Journal of Agrometeorology

ISSN : 0972-1665 (print), 2583-2980 (online)
Vol. No. 25 (3) : 410-418 (September - 2023)
https://doi.org/10.54386/jam.v25i3.2181
https://journal.agrimetassociation.org/index.php/jam

Research paper

Climate change impact on potato (*Solanum tuberosum*) productivity and relative adaptation strategies

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ABSTRACT

WOFOST and InfoCrop crop growth simulation models were used to assess the impact of climate change on potato cultivars and to develop adaptation strategies for future climatic scenarios (2030, 2050 and 2080) under representative concentration pathways (RCP's) 4.5 and 6.0 in Bihar. For impact studies potato cultivars belonging to late (*Kufri Badshah*), medium (*Kufri Jyoti*) and early (*Kufri Pukhraj*) maturity groups were selected. The simulated results revealed variations in potential productivity of potato under both RCP's (4.5 & 6.0) with baseline yields of 43.80 t/ha for *Kufri Badshah*, 41.5 t/ha for *Kufri Jyoti* and 43.6 t/ha for *Kufri Pukhraj*. Under RCP 4.5, elevated concentration of CO_2 projected to increase the productivity of *Kufri Badshah*, *Kufri Jyoti*, and *Kufri Pukhraj*. However, a decline in yield is expected when individual effect of temperature is considered for future climatic scenarios (2030, 2050 & 2080). However, these yield losses is negated when combined effect of CO_2 and temperature is considered by 1.3, 0.7 and 0.3 % in 2030, by -0.4, -1.1 and -2.2 % in 2050 and by 3.5, 4.4 and 5.9 % in 2080, respectively. Likewise, for RCP 6.0, combined effect of CO_2 and temperature offset the yield losses by 2.6, 2.4 and 2.3% in 2030, 2.1, 1.7 and 1.1 in 2050 and 1.1, -0.1 and -1.8 in 2080. In addition, selection of suitable cultivars, shifting the date of planting and proper irrigation and nitrogen management practices can counterbalance the yield losses.

Keywords: WOFOST, InfoCrop, simulation, Climate Change, Irrigation, RCP.

Climate change is evident and posing a severe threat to global agriculture. The sub-optimal growth conditions accompanying global warming affecting plant growth, survival and yield. Such adverse conditions are most likely to aggravate in the future (IPCC 2014). The scientific community widely agreed that concentration of CO_2 would double by the end of 21st century (from 380 ppm to 700 ppm), which is more likely to be linked with a rise in the global air temperature by 0.3 to 4.8°C (IPCC 2014). Although global surface temperature rose by 0.89°C (1.6 °F) above the average for NASA baseline period. This has created a global challenge concerning food security, which urges that the productivity of main food crops demands two-fold increase over the next 50 years to in order fulfil the nutritional requirements of the increasing population (Murchie *et al.,* 2009).

Potato (*Solanum tuberosum* L.) is a major commodity at a global level with a production of 382 million tons in 2014 ranking first highest produced non-cereal food crop and fourth highest produced crop after wheat, corn and rice, globally (FAOSTAT 2017). India ranks as the world's second largest potato producing nation, with a production of 53.03 million tonnes in 2018-2019. Indian major potato producing states are Uttar Pradesh, West Bengal, Bihar, Punjab, Madhya Pradesh, and Haryana. Among these, Bihar ranks third in potato area (320.47 thousand hectares) with a production of 6.1million tonnes (NHB 2017). Plain areas of Bihar, which is part of the Indo-Gangetic region where the impact of climate change can affect potato production acutely. Hence, there is an urgent need for implementing adaptation strategies for minimizing the negative impact of potato production and ensure food security in Bihar state.

Crop models are the scientific means to understand the impact as well as helpful in designing suitable adaptation strategies

Article info - DOI: *https://doi.org/10.54386/jam.v25i3.2181*
Received: 05 April 2023; Accepted: 07 August 2023; Published online : 31 August 2023

against climate change (Ewert *et al.,* 2015). With diverse situations, these models can serve the purpose of simulating yield potential of crops. The principle of crop growth model mainly emphasizes on aggregating the nonlinear dynamics of soil, weather, and crop management practices to estimate crop growth and production under a wide range of conditions. Crop models provide a platform to create virtual experiments. For example, crop models can help to analyse the effect of abiotic stresses during the crop growing cycle or to explore management strategies to improve yields under specific environments (Haverkort and Top 2011).

The various potato simulation model has been already used in the past to forecast the impact of climate change for future projections (Haris *et al.,* 2015; Rana *et al.,* 2020). The scientific community already reported decline of potato productivity at the end of the century; however, this decline was higher for models that do not incorporate atmospheric CO_2 effects as compared with models that include CO_2 (Raymundo *et al.,* 2014). WOFOST has initially been developed as a crop growth simulation model for the assessment of the yield potential of various annual crops (potato, wheat, rice, barley, sugar beet, sugar cane, etc.) in tropical countries (Wolf *et al.,* 2010). It is one of the longest-running operational model in the world. WOFOST is adjudged as the best model for climate change studies in the world. This model is particularly suited to quantify the combined effect of changes in CO_2, temperature, rainfall, and solar radiation on crop development, growth and water use efficiency, as all the processes are simulated separately.

In this study, we evaluate the impact of climate change (CO_2 and temperature) for two intermediate emission scenarios RCP (4.5 and 6.0) for future climatic scenarios (2030, 2050 and 2080). Specifically, this study aims (i) To study the impact of climate change on potato cultivars (*Kufri Badshah*, *Kufri Jyoti*, and *Kufri Pukhraj*). (ii). To develop adaptation strategies by selection of suitable cultivars. (iii) Selection of the best date of planting. (iii). To devise irrigation and nitrogen management practices for optimizing yield for future climatic scenarios (2030, 2050 and 2080). We envisage that this study would help to better understand the climate change impact and how we can overcome potato yield losses following adaptation practices in Bihar.

MATERIALS AND METHODS

WOFOST model

WOFOST (WOrld FOod STudies) is a mechanistic model that represents the growth of crop-based on processes like CO_2 assimilation, phenological development, transpiration, respiration, partitioning of assimilates and dry matter formation and how these processes are influenced by environmental conditions. WOFOST crop growth simulation model has been used by many researchers around the world for many crops to study the effect of climate change on the growth and yield over a wide range of climatic conditions (Wolf *et al.,* 2010).

Time course data on potato growth and development obtained from field experiments conducted at Patna (Bihar) during 1999 to 2001 (Dua *et al.,* 2014), WOFOST model has been calibrated and validated for 11 Indian potato cultivars namely *Kufri Arun, Kufri Garima, Kufri Khyati, Kufri Kanchan, Kufri Lalit, Kufri Sadabahar, Kufri Surya, Kufri Badshah, Kufri Jyoti, Kufri Bahar* and *Kufri Pukhraj* belonging to different maturity groups. Therefore, we used this model to study the impact of climate change on potato productivity, scheduling date of planting and selection of suitable cultivars to mitigate the impact of climate change on future climate scenarios in Bihar state. The model was simulated for thirty districts across Bihar state for impact assessment of climate change on potato cultivars.

InfoCrop-Potato model

InfoCrop-Potato is a generic simulation crop growth model developed by a group of scientists at Indian Agricultural Research Institute, New Delhi (Aggarwal *et al.,* 2006a). The model simulates soil nutrient flow, agronomic management (i.e., planting, nitrogen, residues and irrigation), weather, pests and disease, in order to predict crop growth and yield losses (Aggarwal *et al.,* 2006a). The model structure based on the MACROS, WTGROWS, and ORYZA1 and SUCROS models. Moreover, it is user friendly and written in Fortran Simulator Translator (FST). In the present study, the model has been used to formulate irrigation and nitrogen management strategies, which affects crop growth and yield to a greater extent for future climatic scenarios.

Weather data

For baseline scenario (year 2000), IMD district normal of 1971-2010 used for 30 districts in Bihar and for the generation of temperature scenarios (2030, 2050 and 2080) Marksim weather generator (https:// gisweb.ciat.cgiar.org/ MarkSim GCM/) used. Moreover, in baseline data of Bihar, future climatic scenarios were added (IPCC 2007). Data downloaded in DSSAT friendly format for both the RCP's (4.5 and 6.0) and for future climatic scenarios (2030, 2050 and 2080).

Incorporation of CO_2 impact in the model

In order to incorporate the effect of CO_2 in the WOFOST model, changes have been integrated into parameters, i.e., light-use efficiency and CO_2 assimilation rate of a leaf. In C_3 plants, around 25 to 40% (mean 32.5%) yield increase attributed to the doubling of CO_2 from 355 ppm to 710 ppm (Wolf *et al.,* 2010). Wolf *et al.,* (2010) have made changes in initial angle (+11%) and in a maximum of the CO_2 assimilation – light response curve (+60%) parameters of the WOFOST model for doubling CO_2 concentration from 355 to 710 ppm. Under the experimental conditions with a non-limiting supply of water and nutrients, and where temperatures are kept near the optimum for crop growth, the yield increase for C_3 crops with a doubling of CO_2 has been estimated at 30% (Fuhrer *et al.,* 2003) therefore we have considered these figures as + 10% (30/ 32.5 × 11) and + 55% (30/32.5 × 60) for doubling CO_2 concentration for potato, assuming a roughly linear relationship between the CO_2 increase and the growth processes. Accordingly, these parameters were changed for 2030, 2050 and 2080 for both RCPs (4.5 and 6.0). Based on RCP Database (Version 2.0.4), projected CO_2 concentration for incorporating the effect of change in CO_2 concentration was used in the WOFOST model (http://www.iiasa.ac.at/web-apps/tnt/RcpDb). For RCP 4.5, atmospheric CO_2 concentration was 367 ppm (for baseline), 435 ppm (for 2030), 486 ppm (for 2050) and 531 ppm (for 2080) were considered. Whereas, for RCP 6.0, atmospheric CO_2 concentration 367 ppm (for baseline), 428 ppm (for 2030), 477 ppm (for 2050) and 594 ppm (for 2080) were used in the study. Both models WOFOST and InfoCrop were run at the normal date of planting for the state, *i.e.,* 1st November.

GIS interpolation

Spatial interpolation was performed using the Inverse Distance Weighted (IDW) technique, which is accessible through the ArcGIS® Geostatistical Analyst toolbar. IDW interpolation is a commonly employed method in variable mapping application. The interpolation method is precise and convex, catering specifically to continuous models of spatial variation. The fundamental principle of IDW interpolation involves a weighted linear combination of sample points, employing both statistical and mathematical techniques to generate surfaces and predict values at unmeasured points.

Selection of potato cultivars

For impact studies simulation was carried out for three potato cultivars belonging to different maturity groups *viz.,* late (*Kufri Badshah*), medium (*Kufri Jyoti*) and early (*Kufri Pukhraj*). However, for adaptation model was run for eleven varieties, namely *Kufri Arun, Kufri Garima, Kufri Khyati, Kufri Kanchan, Kufri Lalit, Kufri Sadabahar, Kufri Surya, Kufri Badshah, Kufri Jyoti, Kufri Bahar* and *Kufri Pukhraj*.

Adaptation

In the present investigation, we have advised the following parameters for adaptation strategies:

- Selection of suitable variety.
- Shifting the date of planting (DOP)
- Irrigation and nitrogen management.

WOFOST model was used for the first two parameters, while, for irrigation and nitrogen management, we used the InfoCrop model. WOFOST model was run for 11 potato cultivars for both the RCP's (4.5 and 6.0) for all climatic scenarios (baseline, 2030, 2050 and 2080) for five dates starting from 18th October at weekly intervals. Among the 11 variety, we have selected the most suitable variety, which can withstand the effect of climate change.

However, for irrigation and nitrogen management, the InfoCrop potato crop growth model was used, which was run for both the RCP's (4.5 and 6.0) and for future climatic scenario's (2030, 2050 and 2080). The model was run for different irrigation and nitrogen doses. The application of irrigation at 6-7 day's intervals is practiced in Bihar and nitrogen at the rate of 180 kg ha^{-1} is followed in the region. Thus, the following four treatments of irrigation and nitrogen were considered.

- Irrigation at six days interval (50mm) N with 180 kg ha^{-1}
- Irrigation at six days interval (50mm) N with 240 kg ha^{-1}
- Irrigation at seven days interval (50mm) N with 180 kg ha^{-1}
- Irrigation at seven days interval (50mm) N with 240 kg ha^{-1}

N was applied at 0 and 26 days in two equal splits after planting.

Both (WOFOST and InfoCrop) crop simulation models were run for five districts of Bihar representing different parts of the state *i.e.,* Araria, Aurangabad, Banka, Nalanda and Saran. The results summarized here, without adaptation refers to the application of N at 180 kg ha^{-1} and irrigation at 7-days interval, whereas, adaptation refers to the application of N at 240 kg ha^{-1} and irrigation at 6-days interval.

RESULTS AND DISCUSSION

Impact of climate change on potato productivity

Potato productivity under RCP's (4.5 and 6.0) varied mostly within the state under baseline for *Kufri Badshah* (29.5 to 50.8 t/ha), *Kufri Jyoti* (26.5 to 50.2 t/ha) and *Kufri Pukhraj* (26.9 to 54.4 t/ha). The mean productivity of 30 districts was 43.8, 41.5 and 43.6 t/ha, respectively, for *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj,* respectively (Fig. 1 and 2).

The simulation results using WOFOST model have shown that the potential potato productivity of *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj* for RCP 4.5 & 6.0 was highest in south-western districts (Buxar & Bhojpur) followed by north-eastern districts (Kishanganj & Purnea) and north-western districts (East &West Champaran) of Bihar. However, a decline in potato productivity was noticed on moving from southwest, northeast and northwest to southeast direction in Bihar.

Under RCP 4.5, simulation results revealed a rise in potential productivity for 2030 by 1.3, 0.7 and 0.3 % for *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj,* respectively. However, much decline projected for 2050 (-0.4, -1.1 and -2.2 %) and 2080 (-3.5, -4.4 and -5.9%) for *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj*, respectively. Nonetheless, for RCP 6.0, a decline in yield of *Kufri Badshah* is projected for 2030 (-4.0%); however, an increase of 2.1% and 1.1% expected for 2050 and 2080. Similarly, for *Kufri Jyoti*, the yield is predicted to increase by 2.4 and 1.7% in 2030 and 2050 but expected to decrease by -0.1 % in 2080. However, in the case of *Kufri Pukhraj* potato productivity is likely to increase in 2030 (2.3%) and 2050 (1.1%) but decline by -1.8% in 2080 (Table 1).

Sensitivity analysis

The impact of climate change on the potential productivity of potato is determined by change in three variables *i.e.* weather (temperature; minimum and maximum); light use efficiency of single leaf and CO_2 assimilation rate in the WOFOST model. While the change in temperature variable was done through a change in weather file, the latter two parameters were changed suitably to incorporate the effect of CO_2 concentration, as described in material and methods. The sensitivity analysis was carried out to examine the sensitivity of productivity of potato cultivars to change in CO_2 level and rise in temperature separately and collectively, for all the thirty

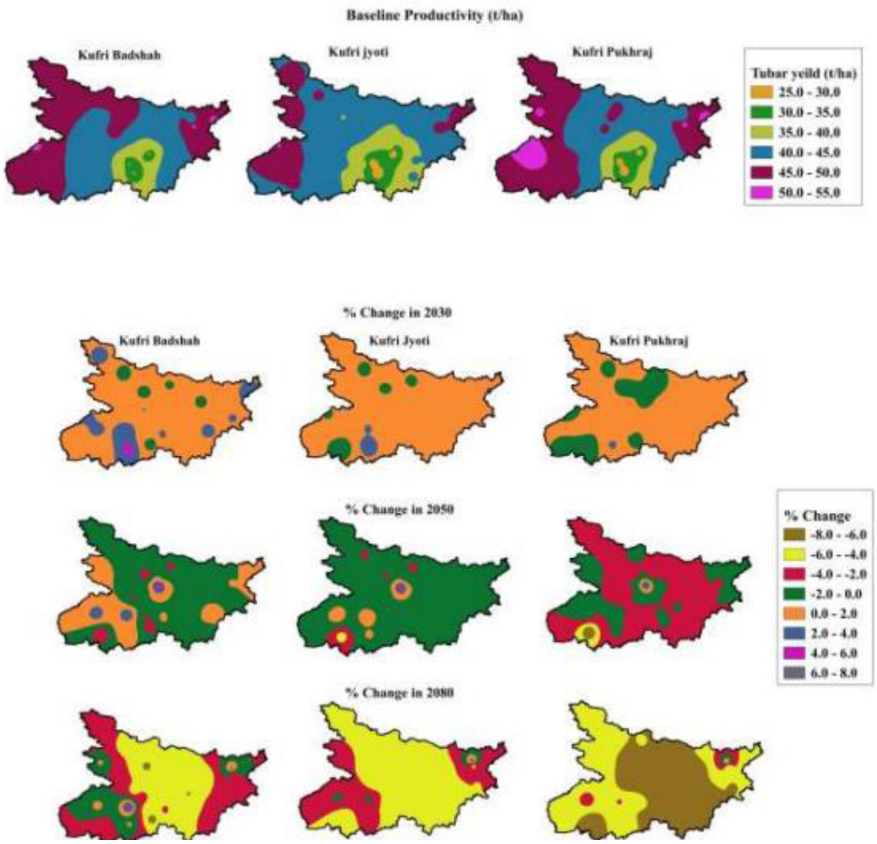

Fig. 1: WOFOST simulated potential yield of potato cultivars under baseline and future climate scenarios (RCP-4.5) at different locations in Bihar (combined effect of temperature and CO_2)

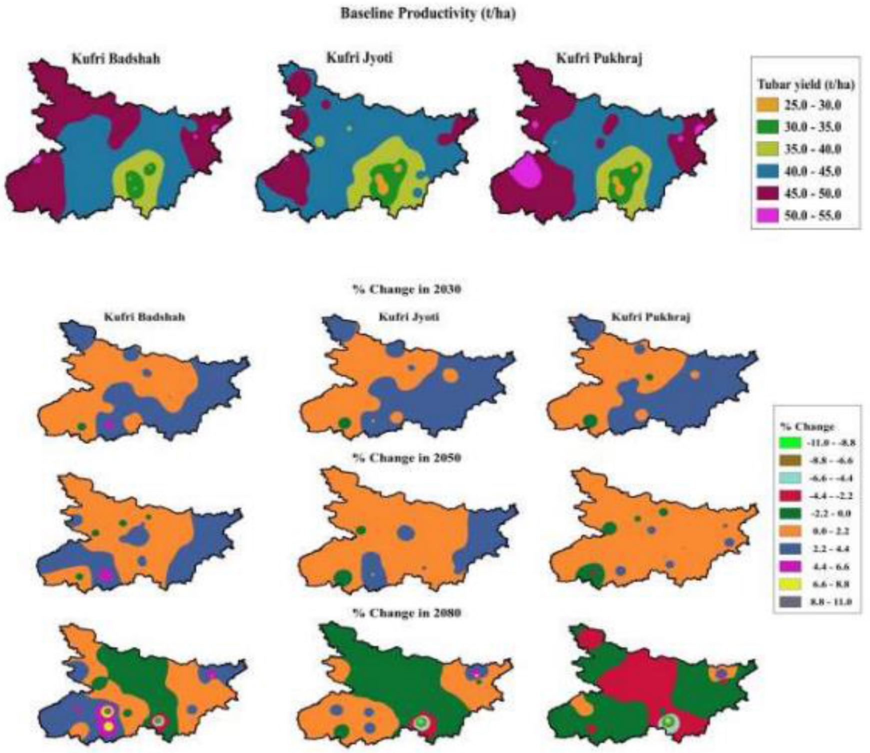

Fig. 2: WOFOST simulated potential yield of potato cultivars under baseline and future climate scenarios (RCP-6.0) at different locations in Bihar (combined effect of temperature and CO_2)

Table 1: WOFOST simulated potential productivity of potato cultivars under (2000) and future climatic scenarios in Bihar Temp: Temperature; CO_2: Carbon dioxide; T + C: Temperature + Carbon dioxide

	2030			2050			2080		
Varieties	Temp	CO_2	T+C	Temp	CO_2	T+C	Temp	CO_2	T+C
				RCP 4.5					
Kufri Badshah	-5.5	7.0	1.3	-10.7	11.3	-0.4	-16.2	14.6	-3.5
Kufri Jyoti	-6.5	7.5	0.7	-12.2	12.1	-1.1	-18.1	15.7	-4.4
Kufri Pukhraj	-6.8	7.4	0.3	-13.1	11.9	-2.2	-19.7	15.4	-5.9
Mean	-6.2	7.3	0.7	-12.0	11.8	-1.2	-18.0	15.2	-4.6
				RCP 6.0					
Kufri Badshah	-4.0	8.3	2.6	-7.8	10.5	2.1	-15.9	19.5	1.1
Kufri Jyoti	-4.4	7.0	2.4	-8.9	11.3	1.7	-18.4	20.8	-0.1
Kufri Pukhraj	-4.3	6.8	2.3	-9.3	11.0	1.1	-19.9	20.5	-1.8
Mean	-4.2	7.4	2.4	-8.6	10.9	1.6	-18.1	20.3	-0.3

locations under study across the Bihar state.

The simulation results for RCP 4.5 showed an increase in the concentration of CO_2 is likely to increase the productivity of *Kufri Badshah* (1.3%), *Kufri Jyoti* (7.5%) and *Kufri Pukhraj* (7.4%) in 2030. The corresponding figures for 2050 (11.3, 12.1 and 11.9%) and 2080 (14.6, 15.7 and 15.4%), when the CO_2 concentration is considered for *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj*, respectively. However, under RCP 6.0, an increase of 8.3, 7.0 and 6.8% are likely to be expected for *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj* in 2030. Whereas, more yield can be expected for 2050 (10.5, 11.3 and 11.0%) and 2080 (19.5, 20.8 and 20.5%) for *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj*, respectively (Table 1).

Rising concentration of CO_2 is expected to vitalize various processes like photosynthesis and light use efficiency, crop yield as well as improve water use efficiency (WUE). Enhancement in the yield can only be obtained by the improvement of photosynthetic light conversion efficiency. Elevated concentration of CO_2 increases the rate of photosynthesis, which ultimately affects the productivity of potato (Fleisher *et al.,* 2006). Moreover, an 89% increase in yield of cassava has been reported by the increase in the concentration of CO_2 (Rosenthal *et al.,* 2012). This notion has been supported by various researchers, which reported that improving photosynthetic efficiency significantly increases the yield of wheat, rye, tobacco and potato (Kromdijk *et al.,* 2016; Dua *et al.,* 2018; Rana *et al.,* 2020). Potato tuber is significantly consisted of photo assimilates i.e starch. Hence, an increase in yield can only be obtained through the enticement of photosynthetic carbon fixation and its translocation of assimilates to stem. Moreover, CO_2 concentration increase the sugars availability in potato thus culminates its production and the activity of sink organs and tuber yield (Schapendonk *et al.,* 2000).

However, for RCP 4.5, when the effect of temperature was considered, it was noticed that the probable increase in temperature is expected to bring down the potential productivity of *Kufri Badshah* by 5.5% (ranges from 1.5% in Gaya to as high as 7.3% in Madhubani district) in 2030. However, a more pronounced reduction is projected with a further increase in temperature in 2050 by 10.7% (ranges from 5.35 in Samastipur to as high as 13.8% in Aurangabad) and by 16.2% (ranges from 8.9 in Jehanabad to as high as 18.6% Khagaria) in 2080. On the other hand, the overall productivity of *Kufri Jyoti* is also likely to face a decline of 6.5% in 2030 (ranges from 3.3% in Gaya to as high as 8.6 in Aurangabad), 12.2% in 2050 (ranges from 6.5% in Samastipur to as high as 15.8 in Aurangabad) and 18.1% in 2080 (11.5% in Araria to as high as 21.1% in Lakhisarai). However, in case of *Kufri Pukhraj*, a decline in productivity is expected in 2030 by 6.8% (ranges from 4.6% in Gaya to 8.9% in Aurangabad), by 13.1% in 2050 (7.2% in Samastipur to as high as 18.1% in Aurangabad) and by 19.7% in 2080 (ranges from 12.3% in Araria to high as 26.25% in Lakhisarai). Irrespective of future climatic scenarios, under RCP 4.5, the highest decline in the productivity of all the three cultivars is expected in Khagaria district (18.6% in *Kufri Badshah*) and Lakhisarai (21.1 % and 26.25% in *Kufri Jyoti* and *Kufri Pukhraj*). Likewise, for RCP 6.0, a rise in temperature reduced the productivity of *Kufri Badshah* (4.0, 7.8 and 15.9%), *Kufri Jyoti* (4.4, 8.9 and 18.4%) and *Kufri Pukhraj* (4.3, 9.3 and 19.9%) for 2030, 2050 and 2080, respectively.

Potato is a cool-weather crop; however, it grows under diverse climatic conditions. Temperature plays a crucial role in balancing phenological changes in development, from germination to vegetative stage to flower initiation and reproductive growth. Although, temperature beyond the optimal level is likely to inhibit its growth, survival and yield loss (Winkler *et al.,* 2018). Also, RuBisCO concentration and its affinity towards CO_2 are also being affected by the rise in temperature (Bae and Sicher 2004). However, mild and severely high temperature is well known to enhance the activity of Rubisco oxygenase that in turn increases the production of H_2O_2, which might be toxic to plant cells (Song *et al.,* 2014). The decline in productivity of potato primarily occurred due to temperature change (above optimum level) and reduction in the maturity period of the crop. For net photosynthesis minimum (0-7°C), optimum (16-25°C) and maximum (40°C) temperature is required for potato (Kooman and Hoverkort 1995). Dua *et al.,* (2018) also reported that an increase in temperature in 2020 and 2055 is likely to restrict the growth and yield of potato by reducing their maturity. Since potato is a vegetative crop and tubers continue to bulk till maturity of the haulms, any reduction in maturity period leads to a decrease in the period available for the bulking of potato tuber, which ultimately results in a reduction in tuber yield.

Under both the RCP's (4.5 and 6.0) and different climatic scenarios (2030, 2050 and 2080), the negative impact of elevated

Table 2: Potential Productivity at normal date planting in baseline (2000) and shift in suitable date of planting in future climates (RCP-4.5)

Variety	2000	2030					2050					2080				
	Productivity (t/ha)	Without Adaptation	With Adaptation	Change (%) Without Adaptation	Change (%) With Adaptation	Best Date of planting	Without Adaptation	With Adaptation	Change (%) Without Adaptation	Change (%) With Adaptation	Best Date of planting	Without Adaptation	With Adaptation	Change (%) Without Adaptation	Change (%) With Adaptation	Best Date of planting
Kufri Arun	41.70	41.90	42.20	0.50	1.30	0 to -7	41.00	41.20	-1.70	-1.20	0 to -7	40.50	40.50	-2.80	-2.80	0 to -7
Kufri Badshah	43.20	43.30	44.30	0.20	2.70	0 to -7	42.20	43.20	-2.10	0.20	0 to -7	41.70	42.60	-3.40	-1.20	0 to -7
Kufri Bahar	44.40	44.60	44.60	0.50	0.50	0 to -7	43.50	43.50	-2.00	-2.10	0 Days	42.90	42.90	-3.40	-3.30	0 to +7
Kufri Garima	45.40	45.60	45.80	0.40	0.80	0 to -7	44.40	44.50	-2.30	-2.00	0 to -7	43.90	43.90	-3.40	-3.30	0 Days
Kufri Jyoti	40.60	41.20	41.20	1.50	1.60	0 Days	40.20	40.20	-1.00	-0.90	0 to +7	39.50	39.70	-2.70	-2.30	0 to +7
Kufri Kanchan	36.20	36.30	36.50	0.30	0.70	0 to -7	35.40	**35.50**	-2.20	-2.10	0 to -7	34.90	**34.90**	-3.60	-3.50	0 Days
Kufri Khayti	50.80	50.90	50.90	0.20	0.10	0 to +7	49.50	49.60	-2.60	-2.40	0 to + 7	48.80	48.90	-3.90	-3.80	0 to +7
Kufri Lalit	41.90	42.20	42.40	0.70	1.30	0 to -7	38.80	41.30	-7.40	-1.50	0 to -7	40.70	40.70	-2.90	-2.90	0 to -7
Kufri Pukhraj	43.00	42.90	43.00	-0.20	0.00	0 to +7	41.40	41.60	-3.70	-3.20	0 to +7	40.80	41.30	-5.10	-4.00	0 to +7
Kufri Sadabahar	40.40	40.60	40.90	0.50	1.20	0 to -7	39.60	39.80	-2.00	-1.60	0 to -7	39.10	39.10	-3.20	-3.10	0 to -7
Kufri Surya	45.20	45.20	45.40	0.00	0.50	0 to +7	43.90	44.30	-3.00	-2.10	0 to +7	43.20	43.60	-4.40	-3.60	0 to +7
Mean	43.00	43.10	43.40	0.40	1.00		41.80	42.20	-2.70	-1.70		41.50	41.60	-3.50	-3.10	

Table 3: Potential Productivity at normal date planting in baseline (2000) and shift in suitable date of planting in future climates (RCP-6.0)

Variety	2000	2030					2050					2080				
	Productivity (t/ha)	Without Adaptation (t/ha)	With Adaptation (t/ha)	Change (%) Without Adaptation	Change (%) With Adaptation	Best Date of planting	Without Adaptation (t/ha)	With Adaptation (t/ha)	Change (%) Without Adaptation	Change (%) With Adaptation	Best Date of planting	Without Adaptation	With Adaptation	Change (%) Without Adaptation	Change (%) With Adaptation	Best Date of planting
Kufri Arun	41.70	42.50	42.90	2.10	3.00	0 to -7	42.10	42.50	0.90	2.00	0 to -7	42.50	42.50	1.90	2.10	0 to -7
Kufri Badshah	43.20	41.70	44.90	-3.30	4.10	0 to -14	44.00	44.60	2.00	3.40	0 to -7	44.20	44.60	2.40	3.40	0 to -7
Kufri Bahar	44.40	45.30	45.50	2.00	2.40	0 to -7	44.80	44.80	0.90	1.00	0 to -7	45.00	45.10	1.30	1.60	0 to +7
Kufri Garima	45.40	46.20	46.60	1.70	2.50	0 to -7	45.40	46.10	0.00	1.40	0 to -7	46.00	46.00	1.20	1.20	0 to +7
Kufri Jyoti	40.60	42.50	42.00	4.70	3.40	0 to -7	42.60	41.40	4.90	2.10	0 to -7	42.30	41.60	4.10	2.60	0 to +7
Kufri Kanchan	36.20	36.80	37.10	1.60	2.50	0 to -7	36.40	36.70	0.60	1.30	0 to -7	36.60	36.60	1.10	1.20	0 to -7
Kufri Khayti	50.80	51.70	51.80	1.80	2.00	0 to -7	51.00	51.10	0.40	0.60	0 to - 7	51.10	51.20	0.50	0.80	0 to +7
Kufri Lalit	41.90	42.80	43.20	2.10	3.00	0 to -7	42.30	42.70	1.00	2.00	0 to -7	42.70	42.80	1.90	2.10	0 to -7
Kufri Pukhraj	43.00	43.80	43.80	1.80	1.80	0 to +7	43.00	43.30	0.00	0.60	0 to +7	42.60	43.20	-0.90	0.50	0 to +7
Kufri Sadabahar	40.40	41.10	41.40	1.70	2.50	0 to -7	40.70	41.10	0.80	1.70	0 to -7	41.00	41.90	1.40	3.80	0 to -7
Kufri Surya	45.20	46.00	46.10	1.70	2.00	0 to +7	45.40	45.60	0.50	0.90	0 to +7	45.30	45.80	0.30	1.20	0 to +7
Mean	43.00	43.70	44.10	1.60	2.70		43.40	43.60	1.10	1.50		43.60	43.80	1.40	1.90	

Table 4: Percent (%) change in potential productivity of potato over baseline and future climatic scenario with and without adaptation (Irrigation and Nitrogen Management) (RCP-4.5 & RCP 6.0)

RCP	Cultivars	Baseline (t/ha)	2030		2050		2080	
			Without Adaptation (%)	With Adaptation (%)	Without Adaptation (%)	With Adaptation (%)	Without Adaptation (%)	With Adaptation (%)
RCP 4.5	*Kufri Badshah*	52.0	-18.4	-7.0	-19.0	-8.7	-20.3	-9.8
	Kufri Jyoti	50.1	-21.8	-7.4	-23.9	-9.5	-26.7	-10.4
	Kufri Pukhraj	50.1	-21.1	-2.0	-22.3	-3.7	-22.5	-4.9
	Mean	50.7	-20.4	-5.5	-21.7	-7.3	-23.2	-8.4
RCP 6.0	*Kufri Badshah*	52.0	-16.1	-6.3	-16.6	-7.5	-16.3	-7.7
	Kufri Jyoti	50.1	-20.5	-6.7	-20.4	-7.7	-20.2	-9.1
	Kufri Pukhraj	50.1	-19.2	-1.8	-18.9	-1.8	-17.2	-2.8
	Mean	50.7	-18.6	-4.9	-18.6	-5.6	-17.9	-6.5

temperature was quite higher than the positive impact of enhanced CO_2 fertilization at all the locations. Although CO_2 fertilization seemed to negate the adverse effects of temperature on potato growth, it could not fully compensate for the damage caused by the enhanced temperature at any of the locations in future climate scenarios (2030, 2050 and 2080).

When the combined effect of temperature and CO_2 is considered, the simulation results indicated that for RCP 4.5, the potential productivity of *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj* showed an increase of 1.3, 0.7 and 0.3% in 2030. Whereas, the productivity of *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj* is expected to face a decline in 2050 (0.4, 1.1 and 2.2%) and in 2080 (3.5, 4.4 and 5.9%). However, for RCP 6.0, the productivity of *Kufri Badshah* decline in 2030 by 4.05%, but expected to rise in 2050 by 2.1% and 1.1% in 2080, over the baseline. Whereas for the *Kufri Jyoti* yield is predicted to increase by 2.4% in 2030 and by 1.7% in 2050, but decrease by 0.1% in 2080. Similarly, for *Kufri Pukhraj*, yield increase in 2030 by 2.3 % and 1.1% in 2050, but expected to decline in 2080 by 1.8% (Table 1).

Adaptation

For adaptation WOFOST model was run for eleven potato cultivars namely; *Kufri Arun, Kufri Badshah, Kufri Bahar, Kufri Garima, Kufri Jyoti, Kufri Kanchan, Kufri Khyati, Kufri Lalit, Kufri Pukhraj, Kufri Sadabahar* and *Kufri Surya* starting from 18th October at seven days of interval. A increase in potential productivity is expected in 2030 (without adaptation 43.1 t/ha, with adaptation 43.4t/ha), whereas, for 2050 (without adaptation 41.8t/ha, with adaptation 42.2t/ha) and 2080 (without adaptation 41.5t/ha, with adaptation 41.6t/ha). Under RCP 4.5, among the eleven cultivars of potato, *Kufri Khyati* emerged to be the least affected variety for all climatic scenarios (2030, 2050 and 2080). However, by following adaptation strategies, major yield losses can be overcome in 2030 by 0.1% by 2.4% in 2050 and by 3.8% in 2080 (Table 2). However, *Kufri Kanchan* emerged to be the most affected variety for future climatic scenarios (2030, 2050 and 2080).

Similarly, for RCP 6.0, *Kufri Khyati* emerged to be the best variety among eleven cultivars concerning the change in climate with an increase in yield by following adaptation for future climatic scenarios (2030, 2050 and 2080). In 2030, yield increase is expected by 1.8% without any adaptation, but by the following adaptation, it might increase by 2.0% over the baseline (Table 3). Likewise, for 2050, the yield is expected to increase by 0.4% without adaptation, although, by following adaptation it will increase to 0.6%. However, for 2080, the productivity of *Kufri Khyati* might increase by 0.5% at normal date of planting, but by shifting one week later, the yield is expected to rise by 0.8% over the baseline. However, *Kufri Kanchan* is most affected by the effect of temperature and CO_2 in all climatic scenarios 2030 (without adaptation 36.8 t/ha and with adaptation 37.1 t/ha), in 2050 (without adaptation 36.4 t/ha and with adaptation 36.7 t/ha) and 2080 (without adaptation 36.6 t/ha and with adaptation 36.6 t/ha).

Irrigation and nitrogen management

RCP 4.5 : The simulation results presented in Table 4 revealed that without any adaptation, potential potato productivity varied from 18.4 to 21.8%, with mean of 20.4% in 2030. However, in 2050, productivity varied from 19.0 to 23.9%, with reduction of 21.7% over the baseline. Likewise, much yield losses are projected for 2080, ranged from 20.3 to 26.7%, with an overall decline of 23.2% over the baseline.

But by following adaptation strategies, yield losses reduced by 7.0% in *Kufri Badshah* (from 18.4% without adaptation), 7.4% in *Kufri Jyoti* (from 21.8% without adaptation) and by 2.0% in case of *Kufri Pukhraj* (from 21.1% without adaptation) in 2030. Likewise, in 2050, yield losses are reduced by 8.7% in *Kufri Badshah* (from 19.0% without adaptation), 9.5% in *Kufri Jyoti* (from 23.9% without adaptation) and by 3.7% in *Kufri Pukhraj* (from 22.3% without adaptation). While, in 2080, reduction in yield is expected in *Kufri Badshah* (from 20.3% without adaptation to 9.8% with adaptation), *Kufri Jyoti* (from 26.7% without adaptation to 10.4% with adaptation) and *Kufri Pukhraj* (from 22.5% without adaptation to 4.9% with adaptation).

In Bihar under RCP-4.5, the trend of these varieties for 2030, 2050 and 2080 was in the order of *Kufri Pukhraj* > *Kufri Jyoti* > *Kufri Badshah*. *Kufri Pukhraj* is most susceptible to management strategy concerning adaptation for future climatic scenarios.

RCP 6.0 : For RCP 6.0, without adaptation reduction in potential productivity of potato varied from 16.1 to 20.5% with mean productivity of 18.6% in 2030. Whereas in 2050, potato yield ranged from 16.6 to 20.4%, with an overall reduction of 18.6%. Similarly, in 2080 more yield losses are projected in a range of 16.3 to 20.2% with an overall decline of 17.9% (Table 4).

But by following adaptation strategies, reduction in losses by 6.3% was noticed in *Kufri Badshah* (from 16.1% without adaptation), 6.7% in *Kufri Jyoti* (from 20.5% without adaptation) and 1.8% in *Kufri Pukhraj* (from 19.2% without adaptation). Similarly, for 2050, yield losses are reduced by 7.5% in *Kufri Badshah* (from 16.6% without adaptation), by 7.7% in *Kufri Jyoti* (from 20.4% without adaptation) and by 1.8% in *Kufri Pukhraj* (from 18.9% without adaptation). Likewise, for 2080, yield losses reduced by 7.7% (from 16.3% without adaptation) in *Kufri Bahar*, in *Kufri Bahar* yield losses are reduced by 9.1% (from 20.2% without adaptation), by 2.8% (from 17.2% without adaptation) in *Kufri Pukhraj* (Table 4). In Bihar, under RCP 6.0, *Kufri Pukhraj* is amenable to management strategy concerning adaptation for 2030, 2050 and 2080.

CONCLUSION

The simulation studies revealed that the productivity of potato cultivars under RCP 4.5, is most likely to be affected positively in 2030 when the combined effect of CO_2 and temperature is considered for *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj*. However, for 2050 and 2080, the potential productivity of *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj* is projected to decline. Although for RCP 6.0, potential productivity is expected to decline in 2030 for *Kufri Badshah*, it is expected to rise in 2050 and 2080. Likewise, for *Kufri Jyoti* and *Kufri Pukhraj* increase in yield is projected for 2030 and 2050 but projected to decline in 2080. However, by following adaptation strategies either by the selection of suitable cultivars or by shifting the date of planting, yield losses could be overcome to some extent. Using the WOFOST model, *Kufri Khyati* emerged to the best variety to cope up with the effects of climate change for future climatic scenarios (2030, 2050 and 2080) for both the RCPs (4.5 and 6.0). Through, irrigation and management practices, yield losses brought down to 5.5% in 2030, 7.3% in 2050 and 8.4% in 2080 under for RCP 4.5. However, under RCP 6.0, yield losses are reduced to 4.9% in 2030, 5.6% in 2050 and 6.5% in 2080.

ACKNOWLEDGEMENTS

The present work was carried out under the Strategic Research Component of National Initiatives on Climate Resilient Agriculture (NICRA). Authors are thankful to NICRA for providing the financial and technical assistance to carry out the present work.

Funding Information: Authors state no funding involved.

Conflict of Interests statement: The authors declare that there is no conflict of interest related to this article.

Data Availability statement: The manuscript have Data Availability Statement from the author (s): To be provided on request; Link for accessing the data used in the study; Can't be shared.

Author's contribution statement: **A Rana:** Data Analysis, Simulation Model analysis, compilation of data, Writing-original draft; **VK Dua:** Investigation, Conceptualization, Methodology, Visualization; **N Chauhan:** Data Analysis; Writing-review and editing; **P Chaukhande:** Review; **M Kumari:** Formal analysis, Simulation Model analysis

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