Journal of Agrometeorology 23 (2) : 213-220 (June 2021)

Performance of SUBSTOR model on growth and yield of potato varieties under different planting dates in a sub-tropical environment

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ABSTRACT

A field experiment was conducted during *Rabi* season of two consecutive years 2016-17 and 2017-18 at research farm, Department of Agricultural Meteorology, CCSHAU, Hisar under sub-tropical environment of Haryana. DSSAT (v4.7) family of SUBSTOR module was employed to simulate the comparison of observed values with simulated values under field conditions with a view to a view to assess the performance of model. The model was calibrated for (2016-17) and derived their genetic coefficient and further outputs were validated for second year (2017-18) experiments. Calibration and validation were done on crop grown under four planting dates *viz.* 8th Oct. (D_1), 22th Oct. (D_2), 5th Nov. (D_3) and 23rd Nov (D_4) in main plot treatment and sub-plots treatments consisted of three varieties Kufri Bahar (V_1), Kufri Pushkar (V_2) and Kufri Surya (V_3) were tested in split plot design with four replications. The results affirms that model overestimated the phenology (days to tuber initiation and physiological maturity) and growth and yield parameters like accumulation of maximum LAI, tuber and biological yield. The model's simulation performance was found satisfactory, and the model overestimated with fair agreement (±10). Performance of model tested with help of Mean absolute error (MAE), Mean bias error (MBE), Root mean square error (RMSE), r (correlation) and PE (Percent error). The model had capability for optimum potato crop management, phenology prediction and future yield estimation.

Keywords**:** Calibration, SUBSTOR model, phenology, tuber yield, validation

Potato (*Solanum tuberosum* L.) is the fourth most important food crop in the world after rice, wheat and maize consumed by more than a billion people worldwide. Potatoes are grown on 19.31 million hectares around the world, with an annual production of around 388 million tonnes with an average yield of 20.11 tonnes ha^{-1}. India ranks 2nd in potato production with an average yield of 22.30 tonnes ha^{-1} (FAOSTAT, 2019) The potato is a crop which has always been the 'poor man's food'. Among vegetables, potato crop has a very high adaptive capacity among the crops which ensures future food security because it gives more economic yield per unit input with shorter life span (mostly < 120 days) as compared to other crops (Adane *et al.,* 2010). Intensive cultivation and urbanization along with changing in climatic conditions will exert more pressure on food system. Now days, crop growth models are widely used for describing crop growth and its development as a function of soil, weather and management practices (Haverkort and Top, 2011). They are mainly used to quantify the impact of climate change on Potato and other tuber crops (Raymundo *et al*., 2014). Crop growth models have ability to improve management decision like optimization in planting dates, varietal difference, ability to cope out weather risks and decision making policies. SUBSTOR (Simulation of Underground Bulking Storage Organ- Potato) module belongs to a family of crop models in the DSSAT-CSM (Decision Support System for Agro-Technology Transfer – Crop simulation Model) software (Hoogenboom *et al*., 2012). SUBSTOR is mechanistic, process oriented model for prediction of tuber yield including crop growth and its development. The module of SUBSTOR simulates the daily phenological development, biomass and yield accumulation (Ritchie *et al*., 1995). The SUBSTOR model has been widely evaluated in various environments (Griffin *et al*., 1993; Stastna *et al.,* 2010). The SUBSTOR model have been validated at field level in various agro-climatic conditions in different countries.

Among the major causes of low potato productivity in the Sub-tropical region is the short and aberrant weather conditions during the growing period. In which temperature affects mostly plant and crop physiological processes underlying yield determination, hence the complexity appears at the final yield response (Asseng *et al.,* 2015). Higher temperature affects crop production negatively, indirectly through accelerated phenology (Lobell *et al.,* 2012) that reduces time for biomass accumulation.

The problem is exacerbated by a late-planted potato crop and poor variety selection. As a result, planting time is critical in order to take maximum advantage of the shorter growing season. As a result, detailed research is needed to evaluate the effect of environmental factors on crop growth and development. Standardization of the best planting date is important not just for yield but also to ensure better tuber quality. These model tools can reduce the cost and time consuming in field experimentation as they can be used to extrapolate the results of research conducted in one season or location to other season and management practices (Arora *et al.,* 2013). However, before crop model can be explored to help and understand the effect of environment on crop response, field data is required for calibration and validation of SUBSTOR model. In view of these facts the present investigation was designed to find out a suitable potato variety and the optimum planting date to maximize crop productivity in the Subtropical zone.

MATERIALS AND METHODS

The present study was carried out during *Rabi* season of year 2016-17 & 2017-18 at research farm, Department of Agricultural Meteorology, CCSHAU Hisar, Haryana. The field area was located adjacent to Agro-meteorological observatory at 29^0 10' N latitude, 75^0 46' E longitude and altitude of 215.2 m. respectively. The main plots treatments consisted four planting dates *viz. viz.* 8^{th} Oct. (D_1), 22^{th} Oct. (D_2), 5^{th} Nov. (D_3) and 23^{rd} Nov (D_4). The sub-plots consisted of three varieties Kufri Bahar (V_1), Kufri Pushkar (V_2) and Kufri Surya (V_3). The forty eight combinations were tested and evaluated in split plot design with four replications.

SUBSTOR model

DSSAT Model (v4.7) is a software application program; it comprises about 42 crops as well as its derived tools were helps to facilitate effective use of the models. SUBSTOR module was one of sixteen FORTRAN-based field crop models included in the DSSAT Model (Hoogenboom *et al.,* 1994). SUBSTOR model was a crop module in the cropping system model framework of the DSSAT (Jones *et al.,* 2003). DSSAT Model (v4.7) also includes improved application programs for seasonal, spatial, sequence and crop rotation analyses that assess the economic risks and environmental impacts associated with irrigation, fertilizer and nutrient management, climate variability, climate changes, soil carbon sequestration and precision management of inputs. However the effects of viruses, insect pests, and natural disasters such as wind and hailstorm damage are not taken into account in this model (Griffin *et al*., 1993).

Experimental file

The experimental description file contains all the data required to simulate various experiment treatments (location, planting period and irrigation), conditions (field characteristics, soil analysis data, initial soil conditions, irrigation, fertilizer and harvest management) and simulation control.

Weather file

The model requires daily weather data for the duration of the growing season. The SUBSTOR model required daily solar radiation (SRAD MJ/m^2/d), maximum temperature (Tmax) (°C) and minimum temperature (Tmin) (°C) and precipitation (mm) to prepare and run the simulation (Holden *et al*., 2003). Therefore, the weather data of 2016-17 and 2017-18 (Oct. - March) were collected from the department of agricultural meteorology, CCS HAU, Hisar. The weather data was formatted in Microsoft Excel 2007® and then imported into WeatherMan in DSSAT.

Soil file

Soil samples were taken from each experimental replicate plot at 0-15, 15-30, 30-60 and 60-90 cm depth from the experimental field before crop period and soil was analyzed for pH, electrical conductivity (EC), percentage of total carbon and nitrogen, cation exchange capacity (CEC) and moisture levels (Prasad *et al*., 2015). Soil data required for each soil layer are the layer-thickness (DLAYER, m), saturated water content (SAT, cm^3/cm^3), drained upper limit of soil water content (DUL, cm^3/cm^3), lower limit of plant extractable water (LL, cm^3 /cm^3), soil bulk density (BD, g/cm^3), root distribution weighing factor (WR, unit less), and the initial soil water content at start of simulation (cm^3 /cm^3) were computed and then collected from the department of soil science, CCSHAU, Hisar. For each depth, physical soil structures were also noted. The soil data was entered into the SUBSTOR model's SBuild tool. Other soil variables, including saturated soil water content, field capacity, permanent wilting point, initial soil water content at the start of the soil water balance simulation, and relative root weighing factor, were determined automatically based on the

Table 1: Layer- wise soil information for input of SUBSTOR model

Soil Parameters	Depth (Bottom)			
	0-15 cm	15-30 cm	30-60 cm	60-90 cm
Master horizon	AP	A1	B2	B2
Clay (%)	10.7	13.4	14.3	15.8
Silt (%)	22.3	25.1	26.2	27.9
Stones (%)	-99	-99	-99	-99
Organic carbon (%)	0.41	0.26	0.23	0.22
pH in water	8.1	8.4	8.3	8.3
Cation exchange capacity (C mol/kg)	11.4	12.4	13.4	17.4
Lower limit of drainage	0.09	0.10	0.11	0.11
Upper limit of drainage	0.18	0.19	0.20	0.21
Saturation	0.41	0.41	0.41	0.40
Bulk density (g/cm^3)	1.49	1.54	1.50	1.49
Saturated hydraulic conductivity (cm/hr)	2.59	2.59	2.59	2.59
Root growth factor (0.0-1.0)	1.00	0.64	0.42	0.21

Table 2: Genetic coefficients of potato varieties for SUBSTOR model

Symbols	Descriptions	Kufri Bahar	Kufri Pushkar	Kufri Surya
G2	Leaf area expansion rate in degree days (cm^2/m^2/d)	2000	2150	2000
G3	Potential tuber growth rate (g/m^2/d)	22.2	24.8	22.4
PD	Index that suppresses tuber growth during the period that immediately follows tuber induction (dimensionless)	0.9	0.7	0.8
P2	Index that relates photoperiod response to tuber initiation (dimensionless)	0.8	0.8	0.7
TC	Upper critical temperature for tuber initiation (°C)	23.2	22.8	21.2

physiochemical properties of the soil. (Hoogenboom *et al.*, 2012)

Calibration of SUBSTOR model

To apply the SUBSTOR module for potato crop and its conditions with respect to climate and soil conditions, a model calibration is n required. The model calibration was involved minimum data sets for calculations include phenology (days to tuber initiation, days to physiological maturity), growth and yield parameters (maximum LAI, tuber yield and biological yield). The procedure for determining genetic coefficients involved in running the model using a range of values of each coefficient, in the order indicated above, until the desired level of agreement between simulated and observed values was reached. Iterations for the coefficients were stopped when the agreement reached ±10 %. SUBSTOR module was calibrated for (2016-17) and derived their genetic coefficients for *cv*. Kufri Bahar, Kufri Pushkar and Kufri Surya. They are validated for second year (2017-18) in field experiment data for different growth and yield parameters. The calibrated genetic coefficients using crop data set of potato varieties are mentioned in Table 2.

Genetic coefficient adjustment

Crop genetic input data, which explains how the life cycle of a cultivar responds to its environment, are not usually available and therefore they were derived interactively using Hunt's method (Hunt, 1993). During calibration, the genetic coefficient were manually adjusted in the Genetic file by comparing phenology (tuber initiation, maturity) and growth (LAI, tuber, and haulm yield) simulation results with observed results until the cultivar parameter modification gave the best performance where the simulated values were closest to the observed values. Researchers have used a similar method to study a variety of other crops (Andarzian *et al.,* 2015; Saythong *et al.,* 2012).

Crop management data and harvesting

Data on previous crops, planting dates, emergence dates, and harvest dates were included in crop management data.

Output file

The output file includes summary of input conditions, crop performance and summary of soil characteristics, cultivar coefficient as well as crop and soil status at various

Table 3: Various statistical test criteria were involved for evaluation of SUBSTOR model

S. No.	Statistical parameters	Formula	Reference
1.	Root mean square error (RMSE)	$RMSE = \left[\sum_{i=1}^{n} (P_i - O_i)^2 / n\right]^{½}$	Langensiepen *et al.,* (2008)
2.	Mean bias error (MBE)	$MBE = \sum_{i-1}^{n} [P_i - O_i]/n$	Panda *et al.,* (2003)
3.	Mean absolute error (MAE)	$MAE = \sum_{i=1}^{n} [P_i - O_i 1]/n$	Panda *et al.,* (2003)
4.	Percent Error (%)	$PE = \sum_{i=1}^{n} [P_i - O_i 1]/O * 100$	Panda *et al.,* (2003)

*For the performance evaluation, following notations were used: Si = Simulated values Oi = Observed values N = Number of observations.

stages of growth.

The model predicts the timing of various phenological stages from emergence to physiological maturity, daily growth of plant components, LAI, final yield, yield components and harvest index.

Model evaluation

Evaluation of model in order to calibrate and validate the model, DSSAT v4.7, following genetic coefficients of potato (*cv.* Kufri Bahar, Kufri Pushkar and Kufri Surya) were analyzed (Table 3). The model performance evaluation strategy was based on the comparison of statistical characteristics of simulated data with observed data. Using an Excel worksheet and the statistical component of the DSSAT software, the observed yield means were compared. Furthermore, Using an Excel worksheet, the correlations (r) to equate the simulated and observed yields were also calculated.

RESULTS AND DISCUSSION

The SUBSTOR model satisfactorily performed in simulating the occurrences of phenological events, maximum LAI accumulation, tuber and haulm yield as indicated by high correlation coefficients and low MAE, MBE, RMSE and PE during 2017-18.

Validation of SUBSTOR model

Phenology

Treatment wise error percentage for days to tuber initiation was ranged between -4 (D_2V_1) to +4 (D_1V_1 and D_4V_1). Mean observed days to tuber initiation of potato varied from 41 (D_1V_1) to 59 (D_4V_1) among different planting date and varieties during 2017-18, while model simulated days to tuber initiation ranged between 40 (D_1V_3) to 60 (D_4V_2) in (Table 4). Lowest error percentage was recorded for first planting dates as compared to other dates due to the prevalence of optimum weather conditions existed during that period. The simulated days for tuber initiation was in good agreement with the observed values *i.e*. SDs, MAE, MBE, RMSE, r and PE of 6.52, 0.04, 0.04, 2.52, 0.91 and 5.03, respectively. The majority of simulated values were nearer to the 1:1 line which shows the equally underestimation and overestimation of model and confirms the positive MBE (Fig. 2a).

Observed days to physiological maturity of potato varied from 70 (D_4V_3) to 102 (D_1V_2) in both planting dates and varieties during 2017-18, while model simulated days to physiological maturity ranged between 72 (D_4V_3) to 104 (D_2V_1). The majority of treatment shows overestimated the days to physiological maturity in all the treatments. Treatment wise error percentage for days to physiological maturity was ranged between -6 (D_3V_2) to +6 (D_1V_3). The negative values of deviation show the under estimation of physiological maturity by model for crop sown on D_4 and D_3, whereas, the model prediction is towards over estimation for October sown crop. The simulated days showed good agreement with the observed values *i.e.* SDs, MAE, MBE, RMSE, r and PE of 10.92, 0.04, 0.04, 3.03, 0.96 and 3.45 respectively. The majority of prediction are closer to the 1:1 line which showed the over estimation of model and confirms the positive MBE (Fig. 2b). The all prediction was within ± 10 % of observed values. Similar results were reported by Patil *et al.,* (2018) in potato at Gujarat (India).

Table 4. Various test criteria involved for evaluation of SUBSTOR model with respect to tuber initiation and physiological maturity of potato varieties

	Tuber initiation			Physiological maturity		
Treatments	Observed	Simulated	P-O	Observed	Simulated	P-O
D_1V_1	41	45	4	97	95	-2
D_1V_2	49	51	3	102	103	1
D_1V_3	42	40	-2	76	82	6
D_2V_1	45	41	-4	102	104	2
D_2V_2	54	57	3	101	102	1
D_2V_3	50	52	2	84	82	-2
D_3V_1	49	53	4	87	90	3
D_3V_2	57	55	-2	97	91	-6
D_3V_3	51	50	-1	79	82	3
D_4V_1	59	58	-1	75	74	-1
D_4V_2	59	60	1	86	84	-2
D_4V_3	49	46	-3	70	72	2
Mean	50.17	50.67	1	87.90	88.42	1
Observed mean	50.16			87.89		
SDo	6.07			11.53		
Simulated mean	50.66			88.41		
SDs	6.52			10.92		
R	0.91			0.96		
MAE	0.04			0.04		
MBE	0.04			0.04		
RMSE	2.52			3.03		
PE	5.03			3.45		

*Whereas SDs (Standard deviation of simulated value), SDo (Standard deviation of observed value), Mean absolute error (MAE), Mean bias error (MBE), Root mean square error (RMSE), r (correlation) and PE (Percent error)

Table 5: Various test criteria involved for evaluation of SUBSTOR-potato model with respect to LAI, tuber and biological yield (kg ha^{-1}) of potato varieties

	Maximum LAI			Tuber yield			Biological yield		
Treatments	Observed	Simulated	P-O	Observed	Simulated	P-O	Observed	Simulated	P-O
D_1V_1	3.73	3.86	0.14	27875	26328	-1547	40809	44118	3309
D_1V_2	4.40	4.87	0.47	29336	26970	-2366	44697	43760	-937
D_1V_3	3.15	3.64	0.49	18438	15883	-2554	33226	33673	447
D_2V_1	4.26	4.52	0.26	33333	35999	2666	42669	48789	6120
D_2V_2	4.85	4.66	-0.19	34115	32067	-2048	46380	41857	-4523
D_2V_3	3.90	3.92	0.02	21528	25627	4099	37197	35417	-1780
D_3V_1	3.58	3.46	-0.12	23090	23968	878	38867	33758	-5109
D_3V_2	4.56	4.82	0.26	27951	25018	-2933	41909	42808	899
D_3V_3	3.33	3.23	-0.09	17361	15400	-1961	33182	35190	2008
D_4V_1	3.25	3.44	0.19	19691	16214	-3477	35251	33004	-2247
D_4V_2	4.22	4.61	0.39	21649	22431	782	36619	32221	-4398
D_4V_3	2.08	2.46	0.39	13906	14229	323	31352	35019	3667
Mean	3.77	3.96	0.18	24022.75	23344.50	-678	38513.14	38301.17	-212
Observed mean	1.77			24022.75			38513.14		
SDo	0.57			6441.63			4842.31		
Simulated mean	1.83			23344.50			38301.17		
SDs	0.43			6876.99			5579.54		
R	0.96			0.94			0.77		
MAE	0.01			56.52			17.67		
MBE	0.01			-56.52			-17.67		
RMSE	0.21			2391.69			3438.61		
PE	9.82			9.96			8.93		

*Whereas SDs (Standard deviation of simulated value), SDo (Standard deviation of observed value), Mean absolute error (MAE), Mean bias error (MBE), Root mean square error (RMSE), r (correlation) and PE (Percent error)

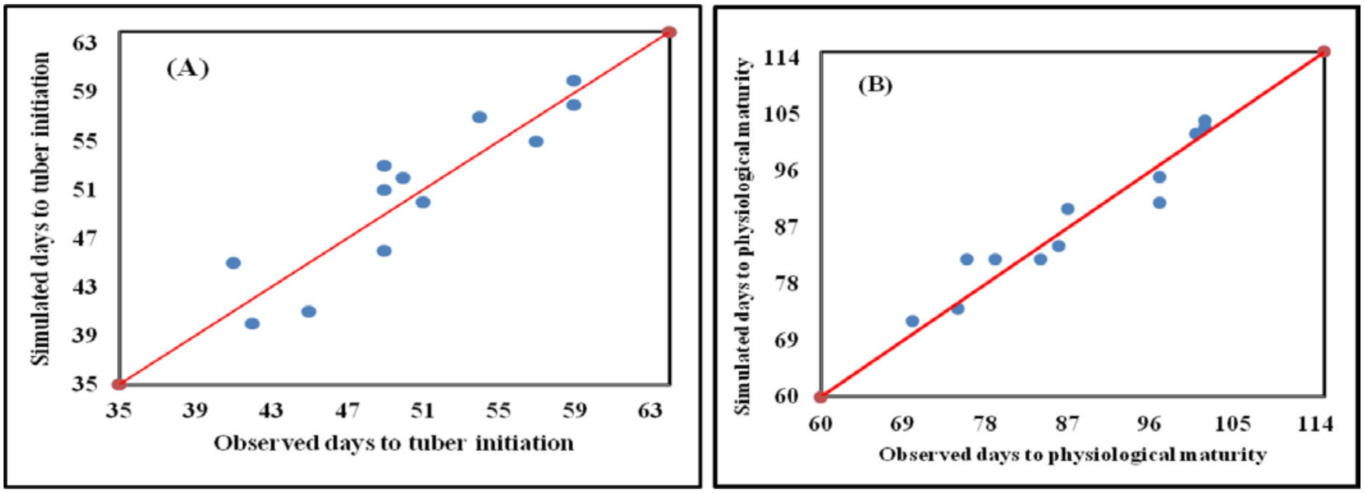

Fig. 1 Comparison of simulated and observed days to tuber initiation (A) and physiological maturity (B) of potato under varying planting time during 2017-18

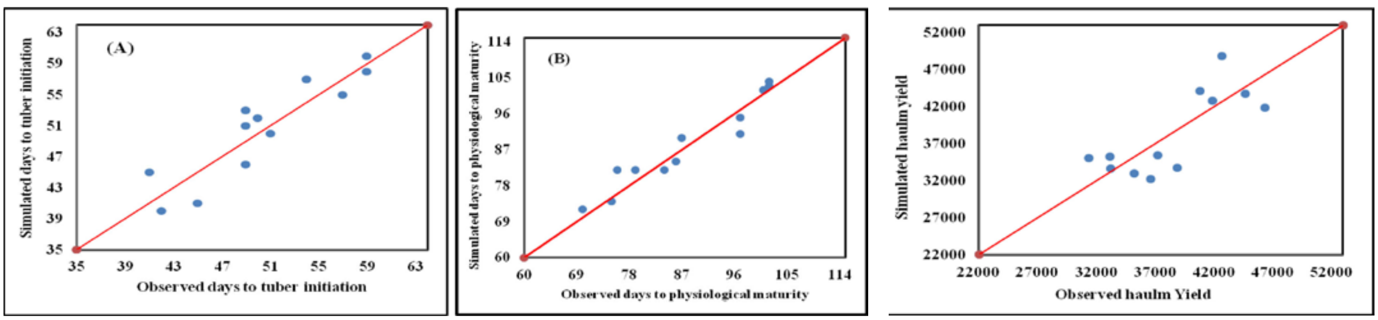

Fig. 2 Comparison of simulated and observed (C) Maximum LAI (D) Tuber yield and (E) Haulm yield of potato under varying planting time during 2017-18

Maximum LAI

The simulated maximum LAI were in good agreement with observed values. Observed maximum LAI of potato varied from 2.08 (D_4V_3) to 4.85 (D_2V_2) in planting dates and varieties during 2017-18, while model simulated maximum LAI ranged between 2.46 (D_4V_3) to 4.87 (D_1V_2). The model overestimated maximum LAI in majority of the treatment. Treatment wise error percentage for maximum LAI was ranged between -0.19 (D_2V_2) to 0.49 (D_1V_3) in (Table 4). Various model test criteria were worked out for maximum LAI *i.e.* SDs, MAE, MBE, RMSE, r and PE of 0.43, 0.01, 0.01, 0.21, 0.96 and 9.82 respectively. The majority of predictions are above the 1:1 line, which showed the overestimation of model and confirms the positive MBE (Fig. 3c). All prediction for maximum LAI was within ± 10 % of observed values.

Tuber yield

The pretend tuber yield was in good agreement with observed values of the experimental field. The observed tuber yield varied between 13906 kg ha^{-1} (D_4V_3) to 34115 kg ha^{-1} (D_2V_2) during 2017-18. Similarly, the corresponding values as simulated by the model ranged between 14229 kg ha^{-1} (D_4V_3) to 35999 kg ha^{-1} (D_2V_1). Under D_2 planting, model simulation showed over estimation in majority and in rest of the planting dates it showed underestimation. The overall simulation of model is towards over estimation. The simulated days for tuber yield also showed good agreement with the observed values *i.e.* SDs, MAE, MBE, RMSE, r and PE of 6876.9, 56.52, -56.52, 2391.69, 0.94 and 9.96 respectively (Table 4). The majority of prediction was above closer to the 1:1 line which showed the overestimation of model and confirms the negative MBE (Fig. 3d). All the prediction of tuber yield was within ± 10 % of observed values. Similar results were reported by Patil *et al.* (2018) and Prasad *et al.* (2015) and Arora *et al*. (2013) in Indian conditions.

Biological yield

The observed biological yield varied between 31352 kg ha^{-1} (D_4V_3) to 46380 kg ha^{-1} (D_2V_2) during 2017-18. Similarly the corresponding values as the simulated by the model ranges between 32221 kg ha^{-1} (D_4V_2) to 48789 kg ha^{-1} (D_2V_1). Under majority of the treatment, simulated results showed equal underestimation and overestimation of biological yield. The simulated biological yield also showed similarity with the observed values *i.e.* SDs, MAE, MBE, RMSE, r and PE of 5579.57, 17.67, -17.67, 3438.61 and 8.93, respectively (Table 4). All the prediction of biological yield was within ± 10 % of observed values. The majority of prediction was far away from the 1:1 line which showed the under estimation of model and confirms the negative MBE (Fig. 3e). The results were supported by Patil *et al.* (2018) and Prasad *et al.* (2015) in Indian conditions.

CONCLUSION

This paper evaluated the performance of SUBSTOR model on growth and yield of potato varieties under planting dates in a sub-tropical environment of Hisar, Haryana during winter (*Rabi*) season of 2016-17 and 2017-18. The validation results revealed that comparison of observed and simulated days to tuber initiation and physiological maturity, Maximum LAI, tuber yield and haulm yield were in satisfactory agreement. The RMSE shows that the efficiency of model to predict the days to tuber initiation and physiological maturity is in reasonable limits. On the basis of outcome, farmers are suggested that second fortnight of October (22th Oct.) planting was more suitable for potato in Sub-tropical region. The simulated tuber yield during November planted crop was underestimated by the model. Simulation performance of the model was found satisfactory with reasonable agreement (±10 %) under different planting dates. The model has proven to be a useful tool for potato crop management optimization, phenology prediction, and potential yield estimation.

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Received : May 2020 : Accepted : May 2021