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Study on maize production under changed climatic scenarios in western Himalaya of India

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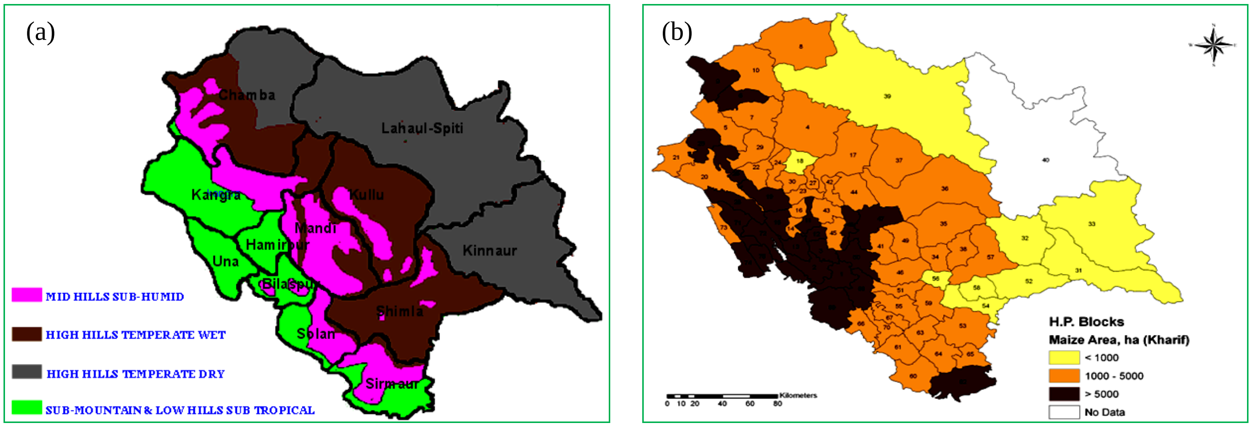
सार – मक्का भारत की अनाज की प्रमुख फसल है और विकासशील देशों में इसके विविध उपयोग के कारण वर्ष 2050 तक इसकी माँग दुगुनी हो जाएगी। हिमाचल प्रदेश में मक्का का उत्पादन महत्वपूर्ण माना जाता है क्योंकि इसमें स्टार्च की मात्रा अधिक होती है। जलवायु परिवर्तन से फसल की ऋतुजैविकी और फसल उत्पादन पर प्रभाव पड़ता है। इस शोध पत्र में फसल मॉडल्स का उपयोग करते हुए मक्का की फसल पर पड़ने वाले प्रभाव की जाँच की गई है। अखिल भारतीय समन्वित अनुसंधान परियोजना (मक्का) द्वारा पालमपुर (हिमाचल प्रदेश) में किए परीक्षणों से तैयार किए गए ऐतिहासिक आँकड़ों के आधार पर इस इन्फ्रो क्रौप मॉडल को वैधीकृत किया गया है। इस मॉडल को 20 एवं 17 वर्षों के लिए क्रमश: 1990 से 2010 तक पालमपुर के लिए और 1993 से 2010 तक धौलाकुँआ मौसम स्टेशन के लिए चलाया गया है। इनसे प्राप्त हुए परिणामों से पता चला है कि उप-आर्द्र तथा उप-शीतोष्ण कृषि जलवायविक जोन (पालमपुर) में बढ़े हुए कार्बन डाइऑक्साइड (CO_2) के प्रभाव की मात्रा वर्षा प्रधान क्षेत्रों से अधिक है। इस क्षेत्र में पैदावार में 3.0 से अधिक वृद्धि हुई और कुल वृद्धि 5.4 प्रतिशत की हुई जब 10 जून के आस पास के समय में फसल की बुआई की गई। हालांकि अधिकतम और न्यूनतम दोनों तापमानों में क्रमश: 1° एवं 2° से. की वृद्धि हुई है और वर्षा में 10 प्रतिशत की कमी होने से पैदावार में कमी हुई है। उपजाऊ और वर्षा प्रधान क्षेत्रों में 10 जून को फसल की बुआई करने पर अनुरूप पैदावार अत्यधिक हुई जबकि उप-उष्णकटिबंधीय निचली पहाड़ी क्षेत्र (धौलाकुँआ) में वर्षा काल में मक्का फसल लगाने का सर्वोतम समय 10 जून था और बढ़ा हुआ तापमान 1 एवं 2° सेल्सियस था। 1 से 10 जून के दौरान फसल की बुआई करने के बजाय 20 जून के बाद फसल की बुआई करने पर मक्का की पैदावार में 2.48 एवं 3.66 क्विंटल/हेक्टेअर अधिक पैदावार हुई। इस प्रकार से वर्षा काल और पोटेंशियल (Potential) काल में होने वाली पैदावार के प्रतिशत में 31 से 34 प्रतिशत का अंतर होता है। कृषि जलवायविक स्थितियों के दोनों ही परिस्थितियों में सामान्य बुआई की तिथि में 10 दिन के विलंब से 1 एवं 2° से. तापमान वृद्धि का प्रभाव कम हो जाता है।

ABSTRACT. Maize is an important cereal crop of India and its demand will be double by 2050 due to its multifarious use in the developing countries. Maize production in Himachal Pradesh assumes importance due to its more starch content. Climate change affects both the crop phenology and crop production. The study examined the impact of climate change on maize using crop models. The InfoCrop model was validated using the historical data generated by the All India Coordinated Research Project (Maize) trials at Palampur (Himachal Pradesh). The model was run for 20 and 17 years from 1990 to 2010 for Palampur and from 1993 to 2010 for Dhaulakuan weather station, respectively. Results showed that under sub humid and sub temperate agro climatic zone (Palampur), the magnitude of impact of elevated CO_2 was more under rainfed conditions. The yield increase of more than 3.0 and 5.4% resulted in 10^{th} June sown crop under potential condition. While, 1 and 2 °C increase both in maximum and minimum temperature and 10% reduction in rainfall decreased the yield. The highest simulated yields under potential and rainfed conditions were obtained on 10^{th} June sown crop. Whereas, under sub tropical low hill zone (Dhaulakuan) under rainfed conditions, the best simulated planting window for maize was 20^{th} June under elevated temperature of 1 and 2 °C. The sowing done after 20^{th} June showed 2.48 and 3.66 q/ha higher yield of maize compared to 1-10^{th} June sowing window. Further, the gap in yield obtained under rainfed and potential conditions ranged between 31 to 34 per cent. Ten days delay in normal sowing date in both agro-climatic conditions reduced the impact of 1 and 2 °C elevated temperature.

Key words – Assessment and adaptation, Climate change, Maize, Simulation.

1. Introduction

Maize (*Zea mays* L.) is predicted to become the crop with the greatest production globally by 2025 and its demand will double by 2050 in the developing world (Murdia *et al*., 2016). Maize has the highest genetic potential, production and productivity among the cereal crops and having multifarious uses in food, feed and industrial segment causing the increasing demand for maize production in the country. Maize is one of the most



Figs. 1(a & b). (a) Agro-ecological zones of Himachal Pradesh and (b) Cultivated area under maize crop in Himachal Pradesh

versatile emerging crop having wider adaptability under varied agro-climatic conditions and contributing nearly 9% in the national food basket. The present growth rate in maize production (8.94%) is much more than its consumption of around 5%. India has great potential to export grain, feed, seed and specialty corn due to low cost of production and less freight charges. Maize is considered a promising option for diversifying agriculture in various agro climatic zones and ranks as the third most important food crop in India. Maize is predicted to be one of India's food crop hardest-hit by climate change (Bhatta, 2012). In mountain state of Himachal Pradesh, evidences of global warming are clearly demonstrated by receding rainfall and increasing temperature (Rana *et al.*, 2012). The rainfall trends during the annual monsoon and post monsoon seasons have shown decreasing trends for the duration of 1991-2010. Whereas, the summer rains have shown increasing trends (Rathore *et al.*, 2013). In the changed climatic scenarios, optimum sowing time is one of the adaptation measures to cope with climatic variability. Shift in sowing dates have a great bearing on phasic development and dry matter partitioning of crop as variation in climate and growing degree days modifies varietal performance. Crop production is variable, posing risks and uncertainties to the agricultural community. Assessing the possible impact of climate change on production risks is therefore necessary to help decision makers and stakeholders identify and implement suitable measures of adaptation (Torriani *et al.*, 2007). The paper presents the effect of projected climate change (Carbon dioxide (CO_2), temperature and rainfall) on performance of maize under two agro-climatic zone representing, sub tropical climatic conditions and sub temperate and sub humid climatic conditions of Himachal Pradesh using InfoCrop, a crop simulation model developed by Aggarwal *et al*. (2006a) considering the coefficients worked out under Indian conditions.

2. Data and methodology

2.1. *Site description*

For the study, two sites located in two agro-climatic zones were selected, *i.e.*, Mid Hills Sub-humid Zone II at Palampur and Sub-Mountain and Low Hills sub-tropical Zone I at Dhaulakuan [Fig. 1(a)].

2.1.1. *Mid hills sub-humid Zone-I (Study site-Palampur region)*

The climatic region falls in sub-humid and sub-temperate type of climate and is located at longitude 72°30' E and 32°20' N latitude with an elevation of 1290 meter above sea level. Long term monthly averages of rainfall and temperatures for Palampur (1973-2013) indicated a mean annual rainfall of 2400 mm, out of which 77% is received during SW-monsoon (June - September), 5% in North East monsoon season (October- December), 8% in winter season (January-February) and 10% in summer season (March-May). Average temperature is highest during May (31 °C) and lowest during February (4.9 °C). During *kharif* season average temperature remains 26 °C throughout the season. The monthly average temperature change at Palampur showed increasing trend in general throughout the year and lowest change of 0.008 °C observed in June. The maximum temperature change per year was recorded to the tune of 0.068 and 0.056 °C in the month of March and December respectively (Rana *et al*., 2012).

2.1.2. *Sub-mountain and low hills sub-tropical Zone-II (Study site-Dhaulakuan region)*

Dhaulakuan is located in district Sirmour of Himachal Pradesh. The area is located at 30°50' N latitude and 77°25′ E longitudes. The elevation of this site is less than 700 meter asl. Cereal and vegetable cropping are the dominant systems of this region. The regions have low to mid-hill in the southern aspect. The climate of the region is sub-tropical type and maximum temperature remains above 30 °C during April to October and more than 19.5 °C in the remaining months. Monthly average minimum temperature varies between 4.3 to 9.4 °C from November to March and 13.6 °C to 24.2 °C in remaining months of the year. Annual average rainfall 1635 mm, SW-monsoon is the dominant rainfall receiving season, however, winter rains are also received in the region due to western disturbances. The climate is represented by the sub-tropical and tropical conditions. The maize crop is widely grown in agro-climatic zone I and II of Himachal Pradesh [Fig. 1(b)]. The InfoCrop growth model validated at Palampur region was used for Dhaulakuan conditions.

2.2. *Model description*

InfoCrop considers the processes such as crop growth and development (phenology, photosynthesis, partitioning, leaf area growth, storage organ numbers, source-sink balance, transpiration, uptake, allocation and redistribution of nitrogen), effects of water, nitrogen, temperature, flooding and frost stresses on crop growth and development, crop-pest interactions (damage mechanisms of insects and diseases), soil water balance, soil nitrogen balance, soil organic carbon dynamics, emissions of green house gases and climate change module. The basic model is written in Fortran Simulation Translator programming language (Jones *et al*., 2001). More details of the model are provided by Aggarwal *et al*. (2006 a & b). InfoCrop has been successfully adapted, calibrated and validated for maize.

2.3. *Model input requirements*

The input data files required for running the InfoCrop growth model are crop/variety master, soil texture master and weather data files.

Crop/variety file: Used to enter the crop variety details and its parameters. These parameters the so called genotypic coefficients, characterize the basic physiological behaviour of a variety.

Weather file: Daily radiation or bright sunshine hours, daily maximum and minimum temperature, rainfall are essential parameters, where as wind speed and vapor pressure are the optional parameters required to run the model. In addition to this latitude, longitude and altitude of the area is also required to calculate the solar radiation receipt on the earth surface in the model.

Soil texture file: For three soil layers depth (mm) the parameters like organic carbon (%), soil texture (sand, silt and clay %), bulk density, hydraulic saturated conductivity and NH_4-N and NO_3-N content are needed.

Plant: Seed rate, specific leaf area of variety, grain weight.

Crop management: Date of sowing, dates of irrigation and fertilizer application.

Output and verifiable variables: The standard output comprises dry weight of roots, stem, leaves, grain number and grain yield, leaf area index, N uptake by crop, soil water & N content, evapotranspiration, N and water stress.

2.4. *Calibration and validation of model*

For calibration and validation of the model for days to maturity and grain yield of maize, the observed data were procured from All India Coordinated Maize Research Improvement Project at Palampur for two dates of sowings, *i.e*., 10^{th} and 20^{th} June for the period of five years (2004-2008). Crop coefficients for maize were calculated by using information from a wide literature survey. These coefficients were used in the subsequent validation & application. To evaluate model performance and accuracy in prediction, statistical indicator of root mean square error (RMSE) was computed from observed and simulated variables (days to maturity and grain yield of maize). An excellent parity between observed and simulated phenological events in varied weather condition reflects the consistency in model performance.

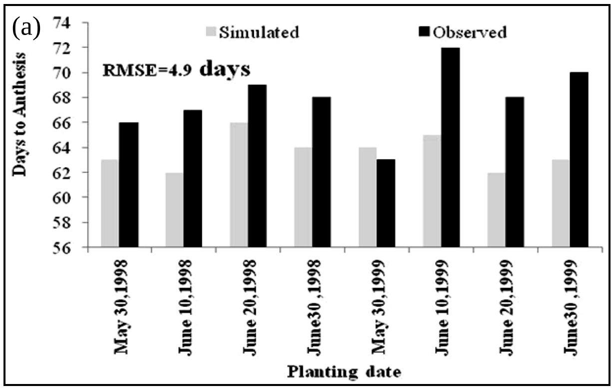
2.5. *Impact assessment of climate change*

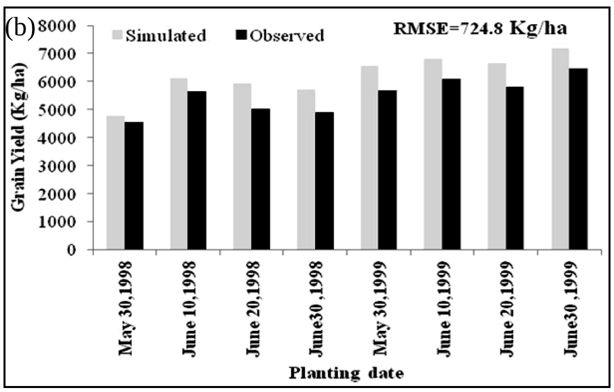
The agro-climatic zone-I and zone II under study regions experience sub-humid sub-temperate climate with mean rainfall of 1700 mm and remains warm and humid during *kharif* season. Seasonal climate scenarios of 1 °C and 2 °C rise in maximum and minimum temperature, elevated carbon dioxide (CO_2) by 50 and 100 ppm and 10% deficit rainfall were used in the model to assess the impact of weather variability. The model was run for 20 years from 1990 to 2010 for Palampur and 17 years from 1993 to 2010 for Dhaulakuan weather stations. The weather data of 1990 to 2010 was used and mean simulated yield of 20 and 17 years and coefficients of variance were worked out.

3. Results and discussion

3.1. *Validation of model*

The InfoCrop model was validated using the historical data generated by the research trials at





Figs. 2(a&b). Simulated and observed (a) days to anthesis of maize and (b) grain yield of maize

Palampur.The weather data and soil data already generated was used. Simulated and observed days for anthesis in maize crop in Palampur were compared and InfoCrop Model was validated for different planting dates. Results showed that observed days to anthesis for maize crop at Palampur were more than that of simulated values. The RMSE for days to anthesis [Fig. 2(a)] is 4.9 days. Similarly, higher simulated grain yield was observed in comparison to actual obtained in the field. The RMSE was 724.8 kg/ha for grain yield which indicated that the average variation in actual and simulated yield observation is 13% [Fig. 2(b)].

3.2. *Mid hills sub - humid zone Palampur region*

3.2.1. *Impact of elevated CO_2 on maize yield*

Impact of elevated CO_2 on maize yield was simulated under both potential, *i.e.*, no resource limitation and rainfed under recommended package and practices under sub humid and subtropical region of Palampur. Results showed that the magnitude of impact of elevated CO_2 was more under rainfed conditions. Under potential conditions 50 and 100 ppm increased levels indicated a yield increase of more than 3.0 and 5.4% in 10th June sown crop (Table 1). The subsequent planting windows, *i.e.*, 20th and 30th June showed 3.8 and 6.3% and 3.4 and 4.4% increase in yield, respectively under 50 and 100 elevated ppm CO_2 levels.

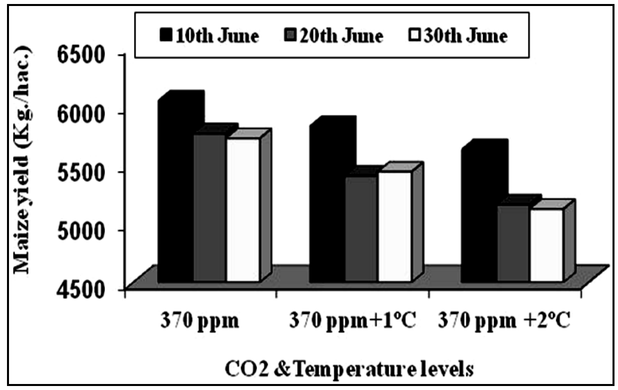


Fig. 3. Simulated impact of CO_2 and 1 °C and 2 °C rise in temperature on maize crop at Palampur

The highest yields under potential conditions were obtained on 10th June sown crop at all levels of CO_2 based on Probability Distribution Function (PDF). Similarly, under rainfed conditions the best planting window was 10th June. It is also supported with the weather data of the region that Palampur region receives pre-monsoon rains during first week of June which is best for the sowing of crop. Under rainfed conditions, 50 and 100 ppm levels indicated a yield increase of more than 4.3 to 8.1% on 10th June sown crop (Table 2). The elevated CO_2 levels, *i.e.*, 420 and 470 ppm showed an increase in yield. The rainfed crop was simulated under recommended package and practices. It was reported that the elevated levels of CO_2 *viz*., 414, 522, 688 and 970 ppm showed increase in yield to the tune of 0.83, 3.16, 6.98 and 11.97% respectively (Sharma *et al*., 2013).

3.2.2. *Combined impact of temperature and rainfall*

The impact of 1 and 2 °C rise in temperature was simulated for maize crop at 370 ppm CO_2 levels (Table 3 and Fig. 3). The result showed decrease in yield due to increase in temperature by 1 °C and 2 °C rise in both maximum and minimum temperature and 2-10% reduction in rainfall. The magnitude of decrease was higher at 20th June (6 and 10.4%) than 30th June (5.0 and 10.5%) sown crop. However, the average reduction in yield was 2-4 q/ha under 10th June and 3-6 q/ha in both 20th and 30th June sown crop. The magnitude of increased yield in subsequent planting windows was less. Reduction in yield due to increase in temperature was also reported by Byjesh *et al.* (2010) and Boomiraj *et al.* (2011).

TABLE 1

Impact of elevated levels of CO_2 on maize yield under no resource limitation condition

Date of sowing	CO_2 Impact			Per cent change on yield	
	370 ppm	420 ppm	470 ppm	50 ppm	100 ppm
10th June	6448 ± 1096	6643 ± 1042	6794 ± 1252	3.0	5.4
20th June	6000 ± 1288	6230 ± 1083	6379 ± 1259	3.8	6.3
30th June	5892 ± 1273	6094 ± 1110	6149 ± 1245	3.4	4.4

TABLE 2

Impact of elevated levels of CO_2 on maize yield under rainfed condition (Palampur)

Date of sowing	CO_2 Impact			Per cent change on yield	
	370 ppm	420 ppm	470 ppm	50 ppm	100 ppm
10th June	6044.6 ± 1221	6287.1 ± 970	6531.97 ± 686	4.3	8.1
20th June	5765.0 ± 1084	5942.5 ± 1110	6047.48 ± 874	3.0	4.9
30th June	5724.0 ± 1257	5882.5 ± 1292	5992.2 ± 1306	1.2	4.7

TABLE 3

Impact of elevated levels of temperatures & CO_2 levels on maize yield under rainfed condition at Palampur

Date of sowing	CO_2 Impact			Per cent change on yield	
	370	370 (Av.T +1 °C)	370 (Av.T +2 °C)	+1 °C	+2 °C
Mean (10th June)	6044.6 ± 1221	5828.2 ± 1172	5631.97 ± 686	- 4.0	-7.0
Mean (20th June)	5765.0 ± 1084	5405.23 ± 1110	5160.0 ± 1130	- 6. 0	-10.4
Mean (30th June)	5724.0 ± 1257	5440.0 ± 1292	5124.9 ± 1306	-5. 0	-10.5

TABLE 4

Impact of elevated CO2 levels on planting windows for maize under potential and rainfed conditions at Palampur

Elevated CO_2 level (ppm)	10th June		20th June		30th June		Best yield	
	Potential	Rainfed	Potential	Rainfed	Potential	Rainfed	Potential	Rainfed
370	6448.4	6044.6	6000.0	5765.0	5892	5724.0	10th June	10th June
420	6643.1	6287.1	6230.0	5942.5	6094	5882.5	10th June	10th June
470	6794.0	6531.9	6379	6047.4	6149	5992.5	10th June	10th June

TABLE 5

Per cent gap in maize yield under potential and rainfed condition at Palampur

Date of sowing	Potential	Rainfed	% Gap
10th June	6448.35	6044.6	21.5
20th June	6643.07	6287.1	28
30th June	6794.0	6531.9	28

TABLE 6

Impact of CO_2 levels on maize yield under no resource limitation at Dhaulakuan

Date of sowing	CO_2 Impact			Per cent change in yield	
	370 ppm	420 ppm	470 ppm	50 ppm	100 ppm
Mean (10th June)	6128 ± 1194	6290 ± 1285	6336 ± 1263	2.6	3.4
Mean (20th June)	5757 ± 1220	5926 ± 1552	6058 ± 1439	2.9	5.2
Mean (30th June)	5297 ± 1338	5410 ± 1397	5696 ± 1370	2.1	7.5

TABLE 7

Impact of elevated CO_2 levels on maize under rainfed conditions at Dhaulakuan

Date of sowing	CO_2 Impact			Per cent change in yield	
	370 ppm	420 ppm	470 ppm	50 ppm	100 ppm
Mean (10th June)	4670 ± 1072	4734 ± 1112	4869 ± 1103	1.4	4.3
Mean (20th June)	4970 ± 1362	5089 ± 1361	5173 ± 1382	2.4	4.1
Mean (30th June)	4888 ± 1288	4982 ± 1305	5084 ± 1323	1.9	4.0

TABLE 8

Impact of 1 °C elevated temperature & CO_2 levels (ppm) at Dhaulakuan under rainfed condition on maize yield

Date of sowing	CO_2 Impact						Per cent change on yield		
	370	370 + 1 °C	420	420 + 1 °C	470	470 + 1 °C	1 °C	1 °C	1 °C
Mean (10th June)	4670	4568	4734	4769	4970	4562	-2.2	-4.6	-6.1
Mean (20th June)	4970	4900	5089	4963	5173	4953	-1.4	-2.4	-4.2
Mean (30th June)	4888	4763	4982	4837	5084	4869	-1.8	-2.9	-4.2

TABLE 9

Impact of 2 °C elevated temperature & CO_2 levels (ppm) at Dhaulakuan under rainfed condition on maize yield

Date of sowing	CO_2 Impact						Per cent change on yield		
	370	370 + 2 °C	420	420 + 2 °C	470	470 + 2 °C	2 °C	2 °C	2 °C
Mean (10th June)	4670	4538	4970	4562	4888	4589	-2.8	-8.2	-6.1
Mean (20th June)	4970	4919	5089	4963	5173	4953	-1.0	-2.4	-4.2
Mean (30th June)	4888	4733	4982	4837	5084	4869	-3.1	-2.9	-4.2

TABLE 10

Impact of elevated CO_2 levels on planting windows of maize under potential and rainfed condition at Dhaulakuan

Elevated CO_2 level (ppm)	10th June		20th June		30th June		Best yield	
	Potential	Rainfed	Potential	Rainfed	Potential	Rainfed	Potential	Rainfed
370	6128	4670	5757	4970	5297	4888	10th June	20th June
420	6290	4734	5926	5089	5410	4982	10th June	20th June
470	6336	4869	6058	5173	5696	5084	10th June	20th June

TABLE 11

Per cent gap in maize yield under potential and rainfed condition at Dhaulakuan

Date of sowing	Potential	Rainfed	% Gap
10th June	6336	4769	32.9
20th June	6290	4684	34.0
30th June	6128	4670	31.2

A recent analysis of more than 20,000 historical maize trial in Africa over an eight year period combined with weather data showed that for every degree day above 30 °C grain yield was reduced by 1 to 1.7% under optimal rainfed and drought conditions, respectively (Lobell *et al.*, 2011). Kumar *et al.* (2011) reported that increase in rainfall in already high rainfall zones is detrimental to crop production, further increase in temperature causes reduction in maize yield in the Western Ghats of India. Lobell and Burke (2010) and Rowhani *et al.* (2011) suggested that an increase in temperature by 2 °C would result in a greater reduction in maize yields within sub-Saharan Africa than a decrease in precipitation by 20%. The results further showed that 10th June was the best simulated planting window based on 20 years weather data under both potential and rainfed conditions at Palampur (Tables 4 and 5).

3.3. *Sub-mountain and low-hills sub-tropical zone-I (Dhaulakuan region)*

3.3.1. *Impact of elevated CO_2 levels on yield*

The two higher levels of CO_2, *i.e.*, 50 and 100 ppm were tried under both potential and rainfed conditions. Under no resource limitations conditions the magnitude of increase was higher at 100 ppm elevated CO_2 level. The best yield was obtained at 10th June planting window under potential conditions. In all the planting windows, maize yield registered an increase in yield with increase in CO_2 levels of 50 and 100 ppm (Table 6). Under rainfed conditions the yield trends also showed an increase with increase in CO_2 levels. There is an increase of 1-2 q/ha increase in yield due to CO_2 levels. In districts of coastal Andhra Pradesh, Kumar *et al.* (2011) suggested 10% increase in rainfed maize yield with increased CO_2 levels. Projected increase in seasonal maximum temperature during *kharif* in these areas is less than 1 °C in the 2030 scenario.

The best yield under potential condition was obtained on 10th June sown crop, whereas under rainfed conditions, the highest yield was recorded on 20th June crop sown. The 20th June planting windows showed an increase of 2.4 and 4.1% respectively at 50 and 100 ppm elevated CO_2 levels under rainfed condition (Table 7).

3.3.2. *Impact of temperature on yield*

The impact of temperature at 370, 420 and 470 ppm levels of CO_2 were simulated for 1 and 2 °C rise in temperature. The model was run for 17 years and Probability Distribution Function was also used for Dhaulakuan region (Tables 8 and 9). Results showed that 1°C rise in temperature caused higher reduction on yield at higher level of CO_2. The impact was more significant on 10th June planting windows. The reduction was 2.2, 4.6 and 6.1% at 370, 420 and 470 ppm of CO_2 levels, respectively with 1 °C rise in temperature. The magnitude of decrease in yield was less on 20th and 30th June planting windows. Two degree rise in temperature also resulted in yield reduction. The reduction was more as compared to 1 °C rise in temperature. The impact of 2 °C rise temperature at 370 ppm CO_2 levels varied between 1.0 to 3.1%, 2.4 to 8.2% at 420 and 4.2 to 6.1% at 470 ppm CO_2. The impact was less at 20th to 30th June planting windows (Tables 9 and 10). Decrease in productivity of some cereals due to increase in temperature was also projected by Schneider *et al.* (2007). The results of simulation study conducted in Jammu region of India showed reduction in yield of maize to the tune of 3.6, 8.0. 16.2 and 26.1% in response to 0.64, 1.6, 2.56 and 3.2° rise in temperature, respectively (Sharma *et al.*, 2013).

The highest simulated yield of maize under rainfed condition from 17 years simulations showed that 20th June to be the best planting window under sub-tropical agro climatic conditions of Himachal Pradesh (Table 10). The study further indicated that under similar agro-climate, the gap in yield obtained under rainfed and potential conditions (with no limiting factors *viz.*, inputs and irrigation etc.) ranged between 31 to 34% (Table 11).

4. Conclusions

At Palampur region, the impact of climate change (*i.e.*, elevated CO_2) was more under rainfed conditions. The highest yields under potential conditions were obtained on 10th June sown crop at all levels of CO_2 based on Probability Distribution Function (PDF). Similarly, under rainfed conditions the best planting window was 10th June. Increase in temperature and decrease in rainfall resulted in yield reduction in maize. The magnitude of decrease was higher at 20th and 30th June sown crop. The results showed that 10th June was the best simulated planting window under both potential and rainfed conditions. Whereas, at Dhaulakuan region under no resource limitation condition, higher yields obtained at 100 ppm elevated CO_2 level on 10th June sown crop. Similarly, under rainfed conditions, increase in CO_2 levels (*i.e*., 50 and 100 ppm) resulted in an increase in maize yield (1-2 q/ha). The best yield was obtained on 20th June sown crop. At higher levels of CO_2 and 1 and 2 °C rise in temperature resulted in yield reduction in maize, but reduction was more in 2 °C rise in temperature as compared to 1 °C rise. The impact was less at 20th to 30th June planting windows.

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