



Research Article

Assessing the Impact of Elevated Temperature on Potato Production Grown in Lower Gangetic Plains of West Bengal using DSSAT Model

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ABSTRACT

DSSAT 4.7 model was used to simulate potato tuber dry and fresh weights for normal weather situation of Kalyani region, West Bengal, and under various Representative Concentration Pathways (RCP) scenarios. The model was calibrated and validated for *Kufri Jyoti* variety with the experimental data collected during 2010-16. Coefficient of Determination (R^2), Root Mean Square Error (RMSE) and Standard Error (SE) indicated that the simulated output closely agreed with actual field results. Sensitivity analysis revealed that the model was able to capture the changes in temperature during various dates of planting. Simulations of the crop yield under elevated thermal condition were performed by adding 1°C, 1.4°C and 2.0°C to the average weather data of Kalyani using the “Environmental Modifications” module of DSSAT. When temperature increases by 1°C, yield decreases by 12%, 17% and 30% for 20th November, 30th November and 10th December planted crop, respectively. When temperature increased by 1.4°C, further decrease in yield is observed. Increase of 2°C temperature poses a deleterious effect on tuber yield compared to the previous situation. Hence, adjustment of planting time will ascertain profitable potato production in this region under elevated temperature condition.

Key words: Climate change, Temperature, Crop growth model, Potato, DSSAT

Introduction

The biggest problem faced by the human civilisation in the present 21st century is ensuring food security for the burgeoning billions. Southeast Asia, where agriculture is a primary source of livelihood, is expected to be seriously affected by adverse effects of climate change (IPCC, 2007). Since most of its economy relies on agriculture and natural resources as a major source of income, climate change has been and will continue to be critical factor affecting its productivity. Potato (*Solanum tuberosum* L.) popularly known as ‘The king of vegetables’, has

emerged as the fourth most important food crop in India after rice, wheat and maize (Manrique, 2000; Fabeiro *et al.*, 2001). The negative impact of climate change on crop production is alarming as the demand for food is expected to increase in the coming years, at a rate of about 2% a year (Banerjee *et al.*, 2014). However, potato production is expected to decline across many parts of the world by 2100 (Raymundo *et al.*, 2014). But, Stockle *et al.* (2010) indicated that, taking into account the positive effect of CO₂ and adaptation strategies on crop production, the current production levels will be sustained under changing climatic scenario.

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Dynamic Crop Growth Simulation Models (CGSMs) use biophysical knowledge through

mathematical equations to simulate the dynamics of the plant-soil-atmosphere system and have successfully assessed the impact of climate change and climatic variability on crop production (Hoogenboom *et al.*, 2000). With the background in view, the present study was undertaken to use DSSAT 4.7 model for predicting the tuber yield of *Kufri Jyoti* variety of potato in the lower Gangetic plains of West Bengal with the following objectives: 1) To calibrate and validate DSSAT 4.7 model for *Kufri Jyoti* variety in the aforesaid region, and 2) To assess the impact of elevated temperature on potato production.

Materials and Methods

Field experiment and secondary data collection

The field experiment was conducted at Kalyani 'C' Block farm of Bidhan Chandra Krishi Viswavidyalaya, West Bengal (22°57'N latitude, 88°20'E longitude and 9.75 m above mean sea level) during *rabi* season of 2016-17. *Kufri Jyoti* cultivar of potato was grown with three dates of planting (23/11/2016, 8/12/2016, 23/12/2016) in a randomized block design. The previous years' crop dataset since 2010 were collected from AICRP on Agrometeorology. The soil was sandy loam type with adequate drainage facility. Recommended dose of N, P and K fertilizers were applied. Row spacing of 50 cm was maintained with planting population of 10 plants m⁻². Daily weather data were collected from the agrometeorological observatory of Bidhan Chandra Krishi Viswavidyalaya, West Bengal situated adjacent to the experimental plot.

Model calibration and validation

Calibration of DSSAT 4.7 was done by adjusting the genetic coefficients for the said variety through iteration method using the crop, soil and weather data from 2010-2012 in such a way so that the simulated output obtained from the model could match closely with the actual field results. Validation of the model was performed by comparing the simulated output with the actual crop data from 2013-2016 with the help of optimized genetic coefficients. R², RMSE, SE and d-stat values of summary results were examined to determine the agreement between observed and simulated values.

Climate change scenarios

Three changed scenarios have been considered for the years which are taken into account for validation, viz, increase of temperature by 1.0°C, 1.4°C and 2.0°C than normal temperature of Kalyani region which are based on RCP2.6, RCP4.5, and RCP8.5 respectively (IPCC, 2013). Under the 'Environmental Modifications' module of DSSAT, the above said temperatures were added to average weather data of Kalyani (for the period 2010 to 2016) and then the model was run to find out the effect of elevated temperature condition.

Results and Discussion

Validation of DSSAT 4.7

After proper calibration through iteration method as described above, the genetic coefficients were worked out and presented in Table 1. Using those coefficients, the tuber fresh

Table 1. Generation of genetic coefficient for *Kufri Jyoti* cultivar of potato

Name	Description	Values
G2	Leaf area expansion rate in degree days (cm ² m ⁻² d ⁻¹)	2000
G3	Potential tuber growth rate (g m ⁻² d ⁻¹)	8.1
PD	Index that suppresses tuber growth during the period that immediately follows tuber induction	0.4
P2	Index that relates photoperiod responses to tuber initiation	0.4
TC	Upper critical temperature for tuber initiation (°C)	14

and dry weights were simulated for the period 2013 to 2016. The simulated data was compared with actual field experimental data and presented in Table 2 and 3.

Simulation of tuber fresh weight reveals that, in case of 15th November and 13th December 2013 and 17th November 2014 sowing dates, the model is over-predicting the tuber fresh weights. In rest

Table 2. Simulated and Actual tuber fresh weight of *Kufri Jyoti* for different years

Treatment number	Date of sowing	Simulated tuber fresh weight (t ha ⁻¹)	Actual tuber fresh weight (t ha ⁻¹)
Y1D1	15.11.13	32.19	29.7
Y1D2	29.11.13	22.32	28.2
Y1D3	13.12.13	18.34	17.8
Y2D1	17.11.14	26.54	26.4
Y2D2	01.12.14	20.18	22.8
Y2D3	15.12.14	14.84	19.7
Y3D1	23.11.15	19.16	23.2
Y3D2	08.12.15	17.66	20.7
Y3D3	23.12.15	9.34	14.2
Y4D1	23.11.16	25.19	25.7
Y4D2	08.12.16	20.82	22.2
Y4D3	23.12.16	15.96	18.9
Mean =	20.21	22.46	
Coefficient of determination (R ²)	= 0.84		
Root Mean Square Error (RMSE)	= 3.31		
Standard Error (SE)	= 2.48		

Table 3. Simulated and Actual tuber dry weight of *Kufri Jyoti* for different years

Treatment number	Date of sowing	Simulated tuber dry weight (kg ha ⁻¹)	Actual tuber dry weight (kg ha ⁻¹)
Y1D1	15.11.13	7038	6745
Y1D2	29.11.13	7012	7861
Y1D3	13.12.13	3669	3136
Y2D1	17.11.14	5308	5591
Y2D2	01.12.14	4037	4664
Y2D3	15.12.14	3738	4201
Y3D1	23.11.15	4203	4800
Y3D2	08.12.15	3531	4019
Y3D3	23.12.15	1869	1988
Y4D1	23.11.16	5038	5581
Y4D2	08.12.16	4163	4484
Y4D3	23.12.16	3192	3456
Mean =	4399.83	4710.5	
Coefficient of Determination(R ²)	= 0.94		
Root Mean Square Error (RMSE)	= 487.74		
Standard Error (SE)	= 386.8		

Table 4. Evaluation of the model through d-STAT value

Variable	Mean observed	Mean simulated	d-STAT
Tuber dry weight (kg ha ⁻¹)	4711	4092	0.828
Tuber fresh weight (t ha ⁻¹)	22.46	20.46	0.884

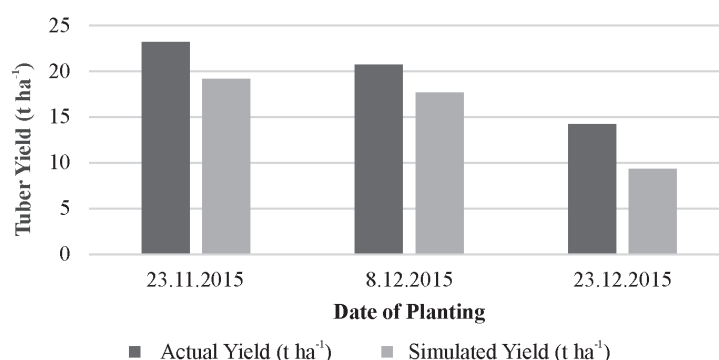
of the treatments, the model is under-predicting the actual tuber fresh weight. Mean values of simulated and actual tuber fresh weight are 20.21 and 22.46 t ha⁻¹, respectively which indicates that the model is actually under-predicting the actual field scenario. Coefficient of determination has a value 0.84 which is significant indicating that the model has a good fit. The RMSE is 3.31, which lies within 16% of the mean simulated tuber fresh weight and SE has a value 2.48 which lies within 12% of the mean simulated output, both of which indicate good performance of the model with low degree of error while simulating tuber fresh weight.

Simulation of tuber dry weight reveals that, for the 15th November and 13th December 2013, the model is over-predicting the results. In rest of the treatments, the model is under-predicting the dry weights. Mean values of simulated and actual tuber dry weight are 4399.83 kg ha⁻¹ and 4710.5 kg ha⁻¹ respectively which indicates that the model is actually under-predicting. Coefficient of Determination has a value 0.94 which is close to 1, indicating that the model has a good fit. RMSE has a value 487.74 which lies within 11% of the mean simulated tuber fresh weight, and SE has a value 386.8 which lies within 8% of the mean simulated output, thereby indicating a good performance of the model with low degree of

error while simulating tuber dry weight. The RMSE and SE values indicate that the model performs better in predicting tuber dry weight than tuber fresh weight. When d-STAT value is close to 1 (Table 4), it indicates that the model can predict the growth and yield of crop in a reliable manner. Hence, the said table reveals that tuber dry weight and tuber fresh weight are very well predicted.

Sensitivity Analysis

Six different dates of sowing were used as treatments to predict the tuber yield of *Kufri Jyoti*. The results revealed that highest yields during 2015 and 2016 were obtained from 23rd November planted crop. Considerable decrease in yield occurred in subsequent planting dates. Lowest yield was obtained from 23rd December planted crop. Thus it can be concluded that an increase in temperature during the tuber development stage of potato for late transplanted crop had a negative impact in the tuber yield of the crop. This may be due to higher photo-respiration at night time because of increase in minimum temperature during 2nd fortnight of February. Hence the model is sensitive to date of planting; vis-a- vis weather impact can be captured by the model. (Fig. 1 and 2).

**Fig. 1.** Sensitivity analysis through observation on yield variation in 2015 due to change in sowing dates

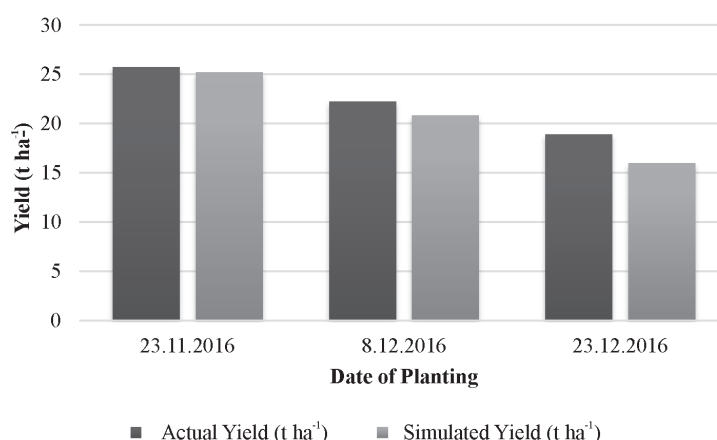


Fig. 2. Sensitivity analysis through observation on yield variation in 2016 due to change in sowing dates

Table 5. Impact of elevated temperature on yield of potato

Date of planting	Actual average yield of 2010-2016 (t ha ⁻¹)	Simulated yield for 1°C temp rise (t ha ⁻¹)	Simulated yield for 1.4°C temp rise (t ha ⁻¹)	Simulated yield for 2°C temp rise (t ha ⁻¹)
20 th Nov	27.68	24.34	23.00	21.20
30 th Nov	25.46	21.05	20.22	18.67
10 th Dec	19.52	13.76	12.69	11.52

Impact of elevated temperature on potato yield

With an objective of assessing the impact of climate change on potato production, three dates of planting, viz, 20th November, 30th November, 10th December have been taken under consideration and presented in Table 5. Actual average yield of potato obtained for these respective dates during the period of 2010-2016 are 27.68, 25.46 and 19.52 t ha⁻¹, respectively. For a 1°C rise in temperature, simulated yield were 24.34, 21.05 and 13.76 t ha⁻¹. For 1.4°C rise in temperature, the simulated yields were 23.00, 20.22 and 12.69 t ha⁻¹. For 2°C rise in temperature, the simulated yields were 21.20, 18.67 and 11.52 t ha⁻¹. Table shows that for each date of planting there is a progressive decrease in yield with increase in temperature.

Agronomic adjustment for future

Due to a 1°C rise in temperature, 12-30% of yield decrease is found in 3 subsequent dates of planting. When temperature is increased by 1.4°C, 17 to 35% yield reductions were recorded. Yield of potato crop is deleteriously affected showing

23 to 40% reduction in yield when temperature is increased by 2°C. Thus under changing climate scenario, 20th November planting can be considered as the most suitable for *Kufri Jyoti* variety so that farmers can obtain maximum yield and profit. Hijmans *et al.*, 2003 observed 18 to 32% reduction in tuber yield due to temperature increase by 1.4°C.

Conclusions

The genetic coefficients of *Kufri Jyoti* were evaluated and the derived genetic coefficients were capable to simulate the yield of the crop in a reliable manner. R² values for tuber fresh weight and dry weight were more than 80% and 90%, respectively. RMSE and SE values were considerably low, thereby indicating good performance of the model. The effect of change of prevailing air temperature was also captured by the model through sensitivity analysis. It was observed that the tuber yield of potato reduced with change in date of planting beyond mid-November. Increase in temperature adversely affected potato tuber yield with each subsequent date of planting.

Adjustment of sowing time will be a key adaptation strategy to combat the harmful effects of climate change on this crop. Sowing done around 20th November will help the farmers to obtain maximum profit under changed climatic scenario.

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