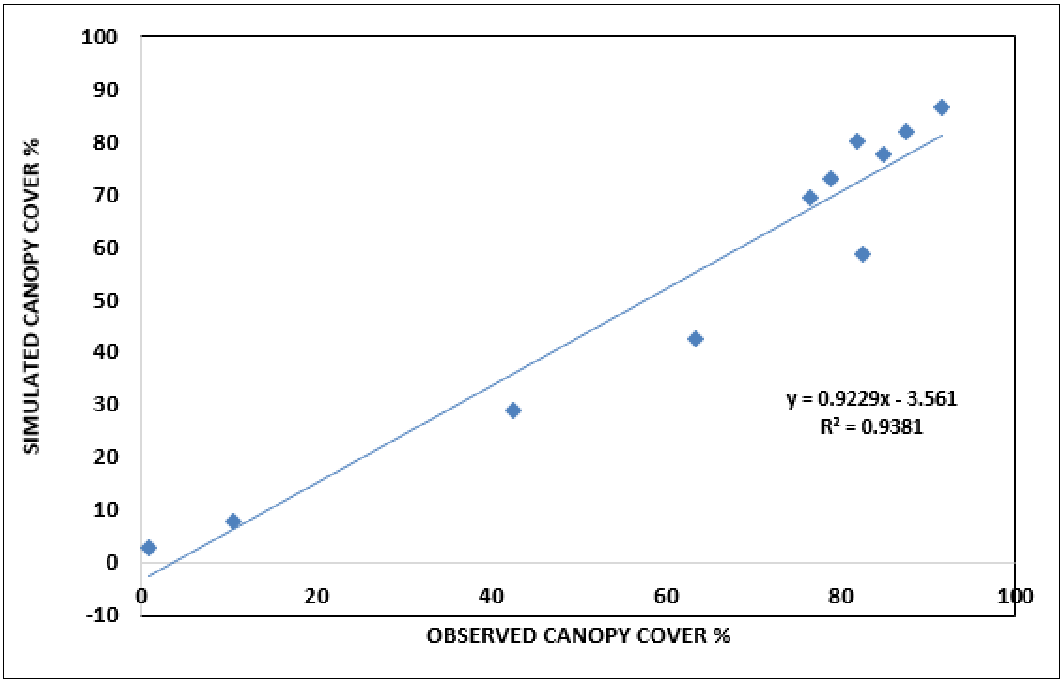


Fig 3: Relationship between observed and simulated yield during validation period for year 2022-23

Table 5: Observed and simulated Canopy cover during calibration of Aqua Crop Model for year 2021-22

Days after sowing	Canopy cover %	
	Observed	**Simulated**
20	2.6	0.89
25	7.8	10.5
32	28.8	42.5
39	42.5	63.4
46	58.6	82.6
53	77.4	84.9
60	86.3	91.6
67	81.8	87.5
74	79.8	81.9
81	72.9	78.9
95	69.4	76.4



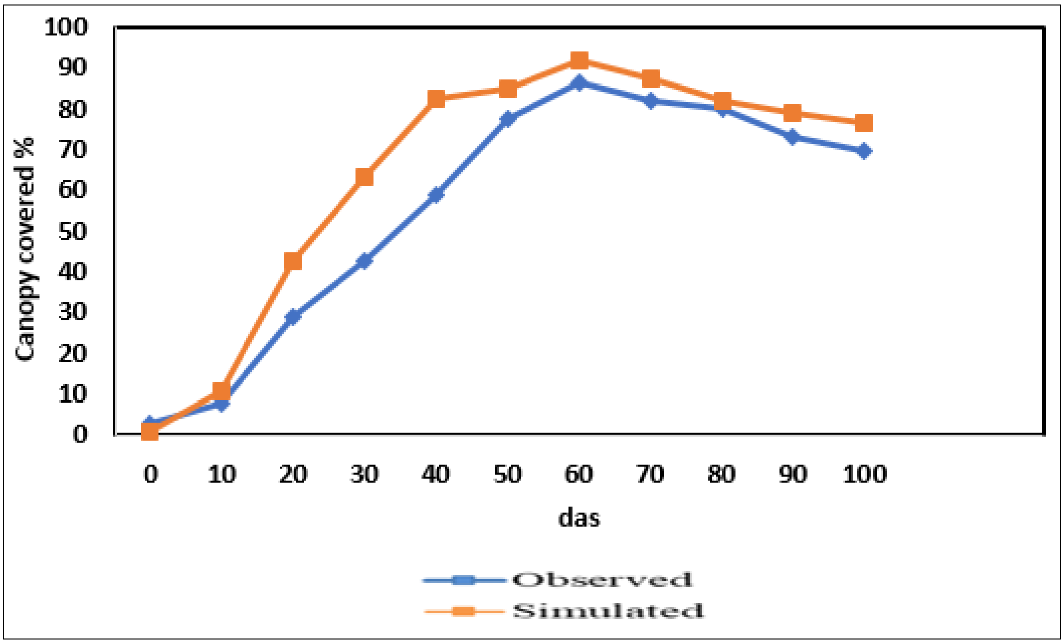
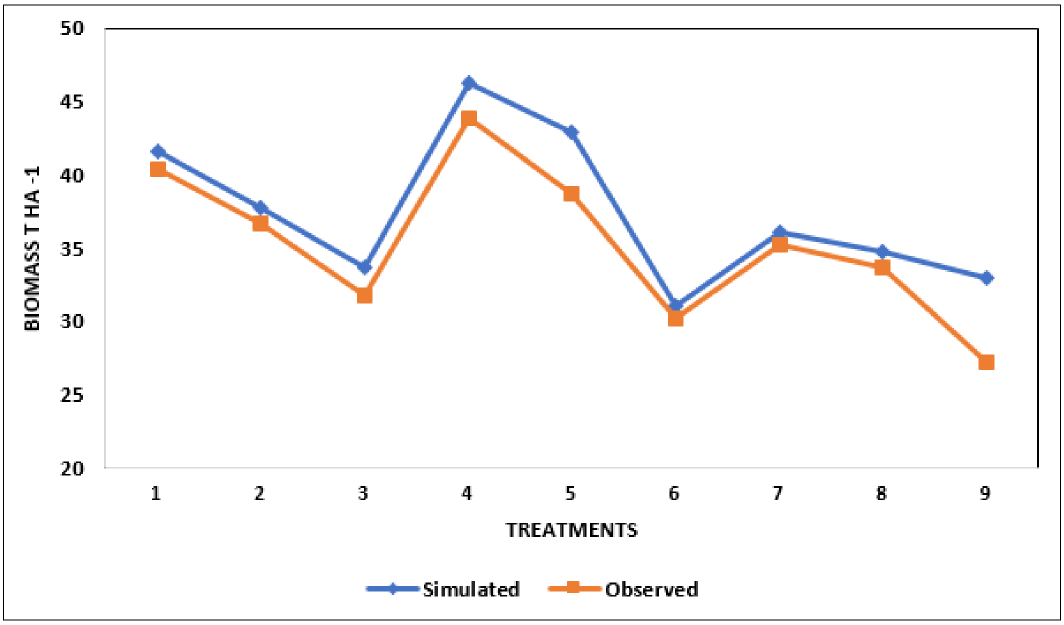


Fig 4: Relationship between observed and simulated Canopy cover for calibration during year 2021-22

Table 6: Observed and simulated biomass during calibration of Aqua Crop Model for year 2020-21

Treatments	Biomass (t ha^{-1})		
	Observed Biomass	**Simulated Biomass**	**Prediction error (%)**
T_1	34.15	35.52	3.85
T_2	32.25	33.54	3.84
T_3	28.30	31.43	9.95
T_4	39.50	42.08	6.13
T_5	35.17	39.58	11.14
T_6	27.24	28.33	3.84
T_7	32.84	33.15	0.93
T_8	31.67	34.94	9.35
T_9	25.30	29.31	13.68
RMSE		0.21	
MAE		0.01	
R^2		0.89	
d(IA)		0.89	



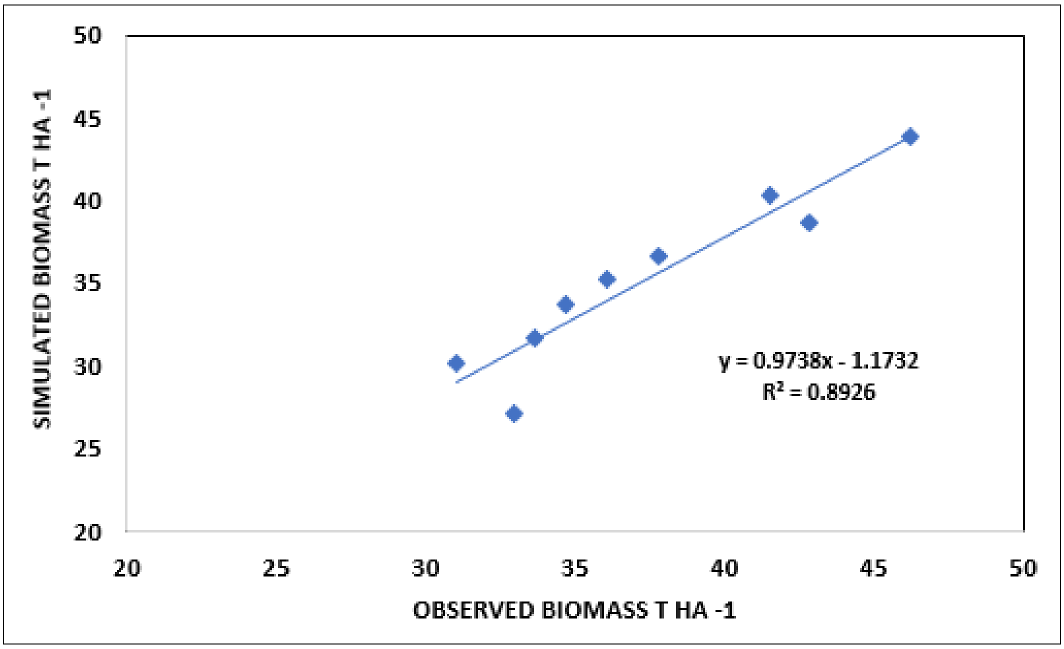
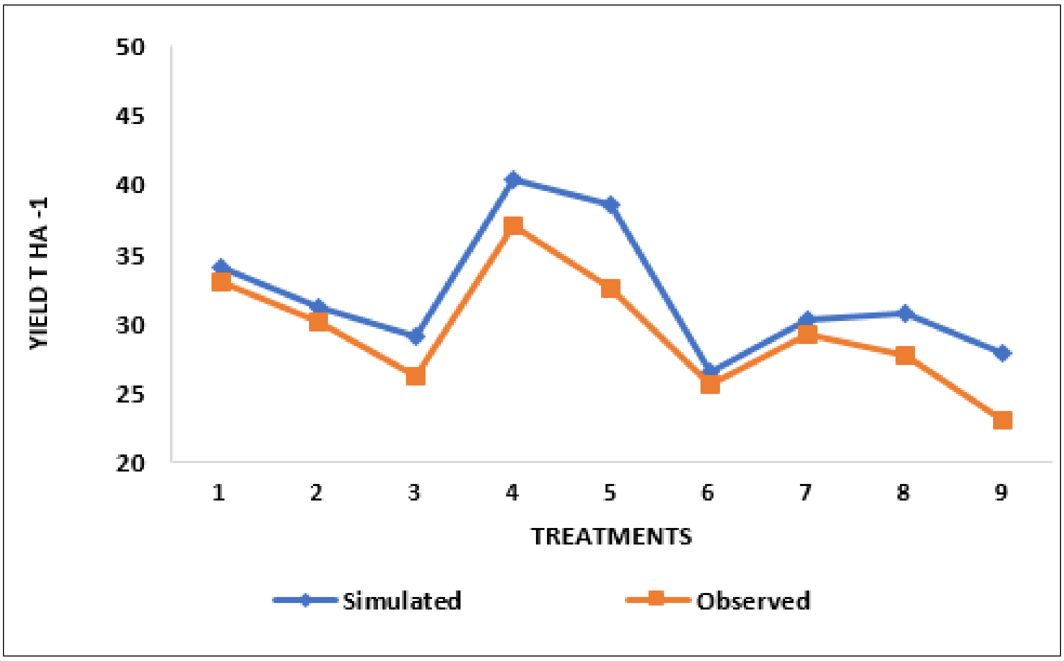


Fig 5: Relationship between observed and simulated biomass for calibration during year 2021-22

Table 7: Observed and simulated yield during calibration of Aqua Crop Model for year 2020-21

Treatments	Yield (t ha^{-1})		
	Observed Yield	**Simulated Yield**	**Prediction error (%)**
T_1	32.96	34.11	3.37
T_2	30.14	31.19	3.36
T_3	26.21	29.13	10.02
T_4	37.13	40.43	8.16
T_5	32.51	38.65	15.88
T_6	25.64	26.54	3.39
T_7	29.24	30.26	3.37
T_8	27.79	30.76	9.65
T_9	23.12	27.93	17.22
RMSE		0.25	
MAE		0.01	
R^2		0.84	
d(IA)		0.86	



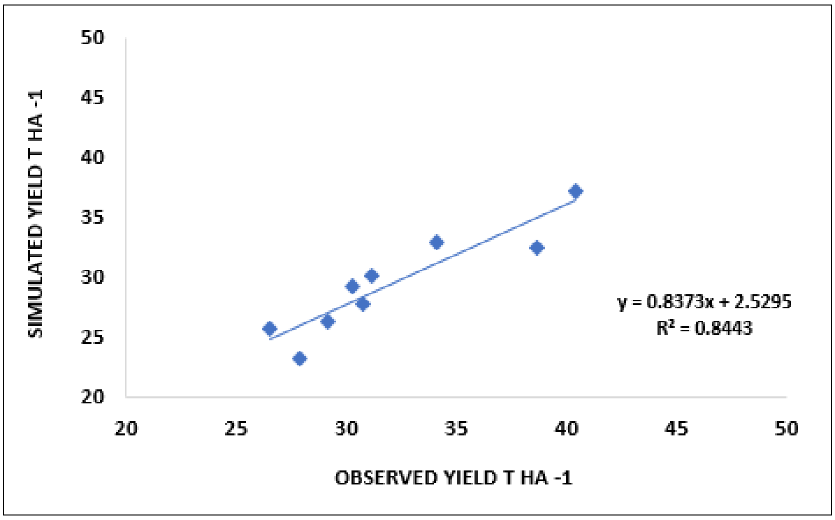


Fig 6: Relationship between observed and simulated yield for calibration during year 2021-22

Validation of Aqua Crop Model (2022-23)

Model validation was in fact the extension of calibration process. Thus, validation was carried out without any further adjustments to the calibrated model parameters. The model was validated for the year 2022 - 2023 for all the treatments. The model is suitable for assessing potato response to water management practices under Rahuri conditions.

The observed and simulated biomass presented in Table 8. It was showed that observed biomass values ranged from 27.14 to 43.88 t ha^{-1} and model predicted biomass ranged from 32.95 to 46.22 t ha^{-1}. The model overestimate biomass though the value of R^2 was as high as 0.89. It was also showed that there was close agreement between observed and simulated values of biomass. The model predicted biomass values at harvest quite well with the calculated values of other statistical parameters i.e RMSE (0.21), MAE (0.01) and d (IA) (0.92) respectively.

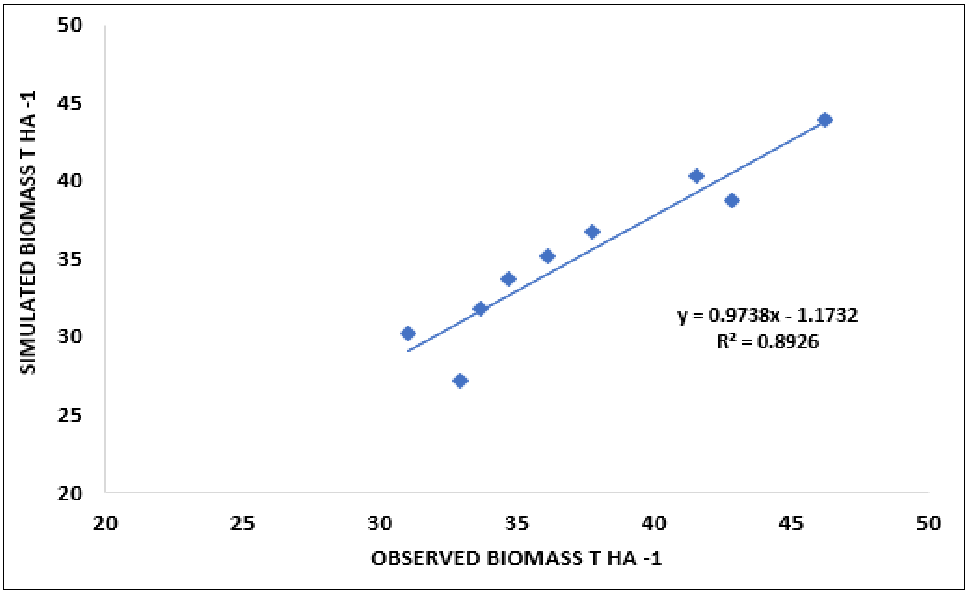
The observed and simulated yield presented in Table 9. It was showed that observed yield ranged from 25.37 to 40.74 t ha^{-1} and model predicted yield was ranged from 29.26 to 41.13 t ha^{-1}. The model overestimate yield though the value of R^2 was as high as 0.81. It was also showed that there was close agreement between observed and simulated values of yield. Aqua Crop model was able to simulate the yield. The model predicted yield values at harvest quite well with the calculated values of statistical parameters i.e RMSE (0.24), MAE (0.01) and d (IA) (0.88), respectively. The scatter plot of observed and simulated values of biomass and yield for validation period are presented in Fig. 7.

Table 8: Observed and simulated biomass during validation of Aqua Crop Model for potato crop during year 2022-23

Treatments	Biomass (t ha^{-1})		
	Observed Biomass	**Simulated Biomass**	**Prediction error (%)**
T_1	40.34	41.55	2.98
T_2	36.68	37.78	2.91
T_3	31.70	33.67	5.85
T_4	43.88	46.22	5.06
T_5	38.70	42.87	9.72
T_6	30.15	31.04	2.86
T_7	35.18	136.11	2.57
T_8	33.72	34.73	2.90
T_9	27.14	32.95	17.63
RMSE		0.21	
MAE		0.01	
R^2		0.89	
d(IA)		0.92	

Table 9: Observed and simulated yield during validation of Aqua Crop Model for potato crop during year 2022-23

Treatments	Yield (t ha^{-1})		
	Observed Yield	**Simulated Yield**	**Prediction error (%)**
T_1	37.29	38.12	2.17
T_2	34.10	35.15	2.98
T_3	29.65	33.95	12.66
T_4	40.74	41.13	0.94
T_5	35.68	39.95	10.68
T_6	27.48	28.14	2.34
T_7	32.08	37.92	15.40
T_8	30.50	31.27	2.46
T_9	25.37	29.26	13.29
RMSE		0.24	
MAE		0.01	
R^2		0.81	
d(IA)		0.88	



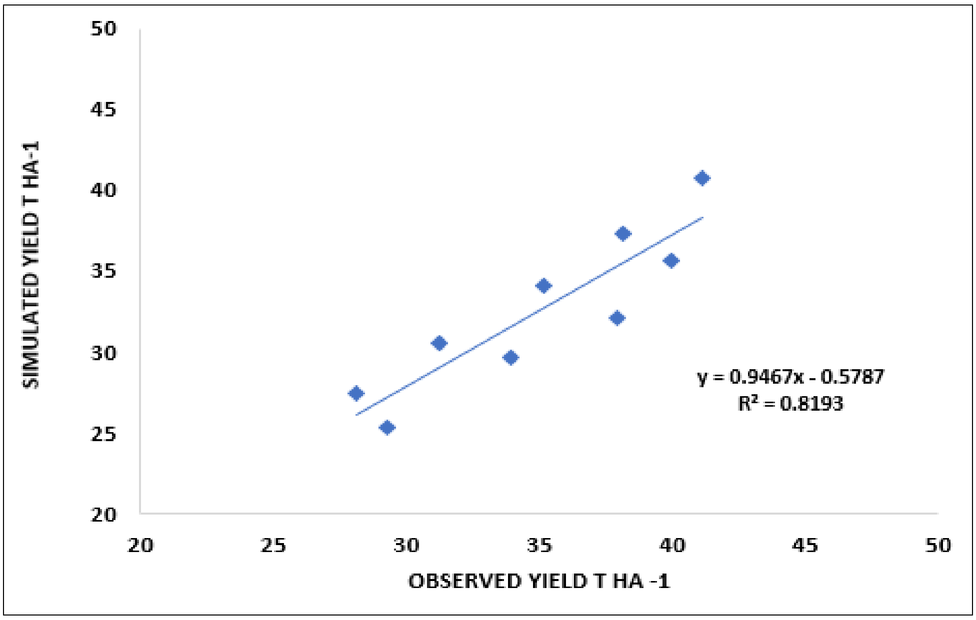


Fig 7: Scatter plot of observed and simulated yield and biomass during validation period for year 2022-23

Conclusion

In this study Performance of AquaCrop model for simulating Canopy cover, biomass and yield production was performed. The performance of AquaCrop model for prediction of yield of potato crop was good with the values of statistical measures of RMSE, MAE, R^2, d(IA) were 0.25, 0.01, 0.84, 0.86 respectively during calibration, as well as model performance was good with the values of RMSE, MAE, R^2, d(IA) were 0.24, 0.01, 0.81, 0.88 respectively, during validation. The performance of AquaCrop model for prediction of biomass of potato crop was good with the values of statistical measures of RMSE, MAE, R^2, d(IA) were 0.25, 0.01, 0.84, 0.86 respectively during calibration, as well as model performance was good with the values of RMSE, MAE, R^2, d(IA) were 0.21, 0.01, 0.84, 0.86 respectively, during validation. Higher yield (41.13 t ha^{-1}) for validation of potato crop can be obtained by providing drip irrigation at 80% of ET_C with Silver black plastic mulch for silty clay soil texture and hence recommended for acceptance in similar conditions. The observed and simulated values of canopy cover, biomass and yield obtained through model were in acceptable range which ascertain that the AquaCrop model can be used effectively for predicting potato yield under varying moisture levels in semi-arid tropical climate.

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