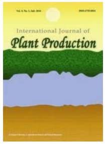


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# Assessment of impact of climate change on potato and potential adaptation gains in the Indo-Gangetic Plains of India


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## Abstract

India is the second largest producer of potato in the world. The Indo-Gangetic plains (IGP) is the main potato growing region accounting for almost 85% of the 1.8 Mha under the crop in India where it is grown as an irrigated crop during the winter season. Since IGP is in sub-tropical plains, duration of the thermally suitable window is the main determinant limiting yields. Hence the impact of climate change on potato in the IGP was assessed using MIROC HI.3.2 A1b and B1, PRECIS A1b, A2, B2 scenarios and estimated the potential adaptation gains. The potato crop duration in the IGP is projected to decrease due to climate change. The evapotranspiration (ET) is projected to increase while the water use efficiency (WUE) for potato yield is projected to decline in future climates as a consequence of low threshold temperatures for decline in WUE and yield than the ET. Results indicate that the upper threshold for ET decrease is ~23 °C while that for WUE is 15 °C. The optimal temperatures for tuber yield is ~17 °C and thus the reduction in WUE in future climates is discernable. Climate change is projected to reduce potato yields by ~2.5, ~6 and ~11% in the IGP region in 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099) time periods. Change in planting time is the single most important adaptation option which may lead to yield gains by ~6% in 2020 and its combination with improved variety or additional nitrogen may be required to adapt to climate change leading to positive gains by ~8% in 2020 and by ~5% even in 2050. However, in 2080 adoption of all the three adaptation strategies may be needed for positive gains. Intra-regional differences in the impact of climate change and adaptation gains are projected; positive impact in north-western IGP, gains in Central IGP with adaptation and yield loss in eastern IGP even with adaptation.

***Keywords:*** Indo-Gangetic plains; Potato; Climate change; InfoCrop; Crop modelling.

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***Abbreviations:*** IGP, Indo-Gangetic Plains; IPCC, Inter-Governmental Panel on Climate Change; NATCOM, National Communication to United Nations Framework Convention on Climate Change; DS, Developmental Stage; RUE, Radiation Use Efficiency; LAI, Leaf area index; SLA, Specific leaf area; NBSSLUP, National Bureau of Soil Science and Land Use; HWSD, Harmonized World Soil Database -v1; FAO, Food and Agricultural Organization; IIASA, International Institute for Applied Systems Analysis; ISRIC, World Soil Information; ISSCAS, Institute of Soil Science-Chinese Academy of Sciences; JRC, Joint Research Centre of the European Commission; NWIGP, Northwestern Indo-Gangetic Plains; MIROC HI.3.2, A Global Climate Model; PRECIS, Providing Regional Climate Scenarios for Impact Studies-A regional climate model.

## Introduction

Potato is an important crop ideally suited to meet the growing food demand associated with population growth in the poor and developing countries of the world especially in the tropics and particularly South Asia including India. Its capability to produce high value food in a short duration and amenability to fit into cropping systems makes it a preferred choice to be grown in a variety of environments. At global level, India ranks second in potato acreage (1.83 Mha) and production (37.3 Mt) during 2009-10 (DES, 2012). More than 85% of potato area is confined to Indo-Gangetic plains (IGP), where it is grown during autumn (October-February) in irrigated conditions and contributes more than 80% to the total potato production of the country (Pandey and Kang, 2003). The duration of thermally suitable window available for potato cultivation varies greatly within the IGP region. Accordingly, three zones *viz.* short-duration two-crop zone in the north-west, long-duration single crop zone in the central IGP and short-duration single crop zone in the eastern IGP have been delineated (Pushkarnath, 1976).

Global studies projected a 10-40% loss in crop production in India by 2080-2100 due to climate change unless farmers adapt to climate change (IPCC, 2007). Projections indicate the adverse impact of climate change on wheat with increase in 1 $^{o}$C temperature throughout the growing period under current land use (Aggarwal and Swarooparani, 2009). As in case of wheat which is grown during winter season in India, potato is also very sensitive to the seasonal weather conditions and its productivity may be greatly influenced in future climates. Though the projected increase in atmospheric levels of $CO_2$ may benefit the potato; a C3 crop, concurrent increase in temperatures may affect the growth and yield in future climates. High temperatures affect the sprout development, tuber initiation, partitioning of assimilates and yield (Levy and Veilleux, 2007) while frost affects the crop growth and at times it even curtails the crop duration. Recent estimates of potato production based on current relative contribution of different states to national production projected a decline in yield by ~2.61 and ~15.32% in 2020 and 2050, respectively due to climate change (NATCOM, 2012). However, detailed assessment of the impact of climate change on potato productivity and the adaptation opportunities in the different zones of the Indo-Gangetic plains is lacking. Hence the objectives of the present study are i) to assess the impact of climate change using the scenarios of MIROC HI 3.2 A1b and B1, PRECIS A1b, A2, B2 for 2020, 2050 and 2080 climates and ii) to evaluate the gain in yield due to different adaptation options including crop scheduling, improved varieties and higher dose of nitrogen in future climates.

## Materials and Methods

### *Data used in the study*

The details of input data on soil and weather have been reported earlier (Naresh Kumar et al., 2011) and the same was used in this study also. Briefly, the input data included i) weather data i.e. $1\times1^{o}$ gridded data for baseline period (1969-1990) from Indian Meteorological Department, Pune, India ii) soil data-texture, water holding characteristics, bulk density, soil pH and depths of three soil layers adopted from the soil database of National

Bureau of Soil Science and Land Used Planning (NBSSLUP), Nagpur, India and Harmonized World Soil Database-HWSD v1.1 (FAO, International Institute for Applied Systems Analysis-IIASA, World Soil Information-ISRIC, Institute of Soil Science-Chinese Academy of Sciences-ISSCAS, Joint Research Centre of the European Commission-JRC, 2009).

*Simulation analysis using InfoCrop-Model description*

The impact of climate change was assessed using InfoCrop simulation model. The InfoCrop version 2 can be downloaded from www. iari.res.in. InfoCrop is a generic crop growth model that can simulate the effects of weather, soil, agronomic managements (including planting dates, nitrogen, residue and irrigation) and major pests on crop growth and yield (Aggarwal et al., 2006). The InfoCrop-POTATO model has been described in detail elsewhere (Singh et al., 2005). The major plant growth processes that are simulated include phenology, leaf area development, dry matter production and partitioning, source-sink balance, nitrogen uptake and partitioning in plant parts and crop response to abiotic as well as biotic stresses. Briefly, it simulates the growth of potato in three development stages (DS) *viz.* from planting to emergence, emergence to tuber initiation and tuber initiation to maturity. Daily growth of the crop is calculated as a function of intercepted radiation and radiation use efficiency (RUE). In the InfoCrop-POTATO model a RUE value of 3.5 g $MJ^{-1}$ photosynthetically active radiation is used. RUE is modified on the account of developmental stage, crop-specific response of photosynthesis to temperature, $CO_2$, water and nitrogen availability and other biotic factors. The leaf area index (LAI) is estimated from specific leaf area (SLA), whose values vary depending upon age of the crop. The dry matter partitioning to the different plant organs is incorporated in the model as a function of development stage while the effect of nitrogen and drought stress on the root: shoot ratio is incorporated through empirical interpolation functions. The model provides for an unlimited tuber sink size, though the number and weight of individual tubers are not simulated. The details of simulation of effect of temperature, $CO_2$ and rainfall on crop growth and development in InfoCrop have been described earlier (Naresh Kumar et al., 2011). As far as influence of $CO_2$ is concerned, in InfoCrop-Potato model, concentration of $CO_2$ influences the rate of photosynthesis and transpiration thus influences the biomass production. The temperature influences the developmental rates, leaf area, radiation use efficiency and tuber initiation and growth. InfoCrop-POTATO uses 25 $^{o}$C as optimum temperature for developmental rate while 20 $^{o}$C is taken as the optimum for bulking. Similarly, water and nitrogen stress influence the developmental rates, leaf area, radiation use efficiency and dry matter partitioning. Apart from the plant processes, the model simulates the soil carbon and nitrogen balance in user defined three soil layers. For this the model simulates processes like mineralization, immobilization, denitrification, nitrification and volatilization. InfoCrop also simulates the emissions of carbon di oxide, nitrous oxide and methane from soils.

The InfoCrop model has been well calibrated and validated for wheat and rice (Aggarwal et al., 2006), maize (Byjesh et al., 2010), sorghum (Srivastava et al., 2010), mustard (Bhoomiraj et al., 2010), potato (Singh et al., 2005) and coconut (Naresh Kumar et al., 2008) crops for Indian region. The calibrated and validated model was used for simulating the yields during baseline period (1969-1990) and also for assessment of impacts of climate change and the potential adaptation gains. The coefficients for the dominant varieties grown in IGP were used from published literature (Singh et al., 2003). Simulations were carried out assuming that the farmers have successfully optimized planting time which ranged from the first week of October in north-western IGP to mid-October in Central IGP and last week of October/early November in eastern IGP. In order to mimic the situation in farmers' field conditions, the crop was provided with 180 kg N ha$^{-1}$ in the form of urea in two equal split doses each at the time of planting and at 35 days after planting. Irrigation was provided as and when soil available water decreased below 85% of soil water holding capacity. It was assumed that the crop was maintained free of pest and disease infestation.

### *Estimating yields in baseline and future climates with current management*

The mean yield of all 22 years (1969-1990) was taken as baseline yield. To coincide with the climate model baseline period (1960-1990), observed gridded data for 1969-1990 period was used. State wise baseline yields were obtained as sum of the weighted yields of each grid in a state. The crop duration, mean temperature of the crop duration, water use efficiency (WUE) and yield were the model outputs recorded in the baseline scenario. For simulating the yield in future climates, the outputs (maximum and minimum temperature and rainfall) of a global climate model (MIROC HI.3.2) -A1b, B1 for 2020, 2050 and 2080 scenarios; and a

regional climate model (PRECIS with HADCM3 as the global climate model) -A1b, A2 and B2 for 2020 and 2080 scenarios were used for analysis. Details of processing of climate data for input into the model have been described earlier (Naresh Kumar et al., 2011; Naresh Kumar et al., 2013). To obtain the 2020, 2050 and 2080 climates, the temperature rise and rainfall changes were added to the observed gridded data by using the following formula (Naresh Kumar et al., 2014).
For temperature,

$$T_S = T_{OB} + T_D \tag{1}$$

where $T_S$=Scenario temperature, $T_{OB}$ = IMD gridded daily temperature, $T_D$= Daily change in temperature. Monthly change in temperature ($T_{Ddmi}$) is linearly interpolated to get the $T_D$. $T_{Dmi}$ = Monthly temperature in scenario - Monthly temperature in modelled baseline.
For rainfall,

$$R_S = R_{OB} \times (1 + R_D) \tag{2}$$

where $R_S$ = Scenario rainfall, $R_{OB}$ = IMD gridded daily rainfall, $R_D$= Relative change in rainfall.

$$R_D = \frac{(R_{Smi} - R_{Bmi})}{R_{Bmi}} \tag{3}$$

where $R_{Smi}$ = Monthly rainfall in scenario, $R_{Bmi}$ -monthly rainfall in modelled baseline.

The projected $CO_2$ levels for respective scenarios-2020-410 (B1), 418 (A1b); 2050-482 (B1), 522 (A1b); 2080- 530 (B1), 552 (B2), 639 (A1b) and 682 (A2), derived by the Bern Carbon Cycle model (IPCC, 2001), were also input into the crop model for simulations. Differences in change in temperature or rainfall between emission scenarios become more prevalent towards the end of the century (IPCC, 2007). Hence we chose the take more emission scenarios in 2080 scenario. All other simulation conditions were similar to that of baseline simulations. Simulated state-wise yields under changed climates were calculated as in case of baseline yields. Changes in potato yield in future climates over the yields in baseline climate, were expressed as the percentage change from mean yields of 2000-07 period.

*Simulating adaptation gains in future climates*

The adaptation options such as change in planting time (1-2 weeks early and late planting relative to current optimal planting time), improved variety in terms of early, normal and late tuber initiation and application of 25% additional nitrogen were tested for their individual and combined effects on yield in future climates. 25% extra nitrogen was included to provide plant with adequate nitrogen and also to compensate increased volatilization loss at higher temperature in climate change scenario. The combination that gave highest yield in each grid was taken as the best suitable adaptation strategy. The change in yield from baseline yield is expressed as the per cent change from the mean yields of 2000-07. The net vulnerability in the respective scenario is obtained from the following formula.

$$V = I - A$$

Where, V is vulnerability (yield reduction from baseline, even after adaptation), I is impact (yield reduction due to climate change) and A is adaptation gain Regions that are projected to lose yields in spite of adaptation are classified as the vulnerable regions for potato cultivation. In case of positive impact of climate change, adaptation gains indicated additional benefits. Regression analysis of the shift in date of planting in different regions under different climate change scenarios were also carried out.

## Results

*Seasonal mean temperature and crop performance*

The mean temperature of the potato crop season ranged from ~11 $^{o}$C to ~25 $^{o}$C in the IGP (Figure 1a). The figure shows that the crop duration decreased linearly from ~110 days to ~60 days as the mean temperature increased from ~11 $^{o}$C to ~25 $^{o}$C. The rate of decrease of crop duration worked out to be 2.76 days per degree rise in mean seasonal temperature. On the contrary, the seasonal evapotranspiration (ET) increased with rise in seasonal mean temperature during the crop growth season (Figure 1b). The ET increased significantly till seasonal mean temperature of ~17 $^{o}$C and thereafter it did not differ much. However, at high mean seasonal temperature i.e. beyond 23 $^{o}$C, ET decreased slightly. The WUE, expressed as tuber yield per unit of irrigation applied, decreased with increase in mean seasonal temperature beyond 15 °C (Figure 1c), but the rate of decrease was less (2.1 $kg.mm^{-1}$ per degree rise in mean temperature). However, the yield trend was entirely different. Tuber yield was high between ~15 °C to ~20 °C with a peak at ~17 °C, while it reduced linearly beyond this seasonal mean temperature range (Figure 1d).

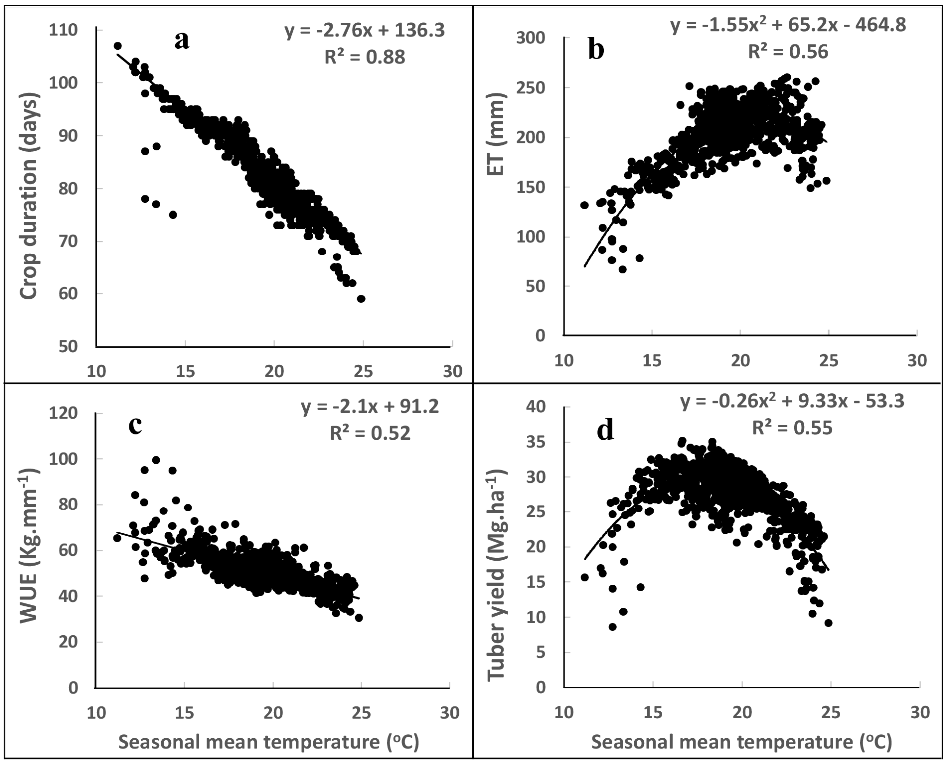


Figure 1. Potato crop duration (a), evapotranspiration (b), water use efficiency-yield per unit of irrigation applied (c) and tuber yield (d) in relation to mean seasonal mean temperatures during the crop growth season in the Indo-Gangetic plains (IGP) of India.

*Impact of climate change on potato in the Indo-Gangetic plains*

Climate change is projected to decrease the potato yields by ~2.5, ~6 and ~11% in 2020, 2050 and 2080, respectively in the Indo-Gangetic plains as a whole, though the magnitude of impacts are projected to vary with the emission scenario (Figure 2). The results also show that there would be regional differences in the impact of climate change in the Indo-Gangetic plains of India. Potato yields in the north-western Indo-Gangetic plains (NWIGP) are projected to gain by ~4.5% and by ~1.5% in 2020 and 2050 respectively due to climate change. However, this region is projected to lose yields by ~10% in 2080. In the central Indo-Gangetic plains (central IGP), climate change is projected to suffer yield reductions by ~4%, ~6% and ~15% in 2020, 2050 and 2080 climate scenarios respectively while in the eastern IGP, the projected yield reductions are likely to be ~6%, ~8% and ~17% in 2020, 2050 and 2080 climate scenarios respectively. The figure also shows that the degree of uncertainty among different scenarios (A1b, A2, B1 and B2 scenarios of MIROC HI3.2 and PRECIS) progressively increased from 2020 onwards till 2080 in NWIGP and Central IGP.

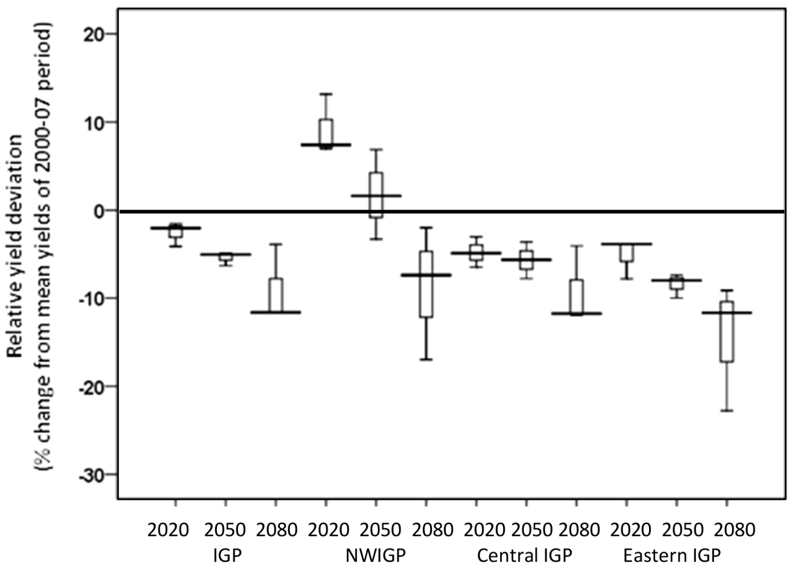


Figure 2. Range of Impact of climate change on potato yields in different regions of Indo-Gangetic plains (IGP) of India. Box-whisker plots indicate the extent uncertainty among different scenarios (A1b, A2, B1 and B2 scenarios of MIROC HI3.2 and PRECIS) for 2020 (1), 2050 (2) and 2080 (3) periods in different regions of India. NWIGP- north-western IGP consists of Punjab and Haryana, Central IGP consists of Uttar Pradesh and Eastern IGP consists of Bihar and West Bengal.

*Adaptation gains in future climate*

As regards adaptation strategies, change in planting time is projected to be the single most important adaptation strategy which can improve yield in 2020 scenario (~6%) while in 2050 and 2080, the change in planting time alone may not prevent a decline in yield (Figure 3).

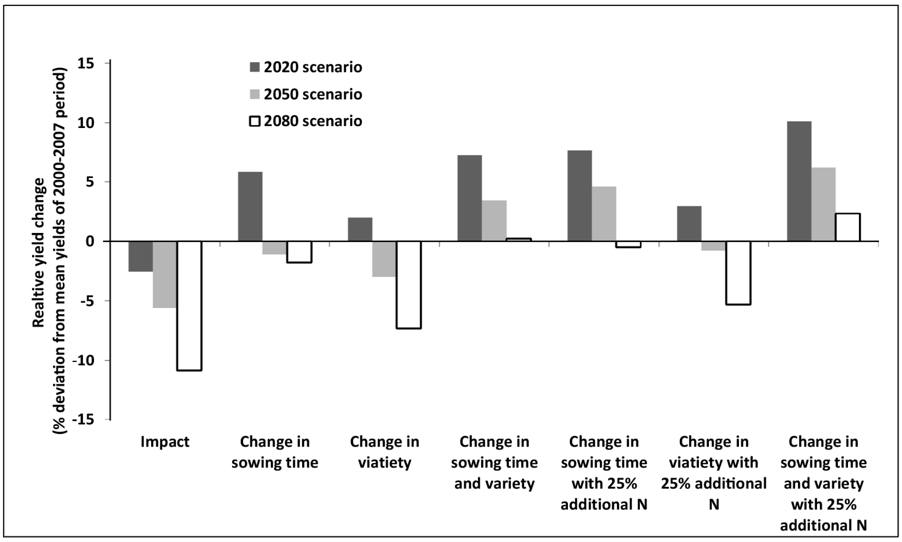


Figure 3. Overall impact and net adaptation gains of potato yields in India in 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099) climate scenarios. Each bar is a mean of data from simulations for different climate scenarios for respective time period and generated from the mean results for 22 years of baseline period (1969-1990) and respective scenario time. The relative deviations are worked out for each grid and up scaled to national level. The net adaptation gain below zero indicates the net vulnerability.

Combination of shift in date of planting with improved variety is projected to increase the yields by ~5% till 2050 but may be barely able to offset the climate change impacts in 2080 (Figure 3). Similar adaptation gains are projected with the combination of change in planting time and application of 25% additional N. The combination of change in planting time and application of 25% additional N is projected to provide slightly higher benefits in 2020 and 2050 than that of the combination of change of planting time and variety.

The shift in date of planting is projected to be least in 2020 and greater in 2050 and 2080 climates. In all the three climate change scenarios viz. 2020, 2050 and 2080, optimal planting time is projected to be delayed by about two weeks in the regions that plant potato in the first week of October (Figure 4) while regions that plant potato during mid-October in current climate may need to shift planting time to end-October in future climates. However, regions that plant potato during the first week of November may need to shift planting time by more than two weeks.

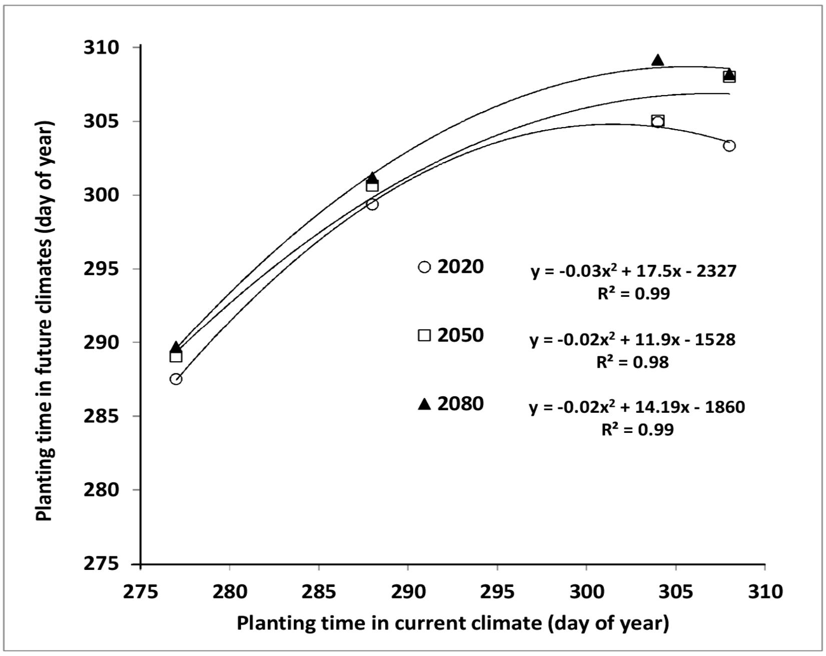


Figure 4. Change in optimum planting time in future climates in Indo-Gangetic plains.

*Vulnerability of potato in the Indo-Gangetic plains to climate change*

States in the IGP could be categorised into three basic categories viz. non-vulnerable states even without adaptation, vulnerable states but become non-vulnerable with adaptation and vulnerable states even with adaptation (Table 1 and Figure 5). The study indicates that in 2020 all regions are vulnerable to climate change except Haryana but they are projected to become non-vulnerable with adaptation. Thus in 2020 climate scenario, potato farming in the IGP region may not be vulnerable to climate change if the farmers' adapt their cultivation practices. In the 2050 scenario, the two eastern states viz. Bihar and West Bengal and the eastern parts of Uttar Pradesh are projected to become vulnerable to climate change while in the 2080 scenario the vulnerable regions extend west-wards and may as well include Jharkhand and a larger part of Uttar Pradesh. Thus adaptation measures comprising change in planting time and improved variety is expected to increase the area having positive impact of climate change in 2020 scenario while in combination with additional nitrogen, the relative yield would be positive in the entire NWIGP (Figure 5). The adaptation measures are likely to result in positive impact in most parts of the NWIGP, the extent of increase being higher when all the three adaptation measures are adopted. In the central IGP the adaptation measures would lead to positive gains in yield in both 2050 and 2080 scenarios while in the north-eastern IGP the net gains in yield is projected to be negative even with adaptation.

Table 1. States falling in different category of climate change impacts with and with-out adaptation.

| Description | Climate period | | |
|---|---|---|---|
| | 2020 | 2050 | 2080 |
| Non-vulnerable states even without adaptation | Haryana | - | - |
| Vulnerable states but become non-vulnerable with adaptation | Punjab<br>Uttar Pradesh<br>Bihar<br>Jharkhand<br>West Bengal | Haryana<br>Punjab<br>Parts of Uttar Pradesh<br>Jharkhand | Haryana<br>Punjab<br>Parts of Uttar Pradesh |
| Vulnerable states even with adaptation | - | Bihar<br>West Bengal<br>Parts of Uttar Pradesh | Bihar<br>Jharkhand<br>West Bengal<br>Parts of Uttar Pradesh |

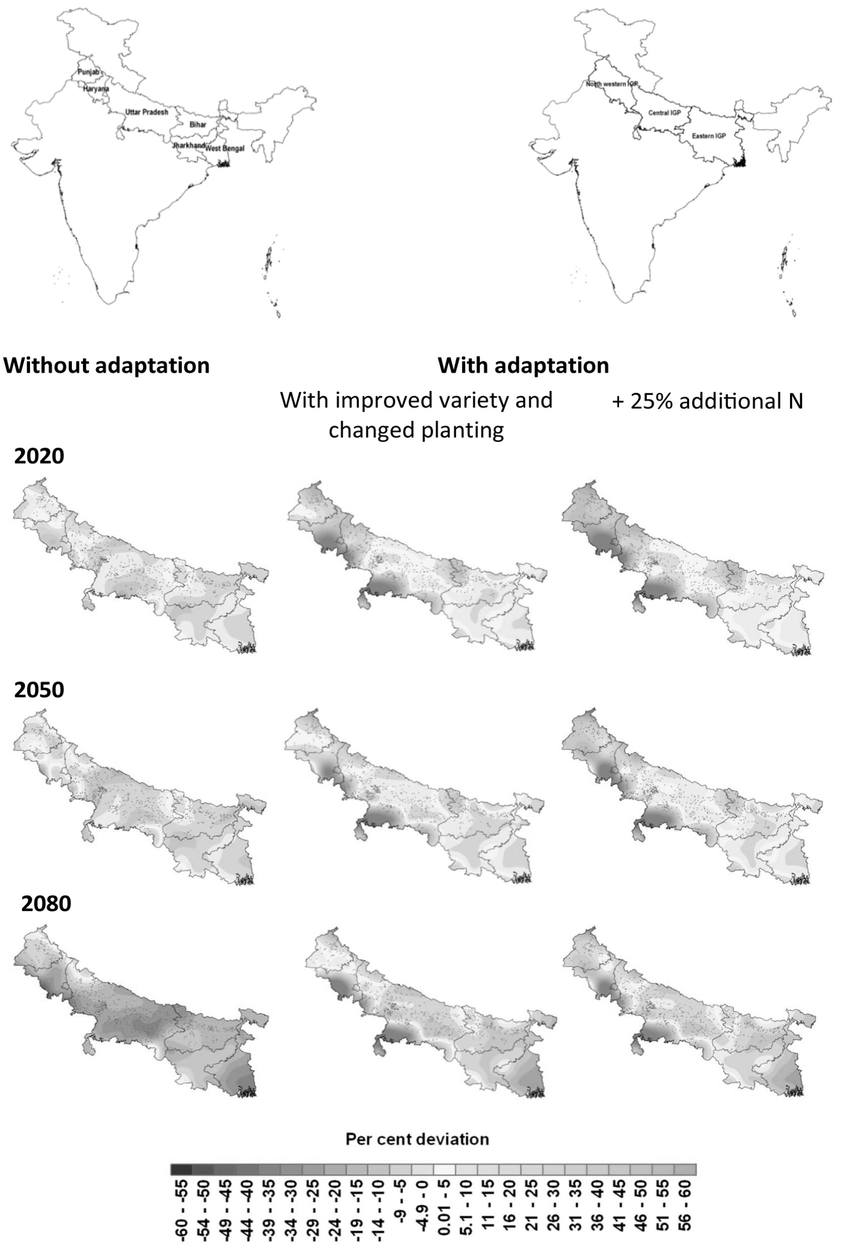


Figure 5. Climate change impacts on potato yields, adaptation gains and vulnerability of IGP for potato yield in future climates. Each dot represents the 5,000 ha potato area.

## Discussion

Plant development can be described as a function of effective temperature sum and a rise in temperature has been reported to reduce the duration of various crop development stages and thus the total crop duration (Carter et al., 1990; Ellis et al., 1990). In this study also, the crop duration decreased. However the decrease was linear as mean temperature increased from ~11°C to ~25°C. As regards the effect of rise in temperature on yield it has been reported to vary at different locations. The yields are projected to increase in England and Wales (Davies et al., 1997), Scotland (Peiris et al., 1996) and Finland (Carter et al., 1996), due to longer growing season under climate change scenario. On the other hand, Rosenzweig et al. (1996) projected an overall decrease in tuber yield in USA. These variations could be because of the differences in mean seasonal temperatures across the locations. Studies suggest that if shortening of the growing season is not fully compensated by a change in ontogenetic development and higher growth vigour at higher temperature a net yield loss may occur (Ellis et al., 1990; Struik and Ewing, 1992). Thus the response to rise in temperature would depend upon the temperatures prevailing during the crop season under the baseline scenario. The crop in the IGP is grown under short day conditions and is having a temperature optimum of ~17 °C for high yield (Figure 1a). This is reported as the optimum temperature for potato under short day conditions (Kooman and Haverkort, 1995). Thus, further increase in temperature due to climate change reduces the crop duration and hence, yield declines in central and eastern IGP where mean seasonal temperature exceeds the optimum.

The WUE is reported to either increase or decrease due to climate change. WUE of potato in different agro-ecosystems in South Africa was projected to increase (Haverkort et al., 2013), while a decline in WUE was projected for semi-arid areas of China (Xiao et al., 2013). This study shows that in the subtropical plains of India where potato is grown in the autumn season under irrigation, increase in ET as well as decrease in WUE are important implications of climate change. The ET at field level is projected to increase due to rise in temperature. However, it will not increase linearly since crop duration decreases with increase in temperature. Apart from this, the transpiration also reduces at high temperatures due to stomatal closure. The threshold temperatures for decrease in WUE and ET differ. In this case, upper threshold for ET decrease is ~23 $^{o}C$ while that for WUE is 15 $^{o}C$. The optimal temperatures for tuber yield is found to be ~17$^{o}C$ thus the reduction in WUE in future climates is discernable. Though increase in $CO_2$ will improve WUE at leaf level (Mi et al., 2012), but WUE for yield at field level is projected to decrease with rise in temperature. Increase in temperatures beyond threshold will reduce the biomass production even as ET increases and therefore the WUE is reduced. The ET at field level is reported to be significantly influenced by the temperature and precipitation (Gholipoor, 2007) while the WUE for yield at field level is influenced by confounding factors such as $CO_2$, temperature and management (Mi et al., 2012).

Hijmans (2003) studied the impact of climate change at the global level and reported that potato yields would decrease in major potato producing countries of the world but adaptation would mitigate climate change induced loss to a large extent. According to him the potato yields in India are expected to decrease by 30% and more importantly adaptation of potato to climate change in India would be difficult due to the short growing period. This is a matter of concern and requires comprehensive investigation. Study of the impact of climate change at different locations in different parts of India, showed that even within the country the impact of climate change is expected to vary and that at locations in Central and Eastern India the impact on yields would be negative due to mean seasonal temperatures increasing beyond the optimum. On the other hand, in the north western parts of the country, yield gains are expected as temperatures move towards optimum from current low temperatures (Singh et al., 2008). The present grid based micro level analysis confirms these findings. Further, it also shows that even in the subtropical plains of India shift in planting time as an adaptation strategy is not only feasible but also the most important adaptation strategy among the three adaptation strategies studied. In the NWIGP yield benefit is expected due to climate change to a large extent under 2020 scenario (Figure 4) and to some extent up to 2050 scenario even without adaptation while the eastern Indo-Gangetic plains have been found to be vulnerable to climate change even after adoption of the adaptation strategies. These differences are due to the prevailing temperatures during the crop season under baseline scenario as discussed earlier.

Apart from temperature, increase in $CO_2$ levels is another significant factor that influences crop growth in changing climate. Rise in atmospheric $CO_2$ is reported to increase photosynthesis in C3 plant species such as potato, which has a large indeterminate sink capacity (Stitt, 1991; Wolf et al., 1998). However, Goudriaan and de Ruiter (1983) reported a slight reduction in yield of potato grown at elevated (740 μ mol. mol$^{-1}$) compared to ambient $CO_2$ particularly when nutrients limited growth potential. Thus, to harvest the increased yield potential due to higher $CO_2$ levels under climate change scenarios, a higher N application is required. The present study shows that additional nitrogen in combination with shift in date of planting can lead to yield gains in future climate (Figure 3). Change in variety alone does not seem to be an effective adaptation strategy in future climate. It however becomes important, since only the combination of all the three adaptation options *viz* change in planting time, improved variety and 25% additional nitrogen is projected to improve yield by ~10% in 2020, ~7% in 2050 and by ~3% in 2080. Thus, with the above adaptation strategies potato yield up to 2080 could be sustained in the IGP region in spite of climate change. Mueller et al. (2012) reported nutrient and water management as important options for closing the yield gaps and these would become all the more important under climate change scenario. Water and nutrient stress have been reported to affect the quality and yield of potato (Cantore et al., 2014; Khan et al., 2014). The present study suggests that it would be possible to sustain yields in the IGP region under climate change scenario with better management including of water and nutrients since it would counter the projected decline in WUE and perhaps reduce the requirement of additional nitrogen.

## Conclusion

The potato crop duration in the Indo-Gangetic plains is projected to decrease due to climate change. The evapotranspiration is projected to increase while the WUE and yield are projected to decline in future climates as a consequence of low threshold temperatures for decline in WUE and yield than the ET. Within the IGP, the north-western IGP is projected to have yield gains even without adaptation while in the central IGP, adaptation would lead to positive yield gains. However, in the eastern IGP plains positive yield gains are not projected even when all the three adaptation strategies *viz* change in planting time, improved variety and 25% additional nitrogen are adopted. Among different management strategies, change in planting time is projected to significantly contribute towards adaptation of potato cultivation to climate change in the Indo-Gangetic plains of India followed by 25% additional N and improved variety in decreasing order. Adoption of all the three adaptation options is likely to sustain yields under future climates.

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