Potato Research (2019) 62:175–191
https://doi.org/10.1007/s11540-018-9406-z

Quantitative Approaches in Adaptation Strategies to Cope with Increased Temperatures Following Climate Change in Potato Crop

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Received: 1 December 2017 / Accepted: 30 October 2018 /
Published online: 7 December 2018

Abstract
Temperatures have a major effect on potato crop growth and yield attributes during the crop growing season. In this study, the SUBSTOR-Potato model was used to simulate the potato crop growth and yield in a sub-tropical region of West Bengal comprising of three districts, namely West Medinipur, Bankura and Birbhum in India. Also, the effect of temperature and planting dates scenario on potato crop growth was evaluated by using 30 years historical weather data of the aforesaid districts. Field experiments were conducted on potato crops of cultivar Kufri Jyoti under two planting dates (10th and 25th of December) and different fertilizer treatments in the years 2013–2014 and 2014–2015, respectively. The statistical results showed the satisfactory performance of the model with an R^2 of 0.82 to 0.98 and d-stat of 0.94 to 0.98 for the year 2013–2014 and an R^2 of 0.89 to 0.98 and d-stat of 0.97 to 0.98 for the year 2014–2015. Evaluation of planting dates with past 30 years historical data showed planting dates 20th and 30th of November resulted in average higher yield than planting dates 10th, 25th and 30th of December, respectively, in current climate scenario. Furthermore, the study suggests that amending the planting dates is an effective climate change adaptation strategy for reducing the effect of temperature on the yield of a potato crop in the near future.

Keywords Planting dates · Potato · SUBSTOR model · Temperature · Yield

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Introduction

Potato (*Solanum tuberosum* L.) is the third most important food crop in the world (Kleinwechter et al. 2016) and fourth in India after rice, wheat and maize (Saxena and Mathur 2013). It is increasingly important for the developing world (Kashyap and Panda 2003) and is regarded as the one commodity in developing countries which always has a consistent increase in per capita consumption (FAO 2013). It can be grown in different environments but is best adapted to temperate climates (Daccache et al. 2011; Kleinwechter et al. 2016). Greatest yields come under long photoperiods and moderate temperatures but can be reduced by soil moisture deficits and high temperatures in the tuber development stage. Assessment of the effect of weather changeability on crop growth and development might help to anticipate and adopt suitable management practices to maximize production (Hoogenboom 2000).

Temperature is the primary factor which influences crop growth and yield. The plant growth rate and development processes are dependent on soil and air temperature (Wheeler et al. 2000). Tubiello et al. (2002) reported that by the end of this century, an increase in greenhouse gases will raise the global annual surface air temperature by 1 to 6 °C. Higher temperatures can affect plant growth and development through increased water demand and may result in a severe reduction in economic yield due to heat stress. Heat stress because of increased temperature is one of the major agricultural problems in many parts of the world (Rykaczewska 2015). Several studies also revealed that warm temperature raised the rate of phenological development but had no effect on leaf area or plant biomass in comparison to normal temperatures (Lobell et al. 2012; Hatfield and Prueger 2015). The effective management of yield as well as tuber growth could possibly be achieved by regulating planting dates with respect to temperature. Thus, understanding the effect of planting dates would be essential to explore more effective adaptation strategies to equilibrise the effect of temperature threshold phenomenon due to climate change (Hatfield and Prueger 2015).

A crop simulation model is a powerful tool, which has the ability to predict the growth, yield and development of a crop utilizing a set of genetic coefficients, with appropriate initial soil parameters, crop management and weather variables (Raymundo et al. 2016). Crop models are principally created to operate at field levels with dependency on field-scale inputs, such as plant genotype, weather and soil to predict yield (Soler et al. 2007; Satapathy et al. 2014). Raymundo et al. (2016) reported that approximately 30 crop models have been developed for potato, some of which have been used for investigation of climate change impact on production of potato. One combination of various dynamic crop simulation models is the Decision Support System for Agro-technology Transfer (DSSAT), which is used to simulate the development, growth and yield of crops (Behera and Panda 2009; Jones et al. 2003), and which was developed in 1982 under the International Benchmark Site Network for Agrotechnology Transfer (IBSNAT) project (Satapathy et al. 2014). DSSAT has been used widely for evaluating climate change impact on food production and has proved to be particularly useful in evaluation of agricultural management adaptation to climate change (Daccache et al. 2011).

The SUBSTOR (Simulation of Underground Bulking Storage Organs) potato model fuses mechanistic (Klepper and Rouse 1991) and empirical sub-models to predict potato growth, development and yield as a function of field management, climate and genetic factors (Ritchie et al. 1995). The model can be used to evaluate uncertainties and risk related to potato production system (Tubiello et al. 2002). It was used to assess the interaction of different planting dates with temperature in order to combat climate change and maintain high potato productivity. Field experiments were done concomitantly with the simulation studies to (a) evaluate the crop model performance for the most predominant cultivar in the eastern region of India and (b) assess the effect of temperature on potato crop and evaluate the different planting times scenario on adaptation to climate change in a sub-tropical region.

Materials and Methods

Experimental Site

Field experiments were conducted on potato crop at the research farm of Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, India (22° 33′ N 87° 33′ E) during the years 2013–2014 and 2014–2015. The soil of this region is lateritic type with sandy loam texture and is taxonomically grouped under 'Alfisol'.

Meteorological Conditions

The climate of Kharagpur is classified as sub-humid with an average temperature range of 15–37 °C. The area receives an average annual rainfall of 1200–1500 mm (Srivastava et al. 2017, 2018a, b). The maximum temperatures recorded (40–45 °C) were in the months of April and May and the minimum temperatures (13–15 °C) in December and January (Halder et al. 2016). The agro-meteorological data were recorded by an automated weather station located at the research farm. The recorded variables were temperature, rainfall, wind speed, relative humidity, sunshine hours and saturation vapour pressure. Figure 1a, b shows the daily value of temperature (maximum and minimum) and rainfall for the years 2013–2014 and 2014–2015 during the crop growing period.

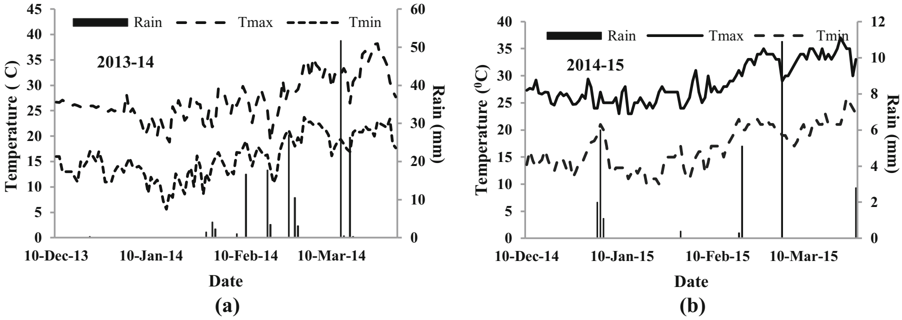

Fig. 1 Daily recorded rainfall and temperature (maximum and minimum) during crop growth periods in the years 2013–2014 (**a**) and 2014–2015 (**b**) at Kharagpur

Crop Experimental Details

Field experiments were conducted on potato crops of cultivar Kufri Jyoti with eight treatments, which included two planting dates (10th and 25th of December) with four quantities of fertilizer, during the years 2013–2014 and 2014–2015. They were harvested 90 days from the planting date. Potato tubers were planted at a depth of 5 cm with 50 cm × 20 cm (row × plant) spacing. Four fertilizer applications (N:P:K, kg/ha) were used 0:0:0 (F_0), 90:80:90 (F_{90}), 120:80:120 (F_{120}) and 150:100:150 (F_{150}). The experiment was conducted in a split plot design with three replications in an area of 1470 m^2. In all treatments, 50% of nitrogen (urea) was applied as basal fertilizer and the remaining nitrogen was distributed equally between vegetative and tuber bulking stages as a split application. The sources of N, P and K fertilizers were urea, single super phosphate and muriate of potash, respectively. Furrow irrigation was applied on the basis of soil moisture measured by time-domain reflectometry (TDR, TRIME, IMKO) (IMKO 2000) from planting to the tuber bulking stage. Figure 2 represents the daily irrigation amount for the years 2013–2014 (a and b) and 2014–2015 (c and d).

Soil, Water and Crop Observations

Daily soil water content measurement was performed with a TDR TRIME (IMKO Gmbh, Germany) by setting the instrument in manual mode (Srivastava et al. 2017). The access tubes were installed vertically down to a depth of 1 m, and the probe was inserted into access tubes at different depths (20, 40, 60 cm) for measuring the soil water content.

Crop growth was recorded at different stages such as vegetative, tuber initiation, tuber bulking and harvesting. Changes in aboveground dry matter weight and tuber fresh and dry weight were determined by sampling at different potato crop growth stages.

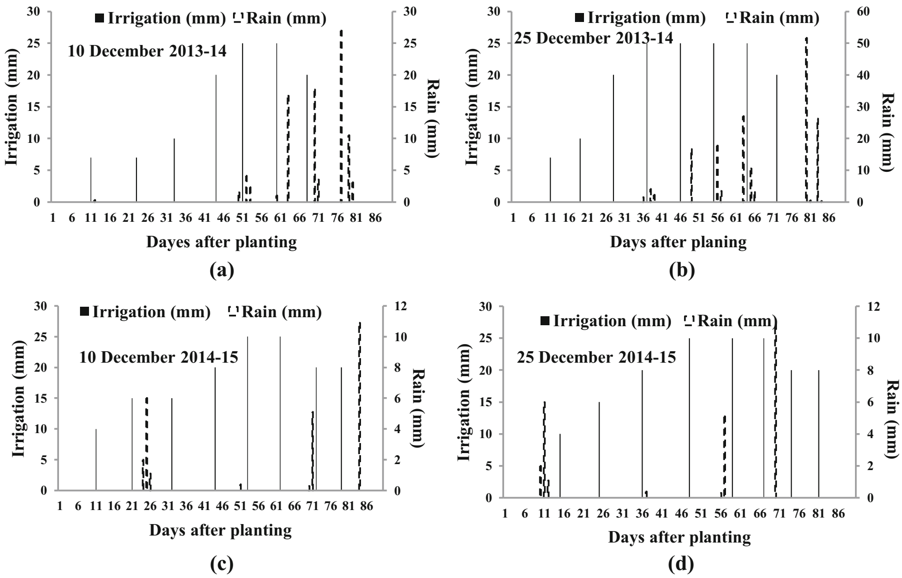

Fig. 2 Irrigation amount applied and rainfall (mm) for two sowing dates (10th and 25th of December) during the years 2013–2014 (**a** and **b**) and 2014–15 (**c** and **d**) for the potato crop

Crop Growth Model

Crop yield was simulated using the DSSAT vs. 4.5 SUBSTOR-Potato crop growth modules in the cropping system model (CSM) framework of DSSAT (Griffin et al. 1993; Ritchie et al. 1995). The model inputs were soil properties, daily weather, genotype and crop management information (Hoogenboom et al. 2012). The SUBSTOR-Potato model adjudges partitioning and accumulation of potato biomass in connection with temperature, intercepted radiation and photoperiodicity (Vashisht et al. 2015). The model takes into account soil water deficit elements that bring about a reduction in photosynthesis and growth (Ritchie et al. 1995; Raymundo et al. 2016). The parameters upper critical temperature for tuber initiation (TC, °C) and tuber initiation sensitivity to photoperiod (P2, dimensionless) affect phenology, and biomass accumulation is affected by potential tuber growth rate (G3, gm^{-2} day^{-1}), leaf area expansion rate (G2, cm^2 m^{-2} day^{-1}) and an index (PD, dimensionless) that suppresses tuber growth (Vashisht et al. 2015; Raymundo et al. 2016).

Calibration of Cultivar Growth Parameters

Calibration of the SUBSTOR-Potato model was done using recommended fertilizer (Trehan et al. 2008) level (F_{120}) for the year 2013–2014 and was validated for both higher (F_{150}) and lower (F_{90}) fertilizer level for the year 2013–2014, and also for the treatments (F_{90}, F_{120}, F_{150}) of the year 2014–2015.

The calibration was done by using several crop parameters: tuber initiation day, aboveground dry matter weight, tuber fresh weight (t/ha) and tuber dry matter weight (kg/ha) obtained during harvesting stage. The aboveground dry matter weight [kg/ha] was also taken at all crop growth stages. The maximum leaf area index used during calibration and validation of the model was obtained from the maximum vegetative stage (tuber bulking stage).

During the calibration, the genetic coefficients were developed and were used for the validation process. The cultivar parameters P2, G2, TC, PD and G3 were derived from the DSSAT-CSM database (Raymundo et al. 2016). Table 2 lists the cultivar parameters derived and utilized for the simulations conducted with the SUBSTOR-Potato model.

Model Validation and Performance Evaluation

Model validation is an essential part of model verification. It requires observed values from the field experiment and simulated values from the model, and then, the comparison is made between simulated and observed values. The validated SUBSTOR-Potato model was used to simulate the seasonal tuber fresh wt (t/ha) from the years 1984–1985 to 2014–2015 using historical weather data (provided by Regional Meteorology Department, Kolkata) for three locations in West Bengal: West Medinipur (24° 40′ N, 87° 38′ E), Bankura (23° 16′ N, 87° 06′ E) and Birbhum (23° 84′ N, 83° 61′ E). The simulated data were compared with observed tuber fresh yield data collected from 'Directorate of Statistical and Evaluation Wing', State Agriculture Department, Government of West Bengal, Kolkata, India. Figure 3a–c shows the 30 years historical weather conditions during the crop growth seasons (December to April).

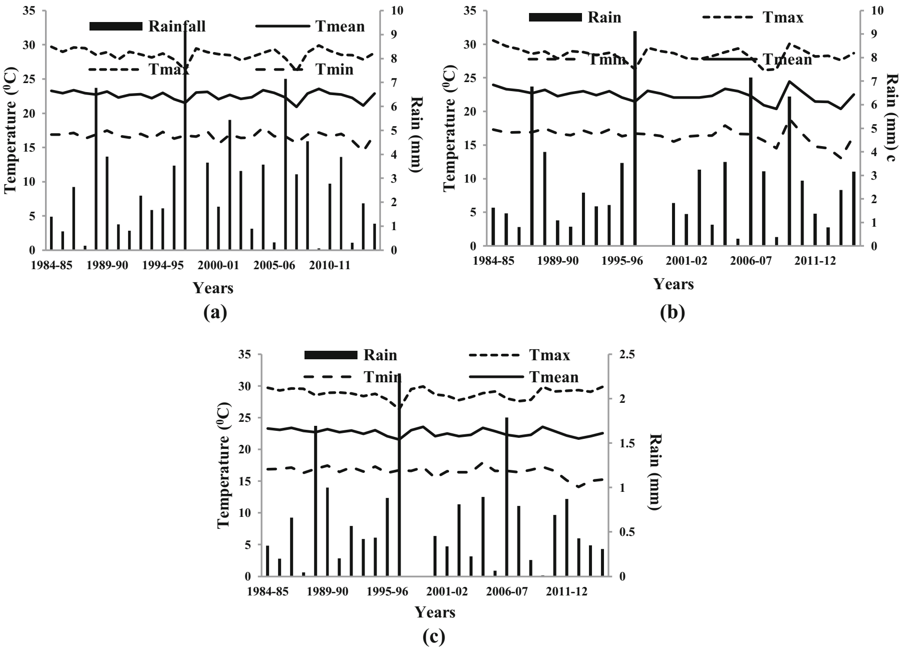

Fig. 3 Historical weather variables: monthly mean temperature and monthly rainfall for West Medinipur (**a**), Birbhum (**b**) and Bankura (**c**) districts for 30 years

Evaluation of Planting Dates

The model was also used to evaluate the planting dates 10th, 20th, and 30th of November and 10th, 20th, 30th of December for the abovementioned districts in two climate scenarios (a) current climate condition and (2) increment of 2 °C on current climate conditions. During the evaluation, the model was used to simulate the seasonal tuber fresh wt (t/ha), tuber dry matter wt (kg/ha) and aboveground dry matter (kg/ha) from the years 1984–1985 to 2014–2015 for both climate scenarios.

Statistical Assessment of Model Performances

The performance of the crop model was adjudged by comparing observed and simulated values of crop parameters during the potato crop experiment. Experimental crop growth and yield measurements included tuber fresh weight at harvest (t/ha), tuber dry matter weight at harvest (kg/ha), leaf area index (LAI), by-product produced (stalk) weight at maturity (kg/ha) and total weight at harvest (kg/ha). For determining the accuracy of the validated model, the statistical criteria R^2, the normalized roots mean square error ($RMSE_n$) (Eq. (2)), mean relative error (− ve value shows underestimation and + ve value shows overestimation in comparison to observed value) (Eq. (1)) and d-stat (Eq. (3)) indices were calculated using the following equations (Satapathy et al. 2014):

$$\mathrm{MRE} = \frac{1}{N}\sum_{i=1}^{n}\frac{X_i - Y_i}{Y_i}\ 100 \qquad (1)$$

$$\mathrm{RMSEn} = 100 \times \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - Y_i)^2}}{\overline{Y}} \tag{2}$$

$$\mathrm{d{-}stat} = 1 - \frac{\sum_{i=1}^{N}(X_i - Y_i)^2}{\sum_{i=1}^{N}\left(\left|X_i - \overline{Y}\right| + \left|Y_i - \overline{Y}\right|\right)^2} \tag{3}$$

where X_i is the estimated value obtained from different models, Y_i is the estimated value obtained from the crop model and $\overline{Y}$ is observed mean value.

Results and Discussion

Calibration and Validation of SUBSTOR-Potato Model

Crop parameters such as tuber weight (dry and fresh) at harvest and time series of aboveground dry matter weight of F_{120} (recommended) treatment during the year 2013–2014 were used for the model calibration. The simulated time series of aboveground dry matter weight, tuber fresh weight and dry weight at harvest were within the range of standard deviation of observed values throughout the growing season during calibration (Fig. 4). The statistical analysis with $\mathrm{RMSE_n}$ (2.36%) and d-stat (0.99) values between the simulated and observed time series of aboveground dry matter weight showed that calibrated model performed well (Table 1). The derived genetic coefficients of potato are presented in Table 2. The genotype coefficients were validated by using treatments (F_{90}, and F_{150}) of the year 2013–14 and treatments (F_{90}, F_{120} and F_{150}) of the year 2014–2015, respectively, for two planting dates.

Figure 5 presents the model validation results for fresh and dry yield and shows a close relation between simulated and observed data. Comparison of simulated and observed aboveground dry matter weight (Fig. 5a), LAI (max) (Fig. 5b), tuber fresh

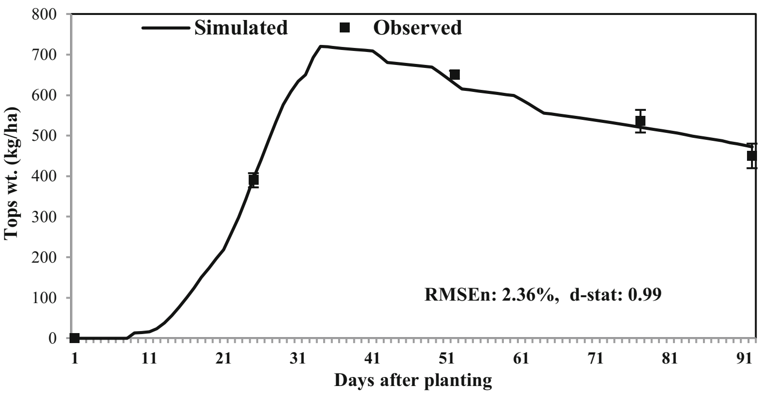

Fig. 4 Comparison of simulated and observed time series of tops wt (kg/ha) with standard deviation of observed value during the field experiment in year 2013–2014 at Kharagpur

Table 1 Comparison of simulated vs. observed crop growth and yield attributes with standard deviation of observed value for the year 2013–2014

Parameters	Observed	Simulated
Tuber initiation day	29	28
Tops dry wt at harvest (kg/ha)	456 (± 30)	472
Tuber fresh wt at harvest (t/ha)	27.78 (± 1.15)	28.01
Tuber dry wt at harvest (kg/ha)	5599 (± 92.49)	5602

weight (Fig. 5c), tuber dry weight (Fig. 5d) and total weight (Fig. 5e) are shown for the years 2013–2014 and 2014–2015, respectively. The statistical evaluation between the simulated and observed data showed $RMSE_n$ of 3.2–6.7% with R^2 of 0.93–0.98 and d-stat of 0.98 for the year 2013–2014, while $RMSE_n$ of 5.2–7.3% with R^2 of 0.95–0.98 and d-stat of 0.98 were obtained for the year 2014–2015, which further confirmed the satisfactory performance of the model. Similar results were reported by Griffin et al. (1993) who tested the SUBSTOR-Potato model in a contrasting environment for simulated and measured yield (range 2–20 t ha^{-1} tuber dry mass) and found a good correlation ($R^2 = 0.81$) for the model. Studies reported by Travasso et al. (1996) in Argentina and Arora et al. (2013) supported the above results for the SUBSTOR-Potato model with a $RMSE_n$ of 14.7% and 12.6%, respectively, for the measured tuber yield. Furthermore, Raymundo et al. (2016) studied the SUBSTOR-Potato model across a wide range of growing conditions and reported a relatively high RMSE of 37.2% and 21.4% for tuber dry and fresh weight, respectively. In contrast, Klepper and Rouse (1991) and Šťastná et al. (2010) reported underestimation of model performance in water-limited conditions because of a significant increase in air temperature.

Model Evaluation and Yield Simulation for Other Locations Used During the Study in West Bengal

The SUBSTOR-Potato model was used to simulate the seasonal yield from the years 1984–1985 to 2014–2015 using historical weather data provided by RMC (Regional Meteorology Department), Kolkata. Figure 6 represents the comparison of simulated (line) vs. observed tuber yield. The statistical analysis with R^2 (0.82–0.87), $RMSE_n$ (5.2–7.3%) and MRE (1.35–1.64%) indicated satisfactory performance of the modelling of a sub-tropical region.

The differences in simulated tuber yield over observed tuber yield can be explained by deviation in maximum and minimum temperatures from optimum temperature (Wheeler et al. 2000; Šťastná et al. 2010; Rykaczewska, 2015). Figure 7a, c and e

Table 2 Calibrated genetic coefficients of potato cultivar Kufri Jyoti in SUBSTOR-Potato model

Cultivar	Genetic coefficients				
	G2 (cm^2/m^2 day^{-1})	G3 (g/m^2 day^{-1})	PD	P2	TC (°C)
Kufri Jyoti	1890	27	0.8	0.8	16.0

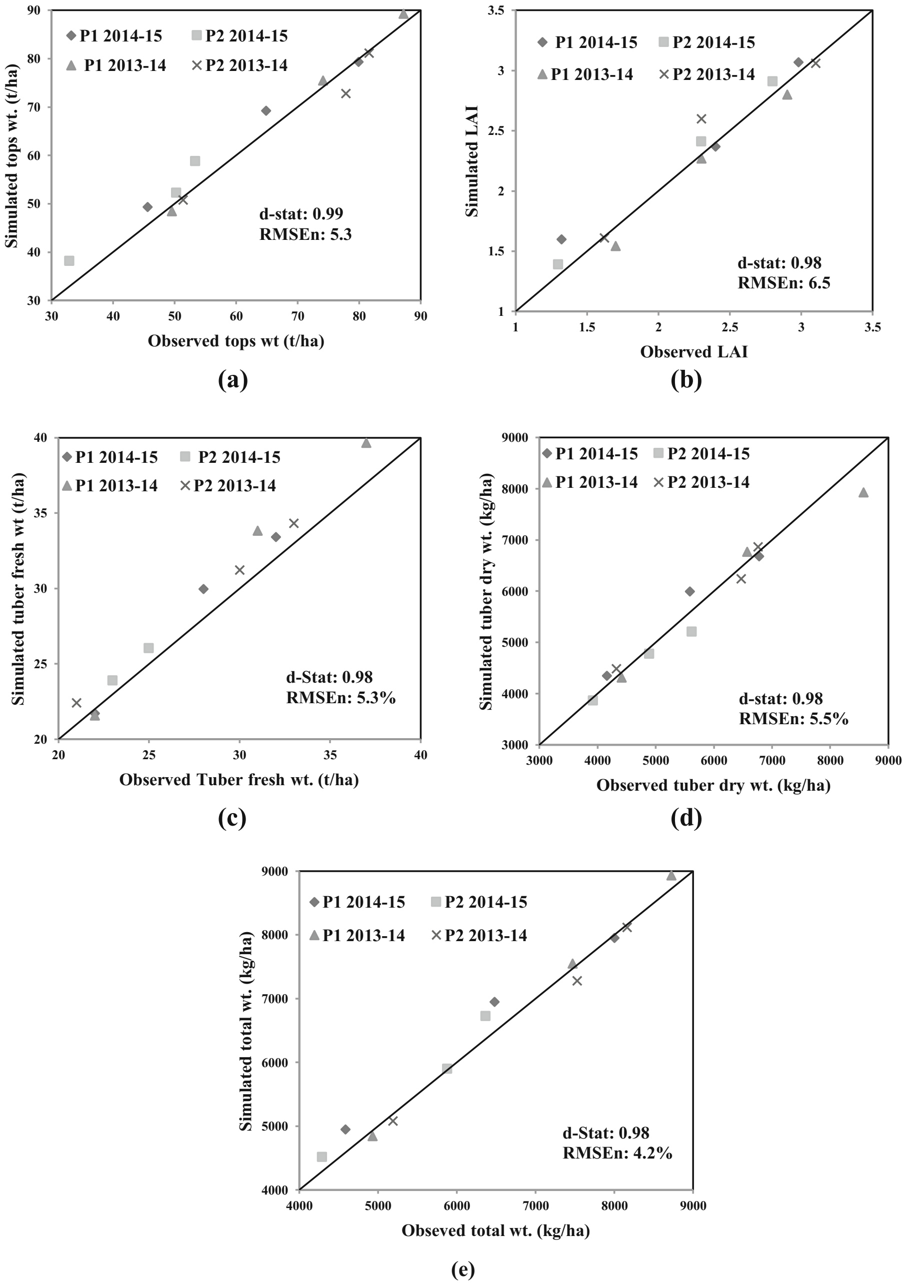

Fig. 5 Comparison of simulated vs. observed tops wt (kg ha^{-1}) (**a**), LAI (max) (**b**), tuber fresh wt (t/ha) (**c**), tuber dry wt (kg/ha) (**d**) and total wt (kg/ha) (**e**) for the planting dates ($P_1$and P_2) and fertilizer rate for the years 2013–2014 and 2014–2015

represents the tuber yield vs. maximum temperature and Fig. 7b, d and f represents the tuber yield vs. minimum temperature for the West Mednipur, Birbhum and Bankura districts, respectively. The trend analysis in Fig. 7 clearly indicated that with an increase

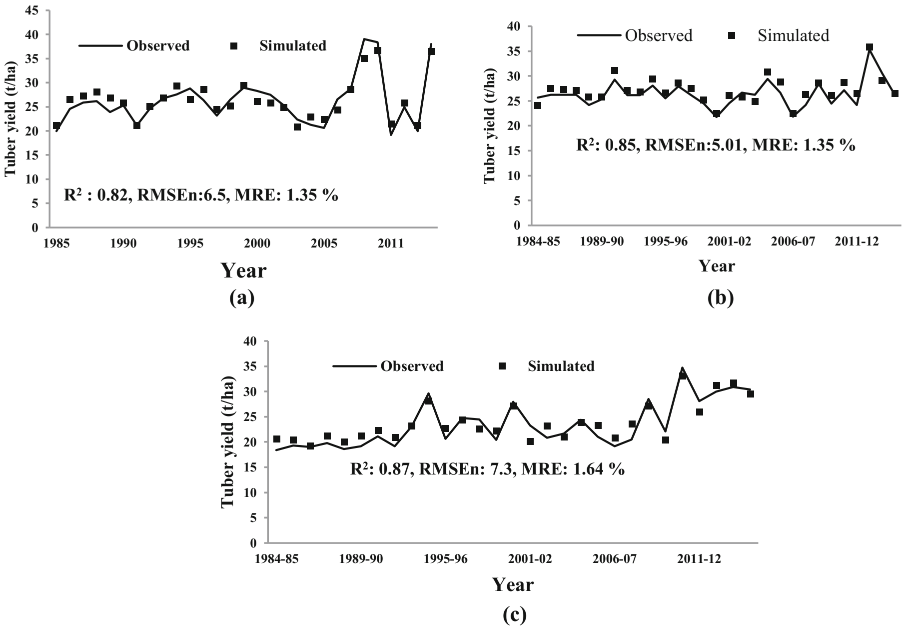

Fig. 6 Comparison of simulated vs. observed tuber fresh wt (t/ha) for West Medinipur (**a**), Bankura (**b**) and Birbhum (**c**) districts using 30 years historical weather data

in temperature irrespective of whether maximum or minimum, there was a reduction in the tuber yield as found by other researchers (Wheeler et al. 2000; Rykaczewska 2015). Figure 7b, d and f also indicated that when the minimum temperature (T_{min}) was in the range 15 to 18 °C, there was a decrease in tuber yield while for the maximum temperature (T_{max}), a similar trend was observed in the temperature range 26 to 30 °C (Fig. 7a, c and e). Similar results were reported by Rykaczewska (2015) who studied the effect of higher temperature on potato development and found that higher temperatures (day/night, 35 °C/25 °C) resulted in more productivity reduction in comparison to optimum temperatures, especially during the flowering period which reduces the yield of potato cultivars by 35%. Likewise, Šťastná et al. (2010) reported that a temperature rise had a negative effect on the tuber yield. Additionally, Tadesse et al. (2001) assessed the effect of temperature on plant development and reported that vegetative growth was stimulated at higher temperatures but was delayed during tuber formation; thus, tuber yields and harvest index were reduced. Furthermore, the performance of SUBSTOR-Potato model was evaluated by Vashist et al. (2015) in present and future climate change scenario. They reported that an increase in maximum and minimum temperature decreased potato yield by about 19–29% while Abdrabbo et al. (2010) reported a decrease in yield to about 11–13%. To further support the fact that temperature plays a major role in potato tuber yield, Pereira and Nova (2008) and Raymundo et al. (2016) reported an underestimation of irrigated potato productivity of less than 10% with increase in temperature. In contrast, Daccache et al. (2011) predicted a future potential yield increase of 13–16% in the humid climate of England with rising temperature and elevated atmospheric CO_2 concentrations.

Planting Dates Analysis Under Current and Increment of 2 °C in Current Climate Scenario

The model was used to simulate seasonal potato tuber yield (fresh and dry weight) and aboveground dry biomass for planting dates (10th, 20th, 30th of November and 10th, 20th, 30th of December) at an interval of 10 days, by using the 30 years historical weather data of the mentioned districts. The simulated tuber yields (fresh and dry weight) and aboveground dry biomass with respect to cumulative probability distribution under different planting dates is shown in Figs. 8 and 9 for West Medinipur, Bankura and Birbhum districts.

From Figs. 8 and 9, it is clear that considerable tuber yield variation was observed for different planting dates. Table 3 indicates that the lowest coefficient of variation for

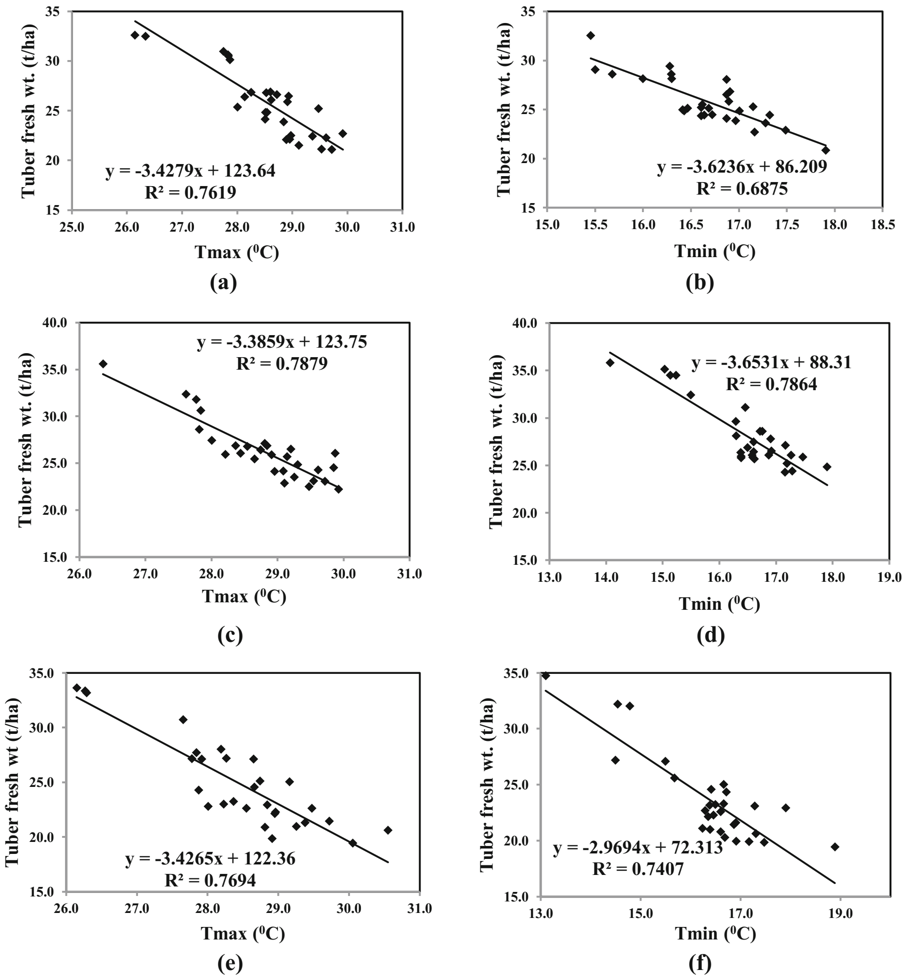

Fig. 7 Regression analysis of simulated yield vs. temperature (maximum and minimum, °C) of West Medinipur (**a**, **b**), Birbhum (**c**, **d**) and Bankura districts (**e**, **f**)

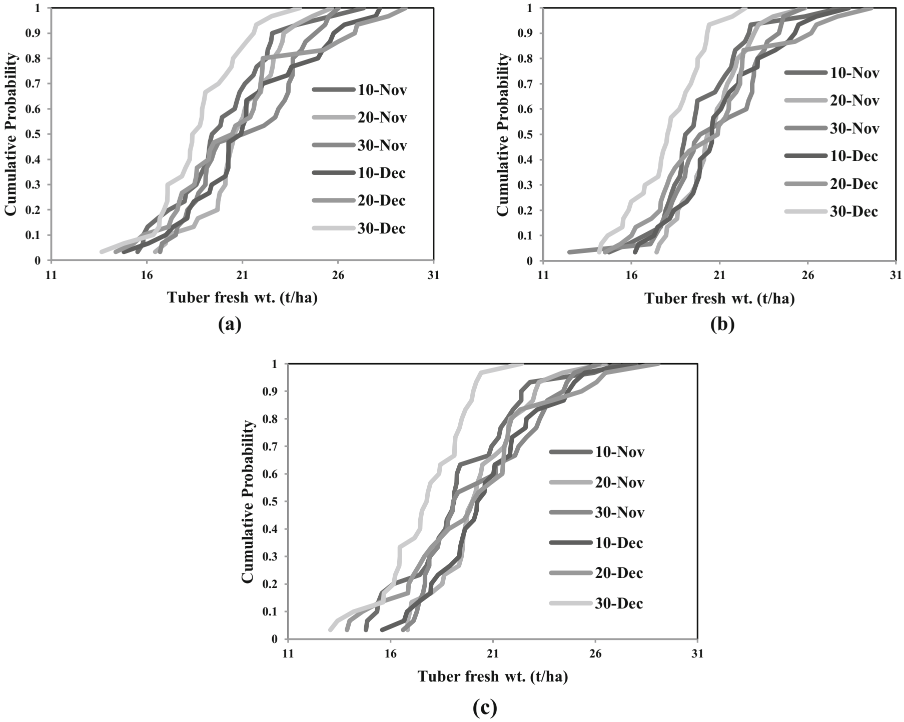

Fig. 8 Seasonal variation in tuber yield under six planting dates under current climate scenario for West Medinipur (**a**), Bankura (**b**) and Birbhum (**c**) districts

average tuber fresh weight was obtained for 20th of November (9.58–11.23%) and 30th of November (13.56–14.44%), respectively, for West Medinipur, Bankura and Birbhum districts. The highest coefficients of variation for average tuber fresh weight were obtained for 20th of December (17.95–18.65%) and followed by 10th of December (13.87–15.98%), respectively, for the same districts (Table 3). Similar results were obtained for tuber dry matter weight and aboveground dry matter for West Medinipur, Bankura and Birbhum districts. Although, the planting date for 30th of December showed less variance in tuber fresh weight, tuber dry matter weight and aboveground dry matter weight, the average yield (fresh and dry matter weight)/biomass was so low that the planting date was not acceptable.

In comparison to the current climate scenario, the future scenario for the three districts showed an average loss for tuber fresh weight with corresponding planting dates as follows: 10th of November (1.96%), 20th of November (2.77%), 30th of November (2.48%), 10th of December (28.20%), 20th of December (24.93%) and 30th of December (18.08%).

Similarly, for tuber dry matter weight, the average loss with corresponding planting dates was 10th of November (1.53%), 20th of November (3.60%), 30th of November (2.18%), 10th of December (30.22%), 20th of December (27.09%) and 30th of December (18.87%).

In contrast, for the aboveground dry matter weight, an average loss with corresponding planting dates was recorded for 20th of November (0.72%), 10th of

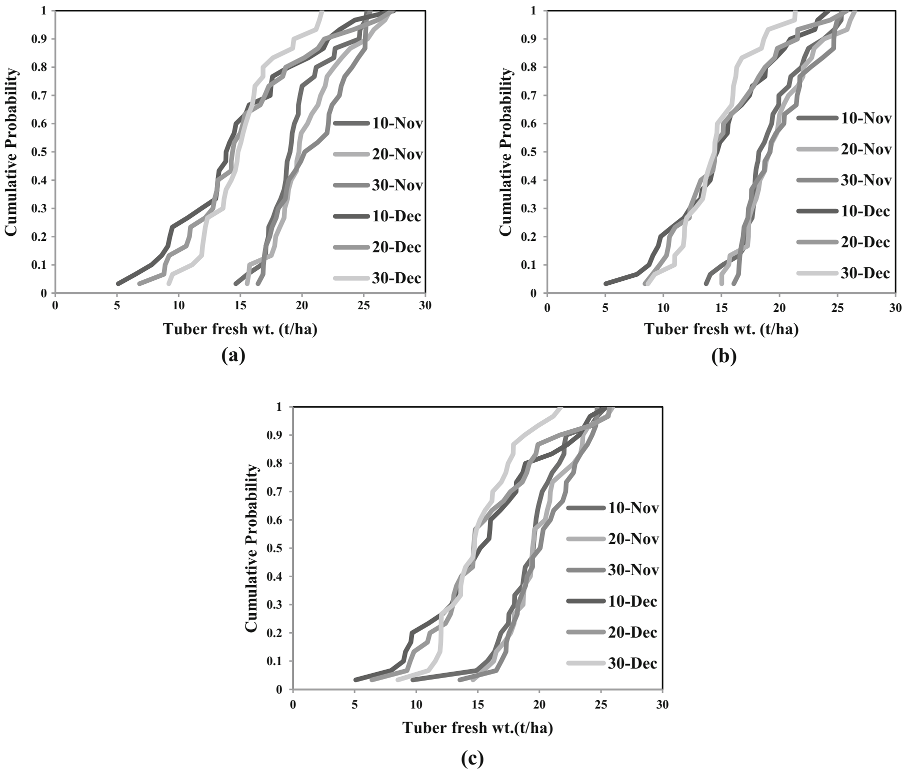

Fig. 9 Seasonal variation of tuber yield for six planting dates under current + 2 °C climate scenario for West Medinipur (**a**), Bankura (**b**) and Birbhum (**c**) districts

December (20.39%), 20th of December (16.83%) and 30th of December (8.93%) while an average increase was observed for 10th of November (2.93%) and 30th of November (0.03%), respectively, which might be attributed to the fact that with increase in temperature from the current scenario, the rate of photosynthesis would have increased leading to higher value of aboveground dry matter in November (Tubiello et al. 2002; Pandit et al. 2015).

Planting on 20th and 30th of November gave higher yields compared with the remaining planting dates (Table 4).This might be due to the effect of night temperature and day length which are the key factors responsible for potato yield (Kawakami et al. 2005). At tuber bulking stage, the plant requires cooler temperatures (Kleinwechter et al. 2016) which may lead to more assimilation of nutrients from the roots, and so increase the tuber yield (Struik and Ewing 1995; Hijmans 2003). Wheeler et al. (1986) and Struik and Ewing (1995) reported that at higher temperatures, a tuber contributes proportionally less to the total dry matter yield, whereas stems and leaves contribute more to yield. Table 3 shows the simulated yield standard deviation and coefficient of variation are lower for 20th of November planting date than for 10th of November planting date, which clearly indicates 20th of November to be the more suitable planting date for potato in comparison to 10th and 20th of December in a sub-humid

Table 3 Districtwise simulated tuber fresh wt (t/ha), tuber dry wt (kg/ha) and above ground dry matter (kg/ha) with standard deviation and coefficient of variation under different planting dates in current climate scenario

	West Medinipur					Bankura					Birbhum				
Planting dates	Tuber fresh wt. (t/ha)			SD	CV %	Tuber fresh wt. (t/ha)			SD	CV %	Tuber fresh wt. (t/ha)			SD	CV %
	Maximum	Minimum	Average			Maximum	Minimum	Average			Maximum	Minimum	Average		
10-Nov	27.34	15.51	19.97	2.86	14.31	27.83	14.72	19.90	2.72	13.66	27.15	14.80	19.44	2.62	13.47
20-Nov	25.67	16.43	20.93	2.17	10.36	25.84	17.43	20.65	1.98	9.58	26.49	16.84	20.39	2.29	11.23
30-Nov	26.02	16.69	21.52	2.92	13.56	25.76	12.49	20.70	2.99	14.44	26.20	16.61	20.40	2.84	13.92
10-Dec	28.18	14.80	21.33	3.41	15.98	28.32	16.21	21.11	2.97	14.06	27.97	15.60	20.76	2.88	13.87
20-Dec	29.51	14.38	20.85	3.89	18.65	29.59	14.50	20.66	3.71	17.95	29.08	13.88	20.14	3.71	18.42
30-Dec	24.00	13.64	18.75	2.26	12.38	22.46	14.18	18.09	2.12	17.20	11.41	13.07	17.75	2.14	12.05
	West Medinipur					Bankura					Birbhum				
Planting dates	Tuber dry matter wt. (kg/ha)			SD	CV%	Tuber dry matter wt. (kg/ha)			SD	CV %	Tuber dry matter wt. (kg/ha)			SD	CV %
	Maximum	Minimum	Average			Maximum	Minimum	Average			Maximum	Minimum	Average		
10-Nov	5468.0	3102.0	3974.9	561.9	14.13	5431.0	2959.0	3885.3	593.7	15.28	5565.0	2944.0	3972.1	538.9	13.56
20-Nov	5133.0	3286.0	4202.7	429.5	10.21	5298.0	3367.0	4109.8	446.0	10.85	5167.0	3486.0	4160.7	386.8	9.29
30-Nov	5204.0	3338.0	4287.9	589.7	13.75	5240.0	3322.0	4144.1	596.6	14.39	5270.0	2499.0	4197.1	615.7	14.66
10-Dec	5637.0	2960.0	4366.1	715.3	16.38	5663.0	3121.0	4269.6	653.3	15.30	5682.0	3242.0	4335.9	655.0	15.10
20-Dec	5903.0	2877.0	4300.1	823.0	19.13	5815.0	2776.0	4164.0	800.7	19.22	5917.0	2900.0	4260.7	792.2	18.59
30-Dec	5392.0	2729.0	3854.8	536.1	13.90	5254.0	2613.0	3670.7	541.4	14.74	5257.0	2835.0	3729.2	531.3	14.24
	West Medinipur					Bankura					Birbhum				
Planting dates	Above ground dry matter (kg/ha)			SD	CV%	Above ground dry matter (kg/ha)			SD	CV %	Above ground dry matter (kg/ha)			SD	CV %
	Maximum	Minimum	Average			Maximum	Minimum	Average			Maximum	Minimum	Average		
10-Nov	6256.0	3512.0	4413.0	610.2	13.82	6188.0	3383.0	4308.0	637.8	14.80	6318.0	3516.0	4407.4	569.2	12.91
20-Nov	5635.0	3683.0	4569.6	445.8	9.75	5788.0	3682.0	4472.0	458.5	10.25	5624.0	3865.0	4523.6	393.7	8.70
30-Nov	5623.0	3784.0	4698.1	614.3	13.07	5672.0	3750.0	4546.0	623.2	13.70	5752.0	2726.0	4590.1	651.1	14.18
10-Dec	6624.0	3661.0	5137.1	758.5	14.76	6738.0	3785.0	5020.3	709.0	14.12	6756.0	3905.0	5083.9	709.1	13.94
20-Dec	6574.0	3494.0	4940.3	875.1	17.71	6474.0	3289.0	4770.1	856.3	17.95	6580.0	3499.0	4871.0	847.4	17.39
30-Dec	6005.0	3099.0	4327.5	597.1	13.71	5847.0	2970.0	4128.5	613.3	14.85	5856.0	3187.0	4184.2	590.5	14.11

region. Similar results were reported by Wolf (2002) who showed that adjustment of planting dates can reduce the loss of potato yield due to heat stress.

Conclusions

In this study, the performance of SUBSTOR-Potato model was evaluated for temperature effects on potato yield at different locations in a sub-tropical region. The reported study revealed that SUBSTOR-Potato model performed well in assessing crop growth and yield. During the model evaluation, the difference in simulated and observed tuber yield indicated that an increase in temperature (maximum and minimum, °C) had significant negative correlation with the tuber yield. Moreover, the study suggested that the optimum planting date (20th of November) would increase potato tuber yield compared with the remaining planting dates in both current and future climate scenarios. Tuber yield negatively responded to increase in temperature, and the optimum planting date was identified as a non-cost climate change adaptation strategy which could effectively increase potato tuber yield for a sub-tropical region.

Table 4 Districtwise simulated tuber fresh wt (t/ha), tuber dry wt (kg/ha) and above ground dry matter (kg/ha) with standard deviation and coefficient of variation under different planting dates in current +2 climate scenario

	West Medinipur					Bankura					Birbhum				
Planting dates	Tuber fresh wt. (t/ha)			SD	CV%	Tuber fresh wt. (t/ha)			SD	CV %	Tuber fresh wt. (t/ha)			SD	CV %
	Maximum	Minimum	Average			Maximum	Minimum	Average			Maximum	Minimum	Average		
10-Nov	25.25	14.64	19.58	2.76	14.09	25.35	14.04	19.26	3.04	15.78	25.43	9.73	19.30	3.11	16.11
20-Nov	27.14	15.55	20.45	3.10	15.15	26.5	15.03	19.78	3.16	15.97	25.97	14.61	20.02	2.85	14.23
30-Nov	25.54	16.43	20.84	3.11	14.92	25.62	16.07	19.93	3.05	15.30	24.68	13.55	20.28	2.86	14.10
10-Dec	27.43	5.11	14.78	5.48	37.07	24.21	5.04	15.03	4.83	32.13	25.50	5.09	15.55	5.22	33.56
20-Dec	27.32	6.83	15.40	5.11	33.18	25.80	8.41	15.25	4.50	29.50	25.69	6.40	15.61	4.80	30.74
30-Dec	21.61	9.20	15.11	3.24	21.44	21.37	8.68	14.59	3.14	21.52	21.75	8.51	15.00	3.11	20.73

	West Medinipur					Bankura					Birbhum				
Planting dates	Tuber dry matter wt. (kg/ha)			SD	CV %	Tuber dry matter wt. (kg/ha)			SD	CV %	Tuber dry matter wt. (kg/ha)			SD	CV %
	Maximum	Minimum	Average			Maximum	Minimum	Average			Maximum	Minimum	Average		
10-Nov	5050.0	2928.0	3913.4	533.7	13.63	5070.0	2739.0	3860.0	588.5	15.24	5085.0	1946.0	3876.9	604.7	15.59
20-Nov	5427.0	3109.0	4073.2	603.4	14.81	5301.0	3006.0	3938.2	612.9	15.56	5195.0	2922.0	4012.7	561.9	14.00
30-Nov	5200.0	3286.0	4209.5	635.0	15.08	5211.0	3213.0	4043.8	633.9	15.67	5274.0	2711.0	4100.3	596.1	14.53
10-Dec	5486.0	1023.0	2962.9	1053.8	35.57	4842.0	1009.0	2999.2	924.0	30.80	5101.0	1018.0	3087.5	996.9	32.28
20-Dec	5464.0	1365.0	3093.2	984.5	31.82	5159.0	1683.0	3060.3	866.4	28.31	5138.0	1279.0	3122.3	917.5	29.38
30-Dec	4741.0	1839.0	3072.2	680.2	22.14	4845.0	1736.0	2994.7	678.5	22.66	4799.0	1701.0	3061.8	662.5	21.63

	West Medinipur					Bankura					Birbhum				
Planting dates	Above ground dry matter (kg/ha)			SD	CV %	Above ground dry matter (kg/ha)			SD	CV %	Above ground dry matter (kg/ha)			SD	CV %
	Maximum	Minimum	Average			Maximum	Minimum	Average			Maximum	Minimum	Average		
10-Nov	6166.0	3318.0	4548.7	632.0	13.98	6154.0	3121.0	4472.2	694.3	15.52	6134.0	3105.0	4491.5	644.2	14.34
20-Nov	6135.0	3537.0	4560.4	670.5	14.70	5848.0	3394.0	4412.1	647.9	14.68	5766.0	3518.0	4494.9	570.4	12.68
30-Nov	6122.0	3760.0	4729.5	694.3	14.68	5778.0	3644.0	4530.0	672.4	14.80	5829.0	3074.0	4579.9	636.2	13.89
10-Dec	6274.0	2407.0	4021.0	988.0	24.57	5946.0	2419.0	4012.7	873.5	21.76	5947.0	2566.0	4098.3	894.6	21.82
20-Dec	6123.0	2683.0	4079.6	935.9	22.94	6051.0	2692.0	3987.9	843.0	21.13	6033.0	2622.0	4058.8	843.6	20.78
30-Dec	5811.0	2592.0	3900.6	699.8	17.94	6058.0	2595.0	3772.8	723.4	19.17	6012.0	2777.0	3835.5	685.6	17.87

Acknowledgements The study was conducted under the Project 'Forecasting of Agricultural output using space, agro-meteorology and land based observation', which is financed and sponsored by the India Meteorology Department and Ministry of Earth Sciences, Government of India.

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