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Effect of projected climate scenarios on the yields of potato crop and agronomic adaptation options as evaluated by crop growth model

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सार – आलू दुनिया में सबसे महत्वपूर्ण गैर-अनाज फसल और भारत में सर्दी के मौसम की सबसे प्रमुख फसल है। आलू की फसल की वृद्धि और उपज उच्च तापमान और नमी की कमी के प्रति बहुत संवेदनशील होती है। इसलिए, भूमंडलीय उष्णन और जलवायु परिवर्तनशीलता के कारण तापमान में अनुमानित वृद्धि का आलू उत्पादन पर प्रतिकूल प्रभाव पड़ेगा। इसे ध्यान में रखते हुए, आलू उत्पादन पर जलवायु परिवर्तन के प्रभाव का आकलन करने और फसल वृद्धि सिमुलेशन मॉडल (सीजीएसएम) के माध्यम से कृषि अनुकूलन विकल्पों का मूल्यांकन करने के उद्देश्य से एक शोध कार्य किया गया है । एक सीजीएसएम, अर्थात् इन्फ्रोक्रॉप के अंशांकन और सत्यापन के लिए न्यूनतम डेटासेट तैयार करने हेतु क्षेत्र प्रयोग किए गए। सत्यापन के बाद, मॉडल का उपयोग राज्य के विभिन्न कृषि जलवायविक क्षेत्रों के अंतर्गत स्थित दस चयनित स्टेशनों पर भविष्य में कंद उपज का पूर्वानुमान करने के लिए किया गया। 2050 के भावी परिदृश्य में, मध्य नवंबर में बोई गई फसल के लिए सिम्यूलेटेड उपज औसत उपज के वर्तमान स्तर से लगभग 11% कम होने की संभावना है। यदि फसल दिसंबर में बोई जाती है, तो उपज में कमी का प्रतिशत लगभग 25% हो सकता है। उच्च अक्षांश के स्टेशनों के लिए अनुमानित उपज में कमी नगण्य पाई जाती है। जलवायु परिवर्तन के प्रतिकूल प्रभावों का मुकाबला करने के लिए अनुकूलन रणनीतियों के रूप में तीन संभावित कृषि अनुकूलन विकल्प जैसे:रोपण की तारीख का समायोजन, बीज दर में वृद्धि और बीज कंदों की अलग-अलग लंबाई के अंकुर को अनुकूलन रणनीतियों के रूप में आजमाया गया है। यह निष्कर्ष निकाला गया है कि मध्य नवंबर में रोपण और बीज अंकुर की अधिक लंबाई सबसे अच्छा अनुकूलन विकल्प रहेगा। हालांकि, बीज की बढ़ी हुई दर एक व्यवहार्य अनुकूलन विकल्प नहीं है।

ABSTRACT. Potato is the most important non-cereal crop in the world and the most prominent winter season crop in India. Growth and yield of potato crop is very much sensitive to higher temperatures and the moisture stress. Hence, the anticipated increase of temperature due to global warming and climatic variability will have anadverse impact on potato production. Keeping this in view, a research work was carried out with the objectives to assess the impact of climate change on potato production and evaluating agronomic adaptation options through a crop growth simulation model (CGSM). Field experiments were carried out to prepare the minimum dataset for calibration and validation of one CGSM, namely InfoCrop. After validation, the model was used to predict the future tuber yield of ten selected stations situated under different agroclimatic regions of the State. In the future scenario 2050, the simulated yield for mid November planted crop likely to be about 11% less than the present level of mean yield. If the crop is planted in December, the percentage of yield reduction may be around 25%.The projected yield reduction, for the stations of higher latitude, is found to be negligible. Three possible agronomic adaptation options, *viz*., adjustment of date of planting, increase of seed rate and varying sprout length of seed tubers, have been tried as adaptation strategies to combat the adverse effects of climate change. It is concluded that the mid-November planting and longer sprout length will be the best adaptation option. However, the enhanced seed rate is not a viable adaptation option.

Key words – Climate change, Adaptation options, Crop growth model, InfoCrop, Potato.

1. Introduction

Change in climatic situation due to global warming is expected to have complex effects on crop growth and yield. In most of the Asian countries, agriculture will be seriously affected by the adverse effect of climate change (IPCC 2007; IPCC 2013). The anticipated increase of temperature due to global warming and climatic variability are the major concern of crop scientists of Asia.The annual mean temperature of Indian sub-continent has already shown significant warming trend of 0.51 °C per 100 year during the period 1901-2007 (Kothawale *et al*., 2010). In this region, the irregular rainfall pattern causes a great impact on annual food-grain production (Sivakumar *et al*., 2000; Revadekar and Preethi, 2011). Potato is not only the third most important food crop in the world after rice and wheat (CIP, 2014), but also the most important winter season crop in India. There has been a significant increase in potato production and consumption in Asia since early 1990s (FAOSTAT, 2012). In 2005, the potato production of developing world exceeded for the first time than that of the developed world. Almost one-third of the world potatoes are harvested in China and India at present. Within India, West Bengal State stands second highest position in potato production and the State has the highest potato productivity since beginning of the current century (Anonymous, 2003). Growth of potato crop is sensitive to higher temperature and the moisture stress on the plant would affect both the quality and yield of tubers (Kiziloglu *et al*., 2006). The current distribution of the crop and modeling climate datasets showed that potato cultivation will be deleteriously affected in many present cultivation areas, mainly due to heat stress (Schafleitner *et al*., 2011; Raymundo *et al*., 2018). Hence, predicting the yield of potato under changed climatic scenario is a great challenge for the scientific community.

Dynamic Crop Growth Simulation Models (CGSMs) are used to assess the impact of climate change and climatic variability on crop production successfully for many years (Jones *et al*., 1998; Hoogenboom *et al*., 1999; Muller and Pierre, 2019). At present, the simulation techniques are also used extensively to evaluate the adaptation options along with the impacts of climate change on agriculture (Banerjee, 2008; Confalonieri *et al*., 2009; Banerjee *et al*., 2016). In the developing countries like India, simple and economically viable agronomic adaptations need to be highlighted. For example, the transplanting date of seedlings has a great impact on rice yield (Jain *et al*., 1980) and this simple fact can be utilized for future adaptations (Jalota *et al*., 2009). The CGSMs are capable to consider the variation of such crop management factors along with weather factors. For biological activities, the assessment of impacts and adaptation potential are more difficult and need precise, region-specific technical assistance (Shivkumar, 2000). There is an immense variety of potential and actual adaptation options available, which may include technological development like development of crops, weather and climate information systems, management of resources, etc. (Smit and Skinner, 2002). Crop suitability changes on regional basis due to climate change should also be evaluated (Lee *et al*., 2020). The equity and efficiency should be taken care of when allocating resources for climate change adaptation (Chen *et al*., 2016). The adaptation options should be economical, easy to acceptable and environment friendly. Moreover, the growers, industry and government need to be updated with probable changes in the crop yields and production pattern to take decisions (Vogel and Bange, 1999; Hammill *et al*., 2008). Considering this background, a research work was carried out with the objectives to assess the impact of climate change on potato production and evaluating agronomic adaptation options.

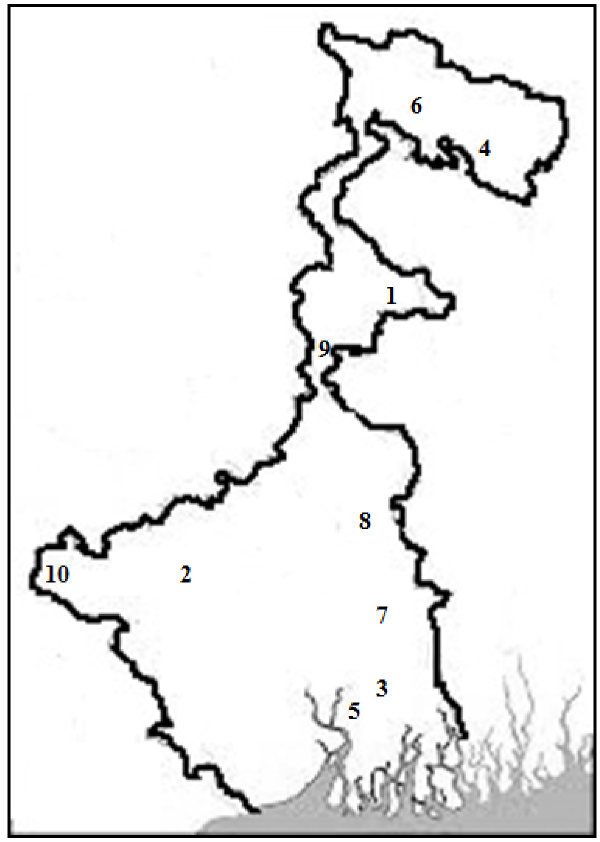

Fig. 1. Map of West Bengal State showing study locations (1 : Balurghat, 2 : Bankura, 3 : Canning, 4 : Coochbehar, 5 : Diamond Harbour, 6 : Jalpaiguri, 7 : Kalyani, 8 : Krishnanagar, 9 : Maldah, 10 : Purulia)

2. Materials and method

2.1. *Study area*

Field experiments were carried out in the Research Farm of Bidhan Chandra Krishi Viswavidyalaya (BCKV, State Agricultural University), Kalyani (22.57° N, 88.20° E and 7.8 m above mean sea level), West Bengal for calibration and validation of InfoCrop model. The

TABLE 1

Geographical co-ordinates and basic features of selected study locations

Location	Location ID as in Fig. 1	Latitude	Longitude	Agro-ecological Zones	Soil type
Balurghat	1	25° 13' N	88° 45' E	Old Alluvial	Loamy
Bankura	2	23° 14' N	87° 03' E	Red Lateritic	Sandy loam
Canning	3	22° 18' N	88° 39' E	Coastal	Fine loamy
Coochbihar	4	26° 19' N	89° 26' E	Terai	Sandy to Sandy loam
Diamond Harbour	5	22° 12' N	88° 12' E	Coastal	Fine loamy
Jalpaiguri	6	26° 31' N	88° 44' E	Terai	Sandy loam to loamy sand
Kalyani	7	22° 57' N	88° 20' E	New Alluvial	Silty clay
Krishnanagar	8	23° 24' N	88° 30' E	New Alluvial	Silty clay
Maldah	9	25° 00' N	88° 08' E	Old Alluvial	Clay loam
Purulia	10	23° 20' N	86° 21' E	Red Lateritic	Sandy to Sandy loam

experimental field was situated in the New Alluvial Agro-climatic Zone of Eastern India. Ten stations (including Kalyani) covering five agro-climatic zones of West Bengal were selected for the climate change impact study, (Fig. 1). The characteristic features and geographical co-ordinates of the selected stations are also listed in Table 1.

2.2. *Crop growth model description*

Info-Crop model, specially designed for Indian sub-continent (Aggarwal *et al*., 2006), was used to simulate the impact of climate change on the growth and yield attributes of potato. The model is written in FORTRAN Simulation Translator programming language, which is recommended by International Consortium for Agricultural Systems Applications (ICASA) as standard language for systems simulation (Jones *et al*., 2001). The InfoCrop model needs weather data, crop phenological data and soil data for simulating crop growth. The above said minimum data set along with actual experimental data and various crop management data like seed rate, fertilizer dose, irrigation level, etc., are required to run and validate any virtual experiment on InfoCrop.

2.3. *Database generated for Info-Crop calibration and validation*

Field experiment was carried out at Kalyani Station taking the most popular cultivar of potato, namely *Kufri Jyoti*. The crop was grown with different dates of sowing for consecutive five years (2009-2013) to generate actual crop data for model calibration and validation. Data on plant parameters (crop height, leaf area index and biomass), phenological observation (period from planting to stolonisation, tuberisation, bulking and maturity) and yield were recorded from the experiment field. Data sets from first two years (2009 and 2010) were considered for model calibration and the remaining data sets (for the years 2011, 2012 and 2013) were used for model validation. The required weather data was collected from Kalyani Meteorological observatory, situated very near to the crop field. Soil data was collected from Annual Progress Report of Forecasting Agricultural Output using Space, Agrometeorology and Land base observation (FASAL) Project (FASAL, 2013). The calibration was done by simple iteration method (*i.e*., trial and error method) and genetic coefficients were slightly modified. After calibration, the simulated yields for the year 2011 to 2013 were compared with actual yield to validate the model.

2.4. *Statistical parameters used for model validation*

The common meteorological parameters, namely, bias, coefficient of determination (R^2), Root Mean Square Error (RMSE), Standard Error (SE), etc., were used to evaluate the performance of the model (Fox 1981). The R^2 value measures the linearity between actual and simulated values, whereas the RMSE describes the mean absolute deviation between simulated and actual data. The accuracy of simulation is characterized by lower RMSE and lower SE. The following standard statistical parameters (Gordon and Shykewich, 2000) were used in the present study:

(*i*) Coefficient of determination (R^2),

(*ii*) Standard error (SE),

TABLE 2

Adjusted genetic coefficients of *Kufri Joyti* cultivar used in InfoCrop model

Parameters	Coefficients
Phenology parameters:	
Thermal time for sowing to germination	300 °C-days
Thermal time for germination to 50% tuber initiation	430 °C-days
Thermal time for 50% tuber initiation to physiological maturity	800 °C-days
Sensitivity to photoperiod (scale 0.5 to1.5)	1
Growth parameters:	
Relative growth rate of leaf area	0.004 °C day^{-1}
Specific leaf area	0.0027 dm^2 mg^{-1}
Extinction coefficient of leaves at tuber initiation	0.6 ha soil per ha leaf fraction
Radiation use efficiency	2.2 g MJ^{-1} day^{-1}
Root growth rate	25 mm day^{-1}
Index of greenness of leaves (Scale 0.8 to 1.2)	1.0
Index of N fixation (Scale 0.7 to 1.0)	1.0
***Source* : sink Balance parameters:**	
Slope of storage organ number per m2 to dry matter during storage organ formation stage (storage organ kg -1 day-1)	1×10^7
Potential storage organ weight (mg per storage organ)	2×10^5
Nitrogen content of storage organ (fraction)	0.015
Sensitivity of storage organ setting to low and high temperature (scale of 0 to 1.5)	1.0

(*iii*) Bias,

(*iv*) Mean absolute error (MAE),

(*v*) Mean square error (MSE) and

(*vi*) Root mean square error (RMSE).

2.5 *Assessing impact of climate change and adaptation method*

Output of regional climate model was used to find the impact of projected climatic scenario. The downscaling model PRECIS output generated from Hadley Centre Coupled Model (HadCM3Q) with 25 km resolution for the year 2050 was used as the input weather file for the InfoCrop model. The projected weather parameters, *viz*., maximum temperature (°C), minimum temperature (°C), precipitation (mm) and solar radiation (Wm^{-2}) were used in the Info-Crop model as per model requirement. Projected weather data of ten selected stations were taken from the nearest grid points. The regional forecasting model indicated a significant linear increasing trend for both maximum temperature (0.2 to 0.6 °C per decade) and minimum temperature (0.2 to 0.5 °C per decade) up to 2050, considering 1981 to 2010 data as baseline. An increasing trend of rainfall was also predicted, whereas no increasing or decreasing trend of solar radiation was projected. The aforesaid climate change scenario was generated through an Asia-Pacific Network Project on Global Changes (Luck *et al*., 2012). The percent yield reduction of potato in respect of present days average yield were worked out for various stations for the year 2050. The simple agronomic adaptation options were evaluated through InfoCrop model, which can be used under the future climatic scenario.

3. Results and discussion

3.1. *Calibration and Validation of the model*

To calibrate and validate the Info-Crop model, the actual field data of potato was collected from AICRP on Agro-Meteorology. The calibration was done by simple iteration (trial and error) method. The phenological parameters and growth parameters of genetic coefficients of the Info-Crop model were modified so that the model can predict the yield with minimum error (Table 2). The

TABLE 3

Measured and simulated yield of potato and statistical analysis

Dates of planting	Observed yield	Simulated yield
13 Nov 11	30.0	29.7
20 Nov 11	28.1	29.1
04 Nov 11	29.2	29.3
06 Nov 12	27.2	27.0
13 Nov 12	26.4	26.8
20 Nov 12	26.0	26.5
11 Nov 13	36.5	32.8
20 Nov 13	27.7	28.4
29 Nov 13	22.3	24.3
Mean	28.15	28.21
Statistical output		
R^2	0.98	
SE	0.93	
Bias	0.56	
MAE	0.99	
MSE	2.19	
RMSE	1.48	

'*source* : sink balance' parameters needed slightest modification.

The observed data was compared with the simulated yield generated through Info-Crop potato model (Table 3). The average observed yield (28.15 tha^{-1}) is very close to average simulated yield (28.21 tha^{-1}). The high R^2 value (0.98) also reveals very close linearity between observed and simulated values. The RMSE value is only about 5% of the average yield and the SE of predicted potato yield is considerably low (0.93). Both the RMSE and SE values indicate that InfoCrop model can predict the potato tuber yield of the study area in a reliable manner; hence the InfoCrop model has been used further to study the climate change impact on tuber yield.

3.2. *Projected yield under climatic scenario of 2050*

The projected weather data of consecutive five years (2048 to 2052) were used as input weather data of Info-Crop model to obtain the potato tuber yield under changed climatic situation. In the present research paper, the average of five years yield data is considered as projected yield in 2050. Table 4 presented the projected yield of various stations under study considering four different dates of planting. It is observed that if potato is planted during first fortnight of November, the average projected yield will be more than delayed planted situation. The average yield as simulated for 13 November planted crop is 24.92 tha^{-1}. This simulated yield is 3.23 tha^{-1} (*i.e.*, more than 11%) less than the observed mean yield as shown is Table 3. If the crop is planted in December, the percentage of yield reduction will be about 25%. Climate change largely affects the phenological development of the crop plants.A rise in temperature has been reported to reduce the duration of crop growth stages and thereby the total crop duration (Carter *et al*., 1996; Racca *et al*., 2015). The rate of decrease of crop duration of potato as worked out by Kumar *et al*. (2015) was reported to be 2.76 days per degree rise in mean seasonal temperature. As in 2050, the mean temperature increase will be around 2 °C, crop duration will be shortened by around 5 days. The shortening of crop duration is the main determining factor for such yield reduction. Moreover, higher temperature causes higher respiration leading to decrease in radiation use efficiency (RUE). Kooman and Haverkort (1995) pointed out that the RUE of potato was drastically reduced beyond 34 °C temperature. Naresh Kumar *et al*. (2015) also observed about 10% yield reduction for the year 2050 for Eastern Indo-Gangetic Plain. Although Hijmans (2003) predicted about 25% yield reduction in West Bengal and adjoining Bangladeshduring 2040-69. In the present study, about 20% yield reduction has been predicted for few stations, namely, Bankura, Purulia and Krisnanagar (Fig. 2).

TABLE 4

Projected yield (in t ha^{-1}) in 2050 as influenced by date of planting

Stations	Dates of planting			
	6th Nov	13th Nov	20th Nov	4th Dec
Balurghat	24.84	24.94	23.75	20.89
Bankura	20.38	22.10	22.14	17.89
Canning	24.40	24.56	21.03	20.50
Coochbehar	28.64	29.00	28.66	23.51
Diamond Harbour	23.32	23.54	20.56	20.27
Jalpaiguri	29.53	29.75	29.00	24.85
Kalyani	23.74	23.37	19.95	19.25
Krishnanagar	23.86	22.93	21.29	20.19
Maldah	25.74	25.64	24.43	23.12
Puruliya	23.00	23.33	21.14	19.15
Average	24.74	24.92	23.19	20.96

The probable yield reduction under Coochbehar and Jalpaiguri stations would be negligible (1.74% and 4.39% respectively). This may be due to their position at higher

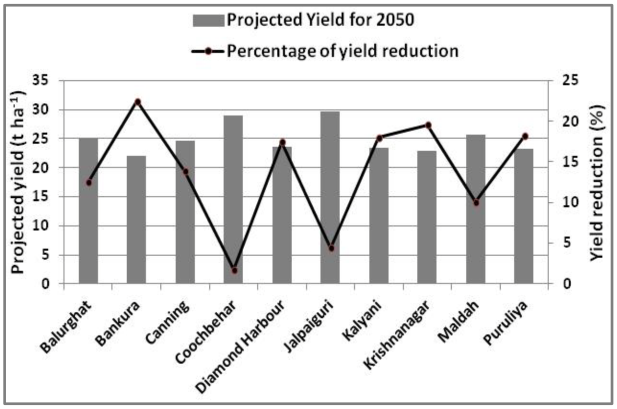

Fig. 2. Projected yield and percentage of yield reduction of potato at different study locations

latitude compare to other stations. On the other hand, Bankura station shows highest yield reduction as it is situated in arid lateritic zone of West Bengal having soil with very low water holding capacity. On an average, 13.80% yield reduction may be observed for the year 2050, which is very close to the finding of Kumar *et al*. (2015).

3.3. *Evaluation of adaptation options through crop growth model*

Three possible agronomic adaptation options have been tried as adaptation strategies to combat the adverse effects of climate change on potato production. These include adjustment of date of planting, increase of seed rate and varying sprout length of seed tubers. Modern potato breeding pools with their relatively narrow genetic base contain only limited variation in drought and heat stress tolerance (Schafleitner *et al*., 2011), hence agronomic adaptation options should be given priority. However, appropriate breeding strategies with the help of wild potato species will be useful to combat extreme weather events.

It is observed that when potato is planted within first fortnight of November under changed climatic scenario (here, in the climatic conditions of 2050), the yield level will be about 4000 kg ha^{-1} more than December planting crop (Table 4). Hence in future, the farmers of the study region should plant the crop within 15th November. Wang *et al*. (2015) also emphasized the adjustment of sowing date and growing period of potato for better harvest under global warming situation. The November planted crop exposed to less night-temperature during tubarization stage compared to late planted crops. Hence, the photorespiration rate is reduced in November planted crop.

TABLE 5

Projected yield (in t ha^{-1})* of 2050 governed by different seed rate

Stations	Seed rate		
	1800 kg ha^{-1}	2000 kg ha^{-1}	2200 kg ha^{-1}
Balurghat	24.70	24.94	25.14
Bankura	21.91	22.10	22.26
Canning	24.47	24.56	24.64
Coochbehar	28.82	29.00	29.14
Diamond Harbour	23.46	23.54	23.63
Jalpaiguri	29.63	29.75	29.86
Kalyani	23.30	23.37	23.44
Krishnanagar	22.83	22.93	23.02
Maldah	25.52	25.64	25.77
Puruliya	23.22	23.33	23.41
Average	24.79	24.92	25.03

* The yield is calculated considering the date of planting is 13th November

TABLE 6

Effect of sprout length on projected yield (in t ha^{-1})* of 2050

Stations	Sprout length	
	5 mm	15 mm
Balurghat	24.94	25.20
Bankura	22.10	21.31
Canning	24.56	24.45
Coochbehar	29.00	28.55
Diamond Harbour	23.54	23.84
Jalpaiguri	29.75	29.93
Kalyani	23.37	24.27
Krishnanagar	22.93	23.64
Maldah	25.64	26.22
Purulia	23.33	23.50
Average	24.92	25.09

* The yield is calculated considering the date of planting is 13th November and 2000 kg ha^{-1} seed rate

In eastern India the seed rate of potato generally varies from 1800 to 2000 kg ha^{-1}. In the simulation process, three different seed rates have been tried ranging from 1800 to 2200 kg ha^{-1} (Table 5). The increment in yield due to higher seed rate is negligible and this option is not an economical and efficient adaptation strategy under climate change scenario. On an average for each 200 kg ha^{-1} increment of seed rate, the yield increment will be only 120 kg ha^{-1}. However if the sprout length of seed potato at the time of planting is increased from 5 mm to 15 mm, about 200 kg ha^{-1} yield increment will be observed (Table 6). In general, the farmers of Eastern India used to keep 5mm sprout length at the time of planting. This adjustment does not involve any additional cost but farmers will get some yield benefit out of this.

4. Conclusions

The study concludes that the projected climatic scenario will adversely affect the yield of potato crop grown in Eastern India. The yield decrease will be more in dry lateritic zone and will be negligible in the Terai region (higher latitudes). On an average, the potato production likely to be reduced by 11% in the year 2050 as compared to present situation. The following simple adaptation options should be taken up by the farming community of the state to cope up the negative impact of climate change:

(*i*) The crop should be planted within first fortnight of November.

(*ii*) The sprout length of seed potato at the time of planting should be kept 15 mm instead of 5 mm which is usual practice at present.

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