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Effect of intra-seasonal variation in temperature on tuber yield of potato in middle Gujarat using SUBSTOR model

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ABSTRACT

Three years (2014-15 to 2016-17) experimental data collected at Main Vegetable Research Station, Anand was used to calibrate and validate the SUBSTOR- potato model for three cultivars of potato (*K. Badshah, K. Lokhar and K. Pokhraj*). The validated model was used to simulate the tuber yield by changing the maximum and minimum temperature (+3^0 to -3^{0}C)in different months (November, December, January and February). Results revealed that the elevated temperature had negative effect on tuber yield and reduced temperature had positive effect on tuber yield. Among the varieties, *K. Lokhar* was least affected by the temperature variation. *K. Pokhraj* was found to be most sensitive to elevated temperature, while *K. Badshah* was most beneficial in reduced temperature. Temperature variation during December and January was found to have maximum effect on normal sown potato crop. The effect of minimum temperature on tuber yield was more than that observed with maximum temperature.

Keywords : Intra-seasonal temperature, potato, SUBSTOR model

Potato (*Solanum tuberosum* L.) is a major world food crop and by far the most important vegetable crop in terms of quantities produced and consumed worldwide (FAO, 2005).In India, potato is grown in all parts of the country (Annon, 2016).Gujarat is the fourth largest potato producing states in the country after Uttar Pradesh, Bihar and West Bengal with average yield of 26.30 t ha^{-1} (Annon, 2015).

The yield of potato has been found to vary significantly over the years due to fluctuations in climatic parameters particularly temperature during winter season. During initial growth stages temperature around 25^{0}Cis most suitable while for tuber development lower temperature (<20^{0}C) are favourable. Planting time plays a very important role in potato production. Tuber growth is sharply inhibited in temperatures below 10°C and above 30°C, while optimum yields are obtained where mean daily temperatures are in the 18 to 20°C range (Haris *et al*., 2015). For best tuber yields, potato crop needs long day conditions during growth and short day conditions during tuberization (Chadha, 2009). Even moderately high temperature drastically reduces tuber yield without much affecting the photosynthesis and total biomass production (Singh *et al.*, 2013).Thus the intra-seasonal variation in temperature has significant influence on tuber yield of potato.

Crop simulation models have been used to study the effect of intra-seasonal variation in weather parameters on yield of wheat crop (Sandhu *et al.,* 2016; Prabhjyot Kaur and Hundal, 2009). In this paper an attempt has been made to assess the effect of intra-seasonal variation in temperatures on tuber yield of potato in middle Gujarat using SUBSTOR potato model.

MATERIALS AND METHODS

Experimental and weather data

The data collected during three years of experimentation (2014-15, 2015-16 and 2016-17) on three cultivars (V_1- *Kufri Badshah*, V_2- *Kufri Lokhar* and V_3- *Kufri Pukhraj*) of potato sown on four dates (D_1- 10th October, D_2- 25th October, D_3- 10th November and D_4- 25th November) and planned in split plot replicated four times, was obtained from Main Vegetable Research Station, Anand Agricultural University, Anand. Tubers were sown with spacing of 50cm x 20cm andwith recommended dose of fertilizer 220:110:110 NPK kg ha^{-1} during all the growing seasons. The soil type of the experimental site was sandy loam a true representative soil of the region. Irrigation was applied between 12 to 15 days of intervals and plant protection measures arefollowed as per the scheduled package of practice. The corresponding weather data was obtained from Department of Agricultural Meteorology, Anand Agricultural University, Anand.

SUBSTOR-potato model

The DSSAT family of SUBSTOR- potato model

Table 1: Mean tuber yield (t ha^{-1}) of potato as affected by dates of sowing and varieties during three years (2014-15 to 2016-17)

Treatments	2014-15	2015-16	2016-17	Mean
Dates of sowing				
D_1 (October 10)	17.49	13.09	13.75	14.78
D_2 (October 25)	23.13	22.02	18.22	21.12
D_3 (November 10)	31.89	31.83	26.91	30.21
D_4 (November 25)	31.79	30.77	26.45	29.67
Cultivars				
V_1 (*Kufri Badshah*)	26.68	22.79	20.67	23.38
V_2 (*Kufri Lokhar*)	28.28	32.37	24.18	28.27
V_3 (*Kufri Pokhraj*)	23.27	18.13	19.14	20.18
Mean	26.07	24.43	21.33	23.94

Table 2: Genotype coefficients of potato cultivars for SUSTOR-potato model

Symbol	Description	*Kufri Badshah*	*Kufri Lokhar*	*Kufri Pokhraj*
G2	Leaf area expansion rate in degree days	2000	2000	2000
G3	Potential tuber growth rate	25.5	25.5	24.5
PD	Index that suppresses tuber growth during the period that immediately follows tuber induction	0.8	0.7	0.7
P2	Index that relates photoperiod response to tuber initiation	0.8	0.7	0.6
TC	Upper critical temperature for tuber initiation	21.5	18.5	19.5

(Griffin *et al.,* 1993) was employed to simulate tuber yield of potato crop. The model was calibrated and validated for different cultivars with the experimental data obtained as described earlier. The pertinent daily weather, soil and crop management data for all the sowing dates and varieties were used as input. The model was calibrated with the two years (2014-15 and 2015-16) of experimental data and validated with the third year (2016-17) data. The cultivar coefficients were estimated by repeated iteration's by running the GLUE coefficient estimator until a close match between simulated and observed tuber yield was obtained. The coefficients thus determined are presented in Table 2.

The model performance was evaluated using test criteria viz. root mean square error (RMSE), mean absolute error (MAE), mean bias error (MBE), coefficient of determination (R^2)and percent error (PE) and calculated according to Willmott (1982).

Impact studies

The validated SUBSTOR-potato model was used to study the effect of intra seasonal variation of temperatures on tuber yield of all three varieties sown on four dates by incremental change in the monthly maximum and minimum temperatures from -3^{0}C to 3^{0}C during November, December, January and February months. The simulated tuber yields were compared with the mean observed yield and the percent departure were calculated.

RESULTS AND DISCUSSION

Tuber yield

The mean observed tuber yield of three cultivars of potato under four dates of sowing during three years are presented in Table 1. Among different dates of sowing, the maximum tuber yield (30.21 t ha^{-1}) was observed in third date i.e. November 10 sown potato followed by November 25 sown crop (29.67 t ha^{-1}) and the lowest (14.78 t ha^{-1}) in early sown (October 10) potato. Among the varieties, the highest tuber yield (28.27 t ha^{-1}) was observed in cultivar *K. Lokhar* followed by *K. Badshah* (23.38 t ha^{-1}). During three years of experimentation, the mean tuber yield varied between 21.33 t ha^{-1} in 2016-17 to 24.43 t ha^{-1} in 2015-16 (Table 1). This is clear that the tuber yield of potato varied significantly with dates of sowing, variety and year.

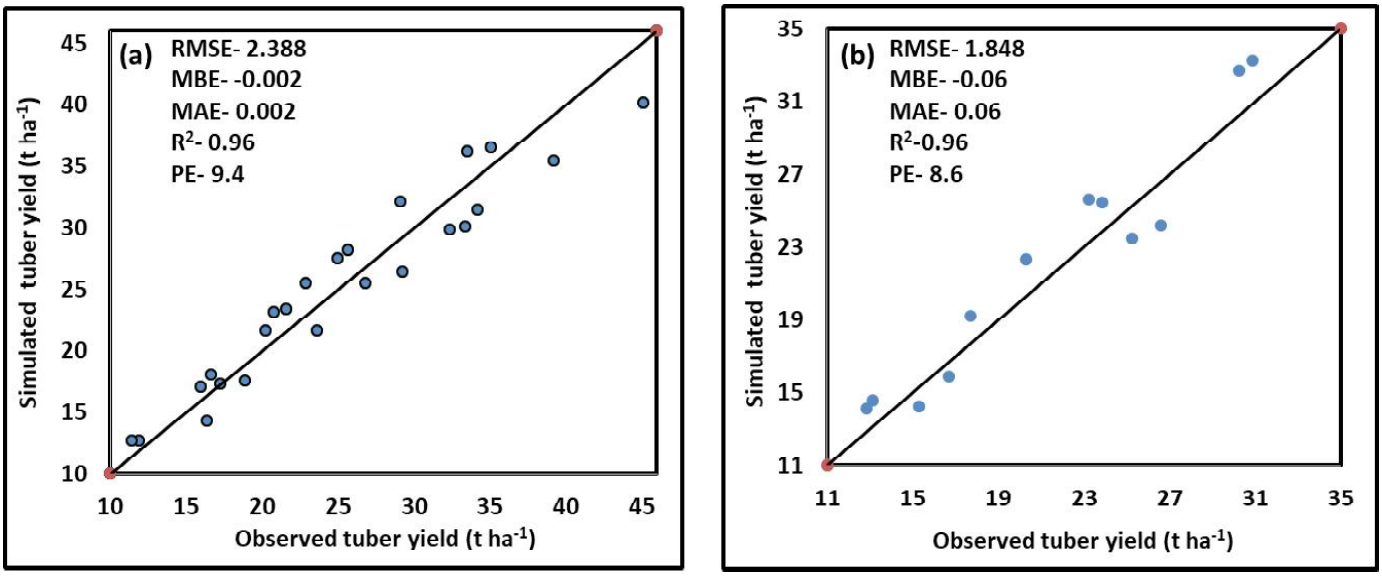

Fig. 1: Observed and simulated yield of potato during (a) calibration period (2014-15 and 2015-16)and (b) validation (2016-17) of SUBSTOR- potato model

Calibration and validation

The observed and simulated tuber yield of potato cultivar during calibration (2014-15 and 2015-16) and validation period (2016-17) are presented in Fig. 1. The model performance evaluated by test criteria viz. RMSE (2.388), MBE (-0.002), MAE (0.002), R^2(0.96) and PE (9.4) for calibration years indicated close relationship with minimum error. During validation period also the performance of model was quite satisfactory as indicated by the test criteria (RMSE- 1.848, MBE- -0.06, MAE- 0.06, R^2- 0.96 and PE- 8.6). Hence, this model can be used to simulate the tuber yield of different cultivars under different environment.

Effect of temperature variations on varieties

The effect of increase and/or decrease in maximum and minimum temperatures from -3^{0}Cto +3^{0}C in different months on tuber yield of three varieties of potato are presented in Table 3. It is seen that the increase in maximum as well as minimum temperature caused decrease in tuber yield in all the cultivars, the magnitude varied with the cultivars, as well as the period and the extent of increase in temperature. During tuber bulking stage (November), due to high temperature tuber yield decreased in all the cultivars as in this stage there is build-up of carbohydrates, water and other nutrients in the tubers. These findings are in agreement with the earlier reported by Kar (2003). The converse is also true as the decrease in temperature caused increase in tuber yield. The minimum temperatures during vegetative stage might have helped in good tuber initiation in all the cultivars. Patel *et al.,*(1999) also reported minimum temperature during vegetative which increased the tuber yield which supports the current findings. Among the varieties, the effect of maximum temperature variation was highest (-14.9 to +15.5%) in *K. Badshah* followed by *K. Pokhraj* and lowest in *K. Lokhar*. However, the response of change in maximum temperature during November was highest (-11.0 to +12.3%) in cv. *K. Lokhar* and lowest (-8.4 to 13.1%) in cv. *K. Badshah*. The change in maximum temperature during December and January had profound influence on tuber yield of cv. *K. Badshah* and *K. Pokhraj* in comparison to other months (Table 3).

The effect of change in minimum temperature on tuber yield of different cultivars was more than that observed with maximum temperature (Table 3). The increase in minimum temperature up to 3^{0}C had highest (-17.0%) yield reduction in cv. *K. Pokhraj* followed by -13.6 per cent in *K. Lokhar* and -10.9 per cent in *K. Badshah*. During November and December, the increase in minimum temperature by 3^{0}C had highest reduction in tuber yield (-15.9 to -16.2%) of *K. Badshah* followed by -13.6 to -15.1 percent reduction in *K. Pokhraj* and -8.6 to -12.5 per cent reduction in *K. Lokhar*. Again, the increase in minimum temperature during February had highest influence (-11.2%) on *K. Lokhar*. Thus the cultivar *K. Lokhar* was least influenced by change in temperatures in comparison to other two cultivars.

Effect of temperature under different sowing dates

The effect of change in maximum and minimum temperature during November, December, January and February month on potato sown on different dates (October

Table 3: Percent change in tuber yield (%) due to intra-seasonal variation of maximum and minimum temperatures in different varieties. (The values in brackets are mean tuber yield of the variety)

Month	Change in temperature (^{0}C)	Maximum temperature			Minimum temperature		
		K. Badshah (Y=23.38 t ha^{-1})	K.Lokhar (Y-28.27 t ha^{-1})	K.Pokhraj (Y-20.18 t ha^{-1})	K. Badshah (Y=23.38 t ha^{-1})	K.Lokhar (Y-28.27 t ha^{-1})	K. Pokhraj (Y-20.18 t ha^{-1})
November	-3	13.1	12.3	10.0	13.5	12.7	10.4
	-2	6.6	6.7	6.7	7.2	7.2	7.2
	-1	4.3	3.5	3.7	4.5	3.6	3.9
	1	-2.5	-3.8	-4.2	-4.2	-5.5	-6.0
	2	-5.4	-8.7	-12.7	-6.2	-9.6	-13.6
	3	-8.4	-11.0	-14.2	-10.9	-13.6	-17.0
December	-3	15.5	13.9	16.2	15.9	14.3	16.6
	-2	12.4	9.9	12.2	12.4	9.9	12.2
	-1	7.1	7.2	8.0	7.2	7.4	8.2
	1	-6.1	-4.3	-7.3	-6.5	-4.7	-7.7
	2	-9.4	-7.6	-10.8	-10.3	-8.5	-11.8
	3	-14.6	-11.1	-13.6	-16.2	-12.5	-15.1
January	-3	10.8	9.7	11.5	11.3	9.9	12.2
	-2	10.6	7.0	8.9	10.9	7.4	9.3
	-1	6.4	2.1	7.1	6.8	2.6	7.5
	1	-4.5	-8.1	-4.2	-2.9	-8.4	-2.7
	2	-10.6	-7.4	-9.4	-11.0	-7.8	-9.8
	3	-14.9	-7.8	-12.7	-15.9	-8.6	-13.6
February	-3	9.6	6.9	9.4	10.4	7.8	10.2
	-2	7.2	5.2	7.1	8.1	6.2	7.9
	-1	4.1	2.1	4.0	4.4	2.4	4.3
	1	-5.4	-0.9	-7.8	-5.9	-1.4	-8.1
	2	-8.0	-4.9	-7.8	-8.3	-5.2	-8.4
	3	-10.6	-7.9	-10.4	-9.3	-11.2	-9.5

10, October 25, November 10 and November 25) revealed that the tuber yield decreased with increase in temperature and vice versa under all the four dates of sowing (Table 4). The extent of effect varied with dates of sowing and period/ month of change in temperature. The increase in maximum temperature by 3^{0}C during November caused highest yield reduction (-13.1%) on crop sown on November 10, followed by October 10 sown crop (-12.5%). December and January months were found to be more sensitive period for yield variation due to change in maximum temperature. About 13 to 13.9 percent yield reduction was observed under October 25 and November 25 sown potato (Table 4). However, for late sown crops (November 25), the yield reduction was maximum (-15.6%) with increase in maximum temperature by 3^{0}C during February. Sandhu *et al.,* (2013) also reported late sowing reduces tuber yield due to high temperature at the end of growing period.

The effect of change in minimum temperature during different months on tuber yield of potato under different dates of sowing was slightly higher than that observed with similar variation in maximum temperature. The early sown potato (October 10) was affected more with change in minimum temperature during November in comparison to other months (Table 4) and late sown crop (November 25) was affected most with change in minimum temperature during February. Under normal sowing date (November 10),

Table 4: Percent change in tuber yield (%) due to intra-seasonal variation of maximum and minimum temperatures under different sowing date. (The values in brackets are mean tuber yield of the variety)

Month	Change in temperature (^{0}C)	Maximum temperature				Minimum temperature			
		D_1 (Oct. 10) (Y=14.78 t ha^{-1})	D_2 (Oct. 25) (Y=21.12 t ha^{-1})	D_3 (Nov. 10) (Y=30.21 t ha^{-1})	D_4 (Nov. 25) (Y=29.67 t ha^{-1})	D_1 (Oct. 10) (Y=14.78 t ha^{-1})	D_2 (Oct. 25) (Y=21.12 t ha^{-1})	D_3 (Nov. 10) (Y=30.21 t ha^{-1})	D_4 (Nov. 25) (Y=29.67 t ha^{-1})
November	-3	14.2	11.1	15.2	5.0	13.5	11.5	12.2	5.9
	-2	12.6	8.2	11.5	3.5	11.3	8.8	7.2	4.2
	-1	6.9	4.6	7.4	2.2	5.2	4.6	4.0	2.9
	1	-5.3	-4.1	-5.9	-2.3	-6.3	-5.6	-5.2	-2.3
	2	-8.8	-7.5	-9.3	-4.6	-9.6	-8.5	-9.8	-5.0
	3	-12.5	-9.2	-13.1	-4.9	-13.7	-10.2	-13.8	-6.1
December	-3	11.1	12.8	10.7	11.7	10.1	13.5	15.6	12.3
	-2	8.9	10.9	8.8	7.8	7.2	11.3	11.5	8.2
	-1	5.7	7.7	5.2	5.2	4.8	8.1	7.6	5.5
	1	-5.1	-4.9	-5.6	-4.2	-6.4	-5.4	-6.3	-5.0
	2	-9.9	-9.6	-9.1	-8.2	-10.8	-10.7	-10.2	-8.8
	3	-13.3	-12.7	-11.8	-10.6	-13.3	-13.8	-14.6	-11.3
January	-3	6.6	11.6	8.6	10.8	5.1	12.5	11.1	11.3
	-2	4.8	7.7	6.5	8.6	4.8	8.2	9.2	9.3
	-1	2.2	4.3	3.4	6.9	1.7	4.9	5.6	7.2
	1	-4.5	-6.2	-4.7	-5.5	-3.3	-6.9	-4.7	-5.9
	2	-6.2	-9.5	-6.9	-9.8	-5.1	-10.7	-9.5	-10.3
	3	-8.5	-13.0	-9.6	13.9	-7.3	-14.2	-12.7	-14.6
February	-3	-	2.9	2.8	11.1	-	3.2	9.5	12.2
	-2	-	2.4	2.2	7.6	-	2.8	7.4	8.3
	-1		1.6	1.3	6.7	-	1.7	3.7	7.1
	1	-	-2.2	-1.7	-7.5	-	-2.4	-5.2	-8.2
	2	-	-3.6	-2.8	-10.6	-	-4.5	-7.2	-11.9
	3	-	-6.0	-3.5	-15.6	-	-7.2	-10.0	-15.9

the impact of minimum temperature during December was the highest (+15.6 to -14.6%) with change in temperature from -3 to +3 ^{0}C. Patel *et al.* (1999) also reported reduction in tuber yield due to minimum temperature during 1st and 3rd week of December.

CONCLUSION

The SUBSTOR-potato model of DSSAT family, calibrated and validated for three cultivars of potato, simulated the tuber yield of potato under different environment satisfactorily with error percent less than 10. Hence this model can be used for studying the effect of different environments and management practices on potato crop in middle Gujarat. The increase and decrease in maximum and minimum temperatures had negative/postive impact of tuber yield of potato, the extent of which varied with cultivars, time of sowing and the period/month of temperature change. It was mostly observed that at developmental phase of the crop the impact was highest. *Kufri Pokhraj* is found to be more sensitive to elevated temperatures while *Kufri Badshah* was found to be more beneficial to reduced temperatures. Overall minimum temperature is found to have more impacted tuber yield in all months as compared to maximum temperature.

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