Impact of climate change on potato productivity in Punjab – a simulation study

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Impact assessment of climate change on potato productivity in Punjab for three potato cultivars of late (Kufri Badshah), medium (Kufri Jyoti) and early (Kufri Pukhraj) maturity groups was carried out for A1FI scenario of temperature and atmospheric CO_2 of the years 2020 and 2055. The simulation study was done using WOFOST crop growth model for potential production at 13 locations in Punjab. The results from the simulation study were interpolated using kriging technique to generate maps of potential productivity and the changes thereon. It was estimated that rise in temperature alone will result in change in productivity of Kufri Badshah from +11.6% (Amritsar) to –10% (Fatehgarh) in 2020, whereas the change in productivity of Kufri Jyoti will be from +11.6% (Amritsar) to –11.6% (Fatehgarh) and of Kufri Pukhraj from +12% (Amritsar) to –11.5% (Mansa). During this period, CO_2 fertilization is expected to increase tuber productivity from +3.9% to +4.5%, depending upon cultivar and location. However, in 2055, a mean decrease of 17.9 (Kufri Badshah), 21.1 (Kufri Jyoti) and 22% (Kufri Pukhraj) is likely in the productivity due to rise in temperature only, while the expected rise in CO_2 is likely to bring about 17.3 (Kufri Badshah) to 18.5% (Kufri Jyoti) increase in potato productivity. It is estimated that under the combined influence of change in temperature and CO_2, the productivity of potato cultivars will not be affected in 2020 over the baseline scenario, but will decline in 2055 (Kufri Badshah, –2.62%; Kufri Jyoti, –4.6% and Kufri Pukhraj, –5.3%), when the total geographical area of Punjab is considered. It is further shown that if the present distribution of potato acreage within Punjab remains unaltered in future, there will be benefits from climate change as the potential productivity of Kufri Badshah, Kufri Jyoti and Kufri Pukhraj will increase by 3.3%, 3.1% and 3.6% in 2020, although the potential productivity will again decline to baseline values in 2055 (+0.1%, –1.5% and –1.9% respectively).

Keywords: Carbon dioxide concentration, climate change, potato productivity, simulation study, WOFOST model.

GLOBAL climate change is an acknowledged fact and global greenhouse gas (GHG) emissions will continue for the next few decades[1]. According to the Inter-Governmental Panel on Climate Change (IPCC) Report released in 2007, 11 of the previous 12 years (1995–2006) ranked among the 12 warmest years in the instrumental record of global surface temperature (since 1850)[2]. It is now reconfirmed that the global atmospheric concentrations of carbon dioxide (CO_2), methane and nitrous oxide have increased markedly as a result of human activities since 1750. The increase in GHGs has resulted in warming of the climate system by 0.74°C between 1906 and 2005. The rate of warming has been much higher in recent decades.

Although increase in atmospheric CO_2 has a fertilization effect on crops with C3 photosynthetic pathway and thus promotes their growth and productivity, on the other hand, it can reduce crop duration. Report of Working Group II of IPCC and a few other global studies[3] indicate a probability of 10–40% loss in crop production in India with increase in temperature by 2080–2100.

Potato is an important food crop of India. We have made tremendous progress in potato production. The growth of potato in India has been phenomenal since 1950 and its per capita availability[4] has increased from 4.37 to 21.52 kg in 2012. Climate change will have a profound effect on the potato growth story in India impacting every aspect of production and profitability, including productivity. The CO_2 concentration and assimilation are positively correlated and a 10% increase in tuber yield is estimated for every 100 ppm increase in CO_2 concentration[5]. These positive effects are attributed to increased photosynthesis[6,7] by 10–40%. Besides, elevated CO_2 concentration reduces evapotranspiration (ET) resulting in water saving[8,9] to the extent of 12–14%. However, increase in temperature has adverse effects on potato growth. High temperature is reported to reduce tuber numbers and size[10,11]. Tuberization and gross photosynthetic rate are inhibited by moderately high temperatures[12,13], which ultimately affects the total biomass production and tuber yield. Increase in temperature and atmospheric CO_2 are both interlinked and occur simultaneously and the CO_2 enrichment does not appear to compensate for the detrimental effects of higher-temperatures on tuber yield[14].

In India, potato is largely grown during winter season and is mainly confined to the Indo-Gangetic Plains. The autumn/winter planted crop in the northern plains of India

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comprising the states of Uttar Pradesh, West Bengal, Bihar, Punjab and Haryana contributes 90% of total potato production in the country[15]. The availability of suitable growing period in India is likely to be impacted seriously by climate change and global warming[14]. According to the IPCC Fourth Assessment Report (AR4), an increase in temperature ranging from 0.78°C during September–November to 1.17°C during December–February is expected under A1FI scenario by 2020 in South Asia. These changes are expected to aggravate and range from 1.71°C during June–August to 3.16°C during December–February[1], i.e. the main potato growing season in 2055. Thus, in 2020 the potato season is likely to be warmer by 0.78–1.18°C and in 2055, by 2.41–3.16°C under A1FI scenario.

There is an urgent need to study the impact of the likely changes in temperature and CO_2 on regional vulnerability of potato productivity in the future, in order to direct our research efforts to meet the challenges and devise adaptation strategies to minimize the impact of climate change. For this purpose, crop growth models are useful as they serve as an excellent tool to simulate crop growth and yield of annual and perennial crops under diverse situations. These models are being used widely throughout the world for generating knowledge about the production potential of the crops under different climatic regions, for yield forecasting, nutrient and water needs of the crop, management decisions, impact analysis of climate change and adaptation strategies, selection of crops and varieties for optimum production, etc.

Keeping the above points in view, a study was undertaken to assess the impact of climate change under A1FI scenario through simulation studies using WOFOST crop growth model on the productivity of three potato cultivars of different maturity groups in Punjab, which accounts for 83.6 thousand ha area under potato cultivation[16].

Material and methods

Selection of simulation model

WOFOST (WOrld FOod STudies) model has been developed at Wageningen University, The Netherlands. It is a mechanistic model which simulates the growth of a crop based upon eco-physiological processes. The major processes are phenological development, CO_2 assimilation, transpiration, respiration, partitioning of assimilates to the various organs and dry matter formation[17]. This model is widely used to assess the effect of climate change on the growth and yield of many crops, including wheat, rice, maize, potato, barley, soybean and sugar beet throughout the world[18,19]. It is one of the three most widely used crop growth models for climate change studies[20]. WOFOST has been calibrated for Indian potato cultivars using the time-course data on potato growth and development[21]. Impact of climate change on potato productivity in the present study was therefore assessed using WOFOST model, which was run for 13 locations spread across Punjab (Figure 1 and Table 1).

Selection of potato cultivars

For simulation studies, three potato cultivars; one each from late (Kufri Badshah), medium (Kufri Jyoti) and early (Kufri Pukhraj) maturity group were selected. Together, these three cultivars account for about 90% of total potato acreage in Punjab[22]. For climate change studies, the planting date was set as 15 October for all the cultivars and for all the locations since this is the present recommendation for planting of the main crop and the

Figure 1. District map of Punjab.

Table 1. List of meteorological stations located in Punjab for which simulation studies were carried out

Meteorological station	Longitude (°N)	Latitude (°E)
Amritsar	31.617	74.850
Bathinda	30.204	74.943
Faridkot	30.670	74.750
Fatehgarh	30.651	76.389
Firozpur	30.917	74.600
Gurdaspur	32.033	75.517
Hoshiarpur	31.530	75.920
Ludhiana	30.910	75.850
Mansa	29.980	75.380
Moga	30.480	75.100
Muktsar	30.283	74.305
Patiala	30.340	76.380
Sangrur	30.230	75.830

simulation was done for potential yields of potato cultivars for all the scenarios.

Weather data

India Meteorological Department (IMD) district normals of 1971–2000 of 13 districts of Punjab (Table 1) were used for baseline scenario in the present study. For calculating total solar radiation, Hargreaves–Samani equation was used which utilizes maximum and minimum temperature to estimate solar radiation and is reported to be best suited for Indian conditions[23,24]. The weather data was then converted into WOFOST weather file format. The simulation studies were carried out for A1FI high-emission scenario. For generating the scenario for 2020 and 2055, projected changes in surface air temperature for sub-regions of Asia under SRES A1FI pathway, based on AR4 atmosphere–ocean general circulation models (AOGCMs) were added to the baseline data[1]. Projected atmospheric CO_2 concentration based on the Bern-CC model for A1FI scenario was used for incorporating the effect of change in CO_2 concentration in the WOFOST model[2]. The figures used in this study for atmospheric CO_2 concentration were 367 ppm (for baseline), 415 ppm (for 2020) and 590 ppm (for 2055).

Incorporation of CO_2 impact in the model

The impact was incorporated in the WOFOST model by making changes in light-use efficiency of single leaf and maximum leaf CO_2 assimilation rate. Wolf *et al.*[18] have reported that doubling of CO_2 from 355 to 710 ppm brings about 25–40% (mean 32.5%) increase in yield in C3 plants and based on the literature reviews they have made changes to the initial angle (+ 11%) and to the maximum CO_2 assimilation – light response curve (+ 60%) parameters of WOFOST model for doubling CO_2 concentration from 355 to 710 ppm. Under experimental conditions with non-limiting supply of water and nutrients, where temperatures are kept near the optimum for crop growth, the yield increase for C3 crops and doubling of CO_2 has been estimated at 30% by various workers[25]. Therefore, we have taken these figures as + 10% (30/32.5 × 11) and + 55% (30/32.5 × 60) for doubling CO_2 concentration for potato, assuming roughly linear relationship between CO_2 increase and growth processes. Accordingly, these parameters were changed for 2020 and 2055 for A1FI scenario (Box 1).

In the present study, the WOFOST model was run for 13 locations spread across Punjab, for all the three potato cultivars for baseline situation and for future climates (2020 and 2055), separately for temperature and CO_2 changes as well as for their combined effect, in order to assess the impact of the two parameters and their interaction with crop growth and productivity.

Kriging

GIS maps of baseline productivity and change in productivity of different potato cultivars under future climate scenarios were generated using remote sensing and GIS software 'Geomatica'. An image of Punjab of 500 m pixel size was used for generating the GIS maps. A point layer of 13 districts of Punjab was created using their geographical locations (Table 1). The attribute data of each district containing productivity under different scenarios were geo-statistically interpolated using kriging technique to produce surface layers of the attributes. For kriging, spherical variogram was chosen for interpolation of the point data. The modelling for per cent change in productivity was done in EASIPACE. GIS software was also used to estimate the area falling under different attribute classes.

Results and discussion

The present study was carried out using the WOFOST crop growth model. The model was validated for the potato cultivars using the time-course data on potato growth and development obtained from field experiments[21] conducted at Jalandhar (Punjab) and Patna (Bihar) between 1999 and 2001. The model performance was evaluated using statistical indicators – maximum error (ME), root mean square error (RMSE), coefficient of residual mass (CRM), modelling efficiency (EF) and coefficient of determination (CD) and was found to be satisfactory.

The validation results showed a close agreement between measured (actual) and simulated important parameters of all the three cultivars (Table 2). The final tuber dry matter yields of all these cultivars varied within ± 6%, which is well within acceptable limits.

Box 1. Change in parameters for A1FI scenario

	2020	2055
Change in light-use efficiency of single leaf	+ 10% × (415 – 367)/355 = +1.4%	+ 10% × (590 – 367)/355 = + 6.28%
Change in maximum leaf CO_2 assimilation rate	+ 55% × (415 – 367)/355 = +7.4%	+ 55% × (590 – 367)/355 = + 34.5%

Table 2. Comparison of measured (actual) and simulated values of some important parameters of potato cultivars

Parameter	Kufri Badshah			Kufri Jyoti			Kufri Pukhraj		
	Measured	Simulated	Difference	Measured	Simulated	Difference	Measured	Simulated	Difference
Emergence (days)	17	15	2 days	15	15	0 days	15	15	0 days
Tuber initiation (days)	37	36	1 days	32	35	3 days	29	36	7 days
Total dry matter yield (t/ha)	14.6	15.5	5.6%	12.3	12609	2.5%	13.1	13.1	0.5%
Tuber dry matter yield (t/ha)	86.9	88.7	2.1%	73.5	7941	7.5%	83.0	82.5	0.6%

Potato productivity in Punjab under future climates

For impact analysis, simulation studies were carried out for A1FI high-emission scenario. As discussed earlier, the WOFOST model was run for baseline (1971–2000 normals), 2020 and 2055 climate scenarios. The productivity was worked out based upon the total geographical area of Punjab, after interpolating the model results through kriging for 13 districts. The results of the simulation studies showed that the productivity potential of Kufri Badshah, a late maturity variety, was minimum at Amritsar (48.7 t/ha) and maximum at Bathinda (56 t/ha), with an overall productivity of 52 t/ha, under baseline scenario (Tables 3 and 4). In this scenario, the maximum geographical area of Punjab (72.9%) had a productivity potential of 50–52.5 t/ha for Kufri Badshah (Table 4 and Figure 2). Under the future climate scenarios, when the effect of temperature and CO_2 fertilization was considered together, productivity of cv. Kufri Badshah is projected to remain unchanged in 2020 (–0.08%), but will reduce by 2.62% in 2055. The productivity of cv. Kufri Jyoti, a variety of medium maturity group, ranged from 45.9 (Amritsar) to 51.8 t/ha (Bathinda) under baseline scenario, with maximum (63%) geographical area having a potential of 47.5–50 t/ha. An insignificant 0.4% increase is expected in 2020 in Kufri Jyoti (from 48.9 to 49.0 t/ha), which will decline by 4.59% (to 46.6 t/ha) in 2055 when compared with baseline yield. Kufri Pukhraj, an early maturity variety, had a productivity range 46.7 (Patiala)–54.7 t/ha (Bathinda). The maximum increase in productivity, from 50.8 to 51.2 t/ha (0.69%) in 2020 and maximum decline (to 48.1 t/ha; 5.33%) in 2055, both are expected in this cultivar.

Sensitivity analysis

In the present study, the two variables that determine the yields are weather (solar radiation, and minimum and maximum temperature) and CO_2 concentration. The sensitivity analysis was carried out for all the 13 locations for these two factors to examine the sensitivities of potential productivity of potato cultivars to change in each of these parameters. The mean values for all the locations are given in Table 3. The increase in atmospheric CO_2 concentration is expected to increase the tuber productivity of Kufri Badshah, Kufri Jyoti and Kufri Pukhraj from 3.9% to 4.2%, 4.1% to 4.5% and 4.1% to 4.4% across 13 locations in Punjab in 2020. Similar figures for 2055 are 16.5% to 17.7%, 17.7% to 19.4% and from 17.6% to 19.1%. CO_2 enrichment up to 550 ppm causes a large increase in radiation use-efficiency and with increasing CO_2 assimilate allocation to tubers become larger, leading to increase in yield[26]. The mean values taken over 13 locations spread across Punjab showed that CO_2 fertilization alone increased the tuber productivity of Kufri Pukhraj by 4.2%, but an increase in temperature, without increase in CO_2, showed a negative effect on yield (4.7%) in 2020. However in 2055, the extent of increase in yield due to CO_2 was 18.3%, which was largely negated by increased temperature (21.95%) during this period with overall reduction in productivity to the tune of 6.48%. Similar trends were also observed in Kufri Jyoti and Kufri Pukhraj (Table 3). The five northernmost districts of Punjab – Gurdaspur, Pathankot, Hoshiarpur, Amritsar and Tarn Taran (Figure 1) – were the only beneficiaries of increased temperature, that too only in 2020, when increase in productivity was observed (Kufri Badshah, 5.0% to 11.8%; Kufri Jyoti, 4.1% to 11.6% and Kufri Pukhraj, 5.1% to 12%). In the remaining districts the effect of increased temperature, without CO_2 fertilization, is expected to decrease the productivity from 3.8% (Faridkot) to 10% (Fatehgarh) in Kufri Badshah, 5.4% (Faridkot) to 11.6% (Fatehgarh) in Kufri Jyoti and 5.3% (Firozpur) to 11.5% (Mansa) in Kufri Pukhraj in 2020. The increase in temperature alone is likely to decrease productivity of all the three cultivars in all the districts during 2055, ranging from 0.6% (Amritsar) to 25.1% (Fatehgarh), 3.6% (Amritsar) to 27.5% (Mansa) and 4.5% (Amritsar) to 29.5% (Mansa) for Kufri Badshah, Kufri Jyoti and Kufri Pukhraj respectively.

The increase in productivity of potato cultivars in Gurdaspur, Hoshiarpur and Amritsar districts is attributed to the prevailing lower temperature during potato crop growth period, which is sub-optimal. The minimum (0–7°C), optimum (16–25°C) and maximum (40°C) temperatures for photosynthesis have been reported[27]. The model used in the present study reduces the gross assimilation rate at a temperature below 5°C, bringing it to zero at 0°C. The number of days during potato growth season in Gurdaspur, Hoshiarpur and Amritsar districts, which had a temperature below 5°C was 51,

Table 3. WOFOST simulated potential yield of potato cultivars under baseline and future climate scenarios at different locations in Punjab

	Kufri Badshah	Change over baseline yield (%)						Kufri Jyoti	Change over baseline yield (%)						Kufri Pukhraj	Change over baseline yield (%)					
		2020			2055				2020			2055				2020			2055		
Station	Baseline yield (t/ha)	Due to temp.	Due to CO_2	Temp. + CO_2	Due to temp.	Due to CO_2	Temp. + CO_2	Baseline yield (t/ha)	Due to temp.	Due to CO_2	Temp. + CO_2	Due to temp.	Due to CO_2	Temp. + CO_2	Baseline yield (t/ha)	Due to temp.	Due to CO_2	Temp. + CO_2	Due to temp.	Due to CO_2	Temp. + CO_2
Amritsar	48.7	11.8	4.2	16.4	–0.6	17.7	17.0	45.9	11.6	4.4	16.4	–3.6	18.7	15.3	48.3	12.0	4.3	16.8	–4.5	18.4	14.3
Bhatinda	56.0	–3.6	4.2	0.5	–19.3	17.8	–4.0	51.8	–5.4	4.5	–1.1	–24.1	19.3	–7.6	54.7	–6.9	4.4	–2.7	–25.6	19.1	–9.6
Faridkot	55.2	–3.8	4.1	0.2	–19.4	17.5	–4.5	51.1	–5.4	4.4	–1.2	–23.1	18.9	–7.1	53.7	–5.7	4.3	–1.6	–24.4	18.7	–9.0
Fatehgarh	50.9	–10.0	3.9	–6.5	–25.1	16.8	–12.5	46.8	–11.3	4.1	–7.5	–27.2	17.7	–13.7	48.0	–11.4	4.1	–7.8	–28.2	17.6	–15.1
Ferozpur	53.1	–3.7	4.0	0.1	–19.5	17.2	–5.7	49.8	–5.6	4.2	–1.7	–22.6	18.0	–8.1	51.5	–5.3	4.1	–1.4	–24.0	17.8	–9.8
Gurdaspur	51.3	5.0	4.1	9.2	–10.2	17.3	5.5	48.6	4.1	4.1	8.6	–12.5	18.2	4.6	50.8	5.1	4.2	9.5	–12.2	18.1	4.7
Hoshiarpur	50.3	8.2	4.2	12.5	–5.5	17.6	11.1	47.5	8.2	4.4	13.0	–8.0	18.5	10.1	49.4	9.9	4.3	14.6	–7.2	18.4	10.8
Ludhiana	52.7	–9.7	3.9	–6.1	–24.1	16.7	–11.1	48.7	–10.6	4.2	–6.8	–26.4	17.8	–12.2	50.6	–11.1	4.1	–7.4	–27.2	17.7	–13.4
Mansa	54.3	–9.5	4.1	–5.8	–23.7	17.5	–9.6	49.9	–10.3	4.4	–6.3	–27.5	18.9	–12.1	52.1	–11.5	4.4	–7.6	–29.5	18.9	–14.0
Moga	52.8	–6.8	4.1	–2.9	–19.6	17.2	–4.9	50.8	–8.6	4.4	–4.5	–23.8	18.7	–8.1	54.0	–9.1	4.3	–5.1	–25.0	18.5	–9.7
Mukatsar	55.6	–3.8	4.1	0.2	–19.4	17.6	–4.5	51.4	–5.4	4.4	–1.2	–23.1	18.9	–7.2	54.0	–5.8	4.3	–1.6	–24.4	18.7	–9.0
Patiala	48.8	–9.8	3.9	–6.3	–23.8	16.5	–10.7	44.9	–10.5	4.2	–6.7	–26.2	17.9	–11.6	46.5	–11.0	4.1	–7.2	–26.5	17.8	–12.5
Sangrur	53.5	–8.9	4.0	–5.3	–22.6	17.0	–8.8	50.0	–10.0	4.3	–6.1	–25.7	18.4	–10.7	52.3	–10.3	4.2	–6.5	–26.6	18.3	–12.0
Mean of 13 districts	52.6	–3.4	4.1	0.5	–17.9	17.3	–3.3	49.0	–4.6	4.3	–0.4	–21.1	18.5	–5.3	51.2	–4.7	4.2	–0.6	–22.0	18.3	–6.5

Table 4. Geographical area of Punjab (%) under different yield classes

	Kufri Badshah			Kufri Jyoti			Kufri Pukhraj		
Potential productivity (t/ha)	Baseline	2020	2055	Baseline	2020	2055	Baseline	2020	2055
37.5–40.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0
40.0–42.5	0.0	0.0	0.0	0.0	2.3	12.7	0.0	0.0	9.4
42.5–45.0	0.0	0.0	7.0	0.1	12.0	19.2	0.0	7.5	14.7
45.0–47.5	0.0	6.4	12.7	24.3	20.0	26.8	5.4	12.4	16.9
47.5–50.0	11.9	15.0	18.9	46.6	20.6	17.1	33.3	17.7	31.3
50.0–52.5	45.8	22.0	20.4	29.0	26.6	20.0	34.4	19.8	6.9
52.5–55.0	28.2	20.3	27.8	0.0	18.4	2.5	26.9	23.2	20.4
55.0–57.5	14.1	36.3	13.2	0.0	0.0	0.0	0.0	19.4	0.4

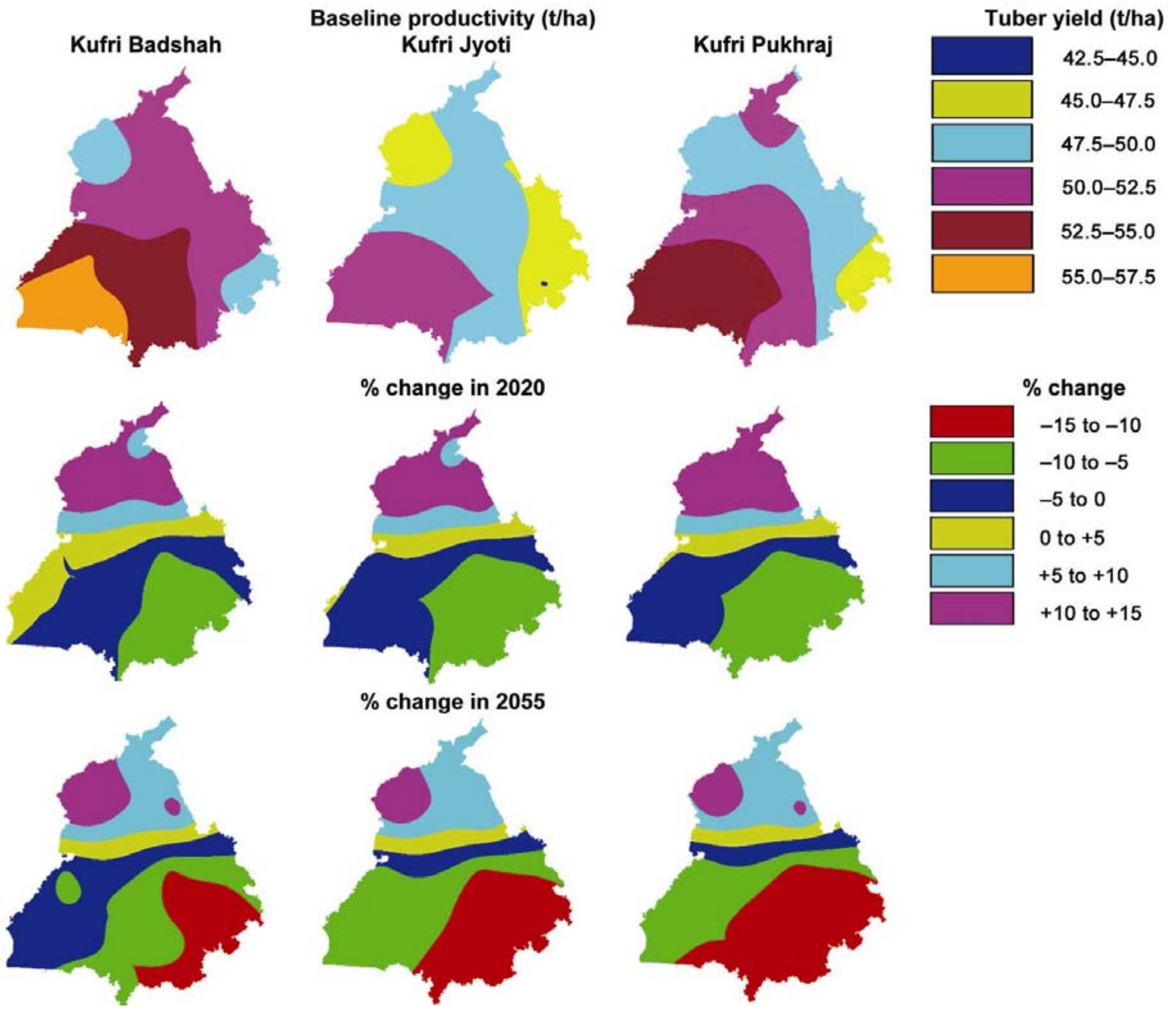

Figure 2. Potential productivity of different potato cultivars under baseline and changes in future climatic scenario.

55 and 62 respectively, while in other districts it ranged from 0 (Fatehgarh, Patiala and Sangrur) to 30 days only (Bathinda and Faridkot). The temperature increase in 2020 brought down the number of days with a temperature below 5°C during potato growth season in Gurdaspur, Hoshiarpur and Amritsar districts to 10, 19 and 29 days during 2020 and zero during 2055 respectively.

The increase in temperature forced the earlier maturity of potato cultivars as the thermal time for different growth stages and total thermal time from potato planting to maturity were achieved early. Kufri Badshah, which matured in 130 days under baseline scenario, matured 10 (7.7%) and 25 days (19.2%) earlier in 2020 and 2055 respectively, and the corresponding figures for Kufri

Jyoti and Kufri Pukhraj were 10 (8.5%) and 24 (20.5%) days and 9 (8.2%) and 23 (20.9%) days respectively. Besides decreased photosynthesis rate due to increase in temperature, this is another reason why potato productivity declined under increased temperature situation. Potato is a vegetative crop and its tubers continue to bulk till the maturity of haulms, i.e. crop maturity. Thus any reduction in growth duration leads to reduction in yield.

The baseline productivity of all the three potato cultivars was highest in SW Punjab, comprising Firozpur, Muktsar, Faridkot and Bathinda districts, and declined towards the east, north and north-east. The trend was similar for all the varieties, although the varieties differed in their production potential (Figure 2). The overall combined effect of temperature and CO_2 was mixed. While the northern districts (Pathankot, Gurdaspur, Amritsar and parts of Tarn Taran, Kapurthala, Jalandhar and Hoshiarpur) witnessed an increase in productivity of all the cultivars in the range 0–15%, the other districts showed a decline in productivity to the tune of 0–10% in 2020. In 2055, the areas witnessing decline will move further south and also record 10–15% decline in potato productivity (Table 3 and Figure 2).

Studies further reveal that during 2020, 54.2%, 64.2% and 63.1% of the total geographical area of Punjab under Kufri Badshah, Kufri Jyoti and Kufri Pukhraj would show a decline in productivity, which would increase to 69.4%, 71.4% and 72.3% in 2055.

In Punjab, out of the 22 districts, most of the potato cultivation is concentrated in 11 districts, namely Amritsar, Hoshiarpur, Pathankot, Tarn Taran, Jalandhar, Kapurthala, Gurdaspur, Ludhiana, Moga, Shahid Bhagat Singh Nagar and Rupnagar (shaded portion in Figure 1). Although their share to the total geographical area of Punjab is 44.4%, their contribution to total potato acreage of the state[28] is about 81.1%. These districts lie in the central and northern parts of Punjab and this is the area which is mostly benefited by the combined effect of likely increase in temperature and CO_2 in 2020 as well as in 2055 (Figure 2). In these districts, the model has predicted a mean increase of 4.6%, 4.7% and 5.4% in the productivity for Kufri Badshah, Kufri Jyoti and Kufri Pukhraj respectively in 2020. However, the corresponding extent of increase is expected to be 1.8%, 1.3% and 0.2% respectively in 2055, although positive but lower than 2020. The remaining 13 districts, which constitute about 55.6% to the state's geographical area and currently contribute only 18.9% to its share of potato acreage, are likely to see a decline in productivity of all the three varieties in 2020 as well as in 2055. The weighted mean taken over these area after accounting for their proportionate share in Punjab's current potato acreage has shown that if the acreage scenario remains the same in future, the overall productivity of Kufri Badshah, Kufri Jyoti and Kufri Pukhraj will increase by 3.3%, 3.1% and 3.6% respectively in 2020. However, this benefit in productivity will be reversed with almost no change in Kufri Badshah (+ 0.1%) and a slight decline in the productivity of Kufri Jyoti (– 1.5%) and Kufri Pukhraj (– 1.9%).

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