A Critical Analysis of Effect of Projected Temperature and Rainfall for Differential Sowing of Maize Cultivars Under RCP4.5 and RCP6.0 Scenarios for Punjab

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Abstract

A simulation study was conducted for two cultivars of maize (PMH1 and PMH2) in four agroclimatic zones of Punjab state of India where climate change depicts a consistent rise in temperature and increased variability in amount and distribution of rainfall. The yield assessment was performed for four agroclimatic zones of Punjab comprising of seven locations because variability in temperature rise and rainfall existed from location to location. Corrected ensemble model weather data (temperature and rainfall) for RCP4.5 and RCP6.0 was used as an input in the calibrated and validated CERES-Maize model and yield was simulated for a period of 70 years. The simulated yield for near as well as far-future was statistically assessed to understand the yield trend in Punjab under current dates of sowing and the results indicated a strong negative correlation between the yield and the weather parameters under the two scenarios at the considered four agroclimatic zones of Punjab. An increase in maximum and minimum temperature was observed ranging 0-4°C and 3-8°C, respectively at all the agroclimatic zones except Faridkot (zone V) where the increase in minimum temperature was observed by 0-3°C during the crop growth season while the rainfall variability ranged from 200-800mm under both the scenarios. At agroclimatic zone II and zone III similar results were obtained with higher yields at later dates of sowing and the rainfall at agroclimatic zone III was higher under RCP6.0 (300-600mm) while the yields for agroclimatic zone IV and V (Abohar) with rainfall variation of 270-450mm and 200-400mm, respectively showed no yield increment. Maize at Faridkot performed well with higher yields at early sowing dates. Among the two cultivars PMH1 showed more high yield years than PMH2 for most of the years. The yield under differential sowing dates showed the first fortnight of June and end June to be the best sowing dates for most of the locations as the yield for these dates were higher for most of the years. Thus, the study can be further applied to decide the future sowing window of maize for the agricultural state like Punjab.

Introduction

Climate change is a phenomenon that has been occurring for a long term now and it does pose the greatest threat to human beings in social, environmental as well as economic terms. The current rate of temperature increment indicates the global warming to reach 1.5°C between 2030 and 2052 (Allen et al. 2018) while 3-5°C by the end-century in relation to pre-industrial times. Limiting the warming to 1.5°C in the twenty-first century wouldn't stop the heating impact and the slow evolving changes in oceans would continue to persist even after 2100 leading to continuous rising of sea levels. IPCC during their fifth assessment report in 2014 adopted Representative Concentration Pathway (RCP) which have been driven in accordance with the estimated volume of greenhouse gases to get emitted in the future years and they describe different climates in future. The four RCPs being used for the studies are RCP2.6, RCP4.5, RCP6.0, and RCP8.5 which are considered to cause radiative forcing of 2.6, 4.5, 6.0 and 8.5 W/m^2, respectively during the year 2100.The report mentions the global mean surface temperature (GMST) to rise with increasing greenhouse gases over the 21st century. The predicted increase in GMST in relation to 1986-2005 would be 0.3 to 1.7°C and 2.6 to 4.8°C while the precipitation would increase by more than 0.05 mm day^{-1} and 0.15 mm day^{-1} under RCP2.6 and RCP4.5, respectively (Collins et al. 2013). The Indian region estimates show an increase in temperature by 1.7 to 3.7°C and 2.3 to 4.7°C during near future and by 2.2 to 4.3°C and 3.7 to 6.1°C during far future under the RCP4.5 and RCP8.5, respectively (Krishnan et al. 2020). Studies show the direct impact of climatic variables on agriculture as all the physiological processes of the plants are linked to climate inputs. The alterations in temperature and precipitation pattern in different regions of the world have an influence on the crop water cycle as it changes the growth period, photosynthesis ability and respiration pattern which ultimately leads to stress on crops and food security (Tao *et al* 2003a, b). Studies represent a substantial reduction in yield of crops under a temperature change upto 2°C during the dry seasons (Lobells *et al.,* 2008; O'Neill 2007). Mall *et al.* (2004) depicted through a study on soybean productivity that under the future climate change, the agricultural production is predicted to be influenced by the changes in growth and transpiration pattern of crops. The physiological processes of crops such as respiration, photosynthesis and photoassimilate partitioning will suffer due to the increasing temperatures (Chartzoulakis and Psarras, 2005; Yang and Zhang, 2006). The rising temperatures are predicted to cause severe yield losses around the world (Awais et al. 2018, Lobell et al. 2011 and Rahimi et al 2018) and the global average yield is projected to decrease by 3.7% per 1°C rise in temperature (Lobell et al 2011and Hatfield et al 2011). The climate change impact has been observed worldwide and at regional levels. For an agricultural country like India it is very important to be familiar with these impacts and how the crops would react to the changing patterns in future. These purposes are being served at various locations worldwide using scientific techniques like artificial chambers but this being expensive is being replaced by crop simulation models which create similar environmental conditions like those at field thus fulfilling the purpose at lower costs. The models simulate yield under future conditions and helps in determining the trend and optimization practices that would prove efficient in combating the climate change impact. Currently, the global circulation models (GCMs) provide scenarios which explain the future radiative forcings under increasing greenhouse gases, these are used as crop model inputs for predicting yield. The crop simulation models project yield decrement for major cereal crops globally but the magnitude of impact of these forcings on yield varies on regional as well as local basis.

A study in the Shaanxi province of China used CERES-Maize 4.6.7 to project future maize yield under RCP2.6, RCP4.5, RCP6.0 and RCP8.5 and the results showed a negative correlation between temperature and maize yield. The yield was projected to decrease upto 9% in the region (Saddique et al. 2020). The predictions for Zambia under RCP4.5 and RCP8.5 from ensemble mean show an increase in temperature and decrease in precipitation. These changes would influence the maize crop for which the anthesis and maturity would shorten in 2050 while the deviation in grain yield would range from 2.78% to 9.94%, −3.81% to −8.88%, and −2.33% to 10.63% under different nitrogen application i.e. 55.2 N kg/ha, 110.4N kg/ha and 165.6 N kg/ha (Chisanga et al. 2020). An experiment in northwestern China studied the impact of climate change on maize yield in the region and it showed a positive impact under temperatures less than 1°C while a yield decrement by 10.8°C per 1°C warming (Han et al. 2021). The north-east region of Iran also depicted yield reduction at all locations during the future century from 2.6% to 82% from the baseline (Bannayan *et al.* 2016).

A calibrated and validated APSIM model was used to evaluate the climate change impact on maize yield in central India and the results showed a decrease -44.4, -20, -19.7 - 17.9 and 22.5% under RCP 4.5 for N 0%, N 50%, N 100%, N 150%, 100% organic, respectively from the baseline (Sinha et al. 2021).The kharif season crop showed yield reduction with rise in temperature for all the locations considered under study in Delhi, India but the magnitude of impact at different locations varied (Singh et al. 2010). The simulated maize yields from INFOCROP-Maize model depicted a reduction in yield under high temperature but the predicted rise in rainfall by HadCM3 model may help in offsetting these crop losses in India (Byjesh *et al.* 2010). simulated maize yields at high atmospheric temperature and found a decline in yield which occurred due to reduced crop duration i.e. days to 50% flowering and grain filling duration (GFD), reduced leaf area index and leaf area duration. A considerable reduction in crop phenology could be seen with the increase in temperature of 16% (days to 50% flowering) and 14% (GFD) at 5°C rise in temperature. Yield components like grain weight, test weight and number of grains were also impacted by high temperature. The results of the study depicted a decrease in the projected maize yield under reduction or no increase in rainfall at fixed temperature simulations. The HadCM3 model scenario indicated a rise in rainfall as projected for various locations in India leading to a slight less impact of climate change on maize yield. The projection for Punjab the maximum temperature to rise from 29.8-31.3°C (baseline) to 30.5-31.6°C, 31.8- 32.8°C, 31.6-32.6°C and 33.6-34.7°C for RCP2.6, RCP4.5, RCP6.0 and RCP8.5, respectively while the minimum temperature is projected to rise from 15.5-20.3°C (baseline) to 17.8-19.1°C, 19.0- 20.2°C, 19.2-20.5°C and 21.1-22.4°C for RCP2.6, RCP4.5, RCP6.0 and RCP8.5, respectively during the end century which will definitely impact this major agricultural state of India (Kaur 2020). An experiment on eastern Indian region depicted the time period 2051-2080 (end-century) to observe major loss in grain yield against the baseline in case of irrigated condition while under rainfed condition an increase in grain yield was observed which clearly explain the reduction in the negative impact of temperature on the crop yield with the increase in rainfall (Srivastava *et al* 2021). The major factor influencing the growth and phenology of maize is temperature increment which causes increase in the development rate and reduction in the growth period of crop leading to yield reduction.

The climate change event is global, but the impact is observed to be more pronounced on the developing countries like India where the economy is disturbed by the effects. India is already known for its wide diversification may it be culture, climate, crops, etc. and agriculture is considered as the backbone of India as most of the states of India depend on agriculture for its economy thus climate change impact analysis is must for the region and these impacts need to be analysed primarily on states contributing majorly to agriculture. Amongst these states comes Punjab which is known to be the major food provider in India and historical as well as current studies clearly show the shifting weather as well as crop patterns in Punjab leading to larger environmental issues and losses. Thus, keeping this scenario in mind the study was conducted on *kharif* maize crop cultivars (PMH1 and PMH2) which are majorly grown in Punjab and the relation between the yield and future projections for four agroclimatic zones of Punjab was analysed along with the weather parameter changes from the actual conditions considered for maize growth.

Materials And Methods

Location

Punjab extends from $29^0$33”N to $32^0$34”N latitude and $73^0$53”E to $76^0$56”E longitude occupying 1.54% of country’s total geographical area in the north-western region of India. The climate of the state is sub-tropical, semi-arid and monsoon type. The annual average minimum and maximum temperature for Punjab ranges between 29 to 32°C and 15 to 20°C, respectively. The temperature variation is observed during the *kharif* and *rabi* season when the mean maximum temperature is 38°C and 25°C, respectively and mean minimum temperature is 23^0C and 8^0C, respectively while the rainfall variation within the state itself is very high in space as well as time with the mean annual rainfall ranging from 400 to 1300mm. The monsoon season is the major contributor (75 to 80%) in rainfall while minor contribution (20-25%) during the remaining eight months is by western disturbances. The high variations in onset, duration and withdrawl time of monsoon causes dry spells during the critical crop growth stages in the state. Punjab state is divided into six agroclimatic zones and five zones that are zone II (Ballowal Saunkhri), zone III (Ludhiana, Amritsar and Patiala), zone IV (Bathinda) and zone V (Abohar and Faridkot) were considered for the study.

Model description

The most widely used crop growth models are the DSSAT models which have been designed to simulate the growth, development and yield of the crops along with the changes in soil water, carbon and nitrogen that takes place over the time under a particular cropping system (Jones *et al* 2003). First version of DSSAT was released in 1989 and it consisted of four crop models that are CERES-Maize (Jones and Kiniry, 1986), CERES-Wheat (Ritchie and Otter 1985), SOYGRO (Wilkerson *et al* 1983) and PNUTGRO (Boote *et al* 1987). Among all these models CERES-Maize continues to dominate, it is in high demand globally and remains the mother-seed of other maize models like APSIM (Keating *et al* 2003) and the CSM-IXIM (Lizaso *et al* 2011). (Jones and Kiniry, 1986) described the CERES-Maize model as a simulation tool to explain the daily phenological growth and development under the influence of environmental factors (soil, weather and crop management).

The study used calibrated and validated CERES-Maize (v 4.7.5) model to simulate the maize yield from 2025 to 2095 under the scenarios (RCP4.5 and RCP6.0) for sowing window (end May to June). Two major maize cultivars long-duration (PMH1) and short-duration (PMH2) were used for determining the future yield trends of maize.

Yield assessment

The GCMs provide daily data for the weather parameters (maximum and minimum temperature, rainfall) and ensemble of the seventeen GCMs was considered for the study. The corrected weather data (Kaur 2020) for two stabilization scenarios which would occur in near as well as end-future that are

RCP4.5 and RCP6.0 were used as input in the calibrated and validated CERES-Maize model for the region. The model used this data to simulate yield for 70 years (2025-95) under the current sowing window of maize in Punjab keeping the management practices constant. The constant management practices helped in determining the impact of temperature and precipitation variations on the maize yield in near as well as far-future. The baseline from which the temperature and precipitation trend during the crop season was studied was taken as recommended for the state (Prabhjyot-Kaur *et al* 2020).

The statistical yield assessment was done using correlation coefficients calculated using Pearson's correlation analysis in SAS (v 9.3) while the yield categories were prepared on the basis of simulated yield to observe the performance of maize crop under the considered scenarios and what further optimization can be done for the better performance of the crop. The study also helped in recognizing the zones that were not suitable for growing maize in Punjab.

Results And Discussion

Temperature, rainfall and yield relationship in Punjab

Punjab

The derived correlation for the maize yield cultivars PMH1 (Fig.1) and (Fig.2) clearly explains the strong negative relationship between the temperature and the maize yield while the relationship is comparatively weaker for the rainfall (Table 1). The rainfall variability is very high within Punjab while temperature variability is low for the different districts considered in the agroclimatic zone. The maximum and minimum temperature showed a continuous increase over the 70year period with maximum during the end-century while the rainfall ranged between 200-600mm under both the scenarios and the considered sowing dates.

Yield assessment under RCP4.5 and RCP6.0

Agroclimatic zone II

Ballowal Saunkhri

The PMH1 cultivar was predicted to perform well at zone II under both the scenarios with high yields (>5000 kg/ha) obtained during the mid-century under early dates of sowing where the predicted maximum and minimum temperatures were higher (0-4°C and 5-7°C), respectively than the normal temperature requirement of the maize crop while the rainfall was variable within 300-500mm (Table 2). The zone indicated medium yield for the end-century where the temperatures were found higher and the rainfall variability lied within the same range for early dates of sowing. However, the cultivar performed well with higher yield under RCP4.5 (Fig. 3 (a)) and RCP6.0 (Fig. 4 (a)) on 15th June. The late two dates of sowing observed a 1°C lower rise in temperature than the early dates which clearly indicates the coolness of temperature at later months of the crop. The analysis of temperature and precipitation impact on cultivar PMH2 indicated medium yield under RCP4.5 for all the future years under early sowing dates while the later two sowing dates showed higher yield under both scenarios during mid-century (Table 2). The yield for PMH2 was lower for the end-future. The maize crop performed well at this zone because of the good rainfall distribution (300-550mm) and less temperature increment if the date of sowing was shifted but PMH2 performed poor due to it being a short-duration crop. Under projected RCP4.5 scenario (Fig. 5 (a)) none of the dates showed low yield years while under projected RCP6.0 scenario (Fig. 6 (a)) the end-century years showed lower yield. The projected temperature and precipitation lead to shortening of the maturity by 9-11 days and 7-22 days, respectively for PMH1 and PMH2. The temperature increment for both the cultivars was observed to be lower for the later dates of sowing representing better conditions for growth and development of crop.

Agroclimatic zone III

Ludhiana

The performance of PMH1 cultivar was good with higher yields in near future and lower during the far-future. The increment in maximum and minimum temperature was observed by 0-2°C and 5-7°C, respectively for both the scenarios while rainfall under RCP4.5 ranged 350-600mm and under RCP6.0 ranged 350-800mm (Table 3). On 15th June the cultivar yielded well under both the scenarios (Fig. 3 (b) & 4(b)) with same temperature and rainfall conditions. The RCP6.0 showed higher rainfall than the baseline during the crop period. During the far-future the cultivar performed well with medium yields. Similarly, the PMH2 cultivar yielded higher during the late dates of sowing while 28th May June gave medium yield for all the years under both the scenarios with higher rainfall (370-780mm) under RCP6.0 (Table 3). 6th June observed lower yields for far-future projections under both scenarios, 15th June observed higher yields for near-future and 24th June observed higher yield for all the years under RCP4.5. PMH2 variety could perform well at late dates of sowing (Fig. 5 (b) & 6(b)) when the temperature variations were low for both the scenarios but rainfall was observed to be higher reaching upto 800mm under RCP6.0. Both the cultivars performed well under late date of sowing. Though PMH1 was found to perform well but shortening of PMH1 duration occurred by 1-8 days which was higher than PMH2 where shortening was by 1-5 days. The cultivars performed well at the location with good rainfall distribution and lower temperature increment at late date of sowing.

Amritsar

Almost similar results were obtained for Amritsar where the PMH1 cultivar showed higher yield during the RCP4.5 scenario on all dates of sowing depicting the good performance of cultivar during near-future and medium yield during far-future (Table 4). The projected maximum and minimum temperatures during the crop season were observed to be higher by 0-1°C and by 5-8°C while the rainfall ranges were variable for RCP4.5 (450-600mm) and RCP6.0 (350-700mm). The lower yield for the cultivar was only obtained on 6th June while the later dates of sowing performed well with higher and medium yields. Similarly, the PMH2 variety performed well with higher yields on 15th and 24th June while the early dates projected lower yield under both the scenarios during the far end-century (Table 4). The variation in results showed lower yields under RCP4.5 during mid-century which may be due to the rainfall variability. The cultivars performed well for the location except PMH2 which did not observe higher yields for early dates of sowing under both the scenarios. The first fortnight and end of June was found to be high yielding with good linear relationship for PMH1 and PMH2 under RCP4.5 (Fig. 3 (c)) & 5 (c)) and RCP6.0 (Fig. 4 (c) & 6 (c)) scenarios. The projected temperature and rainfall variability in the region resulted in shortening of the maturity period by 1-6 days for both the cultivars with maximum shortening during the far-future.

Patiala

The location observed similar results as Ludhiana and Amritsar where PMH1 cultivar performed well under RCP4.5 and observed higher yield for most of the future years. The maximum and minimum temperature were observed to be higher than the normal by 1-2°C and 3-5°C while the rainfall variability was 350-600mm under both the scenarios (Table 5). The medium yield for the cultivar was observed during the far end-century. The cultivar showed good performance at the location with first fortnight of June to be the best under RCP4.5 (Fig. 3 (d)) and some low dips were observed under RCP6.0 during the end-century (Fig. 4 (d)). For PMH2 on 6th June under both the scenarios higher yield was observed for all the future years and none of the sowing dates showed lower yield depicting the cultivar to perform well at the location (Table 5). The first fortnight of June was found to be perform well under both the scenarios but the linear relation was weak under RCP4.5 (Fig. 5 (d)) and strong showing a steep decline during the end-century under RCP6.0 (Fig. 6(d)). Both the cultivars performed well at Patiala where the shortening in maturity days was also observed to be lower than the other locations by 1-5 days for both the cultivars.

Agroclimatic zone IV

Bathinda

The location showed lower yield for all the dates of sowing considered under both the scenarios. Very low yield (<3000kg/ha) was observed on 6th June and 24th June for all the years and both the scenarios (Fig. 3 (e) & 4 (e)). The PMH1 cultivar observed an increase in maximum and minimum temperature during the crop season by 0-2°C and 3-6°C, respectively under both the scenarios while rainfall variability under RCP4.5 was 270-350mm and 270-430mm under RCP6.0 (Table 6). The medium yield for the other two dates of sowing were observed for near (2020s) and mid-future (2030s-2050s). Similar results were obtained for PMH2 at the location where low yield was observed for the four sowing dates except 15th June (Table 6). The cultivar showed a steep decline with strong linear relationship under both the scenarios and all dates of sowing (Fig. 5 (e) & Fig. 6 (e)). The crop season for both the cultivars observed a little higher rainfall under both the scenarios on 24th June. However, neither of the cultivar performed well at the location. The rainfall requirement of the crop during the season is incomplete and also the soil profile for the location does not support maize crop which may have led to lower yields in the region. The maturity days showed shortening by 4-17 days for both PMH1 and PMH2 which may be the major reason for yield loss. The non-suitability of the region for maize crop would also be the reason for yield loss as cotton is the major crop of the region.

Agroclimatic zone V

Abohar

Both the cultivars at the location did not perform well with lower yield (<3000kg/ha) observed for both the scenarios for all the years on 28th may and 6th June. During the crop season of PMH1 the maximum and minimum temperature were projected to increase by 0-2°C and 4-6°C under all the sowing dates and under both the scenarios while the rainfall for the region varied 200-350mm for both RCP4.5 and RCP6.0 (Table 7). Similar increase in temperatures and variability in rainfall was obtained for PMH2 (Table 7). The 15th June observed medium yield under both the scenarios during near-future for PMH1 and only under RCP6.0 for PMH2. A steep decline was observed in the yield of both the cultivars under RCP4.5 (Fig. 3 (f) & 4 (f)) and RCP6.0 (Fig. 5 (f) & 6 (f)). Both the cultivars observed shortening by 1-17 days for the region which would have also contributed to yield loss. Abohar according to the projections does not seem to be a suitable maize growing location similarly as Bathinda. The yield loss at the location maybe attributed mainly to the low rainfall and non-suitability of the region for the crop.

Faridkot

PMH1 cultivar at the location performed well with medium and higher yield being obtained during the early sowing dates under both the scenarios (Table 8). On 6th and 15th June under RCP4.5 all the years were observed to have higher yields and these higher yields were observed during most of the year. The lower yields during the early dates of sowing were observed during the far-future years. The cultivar observed comparatively lower yields under both the scenarios on 24th June (Fig. 3 (g) & 4 (g)). The maximum and minimum temperature were projected to increase by 0-2°C and 0-3°C during both the scenarios while rainfall varied 250-350mm under RCP4.5 and 250-400mm under RCP6.0. The PMH2 cultivar performed well under future conditions with high and medium yields obtained under all the dates of sowing and the two considered scenarios (Table 8). The yield variations observed were quite high during both the scenarios on 24th June. Medium yield for all the dates of sowing was observed during the far end-future under RCP4.5 (Fig .5 (g)) and RCP6.0 (Fig. 6 (g)). Again, for the region the rainfall was a little higher on 24th June than the other dates of sowing considered. The shortening observed for both the cultivars at the location was by 1-6 days thus the yield loss was not much high for the region. 24th June was observed to be the only sowing date simulating medium yield.

The relationship between the yield and the weather parameters as projected for different agroclimatic zones of Punjab clearly depicts the higher temperature occurrence and high rainfall variability during the cropping season of maize in Punjab. According to IPCC the mean annual precipitation is projected to increase in the tropical regions and high northern latitudes while a decrease would be observed in the subtropics thus the fluctuating temperature and rainfall would definitely affect the evaporation and transpiration processes contributing to plant growth. Punjab being a major agricultural crop producing state in India requires attention in relation to the projected climate change scenarios. The corrected weather projections from ensemble model under RCP4.5 and RCP6.0 was used as an input in CERES-Maize model to assess the maize yield in different agroclimatic zones of Punjab. A review showed the CERES-Maize and APSIM models to be the dominant in studying the climate change impact on future maize productions and the overall studies as performed worldwide depicted a reduction in maize yield by 8-38% under RCP4.5 by the end of the 21st century. Also, the climate change data used in the study should be from multi-model ensembles so that better and more accurate predictions are made (Kogo et al. 2019). The scenarios for Punjab under the current sowing dates clearly showed an increase in the maximum and minimum temperature by 0-4°C and 3-8°C except at Faridkot (0-3^{0}C) while rainfall variability was high within the state thus the rainfall for the agroclimatic zones varied between 200-800mm which is quite a large variation. Maize is a major agricultural crop in Punjab where high rainfall variability was observed within the state itself which may be the major reason for yield deviations in low rainfall areas. The maize crop in Punjab is irrigated so under future scenarios if the number of irrigations were increased over the current applied, then this would help in decreasing the temperature effect on the yield. Studies suggest that the increasing temperature and fluctuating precipitation would lead to reduction in available water and crop production (Kang et al. 2009). The varied impact of climate change is such that it would cause an increase in food losses in some regions while decrease in the same for the other regions. Most of the crops are irrigated so if the precipitation is increased or irrigation applications are increased during the crop growth period then the major parameter to be taken in consideration will be the precipitation which acts as an influential factor in deviated crop yields. The soil of Punjab also varies from location to location and under the current soil conditions the agroclimatic zones showed yield increment during the near-future scenarios but the soil conditions may not remain the same in future. The soil of high water holding capacity would perform well under reduced availability of water during future scenarios because it will reduce the drought frequencies and improve the crop yields (Popova and Kercheva 2005). The growing period for most of the crops and as observed under this study for maize would reduce under the predicted scenarios thus there is a need to change the planting dates for higher production. Under the study the growth period for most of the locations and for both the cultivars ranged by 1-6 days but Ballowal Saunkhri and Bathinda observed a major decrease in the crop growth period. The crop duration is shortened under high temperature stress by 6-10 days during mid-century while within 9-22 days during end-century under different emission scenarios (Kaur and Kaur 2020). Sometimes, the crop growth period increases in some regions like higher latitudes and montane ecosystems but still the incidence of pests and diseases remains a menace under climate change along with the soil degradation due to climate change (Lal 2005). The varieties considered in the study are PMH1 (long-duration) and PMH2 (short-duration) and under current weather conditions PMH1 yields higher while under future conditions too the cultivar was observed to yield higher. Quantification is the urgent requirement to determine the predicted variability in yield of major crops and this will also help the scientists in developing varieties suitable to combat these quantified losses. Punjab is dependent on irrigated agriculture but the future projections of decreasing precipitation in the region does require attention and can be solved by increasing the amount of applied irrigation for crop growth and production but this in turn would reduce the crop water productivity thus increasing the crop water productivity remains a bigger challenge for many regions (Kijne et al. 2003). Also, an increase in precipitation at some regions would lead to increased mean annual runoff leading to poor soil water balance so even if farmers apply more irrigation to the crops then it would lead to runoff (Holden and Breton 2006). Study in the Shijin irrigation district of China showed a decrease (10.8 kg) in maize yield with 1°C rise in temperature while the yield would increase (3.3 kg) with 1mm increase in rainfall during the growing period under RCP4.5 (Li et al. 2020). This clearly indicates the rainfall compensating the losses that could be cause due to temperature increase but in Punjab the rainfall is predicted to be highly variable from its normal pattern which disturbs the physiological processes of the crops and also has a negative impact at different phenological stages of the crop. The projected rainfall under RCP6.0 in Punjab was found to be higher for the agroclimatic zone III. An annual and seasonal analysis of corrected GCM data for different districts of Punjab showed an increase in the temperature and rainfall during the *kharif* season as indicated by the positive deviation of these parameters from the baseline. The projections indicated an increase in maximum and minimum temperature ranged 2.9-8.7°C and 3.0-7.6°C, respectively at different locations while the projected increase in rainfall was highest at Ballowal Saunkhri (1075mm) and minimum at Bathinda (117mm) (Kaur and Kaur 2019). However, this study considered the SRES (Special Report on Emission Scenarios) by IPCC while the current study (Kaur 2020) on RCPs depicted similar results for temperatures but the rainfall was projected to decrease. Climate predictions for Ludhiana district of Punjab which is major rice-wheat cropping system area showed an increment in the mean annual temperature by 1.56°C during mid-century and by 3.11°C during end-century while the rainfall decrement was observed by 97.5 mm (12.8%) during mid-century and 89 mm (11.8%) during end-century (Dar et al. 2019). Under SRES scenarios (Kaur and Kaur 2019) the trend analysis for the grain yield showed a negative and linear trend for all the locations during mid and end-century while under the current RCPs the projected weather conditions during the near-future and later dates of sowing were well where higher yields were obtained as the projected temperature increase was 1°C lower than the far-future temperature predictions except at Faridkot lying in agroclimatic zone V. High temperatures are harmful for crops as they lead to changes in morphology, anatomy, physiology and biochemical processes taking place in crops. Under the predicted climate changes from 2015-2050 maize yield in northeast China showed an increase by 34.3% and 25.7% under RCP4.5 and RCP6.0, respectively. The correlation of maize yields with precipitation, wind speed and net solar radiation changes were positive and with relative humidity and temperatures was negative under the two RCPs (Pu et al. 2020). The increase in temperature during critical growth stages of maize crop results in yield losses like an increase of 6°C temperature during grain filling resulted in 10% yield losses in the US corn belt (Thomson 1966) and an increase by 2°C in sub Saharan Africa resulted in greater reductions than the decrease in precipitation by 20% at the location (Lobell and Burke 2010). This clearly explains that the threshold of heat stress damage for reproductive organ is significantly lower than the other organs in crops (Stone 2001). The maize can have a successful grain set with production of viable pollen and its interception by receptive silks, followed by the male gamete transmission to the egg cell where initiation and maintenance of embryo and endosperm development takes place (Schoper et al. 1987) but under high temperature these processes are disturbed which may include decreased number of grains and kernel weight, decreased number of fertilized ovules which ultimately leads to grain losses (Naveenkumar et al. 2018). Estimations tell that the temperature increment acts like a potential stimulator for the insect life cycles too which increases by 5 times during the crop period (Petzoldt and Seaman 2005; Bale et al. 2002; Porter et al.1991) thus leading to poor yields. The current agricultural practices in Punjab use fertilizers and water for higher yields and this is required for fulfilling the food demand however excessive fertilizers are harmful for the environment and over usage of irrigation water has led to a large decline in ground water table in Punjab. Under the current and future climate change scenarios the increase in inputs like fertilizers and irrigation water would improve the yields as the soils of different regions respond differently. A climate change study in the Shandong province of Huanghuaihai under the current soil conditions require increasing fertilizer and irrigation water input for better yield of summer maize (Chen et al. 2012). Future climate impact assessment on maize yield and food security showed an increment in temperatures for the region during the 2020s, 2050s and 2080s by 0.7 °C to 0.8 °C, 1.6 °C to 2.3 °C, and 2.1 °C to 3.3°C, respectively while the predicted rainfall pattern showed high variability. Under these conditions the maize yield is expected to increase or decrease in the range 4.6% to 5.4%, −1.2% to 1.0% and −3.0% to 0.2% for the respective time periods (Stevens and Madani 2016). The study depicted first fortnight of June to be a suitable sowing date for maize cultivars grown in Agroclimatic zone II and III while the zone IV and V (Abohar) were observed to be the non-suitable areas for both the cultivars due to insufficient rainfall conditions and soil conditions in the region. However, Faridkot observed the cultivars to perform well during all dates of sowing except end June when the yield ranged within medium which would be due to low increase in minimum temperature in the region.

Limitations

Climate change studies hold many limitations as the crop growth models take ideal conditions which usually don't occur in India where the climate is highly variable. Also, the long term climate affect on the soils of different regions are not considered under the future climatic projections which leads to uncertain results from the crop growth models.

Conclusions

The results indicated a strong negative correlation between the yield and the weather parameters as projected under the two scenarios and for differential sowing dates at the considered four agroclimatic zones of Punjab. The maximum and minimum temperature as projected for the sowing dates indicated an increase ranging 0-4°C and 3-8°C, respectively at different agroclimatic zones except Faridkot where minimum temperature observed a rise by 0-3^{0}C while the rainfall variability was high ranging from 200-800mm under both the future scenarios. The agroclimatic zone II and zone III depicted similar results with higher yields at later dates of sowing which can be considered for deciding the future sowing window for maize cultivars in Punjab but the rainfall at agroclimatic zone III was higher under RCP6.0 (300-600mm) than under RCP4.5 (300-800mm). Agroclimatic zone IV and V (Abohar) with rainfall variation of 270-450mm and 200-400mm, respectively showed no yield increment for both the cultivars and the low yield categories were more at these locations because of the insufficient rainfall and non-supportive soil conditions for maize crop. Maize at Faridkot performed well with higher yields at early sowing dates though the rainfall at the location was similar as at Abohar and lying in the same agroclimatic zone V but the increase in minimum temperature during the crop period was lower which would be the reason for good crop growth under the considered sowing dates. All the agroclimatic zones depicted medium yield during the far end-future under all the sowing dates and scenarios except agroclimatic zone IV and V (Abohar) where projected yield for all the years was lower. Though, both the maize cultivars performed well at all the agroclimatic zones but higher yield peaks were mostly observed in PMH1 cultivar at most of the zones thus PMH1 can be considered a better performing cultivar under future scenarios. The two scenarios RCP4.5 and RCP6.0 are considered to be the stabilization scenarios thus not much differences in the projected yield results were found.

Punjab is considered as a major agricultural state of India thus the climate change studies in the region require attention. The projected temperature and precipitation conditions in the state varies from location to location so different agroclimatic zones comprising of various locations were considered for the study and the study clearly depicts the requirement of modified agronomic practices for a better food production in future.

Declarations

Statements and Declarations

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Tables

Table 1: Correlation matrix between predicted yield of maize cultivars (PMH1 and PMH2) and weather parameters during 21st century in Punjab

	PMH1			PMH2		
Yield (kg/ha)	**Tmax**	**Tmin**	**Rainfall**	**Tmax**	**Tmin**	**Rainfall**
Zone II (Ballowal Saunkhri)	-0.871***	-0.852***	-0.513***	-0.973***	-0.964***	-0.766***
Zone III (Ludhiana, Amritsar and Patiala)	-0.986***	-0.986***	-0.892***	-0.991***	-0.991***	-0.912***
Zone IV (Bathinda)	-0.978***	-0.968***	-0.851***	-0.990***	-0.992***	-0.800***
Zone V (Abohar and Faridkot)	-0.981***	-0.971***	-0.898***	-0.992***	-0.987***	-0.888***

*****Significant at P<0.001

Table 2: Yield distribution for maize cv PMH1 and PMH2 sown from end May to June at Zone II (Ballowal Saunkhri) during 2025 – 2095 as simulated by CERES-Maize model using projected climate data of the Ensemble model

PMH1 (Baseline: Tmax=34.4^{0}C; Tmin=22.4^{0}C; Rainfall=888mm)									
Yield years (Temperature and Rainfall)	**Yield category**	**28-May**		**6-June**		**15-June**		**24-June**	
		RCP4.5	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**
	Low yield (<3000 kg/ha)	-	-	-	-	-	-	-	-
	Medium yield (3000-5000 kg/ha)	2027-28; 2031-34; 2039-95	2037-38; 2048-95	2033-34; 2036-95	2071-95	-	2088-95	All years	2025-50; 2061-95
		Tmax=35-37^{0}C Tmin=28-29^{0}C RF=300-550mm	Tmax=35-37^{0}C Tmin=28-30^{0}C RF=319-500mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=300-450mm	Tmax=36-37^{0}C Tmin=29-30^{0}C RF=400-500mm		Tmax=36^{0}C Tmin=29^{0}C RF=400-415mm	Tmax=34-35^{0}C Tmin=27-29^{0}C RF=300-500mm	Tmax=34-36^{0}C Tmin=27-29^{0}C RF=360-560mm
	High yield (>5000 kg/ha)	2025-26; 2029-30; 2035-38	2025-36; 2039-47	2025-32; 2035	2025-70	All years	2025-87	-	2051-60
		Tmax=35-36^{0}C Tmin=28^{0}C RF= <350mm	Tmax=35-36^{0}C Tmin=28^{0}C RF=300-350mm	Tmax=35^{0}C Tmin=28^{0}C RF=300-310mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=300-480mm	Tmax=34-36^{0}C Tmin=27-29^{0}C RF=300-500mm	Tmax=34-36^{0}C Tmin=27-29^{0}C RF=300-470mm		Tmax=34^{0}C Tmin=28^{0}C RF=430-450mm
PMH2 (Baseline: Tmax=34.4^{0}C; Tmin=22.4^{0}C; Rainfall=888mm)									
Yield years (Temperature and Rainfall)	**Yield category**	**28-May**		**6-June**		**15-June**		**24-June**	
		RCP4.5	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**
	Low yield (<3000 kg/ha)	-	2066-95	-	2066-95	-	2072-95	-	2085-95
			Tmax=36-37^{0}C Tmin=29-30^{0}C RF=420-490mm		Tmax=36-37^{0}C Tmin=29-30^{0}C RF=400-470mm		Tmax=36^{0}C Tmin=29^{0}C RF=400-470mm		Tmax=35-36^{0}C Tmin=29^{0}C RF=430-480mm
	Medium yield (3000-5000 kg/ha)	All years	2025-65	All years	2025-65	2034; 2043-45; 2047-49	2048-71	2029; 2035-49; 2067-68; 2080-95	2058-84
		Tmax=35-37^{0}C Tmin=28-29^{0}C RF=300-520mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=300-500mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=360-490mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=300-470mm	Tmax=35^{0}C Tmin=28^{0}C RF=300-340mm	Tmax=35^{0}C Tmin=28-29^{0}C RF=340-470mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=350-530mm	Tmax=35^{0}C Tmin=28-29^{0}C RF=440-520mm
	High yield (>5000 kg/ha)	-	-	-	-	2025-33; 2035-42; 2046; 2050-95	2025-47	2025-28; 2030-34; 2050-66; 2069-79	2025-57
						Tmax=34-36^{0}C Tmin=28-29^{0}C RF=300-480mm	Tmax=34-35^{0}C Tmin=27-28^{0}C RF=300mm	Tmax=34-35^{0}C Tmin=27-29^{0}C RF=350-530mm	Tmax=34^{0}C Tmin=27-28^{0}C RF=360-450mm

Table 3: Yield distribution for maize cv PMH1 and PMH2 sown from end May to June at Zone III (Ludhiana) during 2025 – 2095 as simulated by CERES-Maize model using projected climate data of the Ensemble model

PMH1(Baseline: Tmax=34.9^{0}C; Tmin=23.3^{0}C; Rainfall=634mm)									
Yield years (Temperature and Rainfall)	**Yield**	**28-May**		**6-June**		**15-June**		**24-June**	
	category	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**
	Low yield (<3000 kg/ha)	-	-	-	-	-	-	-	-
	Medium yield (3000-5000 kg/ha)	2025-26; 2034; 2036-95	2028-40; 2044-58; 2069-95	2027; 2029-38; 2040-95	2037-40; 2043-47; 2072-95	-	-	All years	2025-56; 2069-95
		Tmax=35-37^{0}C Tmin=28-29^{0}C RF=370-570mm	Tmax=35-37^{0}C Tmin=28-30^{0}C RF=380-780mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=400-520mm	Tmax=35-36^{0}C Tmin=28-30^{0}C RF=420-750mm			Tmax=35-37^{0}C Tmin=28-29^{0}C RF=370-560mm	Tmax=34-35^{0}C Tmin=27-29^{0}C RF=450-750mm
	High yield (>5000 kg/ha)	2027-33; 2035	2025-27; 2041-43; 2059-68	2025-26; 2028; 2039	2025-36; 2041-42; 2048-71	All years	All years	-	2057-68
		Tmax=35-36^{0}C Tmin=28^{0}C RF=370-450mm	Tmax=35-36^{0}C Tmin=28^{0}C RF=390-620mm	Tmax=35^{0}C Tmin=28^{0}C RF=350-420mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=370-760mm	Tmax=34-36^{0}C Tmin=28-29^{0}C RF=370-570mm	Tmax=34-36^{0}C Tmin=27-29^{0}C RF=350-750mm		Tmax=34^{0}C Tmin=28^{0}C RF=500-550mm
PMH2 (Baseline: Tmax=34.9^{0}C; Tmin=23.3^{0}C; Rainfall=634mm)									
Yield years (Temperature and Rainfall)	**Yield**	**28-May**		**6-June**		**15-June**		**24-June**	
	category	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**
	Low yield (<3000 kg/ha)	-	-	2070-73; 2084-95	2087-95	-	-	-	-
				Tmax=36^{0}C Tmin=30^{0}C RF=440-580mm	Tmax=36^{0}C Tmin=29-30^{0}C RF=510-540mm				
	Medium yield (3000-5000 kg/ha)	All years	All years	2025-69; 2074-83	2025-86	2048-95	2068-95	-	2072-95
		Tmax=35-37^{0}C Tmin=28-29^{0}C RF=370-560mm	Tmax=35-37^{0}C Tmin=28-30^{0}C RF=370-780mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=350-530mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=400-760mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=470-530mm	Tmax=35-36^{0}C Tmin=29^{0}C RF=510-750mm		Tmax=34-35^{0}C Tmin=28-29^{0}C RF=560-750mm
	High yield (>5000 kg/ha)	-	-	-	-	2025-47	2025-67	All years	2025-71
						Tmax=34-35^{0}C Tmin=27-28^{0}C RF=350-430mm	Tmax=34-35^{0}C Tmin=27-29^{0}C RF=350-500mm	Tmax=34-35^{0}C Tmin=27-28^{0}C RF=410-560mm	Tmax=34^{0}C Tmin=27-28^{0}C RF=410-760mm

Table 4: Yield distribution for maize cv PMH1 and PMH2 sown from end May to June at Zone III (Amritsar) during 2025 – 2095 as simulated by CERES-Maize model using projected climate data of the Ensemble model

Yield years (Temperature and Rainfall)	Yield category	28-May RCP4.5	28-May RCP6.0	6-June RCP4.5	6-June RCP6.0	15-June RCP4.5	15-June RCP6.0	24-June RCP4.5	24-June RCP6.0
PMH1 (Baseline: Tmax=35.6^{0}C; Tmin=22.5^{0}C; Rainfall=579mm)									
	Low yield (<3000 kg/ha)	-	-	-	2080-81; 2086-95	-	-	-	-
					Tmax=36-37^{0}C Tmin=29^{0}C RF=570-650mm				
	Medium yield (3000-5000 kg/ha)	2025-95	2039-95	2045-95	2047-79; 2082-85	2079-95	2091-95	2044-95	2054-95
		Tmax=35-37^{0}C Tmin=27-29^{0}C RF=490-610mm	Tmax=36-37^{0}C Tmin=27-29^{0}C RF=470-670mm	Tmax=37-38^{0}C Tmin=29-30^{0}C RF=360-590mm	Tmax=35-37^{0}C Tmin=28-29^{0}C RF=540-620mm	Tmax=36^{0}C Tmin=28^{0}C RF=520-480mm	Tmax=37^{0}C Tmin=29^{0}C RF=600mm	Tmax=36-37^{0}C Tmin=28-29^{0}C RF=480-600mm	Tmax=35-36^{0}C Tmin=27-29^{0}C RF=490-690mm
	High yield (>5000 kg/ha)		2025-38	2025-44	2025-46	2025-78	2025-90	2025-43	2025-53
			Tmax=35-36^{0}C Tmin=27^{0}C RF=540-560mm	Tmax=35-36^{0}C Tmin=27-28^{0}C RF=540-560mm	Tmax=35^{0}C Tmin=27-28^{0}C RF=540-560mm	Tmax=34-36^{0}C Tmin=27-28^{0}C RF=450-550mm	Tmax=34-36^{0}C Tmin=27-29^{0}C RF=500-670mm	Tmax=35-36^{0}C Tmin=27-28^{0}C RF=500-570mm	Tmax=34-35^{0}C Tmin=27^{0}C RF=570-590mm
PMH2(Baseline: Tmax=35.6^{0}C; Tmin=22.5^{0}C; Rainfall=579mm)									
	Low yield (<3000 kg/ha)	-	2084-95	2053-56; 2093-95	2074-95	-	-	-	-
			Tmax=37^{0}C Tmin=29^{0}C RF=580-670mm	Tmax=36^{0}C Tmin=28-29^{0}C RF=550-600mm	Tmax=36-37^{0}C Tmin=29^{0}C RF=570-650mm				
	Medium yield (3000-5000 kg/ha)	All years	2025-83	2025-52; 2057-92	2025-73	2038-95	2054-95	2071-95	2076-95
		Tmax=35-37^{0}C Tmin=27-29^{0}C RF=530-600mm	Tmax=35-37^{0}C Tmin=27-29^{0}C RF=540-660mm	Tmax=35-37^{0}C Tmin=27-29^{0}C RF=480-570mm	Tmax=35-36^{0}C Tmin=27-29^{0}C RF=540-650mm	Tmax=35-36^{0}C Tmin=28^{0}C RF=450-580mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=500-680mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=350-530mm	Tmax=35^{0}C Tmin=28^{0}C RF=600-690mm
	High yield (>5000 kg/ha)	-	-	-	-	2025-37	2025-53	2025-70	2025-75
						Tmax=34-35^{0}C Tmin=27^{0}C RF=540-550mm	Tmax=34-35^{0}C Tmin=27-28^{0}C RF=570-590mm	Tmax=34-35^{0}C Tmin=27-28^{0}C RF=450-550mm	Tmax=34-35^{0}C Tmin=27-29^{0}C RF=500-680mm

Table 5: Yield distribution for maize cv PMH1 and PMH2 sown from end May to June at Zone III (Patiala) during 2025 – 2095 as simulated by CERES-Maize model using projected climate data of the Ensemble model

PMH1 (Baseline: Tmax=35.0^{0}C; Tmin=23.9^{0}C; Rainfall=649mm)									
Yield years (Temperature and Rainfall)	Yield	28-May		6-June		15-June		24-June	
	category	RCP4.5	RCP6.0	RCP4.5	RCP6.0	RCP4.5	RCP6.0	RCP4.5	RCP6.0
	Low yield (<3000 kg/ha)	-	-	-	-	-	-	-	-
	Medium yield (3000-5000 kg/ha)	2060-63	2076-95	-	2056-95	-	2082; 2085; 2093-95	2072-95	2069-95
		Tmax=37^{0}C Tmin=29^{0}C RF=500mm	Tmax=37^{0}C Tmin=29^{0}C RF=510-550mm		Tmax=36-37^{0}C Tmin=28-29^{0}C RF=450-550mm		Tmax=36C Tmin=29^{0}C RF=550mm	Tmax=37^{0}C Tmin=29^{0}C RF=560-580mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=540-590mm
	High yield (>5000 kg/ha)	2025-59; 2064-95	2025-75	All years	2025-55	All years	2025-81; 2083-84; 2086-92	2025-71	2025-68
		Tmax=36-37^{0}C Tmin=28-29^{0}C RF=370-560mm	Tmax=36-37^{0}C Tmin=27-29^{0}C RF=370-570mm	Tmax=35-37^{0}C Tmin=28-29^{0}C RF=360-560mm	Tmax=35-36^{0}C Tmin=27-28^{0}C RF=350-470mm	Tmax=35-36^{0}C Tmin=27-29^{0}C RF=360-560mm	Tmax=35-36^{0}C Tmin=27-29^{0}C RF=360-560mm	Tmax=36-37^{0}C Tmin=28-29^{0}C RF=370-570mm	Tmax=34-35^{0}C Tmin=27-28^{0}C RF=400-490mm
PMH2 (Baseline: Tmax=35.0^{0}C; Tmin=23.9^{0}C; Rainfall=649mm)									
Yield years (Temperature and Rainfall)	Yield	28-May		6-June		15-June		24-June	
	category	RCP4.5	RCP6.0	RCP4.5	RCP6.0	RCP4.5	RCP6.0	RCP4.5	RCP6.0
	Low yield (<3000 kg/ha)	-	-	-	-	-	-	-	-
	Medium yield (3000-5000 kg/ha)	2031-95	2042-95	All years	All years		2068-95	2072-95	2073-95
		Tmax=36-37^{0}C Tmin=28-29^{0}C RF=370-590mm	Tmax=36-37^{0}C Tmin=28-29^{0}C RF=460-560mm	Tmax=35-37^{0}C Tmin=28-29^{0}C RF=360-560mm	Tmax=35-37^{0}C Tmin=27-29^{0}C RF=370-550mm		Tmax=36-37^{0}C Tmin=28-29^{0}C RF=500-560mm	Tmax=35-36^{0}C Tmin=28^{0}C RF=590-600mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=540-590mm
	High yield (>5000 kg/ha)	2025-30	2025-41	-	-	All years	2025-67	2025-71	2025-72
		Tmax=36^{0}C Tmin=28^{0}C RF=383mm	Tmax=36^{0}C Tmin=27-28^{0}C RF=370-380mm			Tmax=35-36^{0}C Tmin=27-29^{0}C RF=360-560mm	Tmax=35-36^{0}C Tmin=27-28^{0}C RF=370-470mm	Tmax=34-35^{0}C Tmin=27-28^{0}C RF=400-500mm	Tmax=34-35^{0}C Tmin=27-28^{0}C RF=400-590mm

Table 6: Yield distribution for maize cv PMH1 and PMH2 sown from end May to June at Zone IV (Bathinda) during 2025 – 2095 as simulated by CERES-Maize model using projected climate data of the Ensemble model

PMH1 (Baseline: Tmax=36.7^{0}C; Tmin=23.9^{0}C; Rainfall=427mm)									
Yield years (Temperature and Rainfall)	**Yield category**	**28-May**		**6-June**		**15-June**		**24-June**	
		RCP4.5	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**
	Low yield (<3000 kg/ha)	2025-95	2032-95	All years	All years	2048-67; 2082-95	2062-95	All years	All years
		Tmax=37-38^{0}C Tmin=28-29^{0}C RF=270-320mm	Tmax=37-39^{0}C Tmin=28-30^{0}C RF=270-390mm	Tmax=36-38^{0}C Tmin=28-29^{0}C RF=270-300mm	Tmax=36-38^{0}C Tmin=28-30^{0}C RF=270-390mm	Tmax=37^{0}C Tmin=28-29^{0}C RF=270-290mm	Tmax=37-38^{0}C Tmin=29-30^{0}C RF=270-370mm	Tmax=35-37^{0}C Tmin=27-29^{0}C RF=320-340mm	Tmax=35-37^{0}C Tmin=27-29^{0}C RF=320-420mm
	Medium yield (3000-5000 kg/ha)		2025-31	-	-	2025-47; 2068-81	2025-61	-	-
			Tmax=37^{0}C Tmin=28^{0}C RF=270-300mm			Tmax=36-37^{0}C Tmin=28-29^{0}C RF=270-290mm	Tmax=36-37^{0}C Tmin=27-28^{0}C RF=270-280mm		
	High yield (>5000 kg/ha)	-	-	-	-	-	-	-	-
PMH2(Baseline: Tmax=36.7^{0}C; Tmin=23.9^{0}C; Rainfall=427mm)									
Yield years (Temperature and Rainfall)	**Yield category**	**28-May**		**6-June**		**15-June**		**24-June**	
		RCP4.5	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**
	Low yield (<3000 kg/ha)	All years	All years	All years	All years	2026-95	2040-95	All years	All years
		Tmax=37-38^{0}C Tmin=28-29^{0}C RF=270-320mm	Tmax=37-39^{0}C Tmin=28-30^{0}C RF=270-390mm	Tmax=36-39^{0}C Tmin=29-31^{0}C RF=270-300mm	Tmax=36-38^{0}C Tmin=28-30^{0}C RF=270-390mm	Tmax=36-37^{0}C Tmin=28-29^{0}C RF=270-290mm	Tmax=36-38^{0}C Tmin=28-30^{0}C RF=270-375mm	Tmax=35-37^{0}C Tmin=27-29^{0}C RF=320-335mm	Tmax=35-37^{0}C Tmin=27-29^{0}C RF=320-425mm
	Medium yield (3000-5000 kg/ha)	-	-	-	-	2025	2025-39	-	-
						Tmax=36^{0}C Tmin=28^{0}C RF=275mm	Tmax=36^{0}C Tmin=27-28^{0}C RF=270-280mm		
	High yield (>5000 kg/ha)	-	-	-	-	-	-	-	-

Table 7: Yield distribution for maize cv PMH1 and PMH2 sown from end May to June at Zone V (Abohar) during 2025 – 2095 as simulated by CERES-Maize model using projected climate data of the Ensemble model

PMH1 (Baseline: Tmax=35.7^{0}C; Tmin=24.0^{0}C; Rainfall=262mm)									
Yield years (Temperature and Rainfall)	**Yield**	**28-May**		**6-June**		**15-June**		**24-June**	
	category	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**
	Low yield (<3000 kg/ha)	All years	All years	All years	All years	2033-95	2048-95	All years	All years
		Tmax=36-38^{0}C Tmin=28-30^{0}C RF=220-300mm	Tmax=36-38^{0}C Tmin=28-30^{0}C RF=220-300mm	Tmax=36-38^{0}C Tmin=29-30^{0}C RF=220-300mm	Tmax=36-38^{0}C Tmin=28-30^{0}C RF=220-300mm	Tmax=36-37^{0}C Tmin=29-30^{0}C RF=220-270mm	Tmax=36-37^{0}C Tmin=29-30^{0}C RF=220-300mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=260-340mm	Tmax=35-37^{0}C Tmin=28-30^{0}C RF=250-340mm
	Medium yield (3000-5000 kg/ha)	-	-	-	-	2025-32	2025-47	-	-
						Tmax=35-36^{0}C Tmin=28-29^{0}C RF=225mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=220-230mm		
	High yield (>5000 kg/ha)	-	-	-	-	-	-	-	-

PMH2(Baseline: Tmax=35.7^{0}C; Tmin=24.0^{0}C; Rainfall=262mm)									
Yield years (Temperature and Rainfall)	**Yield**	**28-May**		**6-June**		**15-June**		**24-June**	
	category	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**
	Low yield (<3000 kg/ha)	All years	All years	All years	All years	All years	2028-95	2031-95	2025-29; 2050-95
		Tmax=36-38^{0}C Tmin=29-30^{0}C RF=220-300mm	Tmax=36-38^{0}C Tmin=28-30^{0}C RF=220-300mm	Tmax=36-38^{0}C Tmin=29-30^{0}C RF=220-300mm	Tmax=36-38^{0}C Tmin=28-30^{0}C RF=220-300mm	Tmax=35-37^{0}C Tmin=28-30^{0}C RF=220-300mm	Tmax=35-37^{0}C Tmin=28-30^{0}C RF=220-300mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=260-340mm	Tmax=35-37^{0}C Tmin=28-30^{0}C RF=250-340mm
	Medium yield (3000-5000 kg/ha)	-	-	-	-	-	2025-27	2025-30	2030-49
							Tmax=35^{0}C Tmin=28^{0}C RF=226mm	Tmax=35^{0}C Tmin=28^{0}C RF=260-270mm	Tmax=35^{0}C Tmin=28^{0}C RF=250-265mm
	High yield (>5000 kg/ha)	-	-	-	-	-	-	-	-

Table 8: Yield distribution for maize cv PMH1 and PMH2 sown from end May to June at Zone V (Faridkot) during 2025 – 2095 as simulated by CERES-Maize model using projected climate data of the Ensemble model

PMH1(Baseline: Tmax=35.1^{0}C; Tmin=26.7^{0}C; Rainfall=382mm)									
Yield years (Temperature and Rainfall)	**Yield**	**28-May**		**6-June**		**15-June**		**24-June**	
	category	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**
	Low yield (<3000 kg/ha)	-	-	-	-	-	-	All years	All years
								Tmax=35-36^{0}C Tmin=28-29^{0}C RF=260-340mm	Tmax=35-37^{0}C Tmin=28-30^{0}C RF=250-340mm
	Medium yield (3000-5000 kg/ha)	2067-95	2074-95	-	2084-95	-	2091-95	-	-
		Tmax=36-37^{0}C Tmin=29^{0}C RF=270-290mm	Tmax=36-37^{0}C Tmin=29-30^{0}C RF=270-370mm		Tmax=36-37^{0}C Tmin=30^{0}C RF=350-370mm		Tmax=36^{0}C Tmin=29^{0}C RF=274mm		
	High yield (>5000 kg/ha)	2025-66	2025-73	All years	2025-83	All years	2025-90	-	-
		Tmax=35-36^{0}C Tmin=28-29^{0}C RF=260-290mm	Tmax=35-37^{0}C Tmin=28-30^{0}C RF=280-490mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=260-290mm	Tmax=35-36^{0}C Tmin=28-30^{0}C RF=250-290mm	Tmax=34-36^{0}C Tmin=27-29^{0}C RF=260-275mm	Tmax=34-36^{0}C Tmin=27-29^{0}C RF=355mm		
PMH2(Baseline: Tmax=35.1^{0}C; Tmin=26.7^{0}C; Rainfall=382mm)									
Yield years (Temperature and Rainfall)	**Yield**								
	category	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**	**RCP4.5**	**RCP6.0**
	Low yield (<3000 kg/ha)	-	-	-	-	-	-	-	-
	Medium yield (3000-5000 kg/ha)	2060-95	2071-95	-	2083-95	2073-95	2078-95	2025-65; 2070-74; 2091-95	2025-64; 2066-67; 2069-77; 2079; 2081; 2083; 2095
		Tmax=36-37^{0}C Tmin=29^{0}C RF=270-300mm	Tmax=36-37^{0}C Tmin=29-30^{0}C RF=270-370mm		Tmax=36-37^{0}C Tmin=29-30^{0}C RF=280-370mm	Tmax=36^{0}C Tmin=29^{0}C RF=270-275mm	Tmax=36^{0}C Tmin=29^{0}C RF=270-360mm	Tmax=34-36^{0}C Tmin=27-29^{0}C RF=310-330mm	Tmax=34-36^{0}C Tmin=27-29^{0}C RF=300-330mm
	High yield (>5000 kg/ha)	2025-59	2025-70	All years	2025-82	2025-72	2025-77	2066-69; 2075-90	2061; 2065; 2068; 2078; 2080; 2082; 2084-94
		Tmax=35-36^{0}C Tmin=28-29^{0}C RF=260-290mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=250-280mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=260-290mm	Tmax=35-36^{0}C Tmin=28-29^{0}C RF=250-280mm	Tmax=34-36^{0}C Tmin=27-29^{0}C RF=260-270mm	Tmax=34-36^{0}C Tmin=27-29^{0}C RF=250-280mm	Tmax=35^{0}C Tmin=29^{0}C RF=320-325mm	Tmax=35^{0}C Tmin=28-29^{0}C RF=310-410mm

Figures

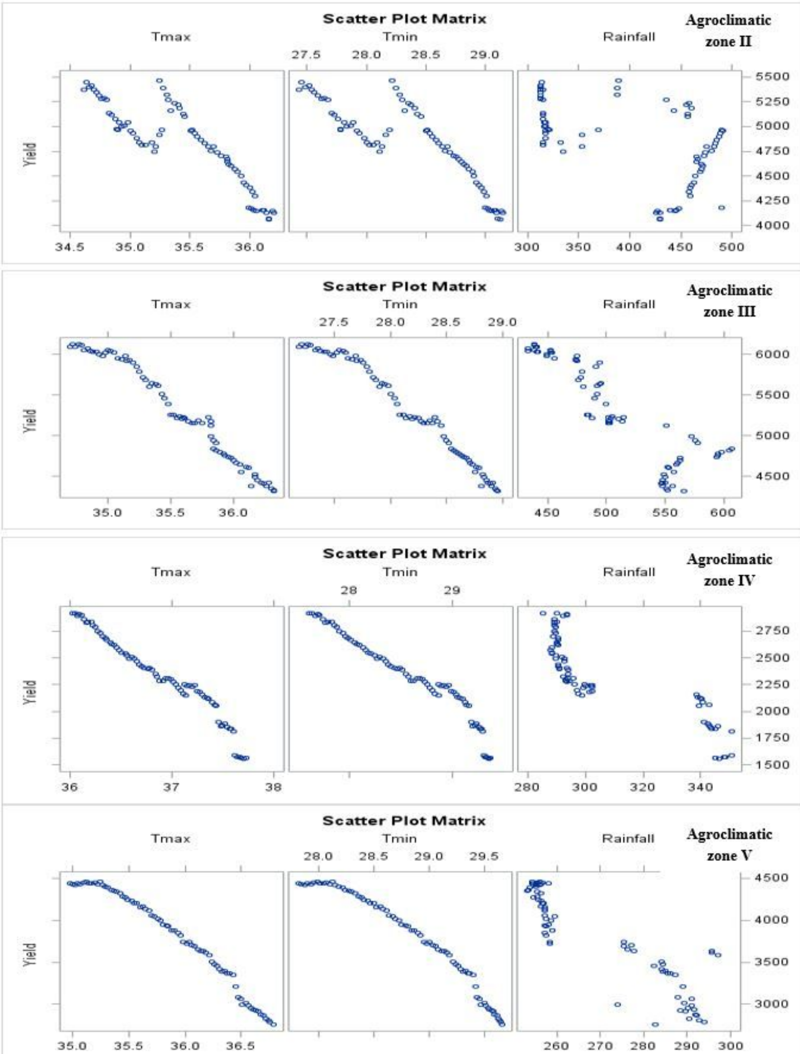

Figure 1

Correlation matrix between projected yield of maize cv PMH1 and weather parameters (temperature and rainfall) during 21st century at different agroclimatic zones of Punjab

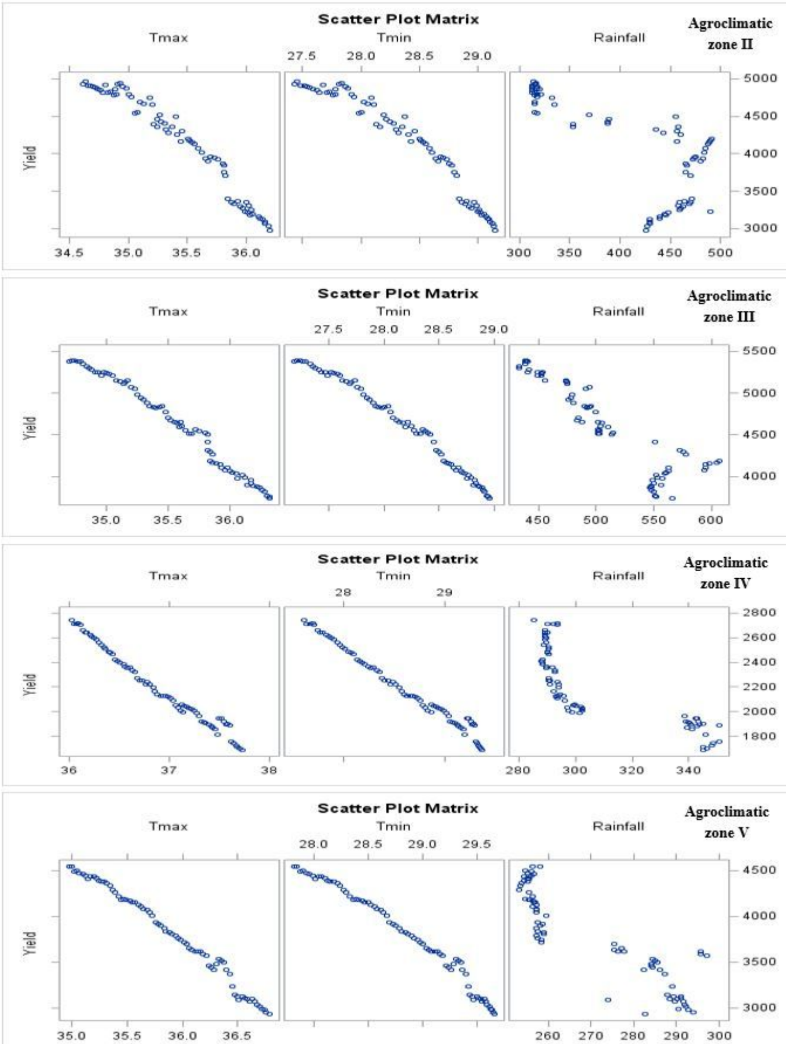

Figure 2

Correlation matrix between projected yield of maize cv PMH2 and weather parameters (temperature and rainfall) during 21st century at different agroclimatic zones of Punjab

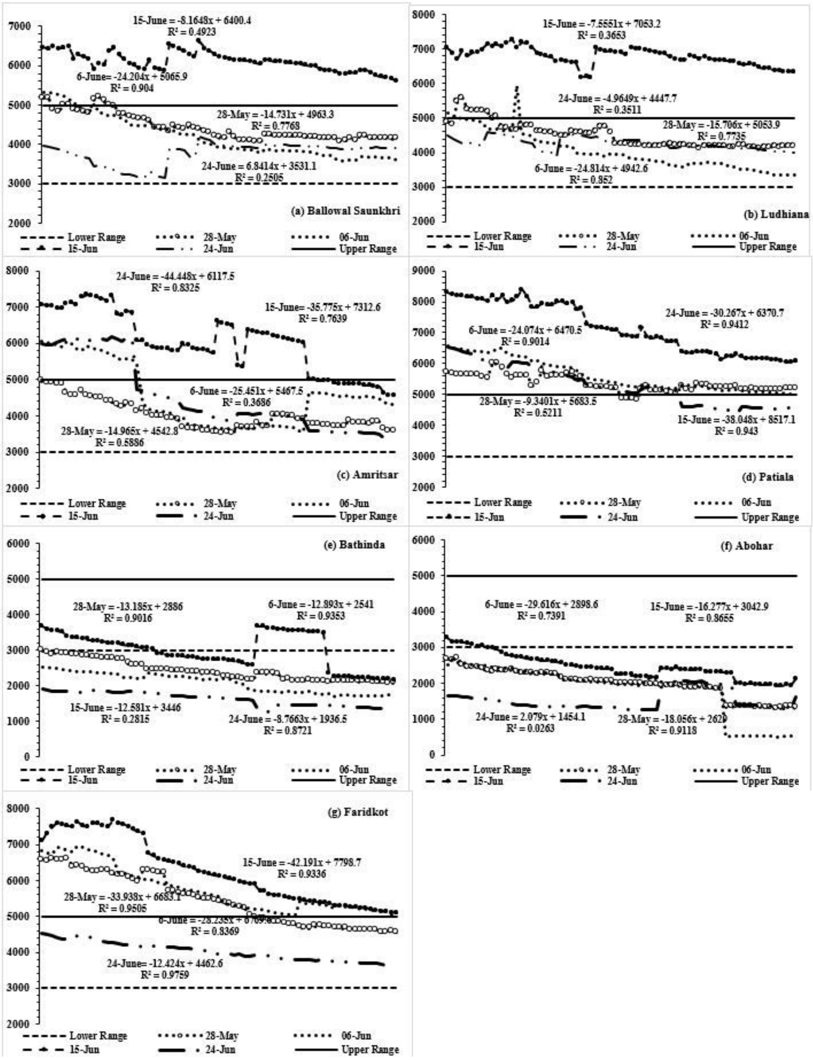

Figure 3

Yield assessment for maize cv PMH1 sown from end May to June at different locations during 2025 – 2095 as simulated by CERES-Maize model using projected climate data of the Ensemble model under RCP4.5

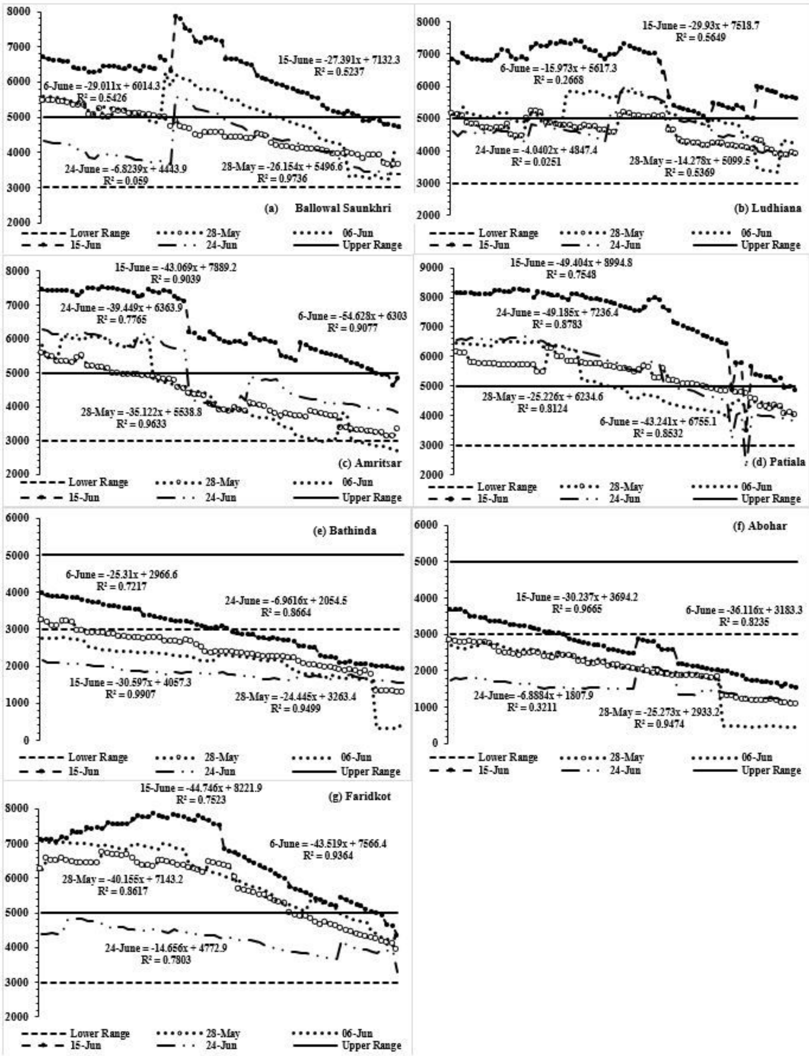

Figure 4

Yield assessment for maize cv PMH1 sown from end May to June at different locations during 2025 – 2095 as simulated by CERES-Maize model using projected climate data of the Ensemble model under RCP6.0

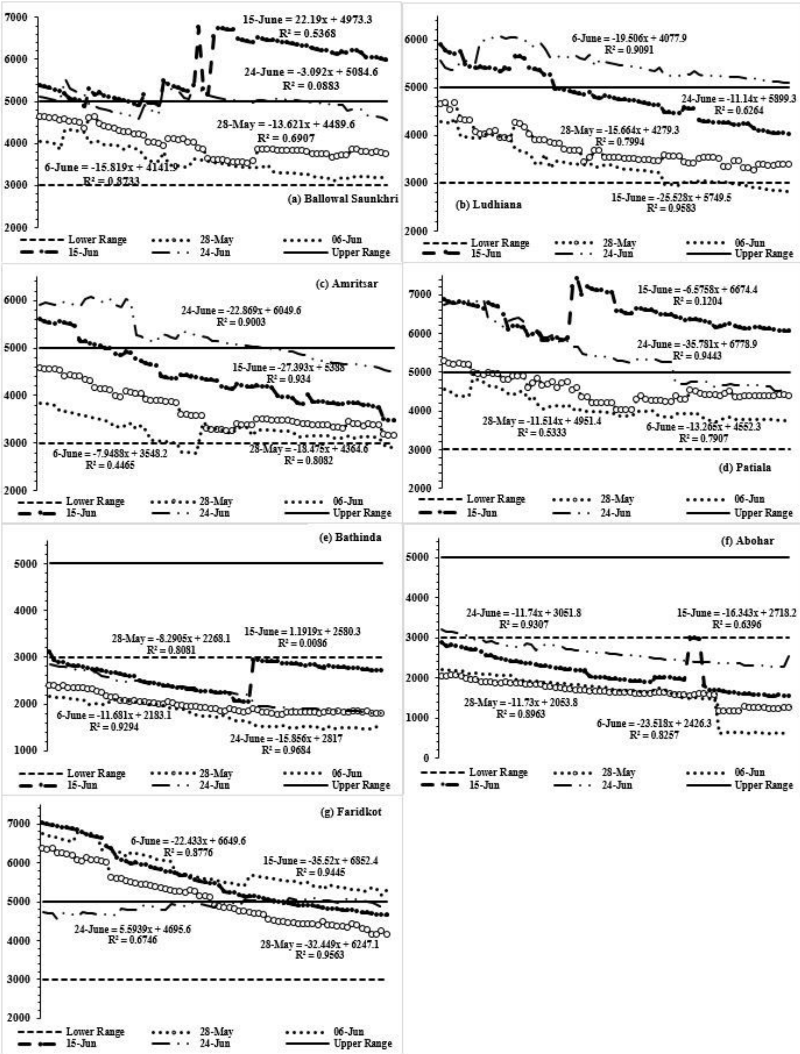

Figure 5

Yield assessment for maize cv PMH2 sown from end May to June at different locations during 2025 – 2095 as simulated by CERES-Maize model using projected climate data of the Ensemble model under RCP4.5

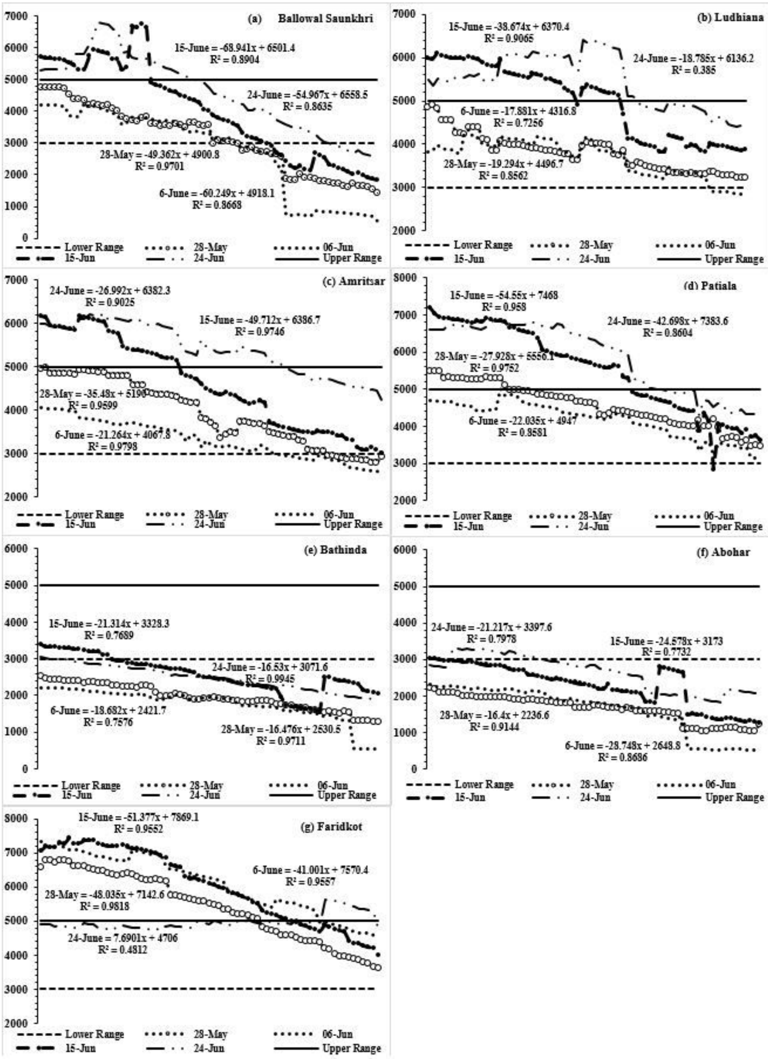

Figure 6

Yield assessment for maize cv PMH2 sown from end May to June at different locations during 2025 – 2095 as simulated by CERES-Maize model using projected climate data of the Ensemble model under RCP6.0