

Impact of climate change on potato (*Solanum tuberosum*) productivity in Bihar and relative adaptation strategies

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Received : June 2015; Revised accepted : October 2015

ABSTRACT

A study was carried out for Bihar state to assess the impact of climate change on potato (*Solanum tuberosum* L.) productivity using WOFOST crop growth simulation model. Three different maturity group potato cultivars were used ('Kufri Badshah'—late maturing; 'Kufri Jyoti'—medium maturing; and 'Kufri Pukhraj'—early maturing). The study was done for baseline scenario (2000) and for future climate scenarios for the years 2020 and 2055 using A1FI scenario of temperature (SRES A1FI pathway) and atmospheric CO₂ (based on the Bern-CC model for A1FI scenario). Potential production of potato cultivars was estimated for 29 different locations across Bihar. Kriging technique was used to interpolate the data generated through the model and thematic maps were created based on potential productivity in 2000 and changes thereon in future climates. Under baseline scenario, the mean productivity of 'Kufri Badshah', 'Kufri Jyoti' and 'Kufri Pukhraj' was 40.7, 38.7 and 40.8 t/ha respectively. Though the increase in CO₂ concentration is expected to bring an increase of 4.2 to 4.5% in productivity in 2020 and 17.7 to 19.3% in 2055, the corresponding increase in temperature is likely to decrease the mean productivity by 9.0 to 11.0% and 24.3 to 29.1% in 2020 and 2055, respectively. Overall, under the combined influence of increased CO₂ and temperature, the model projected a decline of 5.1, 6.2 and 6.9% in productivity of 'Kufri Badshah', 'Kufri Jyoti' and 'Kufri Pukhraj', respectively, in 2020; and 8.7, 10.8 and 12.7%, respectively, in 2055 without adaptation. Rescheduling planting date can be an immediate option against climate change in Bihar. However, development of short-duration, heat-tolerant as well as nutrient and water-use efficient cultivars with high harvest index along with proper agronomic interventions are required to meet the challenges posed by climatic change.

Key words : Adaptation, Climate change, CO₂ concentration, Potato productivity, Simulation, Temperature, WOFOST model

Climate change is posing serious threat to human survival on the Earth in one or the other way. The disturbances in earth's climate have been greatly accelerated during the past century and 11 of the previous 12 years (1995–2006) ranked among the 12 warmest years since 1850 (IPCC report, 2007). It's a well established fact that green house gas (GHG) emission is responsible for climate change and is increasing rapidly at an alarming rate. Globally, the atmospheric concentrations of greenhouse gases (GHGs), viz. carbon dioxide, methane and nitrous oxide, have increased markedly as a result of human activities since 1750. These increases in GHGs have resulted in warming of the climate system by 0.74°C between 1906 and 2005, which has been much higher in recent decades.

After rice and wheat, potato is the third major food commodity of India in terms of production. India has achieved self sufficiency in potato production and now the per capita availability of potato has increased from 4.37 kg in 1950 to 21.52 kg in 2012 (Singh *et al.*, 2008). This changing climate is expected to have a negative effect on potato growth, including production and productivity in India. There is positive correlation between CO₂ concentration and assimilation of photosynthates in potato. A 10% increase in tuber yield is estimated for every 100 ppm increase in CO₂ concentration (Miglietta *et al.*, 1998) due to increased photosynthesis by 10 to 40% (Katny *et al.*, 2005; Schapendonk *et al.*, 2000) and reduced evapotranspiration (ET) which results in water saving of 12 to 14% (Magliulo *et al.*, 2003; Olivo *et al.*, 2002). This raised CO₂ concentration leads to increase in temperature, which ultimately has undesirable effects on growth and development of potato crop. High temperature reduces tuber number and size (Peet *et al.*, 2000; Khan *et al.*, 2003).

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Tuberization in potato is inhibited by even moderately high temperatures as well as gross photosynthetic rate (Ewing *et al.*, 1997; Fleisher *et al.*, 2006) ultimately affecting the total biomass and tuber yield of potato. Increasing temperature and atmospheric CO₂ level are interlinked and occur simultaneously and the CO₂ enrichment does not appear to compensate for the detrimental effects of higher temperature on tuber yield.

Potato is a popular temperate crop and is largely grown during the winter season in India. Its cultivation is mainly confined to Indo-Gangetic plains where it is taken as autumn/winter crop in northern plains comprising the states of West Bengal, Bihar, Punjab and Haryana contributing about 90% of total potato production in India (APEDA, 2012). According to 4th IPCC assessment report, an increase in temperature ranging from 0.78°C during September, October, November to 1.17°C during December, January, 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, July, August to 3.16°C during December, January, February, i.e. the main potato growing season in 2055. Thus, in 2020 the potato season is likely to be warmer by 0.78 to 1.18°C and in 2055, by 2.41 to 3.16°C under A1FI scenario. This situation is likely to have serious impact on the availability of favourable cultivation period for potato in India (Ewing *et al.*, 1997).

In India, Bihar is the third largest potato-producing state after Uttar Pradesh and West Bengal. With a production of 6.1 million tonnes, it contributes about 14.7% of national potato production (NHB database, 2012). There is an urgent need to study the likely impact of raising temperature and CO₂ concentration on regional vulnerability of potato productivity in this state, so as to develop suitable management strategies for adapting potato crop to climate change in near future and also to focus our research efforts to maintain the production by minimizing the likely impact of climate change. Crop-growth models are very useful for this purpose, as they serve as an excellent tool to simulate crop growth and yield of annual and perennial crops under diverse situations. At global level, crop growth simulation models are being used extensively for various purposes like yield forecasting, working out nutrient and water needs of the crop, generating knowledge about the production potential of the crops under different climatic situations, management decisions, impact analysis of climate change and adaptation strategies, selection of suitable crops and varieties for optimum production etc.

Hence, a study was carried out to evaluate the impact of climate change on potato productivity in Bihar under A1FI scenario and develop adaptation strategy through suitable cultivars and date of planting using WOFOST

crop growth model.

MATERIALS AND METHODS

Selection of model

WOFOST (WORLD FOOD STUDIES) crop growth simulation was used in the present study. The WOFOST was developed at the Wageningen University, the Netherlands, which is a mechanistic model that simulates the growth of a crop based upon eco-physiological processes. Phenological development, CO₂-assimilation, transpiration, respiration, partitioning of assimilates to the various organs, and dry-matter formation are the major processes studied under this model. Worldwide this model is widely used to assess the effect of climate change on the growth and yield of many crops, viz. wheat, rice, maize, potato, barley, soybean and sugarbeet. This model has been validated for 3 potato cultivars under study using the time course data on potato growth and development derived from field experiments conducted at Jalandhar (Punjab) and Patna (Bihar) during 1999 to 2001 (Dua *et al.*, 2014). Thus, it was used to study the potential impact of climate change on potato productivity and scheduling planting date thereby making wise selection of suitable cultivar to minimize the losses of climate changes in Bihar. The model was run for 29 stations situated across Bihar (Table 1).

Selection of potato cultivars

The simulation studies was carried with 3 potato cultivars of 3 different maturity groups, viz. late 'Kufri Badshah', medium 'Kufri Jyoti' and early 'Kufri Pukhraj' which are cultivated extensively in Bihar. The simulation study was carried out for potential yields of potato cultivars planted on 1 November (the usual/ recommended date of planting in Bihar) for all the scenarios.

Weather data

In the present study, IMD district normals of 1971–2000 of 29 districts of Bihar (Table 2) were used for baseline scenario (year 2000). Hargreaves-Samani equation was employed for working out total solar radiation. The equation uses the maximum and minimum temperature to estimate solar radiation and is reported to be best suited for Indian conditions (Samani *et al.*, 2000; Bandyopadhyay *et al.*, 2008). The weather data were then converted into WOFOST weather file format. The simulation studies were carried out for A1FI high emission scenario. For generation of scenario for 2020 and 2055, projected changes in surface air temperature for sub-regions of the Asia under SRES A1FI pathway, based on the Fourth Assessment Report (AR4) Atmosphere-Ocean General Circulation Models (AOGCMs) were added on the baseline data (IPCC, 2007). Projected atmospheric

CO₂ concentration based on the Bern-CC model for A1FI scenario was used for incorporating the effect of change in CO₂ concentration in WOFOST model (IPCC, 2001). The figures used in this study for atmospheric CO₂ concentration were 367 ppm (for baseline), 415 ppm (for 2020) and 590 ppm (for 2055).

Incorporation of CO₂ impact in the model

For incorporating the impact of CO₂ in the WOFOST model, changes were made in the parameters—light-use efficiency of single leaf and maximum leaf CO₂ assimilation rate. A 25 to 40% (mean 32.5%) increase in yield in C₃ plants owing to doubling of CO₂ from 355 ppm to 710 ppm has been reported (Wolf *et al.*, 2010). Based on literature reviews, Wolf *et al.* (2010) have made changes in initial angle (+11%) and in maximum of the CO₂ assimilation – light response curve response curve (+60%) parameters of WOFOST model for doubling CO₂ concentration from 355 to 710 ppm. Under the experimental conditions with non-limiting supply of water and nutrients, and where temperatures are kept near the optimum for crop growth, the yield increase for C₃ crops with a doubling of CO₂ has been estimated at 30% by various workers (Fuhrer *et al.*, 2003) therefore we have taken these figures as + 10% (30/32.5 × 11) and + 55% (30/32.5 × 60) for doubling CO₂ concentration for potato, assuming roughly linear relationship between the CO₂ increase and the growth processes. Accordingly, these parameters were changed for 2020 and 2055 for A1FI scenario as follows:

	2020	2055
Change in light-use efficiency of single leaf	+ 10% × (590–367)/355 = + 1.4%	+ 10% × (415–367)/355 = + 6.28%
Change in maximum leaf CO ₂ assimilation rate	+ 55% × (415–367)/355 = + 7.4%	+ 55% × (590–367)/355 = + 34.5%

The WOFOST model was run for 29 locations spread across Bihar, for all the 3 potato cultivars for baseline situation and for future climates (2020 and 2055) in the present study, separately for temperature and CO₂ changes as well as for their combined effect, in order to assess the impact of these 2 parameters and their interaction on crop growth and productivity.

For adaptation studies, model was run for 5 different locations representing different parts of state, viz. Saran (25.92°N, 84.75°E-North-western part), Araria (26.13°N, 87.47°E-North-eastern part), Aurangabad (24.75°N, 84.37°E-South-western part), Banka (24.88°N, 86.92°E-South-eastern part) and Nalanda (25.14°N, 85.44°E -Central Bihar). The model was run for all the three cultivars of potato, for all the 3 climatic scenarios (baseline-2000, and

future climate scenarios for the years 2020 and 2055), for 9 dates at 10 days interval starting from 12 October.

Kriging

‘Geomatica’ software was used for creation of maps of the baseline productivity and change in productivity of different potato cultivars under future climate scenarios. An image of Bihar of 500 m pixel size was used for generation of GIS maps. A point layer of 29 districts of Bihar was created using their geographical locations (Table 1). The attribute data of each district containing productivity and change in productivity under different future climate scenarios were geo-statistically interpolated using Kriging technique and surface layers of the attributes were produced. The modeling for per cent change in productivity and for estimation of the area falling under different class of attributes was done in EASIPACE.

RESULTS AND DISCUSSION

Potato productivity

The potato productivity varied largely within the state under baseline scenario (26.6–45.8, 23.9–45.3 and 24.2–49t/ha, for ‘Kufri Badshah’, ‘Kufri Jyoti’ and ‘Kufri Pukhraj’ respectively). The average productivity of 29 districts was 38.7, 37.2 and 39.1 t/ha, respectively, for ‘Kufri Badshah’, ‘Kufri Jyoti’ and ‘Kufri Pukhraj’ (Table 1). The extrapolated results have shown a baseline productivity of 40.7, 38.7 and 40.8 t/ha for these cultivars (Table 3). The WOFOST simulated potato productivity was the highest in south-western districts, particularly Buxur and Bhojpur (Table 1; Fig. 1). The comparable productivity was also simulated for north-eastern districts, Kishanganj and Purnia and north-western districts (East and West Champaran). A decline in potato productivity was observed on moving from south–west, north east and north–west to south–east direction in Bihar. Under the future climate, model results have shown decline in the productivity of ‘Kufri Badshah’, ‘Kufri Jyoti’ and ‘Kufri Pukhraj’ to the tune of 5.9, 5.8 and 6.5% in 2020; and 10.0, 11.1 and 13.1% in 2055, averaged over 29 locations (Table 1). When the complete geographical area of Bihar state was considered, the interpolated results have shown 5.1, 6.2 and 6.9% drop in 2020 and 8.7, 10.8 and 12.7% drop in 2055 in the productivity of ‘Kufri Badshah’, ‘Kufri Jyoti’ and ‘Kufri Pukhraj’ respectively (Table 3). In general, in 2020, the lesser reduction in ‘Kufri Badshah’ productivity is expected in western part of Bihar (0–5%). In case of ‘Kufri Jyoti’ and ‘Kufri Pukhraj’, the south–western part could see productivity little changed (0–5%) in 2020 compared to rest of the state where, productivity is likely to fall by 6–10% (Fig. 1).

The simulation results have shown that ‘Kufri Badshah’

Table 1. WOFOST simulated potential productivity of potato cultivars under baseline (2000) and future climate scenarios at different locations under study in Bihar

Sl. No.	Station	'Kufri Badshah'						'Kufri Jyoti'						'Kufri Pukhraj'								
		Change over baseline yield (%)			Base line yield (t/ha)	Change over baseline yield (%)			Base line yield (t/ha)	Change over baseline yield (%)			Base line yield (t/ha)	Change over baseline yield (%)			Base line yield (t/ha)	Change over baseline yield (%)				
		2020	Due to temp.	CO ₂		2055	Due to temp.	CO ₂		2020	Due to temp.	CO ₂		2055	Due to temp.	CO ₂		2020	Due to temp.	CO ₂	2055	Due to temp.
1	Araria	38.7	-9.7	4.2	-5.9	-24.3	17.7	-10.0	36.0	-10.0	4.4	-6.0	-26.3	19.1	-10.7	37.6	-10.8	4.3	-6.9	-27.3	18.8	-12.4
2	Aurangabad	42.3	-7.7	4.2	-3.8	-21.9	18.1	-7.1	40.9	-9.2	4.5	-5.1	-24.8	19.1	-9.1	43.3	-9.6	4.3	-5.5	-26.2	18.8	-11.1
3	Banka	38.8	-9.4	4.2	-5.6	-23.5	18.0	-9.0	36.4	-10.3	4.4	-6.2	-26.8	19.1	-11.3	38.0	-11.6	4.4	-7.7	-28.5	19.0	-13.6
4	Bhagalpur	38.3	-8.8	4.3	-4.8	-23.1	18.6	-7.8	36.4	-11.0	4.6	-6.7	-27.7	20.1	-11.5	38.0	-11.4	4.6	-7.2	-29.3	20.0	-13.2
5	Bhojpur	44.4	-5.7	4.4	-1.3	-19.0	18.6	-2.0	44.6	-9.0	4.8	-4.5	-24.4	20.2	-7.2	49.0	-9.9	4.7	-5.5	-26.2	20.2	-9.3
6	Buxur	45.7	-6.3	4.3	-2.2	-20.1	18.3	-4.1	45.3	-8.9	4.6	-4.5	-23.8	19.6	-7.2	48.8	-8.8	4.5	-4.6	-24.5	19.5	-8.1
7	Champan East	43.2	-8.2	4.2	-4.3	-23.3	17.8	-9.2	41.0	-9.6	4.4	-5.5	-25.2	18.8	-10.0	43.0	-9.6	4.3	-5.7	-26.6	18.5	-12.1
8	Champan West	43.7	-8.0	4.2	-4.1	-22.8	17.9	-8.6	41.7	-9.4	4.4	-5.4	-25.2	18.9	-10.1	43.7	-9.5	4.3	-5.6	-26.6	18.5	-12.1
9	Darbhanga	42.6	-9.5	4.2	-5.6	-24.7	18.1	-10.6	39.6	-10.2	4.4	-6.2	-27.2	19.2	-11.9	41.4	-10.8	4.3	-6.8	-28.2	18.8	-13.7
10	Gaya	40.4	-6.2	4.2	-2.2	-18.3	18.0	-2.9	40.3	-8.0	4.4	-3.8	-23.8	19.0	-7.9	43.2	-9.4	4.3	-5.3	-26.1	18.6	-11.0
11	Jahanabad	38.5	-4.5	4.1	-0.5	-23.7	17.6	-7.4	39.8	-7.2	4.4	-2.9	-23.0	18.6	-7.1	43.0	-9.4	4.3	-5.3	-26.0	18.5	-11.0
12	Jamui	26.8	-10.0	4.4	-6.0	-29.2	18.8	-14.3	24.1	-11.2	4.8	-6.7	-38.0	20.8	-16.5	24.4	-11.0	4.6	-6.5	-44.4	20.2	-19.3
13	Katihar	42.5	-9.5	4.3	-5.6	-24.1	18.3	-9.6	39.9	-10.1	4.5	-6.1	-26.9	19.4	-11.2	42.0	-10.9	4.4	-6.8	-27.9	19.1	-12.9
14	Khagaria	36.0	-10.1	4.2	-6.3	-24.4	18.2	-9.8	33.4	-10.7	4.5	-6.6	-27.3	19.5	-11.6	34.5	-11.3	4.4	-7.3	-29.0	19.3	-13.4
15	Kishanganj	45.6	-8.4	4.3	-4.3	-23.2	18.5	-8.1	43.5	-9.9	4.6	-5.7	-26.4	19.7	-10.4	46.4	-10.8	4.5	-6.6	-28.1	19.4	-12.8
16	Lakhisarai	26.7	-10.0	4.4	-6.0	-29.2	18.8	-14.3	23.9	-11.2	4.7	-6.7	-38.0	20.7	-16.5	24.3	-11.1	4.6	-6.5	-44.5	20.2	-19.3
17	Madhepura	40.3	-9.6	4.2	-5.8	-24.2	17.9	-10.0	37.6	-10.2	4.4	-6.2	-26.8	19.0	-11.5	39.2	-10.8	4.3	-6.8	-27.7	18.8	-13.1
18	Madhubani	42.5	-9.5	4.2	-5.6	-24.7	18.1	-10.6	39.5	-10.2	4.4	-6.2	-27.2	19.2	-12.0	41.2	-10.8	4.3	-6.8	-28.2	18.8	-13.7
19	Monghyr	26.6	-10.0	4.3	-6.0	-29.2	18.8	-14.3	23.9	-11.1	4.8	-6.7	-38.0	20.7	-16.5	24.2	-11.1	4.6	-6.5	-44.5	20.2	-19.4
20	Muzaffarpur	38.6	-9.5	4.1	-5.7	-24.3	17.5	-10.5	35.9	-10.0	4.3	-6.0	-26.3	18.6	-11.4	37.2	-10.8	4.2	-6.9	-27.1	18.4	-12.8
21	Nalanda	39.1	-9.5	4.2	-5.7	-23.5	17.9	-9.1	36.9	-9.8	4.4	-5.7	-25.3	19.0	-9.8	38.9	-10.6	4.3	-6.6	-26.7	18.7	-12.0
22	Nawada	36.9	-9.4	4.2	-5.5	-23.3	18.0	-8.7	34.8	-9.6	4.4	-5.5	-25.8	19.1	-10.2	36.5	-10.8	4.3	-6.7	-27.2	18.8	-12.3
23	Patna	40.3	-8.6	4.1	-4.8	-23.3	17.7	-9.3	37.9	-9.7	4.3	-5.7	-25.7	18.7	-10.6	39.6	-10.3	4.3	-6.4	-27.1	18.4	-12.7
24	Purnea	45.8	-8.4	4.3	-4.3	-23.1	18.5	-8.0	43.7	-9.9	4.6	-5.6	-26.4	19.8	-10.4	46.6	-10.8	4.5	-6.6	-28.1	19.5	-12.7
25	Samastipur	42.8	-9.4	4.2	-5.6	-24.7	18.1	-10.5	39.8	-10.2	4.4	-6.1	-27.1	19.2	-11.9	41.6	-10.7	4.3	-6.8	-28.2	18.8	-13.6
26	Saran	37.6	-9.1	4.1	-5.3	-24.3	17.5	-10.5	35.0	-10.2	4.4	-6.3	-26.9	18.6	-12.2	35.9	-10.5	4.2	-6.7	-27.5	18.3	-13.4
27	Sheikhpura	34.2	-8.3	4.2	-4.5	-22.7	18.1	-7.9	32.4	-10.7	4.3	-6.5	-27.0	19.4	-11.4	33.4	-11.2	4.4	-7.2	-27.8	19.3	-12.5
28	Sitamarhi	41.9	-9.7	4.2	-5.9	-25.3	17.9	-11.6	38.6	-10.1	4.4	-6.1	-26.3	18.8	-11.3	40.1	-10.3	4.3	-6.4	-27.2	18.5	-12.8
29	Vaishali	39.7	-9.3	4.1	-5.5	-24.3	17.7	-10.3	36.9	-9.8	4.4	-5.9	-26.4	18.8	-11.4	38.4	-10.7	4.3	-6.8	-27.5	18.5	-13.2
	Mean	38.7	-9.7	4.2	-5.9	-24.3	17.7	-10.0	37.2	-9.9	4.5	-5.8	-27.2	19.3	-11.1	39.1	-10.5	4.4	-6.5	-29.1	19.0	-13.1

Temp., Temperature

is the cultivar which is likely to see the least reduction in productivity in 2055. While the 70 to 89% of the geographical area is likely to witness a decline in productivity of ‘Kufri Jyoti’ and ‘Kufri Pukhraj’ within the range of 11 to 15%. Only 21% of the geographical area could fall under this category for ‘Kufri Badshah’.

In case of all the potato cultivars, it is observed that under both the future climates the decrease in the productivity is more in those pockets which are already having poor productivity. Conversely, the area with high productivity (north–western, north–eastern and south–western districts) might see a lesser decline in productivity in future climates (Fig. 1).

Sensitivity analysis

In WOFOST model used in the present study, future climates’ effect on potato productivity is incorporated through change in 3 variables, viz. weather (temperature – min. and max.), light-use efficiency of single leaf and maximum leaf CO₂ assimilation rate. While the change in temperature variable was done through change in weather file, later two parameters were changed suitably to incorporate the effect of CO₂ concentration, as described in materials and methods. The sensitivity analysis was car-

ried out to examine the sensitivity of potential productivity of potato cultivars to change in temperature and CO₂ concentration, separately and together, for all the 29 locations under study, spread across Bihar. The WOFOST model derived results have revealed that an increase in CO₂ concentration to 415 ppm in 2020 from the baseline (2000) concentration of 367 ppm is likely to bring 4.1 to 4.8% increase in the productivity of potato cultivars with mean increase of 4.2, 4.5 and 4.4% in case of ‘Kufri Badshah’, ‘Kufri Jyoti’ and ‘Kufri Pukhraj’ respectively, averaged over the location (Table 1). On the other hand, the corresponding increase in temperature during the same period is expected to bring down the productivity by 4.7 to 11.6%, depending on cultivar and location. Although CO₂ fertilization seemed to negate the negative effects of temperature of potato growth, it could not fully compensate the damage caused by the enhanced temperature at any of the location in both the future climates. Overall, CO₂ fertilization is expected to bring down the decline in productivity caused by temperature, from 9.7 to 5.9, 9.9 to 5.8 and 10.5 to 6.5% for ‘Kufri Badshah’, ‘Kufri Jyoti’ and ‘Kufri Pukhraj’ respectively (Table 1). The decrease in productivity of potato was due to higher than the optimum temperature for potato growth and secondly due to reduc-

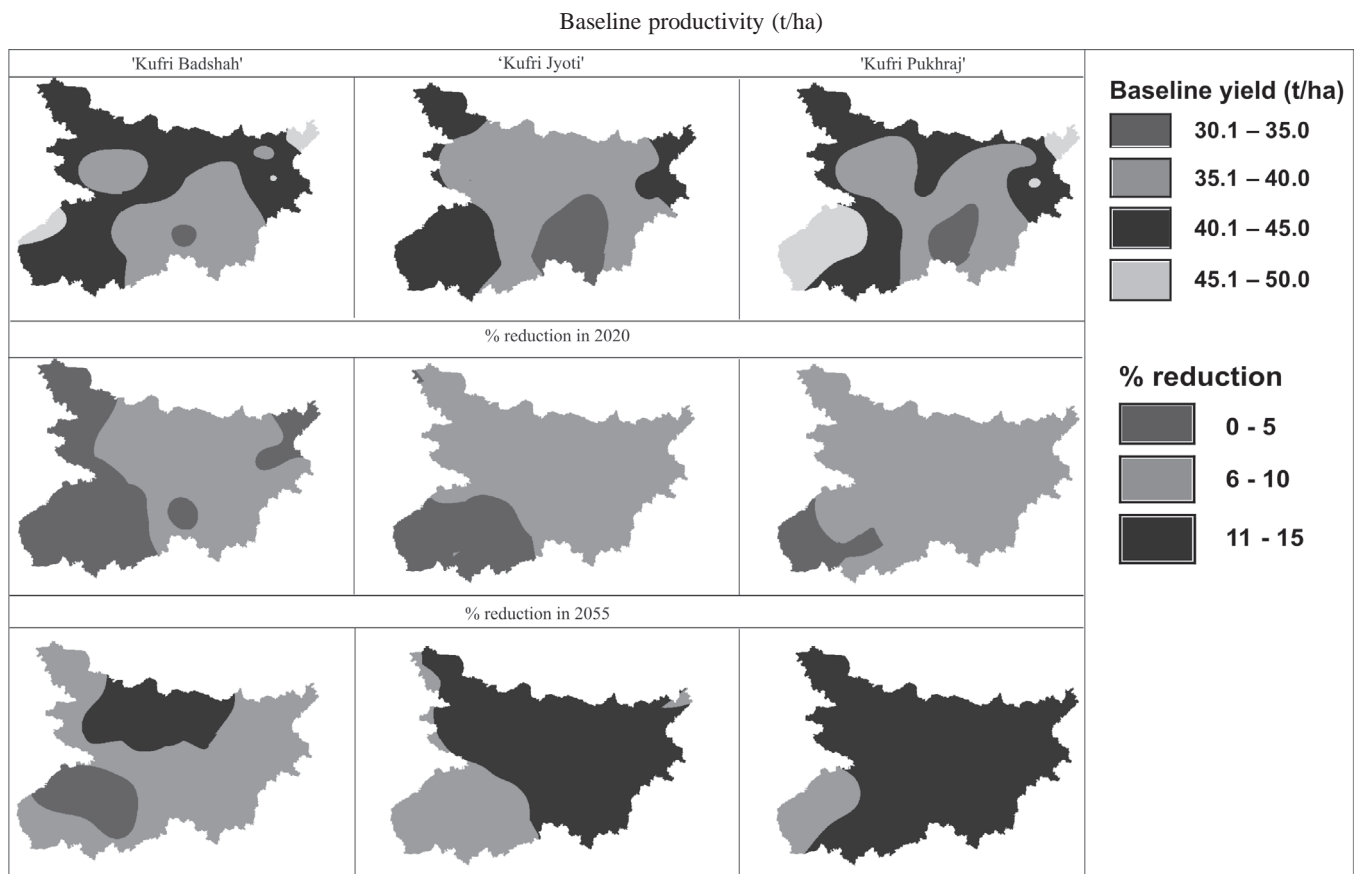


Fig. 1. Potential productivity of different potato cultivars under baseline and changes in future climatic scenario

tion in maturity period of the crop. For net photosynthesis, minimum (0–7°C), optimum (16–25°C) and maximum (40°C) temperatures have been reported (Kooman *et al.*, 1995). A scrutiny of temperature of some of the locations studied has shown that the baseline temperatures were in general slightly higher than the optimum range (Table 4). The reduction in maturity period is another reason for the low yield with increase in temperature. Due to increase in temperature, the thermal time for different growth stages and total thermal time from planting to maturity was achieved earlier, leading to forced early maturity of the potato cultivars. Since potato is a vegetative crop and tubers continue to bulk till maturity of the haulms, any reduction in maturity period leads to reduction in the period available for bulking of potato tubers which ultimately results in reduction in tubers yield. Averaged over different locations, ‘Kufri Badshah’ matured in 107 days, while ‘Kufri Jyoti’ and ‘Kufri Pukhraj’ matured in 97 and 92 days respectively. The increased temperature in 2020 caused 6–8 days earlier maturity while the cultivars matured 10–14 days earlier in 2055 compared to baseline year (2000).

In 2055, the expected CO₂ concentration of 590 ppm in A1FI scenario is likely to bring a substantial increase, ranging from 17.5 to 20.8%, in the potato productivity. The simulation results have shown that the increase in CO₂ concentration alone can bring about 17.7, 19.3 and 19.0% increase in mean productivity of ‘Kufri Badshah’,

‘Kufri Jyoti’ and ‘Kufri Pukhraj’. Wolf *et al.* (2003) also reported that CO₂ enrichment up to 550 ppm causes a strong increase in radiation-use efficiency and with increasing CO₂ assimilate allocation to tubers become stronger, leading to yield increase. However, the increase in temperature during the corresponding period is likely to decrease the productivity of these cultivars within a range of 14.7–44.5%. The fertilization effect of CO₂ in 2055 is likely to bring down the decrease in the productivity of potato cultivars caused due to prevailing high temperature by more than half. It is expected that the mean decline of 24.3, 27.2 and 29.1% in the productivity of ‘Kufri Badshah’, ‘Kufri Jyoti’ and ‘Kufri Pukhraj’, respectively, due to temperature alone could be reduced to 10.0, 11.1 and 13.1% due to beneficial effect of CO₂ fertilization in 2055.

Adaptation strategies for climate change

The productivity of all the cultivars at the respective sites was the highest in baseline year (2000) and declined in future climate (Fig. 2). Baseline productivity of ‘Kufri Badshah’ was the highest on 21 October planting of all the representative sites, while that of ‘Kufri Jyoti’ and ‘Kufri Pukhraj’ was the highest when planted on 1 November. Potato tubers continue to bulk till the haulms remain green, i.e. till the physiological maturity of crop. In the north–western plains, the climate tends to be warmer towards the end of the potato crop growth season. ‘Kufri

Table 2. Geographical area of Bihar (%) under different yield classes in 2000

Potential productivity (t/ha)	‘Kufri Badshah’	‘Kufri Jyoti’	‘Kufri Pukhraj’
30–35	1.2	12.1	5.7
35.1–40	37.6	55.7	40.3
40.1–45	57.6	31.9	39.8
45.1–50	3.6	0.3	14.2

Table 3. Productivity of potato cultivars in baseline year and changes thereof in future climates (interpolated results for total geographical area of Bihar)

	‘Kufri Badshah’	‘Kufri Jyoti’	‘Kufri Pukhraj’
Baseline yield (t/ha)	40.7	38.7	40.8
Overall reduction in yield (%)			
2020	5.1	6.2	6.9
2055	8.7	10.8	12.7
Yield reduction classes (%) in 2020	% geographical area of Bihar		
0–5%	46.3	23.4	9.6
6–10%	53.7	76.6	90.4
11–15%	0.0	0.0	0.0
Yield reduction (%) classes in 2055			
0–5%	13.5	0.0	0.0
6–10%	65.5	29.8	11.0
11–15%	21.0	70.2	89.0

Badshah' is a long-duration cultivar and in the baseline year, it matured in 107 days, while 'Kufri Jyoti' and 'Kufri Pukhraj' matured in 97 and 92 days, respectively, i.e. 10 and 15 days earlier than 'Kufri Badshah'. Thus, the 'Kufri Badshah' planted on 21 October and 'Kufri Jyoti' and 'Kufri Pukhraj' planted on 1 November matured almost at the same time and the tuber bulking phase of all the 3 cultivars faced the similar climatic conditions. since this

period was most favourable for crop growth, the highest yield was simulated for 21 October planted 'Kufri Badshah' and 1 November planted 'Kufri Jyoti' and 'Kufri Pukhraj' (Table 5).

Model results for Nalanda and Aurangabad have shown that in the south-west part of Bihar, 10 days earlier potato planting from normal will off-set the climatic effect on potato productivity to great extent. While the mean pro-

Table 4. Fortnightly mean minimum and maximum temperatures (°C) of some locations under study in Bihar during baseline scenario (2000)

Month	Fort-night	Aurangabad		Araria		Banka		Nalanda		Saran	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
October	I	22.6	32.3	23.5	32.0	23.8	32.4	22.6	31.8	24.1	32.2
	II	19.2	31.1	20.9	31.5	21.2	31.8	19.7	30.9	21.3	31.2
November	I	15.8	29.8	17.5	30.0	18.1	30.2	16.6	29.7	18.2	29.6
	II	12.9	28.0	14.5	28.6	14.8	28.6	13.8	28.0	14.8	27.6
December	I	10.2	25.4	11.6	26.5	11.7	25.9	11.1	25.6	12.3	25.1
	II	8.9	24.0	10.3	24.8	10.4	24.4	9.9	24.2	10.9	23.3
January	I	8.4	23.0	9.6	23.1	9.7	23.5	9.7	23.4	10.5	22.1
	II	9.1	23.6	10.4	23.6	10.3	24.0	10.3	24.0	10.5	22.6
February	I	10.5	25.3	11.0	24.8	12.0	25.6	11.5	25.3	11.6	24.6
	II	12.6	28.3	12.9	27.2	13.9	28.0	13.4	27.9	13.5	27.5
March	I	14.7	31.2	14.8	29.7	15.7	30.4	15.5	30.6	15.8	30.2
	II	17.8	35.0	17.4	32.8	18.3	33.4	18.3	33.9	18.6	34.0

Table 5. Potential productivity at normal date of planting in baseline year (2000) and change in date of planting in future climates

Location	2000		2020				2055			
	Normal DOP*	Productivity (t/ha)	Best DOP	Productivity (t/ha)	Change over baseline		Best DOP	Productivity (t/ha)	Change over baseline	
					Best DOP (days)	Productivity (%)			Best DOP (days)	Productivity (%)
'Kufri Badshah'										
Aurangabad	1 Nov.	42.3	21 Oct.	41.9	-10	-0.9	22 Oct.	39.5	-10	-6.6
Araria	1 Nov.	38.7	1 Nov.	36.5	0	-5.9	1 Nov.	34.9	0	-10.0
Banka	1 Nov.	38.8	1 Nov.	36.6	0	-5.6	1 Nov.	35.3	0	-9.0
Nalanda	1 Nov.	39.1	22 Oct.	37.7	-10	-3.6	22 Oct.	36.6	-10	-6.4
Saran	1 Nov.	37.6	1 Nov.	35.6	0	-5.3	1 Nov.	33.7	0	-10.5
Mean		39.3		37.7		-4.3		35.8		-8.5
'Kufri Jyoti'										
Aurangabad	1 Nov.	40.9	1 Nov.	38.8	0	-5.1	1 Nov.	37.1	0	-9.1
Araria	1 Nov.	36.0	1 Nov.	33.9	0	-6.0	1 Nov.	32.2	0	-10.7
Banka	1 Nov.	36.4	1 Nov.	34.2	0	-6.2	11 Nov.	32.6	+10	-6.2
Nalanda	1 Nov.	36.9	1 Nov.	34.8	0	-5.7	1 Nov.	33.3	0	-9.8
Saran	1 Nov.	35.0	11 Nov.	32.9	+10	-3.0	11 Nov.	31.4	+10	-10.3
Mean		37.0		34.9		-5.8		33.3		-9.2
'Kufri Pukhraj'										
Aurangabad	1 Nov.	43.3	1 Nov.	40.9	0	-5.5	1 Nov.	38.5	0	-11.1
Araria	1 Nov.	37.6	11 Nov.	35.3	+10	-6.1	11 Nov.	33.6	+10	-10.6
Banka	1 Nov.	38.0	11 Nov.	35.8	+10	-5.8	11 Nov.	34	+10	-10.5
Nalanda	1 Nov.	38.9	1 Nov.	36.9	0	-5.1	1 Nov.	34.2	0	-12.1
Saran	1 Nov.	35.9	11 Nov.	33.9	+10	-5.6	11 Nov.	32.3	+10	-10.0
Mean		38.7		36.3		-5.6		34.5		-10.9

*DOP, Date of planting

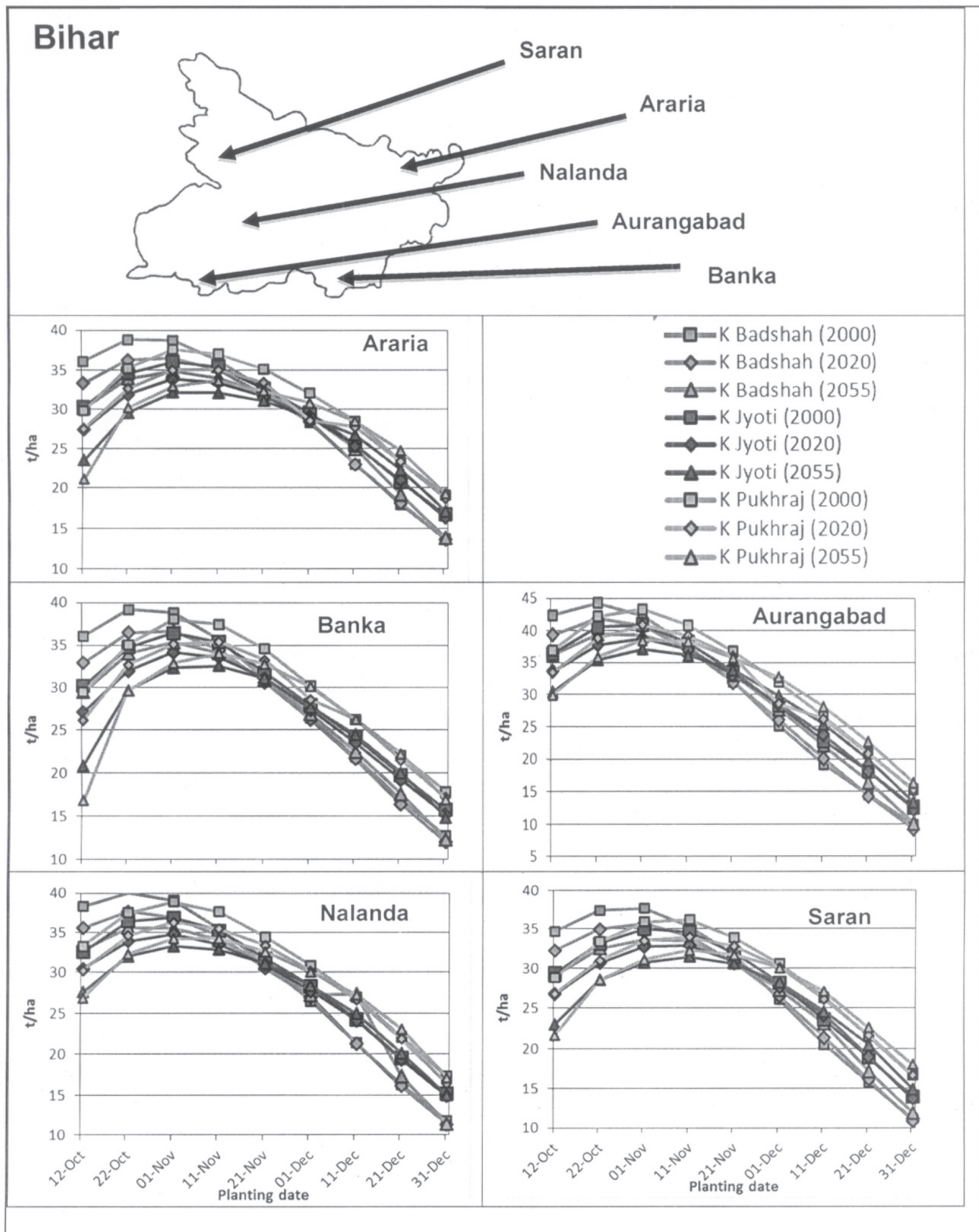


Fig. 2. Simulated productivity of different potato cultivars in different districts of Bihar as affected by date of planting under baseline and future climate scenario

Table 6. Potential productivity of potato cultivars at representative locations in Bihar under baseline (2000) and future climate scenarios

Location	Baseline (2000)				2020				2055						
	Normal DOP*	Productivity (t/ha) 'Kufri Badshah'	Productivity (t/ha) 'Kufri Jyoti'	Productivity (t/ha) 'Kufri Pukhraj'	Mean DOP	Highest yielding cultivar	DOP	Productivity (t/ha)	Change over baseline mean DOP (days)	Change over baseline mean Productivity (%)	Highest yielding cultivar	DOP	Productivity (t/ha)	Change over baseline mean DOP (days)	Change over baseline mean Productivity (%)
Aurangabad	1 Nov.	42.3	40.9	43.3	42.2	'Kufri Badshah'	22 Oct.	41.9	-11	-3.2	'Kufri Badshah'	22 Oct.	39.5	-10	-6.6
Araria	1 Nov.	38.7	36.0	37.6	37.4	'Kufri Badshah'	1 Nov.	36.5	0	-5.7	'Kufri Badshah'	1 Nov.	34.9	0	-9.8
Banka	1 Nov.	38.8	36.4	38.0	37.7	'Kufri Badshah'	1 Nov.	36.5	0	-5.9	'Kufri Badshah'	1 Nov.	35.3	0	-9.0
Nalanda	1 Nov.	39.1	36.9	38.9	38.3	'Kufri Badshah'	22 Oct.	37.7	-11	-3.6	'Kufri Badshah'	22 Oct.	35.6	-10	-9.0
Saran	1 Nov.	37.6	35.0	35.9	36.2	'Kufri Badshah'	1 Nov.	35.6	0	-5.3	'Kufri Badshah'	1 Nov.	33.7	0	-10.4
Mean		39.3	37.0	38.7				37.6		-4.7			35.8		-9.0

*DOP; Date of planting

ductivity under normal date of planting is expected to decline by 6.1 and 11.4% in 2020 and 2055 respectively (Table 6), a 10 days earlier planting might bring down these figures in south–west Bihar to 3.2 to 3.6% in 2020 and 6.6 to 9% in 2055. Although shifting of date of planting could not be suitable option in rest of Bihar, use of 'Kufri Badshah' in place of 'Kufri Jyoti' and 'Kufri Pukhraj' in these areas is a better option for farmers to compensate the yield losses in future climates.

Thus the mean potato productivity in Bihar is likely to decline by 5.1 to 6.9% in 2020 and by 8.7 to 12.7% in 2055 over the baseline (2000) yield, under A1FI emission scenario. Although changing date of planting can bring down the climate change impact to some extent, it is not enough to meet the threats of climate change unless we have improved potato cultivars with high nutrient and water-use efficiency which can mature in shorter duration and have tolerance to higher temperature. There is a need to develop potato cultivation with above traits to be supplemented with agronomic adaptation including altered cultural management, use of crop residue mulches and relocation and identification of new areas for potato cultivation as a strategy for meeting the challenge posed by the climate change.

REFERENCES

APEDA. 2012. APEDA online database on Indian Production of Potato available at (http://agriexchange.apeda.gov.in/india%20production/India_Productions.aspx?hscode=07019000.2012)

Bandyopadhyay, A., Bharda, A., Raghuvanshi, N.S. and Singh, R. 2008. Estimation of monthly solar radiation from measured air temperature extremes. *Agriculture and Forest Meteorology* **148**: 1,707–18.

Dua, V.K., Govindkrishnan, P.M. and Singh, B.P. 2014. Calibration of WOFOST model for potato in India. *Potato Journal* **41**(2): 105–12.

Ewing, E.E. 1997. Potato (In:) *The Physiology of Vegetable crops*, pp. 295–344. Wien H.C. (Ed.), CAB International, Wallingford, UK.

Fleisher, D.H., Timlin, D. J. and Reddy, V. R. 2006. Temperature influence on potato leaf and branch distribution and on canopy photosynthetic rate. *Agronomy Journal* **98**: 1,442–52.

Fuhrer, J. 2003. Agroecosystem responses to combinations of elevated CO₂, ozone, and global climate change. *Agriculture, Ecosystems and Environment* **97**: 1–20.

IPCC, Climate Change. 2001. *The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 881. Houghton J.T., Ding Y., Griggs D.J., Noguer M., van der Linden P.J., Dai X., Maskell K. and Johnson C.A. (Eds), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, Climate Change. 2007. *Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate*

- Change*, pp. 976. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (Eds). Cambridge University Press, Cambridge, UK.
- Katny, M.A.C., Hoffmann, G.T., Schrier, A.A., Fangmeier, A., Jager, H.J. and Bel van, A.E.J. 2005. Increase of photosynthesis and starch in potato under elevated CO₂ is dependent on leaf age. *Journal of Plant Physiology* **162**: 429–38.
- Khan, I.A., Deadman, M.L., Al Nabhani, H.S. and Al Habsim K, A. 2003. Interactions between temperature and yield components in exotic potato cultivars grown in Oman. *Acta Horticulturae* **619**: 353–59.
- Kooman, P.L. and Haverkort, A.J. 1995. Modelling development and growth of the potato crop influenced by temperature and daylength: Lintul-Potato. (In:) *Potato Ecology and Modelling of Crops under Conditions Limiting Growth*, Haverkort, A.J. and MacKerron, D.K.L. (Eds). Kluwer Academic Publishers, Dordrecht. pp. 41–60.
- Magliulo, V., Bindi, M. and Rana, G. 2003. Water use of irrigated potato (*Solanum tuberosum* L.) grown under free air carbon dioxide enrichment in central Italy. *Agriculture, Ecosystems and Environment* **97**: 65–80.
- Miglietta, F., Magliulo, V., Bindi, M., Cerio, L., Vaccari, F. P., Loduca, V. and Peressotti, A. 1998. Free air CO₂ enrichment of potato (*Solanum tuberosum* L.): Development, growth and yield. *Global Change Biology* **4**: 163–72.
- NHB Database. 2012. *Indian horticulture database-2012*, 152 pp. Tiwari, R.K., Mistry, N.C., Singh, Brajendra and Gandhi, C.P. (Eds), National Horticulture Board, Ministry of Agriculture, Government of India, Gurgaon, India.
- Olivo, N., Martinez, C.A. and Oliva, M.A. 2002. The photosynthetic response to elevated CO₂ in high altitude potato species (*Solanum curtilobum*). *Photosynthetica* **40**: 309–13.
- Peet, M.M. and Wolfe, D.W. 2000. Crop ecosystem responses to climate change: Vegetable Crops, (In:) *Climate Change and Global Crop Production*. Reddy, K.R. and Hodges, H.F. (Eds). CAB International, Wallingford, U.K. pp. 213–43.
- Samani, Z. 2000. Estimating solar radiation and evapotranspiration using minimum climatological data. *Journal of Irrigation and Drainage Engineering* **126**: 265–67.
- Schapendonk, A.H.C.M., Oijen van, N., Dijkstra, P., Pot, C.S., Jordi, W.J.R.M. and Stoopen, G.M. 2000. Effects of elevated CO₂ concentration on photosynthetic acclimation and productivity of 2 potato cultivars grown in open-top chambers. *Australian Journal of Plant Physiology* **27**: 1,119–30.
- Singh, J.P., Lal, S.S., Govindakrishnan, P.M., Dua, V.K. and Pandey, S.K. 2008. Impact of climate change on potato. (In:) *Impact Assessment of Climate Change for Research Priority Planning in Horticultural Crops*. Lal, S.S., Govindakrishnan, P.M., Dua, V.K., Singh J.P. and Pandey S.K. (Eds), Central Potato Research Institute, Shimla, H.P., India.
- Wolf, J. and Van Oijen, M. 2003. Model simulation and effects of changes in climate and atmospheric CO₂ and O₃ on tuber yield potential of potato (cv. Bintje) in the European Union. *Agriculture, Ecosystems and Environment* **94**: 141–57.
- Wolf, J., Mandryk, M., Kanellopoulos, A., van Oort, P., Schaap, B., Reidsma, P. and van Ittersum, M. 2010. Methodologies for analyzing future farming systems and climate change impacts in Flevoland as applied within the AgriAdapt project. *AgriAdapt Project Report no. 1*. Wageningen University, Groups Plant Production Systems & Centre for Crop Systems Analysis, The Netherlands. pp. 108.