Assessing the vulnerability of Indian mustard to climate change

K. Boomiraj a,*, B. Chakrabarti a, P.K. Aggarwal a, R. Choudhary a, S. Chander b

a Division of Environmental Sciences, Indian Agricultural Research Institute, NBL Building, New Delhi 110012, India
b Division of Entomology, Indian Agricultural Research Institute, New Delhi 110012, India

A R T I C L E   I N F O
Article history:
Received 27 October 2009
Received in revised form 25 May 2010
Accepted 26 May 2010
Available online 18 June 2010

Keywords:
InfoCrop
Simulation
Sensitivity
Impact
Mustard
Climate change

A B S T R A C T
Rapeseed-mustard (Brassica spp.) is a major group of oilseed crop in the world with India being the second largest cultivator after China. Although there has been a significant increase in oilseed production since 1960s, the demand for oilseeds production in the future is likely to go up due to population increase and their income. Mustard is much sensitive to climatic variables and hence climate could have significant effect on its production. There are very limited studies to assess the impact of climate change on oilseed crops as compared to cereals. This paper presents results of a simulation study to evaluate the impact of projected climate change on Indian mustard (Brassica juncea) in contrasting agro-environments of the tropics. InfoCrop, a generic dynamic crop model, provides integrated assessment of the effect of weather, variety, pests and soil management practices on crop growth and yield, as well as on soil nitrogen and organic carbon dynamics in aerobic, anaerobic conditions and also greenhouse gas emissions. The validated model (InfoCrop-mustard) has reasonably predicted phenology, crop growth and yield of mustard crop. The crop was found to be sensitive to changes in carbon dioxide (CO2) and temperature. Future climate change scenario analysis showed that mustard yields are likely to reduce in both irrigated and rainfed conditions. However, these reductions have spatial variation in different mustard growing region of India. In both irrigated and rainfed conditions, yield reduction would be higher in eastern India (67 and 57%) followed by central India (48 and 14%) and northern India (40.3 and 21.4%). This was due to maximum temperature rise in eastern part of the country, projected for 2080. In northern India, yield reduction of irrigated mustard was comparatively less due to prevailing lower temperature in this region during the crop growth period. But rainfed crop was found to be more susceptible to changing climate in north India due to projected reduction in rainfall in future scenarios. Adoption of adaptation measures like late sowing and growing long-duration varieties would be helpful in preventing yield loss of irrigated mustard in different locations of the country.

1. Introduction

India is among the top few vegetable oil economies of the world. Here, oilseeds are an important component of the agricultural economy, next to food grains, in terms of area, production and value. Rapeseed-mustard (Brassica spp.) is a major group of oilseed crop of the world being grown in 53 countries across the six continents, with India being the second largest cultivator after China (Hedge, 2005). But still India is a net importer of vegetable oils and almost 40% of its annual edible oil needs are met by importation. In future, the demand for oilseeds production is likely to go up significantly due to increase in population and income.

The IPCC has projected a temperature increase of 0.5–1.2 °C by 2020, 0.88–3.16 °C by 2050 and 1.56–5.44 °C by 2080 for the Indian region, depending on the scenario of future development (IPCC, 2007). Himalayan glaciers and snow cover are projected to contract leading to much higher variability in irrigation water supplies. It is very likely that hot extremes, heat waves and heavy precipitation events will become more frequent. Overall, the temperature increases are likely to be much higher in winter season when crops such as mustard are grown. In this season, precipitation is also likely to decrease.

These changes in the global climate may affect the crop yields, incidence of weeds, pests and plant diseases and the economic costs of agricultural production. Easterling et al. (2007) analyzed modeling results to show that in low-latitude regions, a temperature increase of 1–2 °C is likely to have negative yield impacts for major cereals. There is a probability of 10–40% loss in crop production in India with increase in temperature by 2080–2100 (Fischer et al., 2007; Parry et al., 2004; IPCC, 2007). There are a few Indian studies (Saseendran et al., 2000; Aggarwal, 2008) which also confirm...
decline in the agricultural production with climate change. Winter
crops are especially vulnerable to high temperature during repro-
ductive stages. Mall et al. (2004) reported that crop production in
winter season might become comparatively more vulnerable due
to larger increase in temperature and higher uncertainties in rain-
fall. On the other hand, global warming impact was likely offset
to some extent by increased CO2 levels in atmosphere, although
the magnitude of these effects are uncertain and this needs more
debate and research (Long et al., 2005, 2006).

There are limited studies had been done to assess the impact
of climate change on oilseed crops as compared to cereals. Some
studies have been done on soybean (Adams et al., 1990; Singh et al.,
1997; Long et al., 2005; Easterling et al., 2007) and they have shown
that despite CO2 benefits on photosynthesis, crop yields decrease
with increasing temperature. Similar results are also reported for
groundnut (Gadgil et al., 1999; Duivenbooden et al., 2002; Challinor
et al., 2006).

Mustard is much sensitive to climatic variables and hence cli-
mate change could have significant effect on its production. A
part of the decline and/or stagnation in mustard yields causing
negative growth rate from 1997 was possibly due to unfavor-
able monsoon which created moisture stress (drought and excess
rainfall) and temperature increases (Arvind Kumar, 2005). High
temperature during mustard crop establishment (mid September
to early November), cold spell, fog and intermittent rains during
crop growth also affect the crop adversely and cause considerable
yield losses by physiological disorder along with appearance and
proliferation of aphid pest, white rust, downy mildew and stem
rot diseases. In a recent paper, it has been shown that in coming
decades, fungicide treated oilseed crops will show an increase in
yield of up to 0.5 t ha−1 in Scotland while associated rising temper-
ature will increase severity of stem canker disease which is likely to
decrease the yields in southern England (Butterworth et al., 2009).
A crop growth model was combined with a disease epidemic mod-
els and climate change forecasts for the 2020s and 2050s to derive
these results.

There are almost no studies to assess the probable impact of
climate change on mustard productivity in tropical regions. The
objective of this study was therefore to quantify the impact of
future climate change on mustard crop. Since crop growth mod-
els are important for such an assessment and models for tropical
mustard do not exist, another objective was to develop, calibrate
and validate a mustard model for this purpose. An additional objective
of the study was to assess the benefits of simple autonomous
adaptation strategies.

2. Materials and methods

2.1. Model description

InfoCrop model, a generic dynamic crop simulation model with
sensitivity to variety, agronomic management, soil, weather,
flooding, frost and pests and modified to include high CO2 and
temperature responses was used in this study (Aggarwal et al.,
2006a). The model has been earlier validated for its performance
across varying climates, soils and management conditions at the
field level. The model simulates all major processes of crop growth,
soil water and nutrient balances; greenhouse gases emissions and
crop–pest interactions. A detailed description of these is available
in Aggarwal et al. (2006b) and only a brief report of the processes
significantly affected by temperature and CO2 in the model is given
here. The model simulated the effect of higher CO2 on net assimila-
tion by multiplying the net rate (RUE) by a factor following the
studies of Peart et al. (1988). The multiplier has a value of 1.0
at 360 ppm CO2, linearly increasing to 1.15 as CO2 increased to
550 ppm and to 1.23 until CO2 level became 770 ppm. A quick test
indicated that this relation generally results in a net crop yield
increase of 10–15% in well-irrigated and fertilized crops. This was
very similar to the recent conclusions based on several FACE studies
(Long et al., 2005). The effects of water, nitrogen and temperature
stress on the net photosynthesis in increased CO2 environments are
mediated through their effects on leaf area growth and hence radi-
atation absorption. Evapotranspiration in the model also responds
to increased CO2 by increasing stomatal resistance. Increase in
temperature, effects crop duration, senescence, net assimilation,
spikelet fertility and soil chemical processes. InfoCrop-mustard
is written in FORTRAN SIMULATION TRANSLATOR (FST) language
(Van Kraalingen, 1995). Time step of the model is 1 day.

InfoCrop has been successfully adapted, calibrated and validated
for rice (Aggarwal et al., 2006b), wheat (Aggarwal et al., 2006b),
potato (Singh et al., 2005), cotton (Hebar et al., 2008), sorghum
(Aditi et al., 2009, unpublished), soybean and groundnut (Bhatia et
al., 2009, unpublished), and even coconut (Kumar et al., 2008). The
key features of adaptation of the model for mustard are given here.

2.1.1. Phenological development

The total development of mustard crop model has been quanti-
fied based on development stages (DSs), a dimensionless variable
having a value of 0 at sowing, 0.1 at seedling emergence, 1.0 at
flowering and 2.0 at maturity (Keulen and Seligman, 1987).
The daily rate of phenological development is a function of ther-
mal time, which is modified by day and night temperatures and
nitrogen and water stress experienced by the crop. Optimum tem-
perature for crop growth is 20–25 °C, but the crop can tolerate
maximum temperature up to 40 °C. Whole life cycle of mustard
plant has been divided into three development stages (DSs), sowing
to seedling emergence, seedling emergence to flowering and flow-
ering to maturity. Rate of development of each phase is controlled
by the user-specified thermal time.

2.1.2. Dry matter production

The leaf and root weights at seedling emergence are initialized
based on the user-specified seedling rate. A seed rate of 5 kg ha−1
was used as an input in the model. Growth rate of the crop was cal-
culated as a function of radiation use efficiency, photosynthetically
active radiation, leaf area index, radiation captured by the pests and
a crop/cultivar specific extinction coefficient.

2.1.3. Dry matter partitioning among plant organs

The net dry matter available at each day for crop growth is parti-
tioned into roots, leaves, stems and storage organs as a crop-specific
function of development stage. Allocation is first made to roots
and then remaining dry matter is allocated to shoot from which a
fraction is allocated to leaves, stems and storage organs.

Table 1

<table>
<thead>
<tr>
<th>Soil</th>
<th>Plant</th>
<th>Weather (daily)</th>
<th>Crop management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three soil layers depth (mm), organic carbon (%), soil texture (sand, silt, clay%), bulk density, initial soil NH4–N and NO3 content</td>
<td>Seed rate, specific leaf area and test grain weight (g)</td>
<td>Maximum and minimum temperature (°C), solar radiation (kJ m−2 d−1), vapour pressure (kPa), wind speed (m s−1), and rainfall (mm)</td>
<td>Date of sowing, dates and amount of irrigation and fertilizer application</td>
</tr>
</tbody>
</table>
2.1.4. Leaf growth and senescence

The leaf area index is calculated by multiplying the leaf weight with the pre-defined, crop age dependent specific leaf area. Simulation of senescence is based on several empirical constants relating to shading, ageing, nitrogen mobilization, temperature, water stress and death due to pests and diseases. Higher or lower temperatures than optimal and water and nitrogen stresses can accelerate rate of senescence.

2.1.5. Dry matter accumulation in storage organs

Storage organs (SOs) are formed during a crop-specific period, shortly before anthesis. Net growth during this period and a crop-specific factor relating to storage organ to growth are utilized to calculate the increase in the number of SO. A part of the storage organ formed could be lost due to pests’ attack and adverse temperatures. In InfoCrop, a part of the storage organ becomes sterile if either maximum or minimum temperatures of the day deviate from their respective threshold values during a short period between anthesis and a few days afterwards.

2.2. Model input requirements

See Table 1.

2.3. Model output and verifiable variables

The standard output comprises of dry weight of roots, stems, leaves, grain number and grain yield, leaf area index, N uptake by crop, soil water and N content, evapotranspiration, N and water stress.

2.4. Calibration and validation of model

Two field experiments dealing with water and nitrogen levels and dates of sowing were conducted for calibration and validation of the model. These experiments were conducted during 2005–2006 and 2006–2007 at I.A.R.I., research farm, New Delhi, India. New Delhi has a semi-arid, sub-humid and sub-tropical climate with hot dry summers and severe cold winters. The soil reaction of experimental site was slightly alkaline with low electrical conductivity values and sandy clay loam in texture (Typic Haplusept). Soil was medium in organic carbon content and available nitrogen.

Data on phenology, leaf area, dry matter partitioning and yield were collected for calibration of the model. Crop coefficients for mustard were calculated by using information from a wide literature survey. Further calibration of these coefficients was done by the observations recorded from the field experiment conducted in 2006–2007. These coefficients were used in the subsequent validation and application.

Besides this, performance of the model was also tested against several field experimental data sets collected from All India Coordinated Research trials conducted at various mustard growing regions of the country (Hisar, Ludhiana, Kanpur, Sriganganagar, Delhi, Gwalior, Pantnagar, Akola and Varanasi). Management practices relating to date of sowing, time and amount of application of irrigation and nitrogen as measured in different treatments were given as inputs for validation of the model. These experiments were conducted over a period of 9 years (1992–2000). Maximum temperature in these locations varied from 9.8 to 37.9 °C, whereas minimum temperatures varied from 0.4 to 23.5 °C during mustard growing period. Rainfall during the cropping season varied from 2.3 to 79.3 mm. The experiments consisted of several treatments varying on dates of sowing, irrigation and nitrogen dose. Weather data for these locations was collected from the concerned research
stations. Database used for calibration and validation of the model is given in Table 2.

2.5. Statistical analysis

Model performance using the coefficients developed was evaluated by calculating different statistical parameters viz. Coefficient of Determination ($R^2$), Residual Mean Square Error (RMSE) (Fox, 1981), Coefficient of Residual Mass (CRM), $D$-index (Willmott, 1982) and Model Efficiency (EF) (Kabat et al., 1995 and Singh et al., 2003). The $R^2$ of conventional statistics was used to estimate the linearity between measured and simulated values. The RMSE describes mean absolute deviation between simulated and observed and accuracy of simulation is characterized by lower RMSE. CRM value provides a comparison of the observed and simulated values and gives the ideal value of zero when observed and predicted values are equal. The $D$-index value ranges from 0 to 1, is another method of evaluating modeling performance. Model efficiency is another method to evaluate the model in terms of the accuracy of its prediction. It allows negative values and compares the deviation between simulated and observed state variables with the variance of observed values. Maximum value of EF is 1.

2.6. Impact assessment

2.6.1. Calibrated change in temperature and CO$_2$

The validated model was tested for its sensitivity to atmospheric CO$_2$ and temperature in scenarios of climate change. The effect of change in temperature and CO$_2$ was studied in irrigated and rainfed mustard for gradual increase in CO$_2$ (369, 450 and 550 ppm) and temperature (0, 1, 2, 3, 4 and 5 °C) during the entire crop growth period. Weather and agronomic management practices vary considerably in different parts of India, which influences crop growth and yield. So, three locations were identified for the study in mustard growing tract of the country. These three locations are situated in northern, central and eastern part of the country. Ganganagar of Rajasthan represented northern, Gwalior in Madhya Pradesh for central and Kolkatta in West Bengal for eastern region of India (Map 1).

2.6.2. Climate change scenarios

Impact of projected climate change scenarios was assessed by running the regional validated (HadCM$_3$) model for 2020, 2050 and 2080. The functions were from the output of the regionally validated HadCM$_3$ model under A1, A2 and B2 emission scenarios. Under A1 emission scenario is characterized by rapid economic growth with population increase till 2050. Under A2 emission scenario has continuous population rise along with regionally oriented economic development, while in B2 emission scenario rate of population growth is less than A2 emission scenario.

Projected temperature rise during the mustard growing season is given in Table 3 for different locations. Projected rainfall also varied in all three regions during rabi season. Impact of changing climate on mustard crop in these three scenarios was assessed and mean values of change in yield were calculated.

2.6.3. Climate change adaptations

Two adaptation strategies (S1 – late sowing by 7 days and S2 – long-duration variety) were selected and crop model was run for future climate change scenarios. Yield loss of irrigated mustard was compared with current as well as with adaptation measures.

### Table 3

Projected mean temperature rise (°C) during mustard growing season in A1, A2 and B2 scenarios.

<table>
<thead>
<tr>
<th>Location</th>
<th>2020</th>
<th>2050</th>
<th>2080</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern India</td>
<td>1.3</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Central India</td>
<td>1.5</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Eastern India</td>
<td>1.5</td>
<td>1.0</td>
<td>1.3</td>
</tr>
</tbody>
</table>

### Results and discussion

3.1. Calibration of model

InfoCrop-mustard was calibrated satisfactorily by specific crop growth parameters. Results showed that InfoCrop model was in general able to simulate the temporal change of leaf area and dry
matter production satisfactorily in all three treatments (Fig. 1). The model also satisfactorily simulated mustard phenology and yield with and without aphid infestation (Table 4).

3.2. Validation

3.2.1. Phenology

3.2.1.1. Days to 50% flowering. Simulated days to 50% flowering were compared with observed data for both normal and late sown crop. The observed flowering duration varied from 42 to 64 days while simulated one ranged from 43 to 65 days. This result showed that the model was able to simulate flowering period reasonably well for all treatments (slope = 0.9013; intercept = 4.9; $R^2 = 0.87$). However, in some treatments of late sown crop, the model underestimated the days to 50% flowering of mustard. The RMSE was 2.1 against the mean value of 52.18 days.

3.2.1.2. Days to physiological maturity. InfoCrop-mustard model satisfactorily simulated days to physiological maturity. The observed and simulated values varied from 116 to 134 and from 110 to 137 days respectively. Simulated number for days to physiological maturity in different agro-ecological zones was also in satisfactory agreement (slope = 0.8253; intercept = 23.2; $R^2 = 0.82$) with the observed value. The model slightly underestimated number of days to physiological maturity for normal sown crop in Delhi and Sriganganagar region. In late sown crop, the simulated days to maturity were found to be higher than the observed one, irrespective of the region. RMSE was 4.3 against a mean value of 134.8.

Table 4
Calibration of InfoCrop-mustard model for phenology and yield.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Days to 50% flowering (days)</th>
<th>Days to maturity (days)</th>
<th>Yield without aphid infestation (kg ha$^{-1}$)</th>
<th>Yield with aphid infestation (kg ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 1st sown</td>
<td>49</td>
<td>48</td>
<td>130</td>
<td>128</td>
</tr>
<tr>
<td>October 15th sown</td>
<td>51</td>
<td>50</td>
<td>132</td>
<td>131</td>
</tr>
<tr>
<td>November 1st sown</td>
<td>53</td>
<td>55</td>
<td>134</td>
<td>136</td>
</tr>
</tbody>
</table>
Table 5
Statistical estimates for the comparison of observed and simulated parameters.

<table>
<thead>
<tr>
<th>Statistical estimates</th>
<th>Days to anthesis (days)</th>
<th>Days to maturity (days)</th>
<th>Leaf area index</th>
<th>Dry matter production (Mg ha$^{-1}$)</th>
<th>Seed yield (Mg ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R^2$ value</td>
<td>0.87</td>
<td>0.83</td>
<td>0.75</td>
<td>0.96</td>
<td>0.86</td>
</tr>
<tr>
<td>RMSE</td>
<td>2.11</td>
<td>4.37</td>
<td>0.46</td>
<td>0.49</td>
<td>0.26</td>
</tr>
<tr>
<td>$D$-Index</td>
<td>0.96</td>
<td>0.95</td>
<td>0.93</td>
<td>0.98</td>
<td>0.96</td>
</tr>
<tr>
<td>CRM</td>
<td>0.004</td>
<td>0.002</td>
<td>0.06</td>
<td>-0.13</td>
<td>-0.05</td>
</tr>
<tr>
<td>EF</td>
<td>0.86</td>
<td>0.82</td>
<td>0.75</td>
<td>0.92</td>
<td>0.83</td>
</tr>
</tbody>
</table>

3.2.2. Growth and yield

3.2.2.1. Leaf area index (LAI). InfoCrop model was evaluated for leaf area index (LAI) of mustard measured at different crop growth stages. The simulated LAI at different crop growth stages followed similar pattern as that of measured LAI in all the treatments. There was good agreement between the measured and simulated values of maximum LAI (slope = 0.9066; intercept = 0.05; $R^2 = 0.75$). RMSE of LAI was 0.46 showing relatively less error in simulation.

3.2.2.2. Dry matter production. Simulated values of total biomass of mustard in different treatments were in good agreement with the corresponding measured values (slope = 1.002; intercept = 0.30; $R^2 = 0.95$). Observed values of total dry matter varied from 0.29 to 7.05 Mg ha$^{-1}$ in different locations for both irrigated and rainfed crop, while simulated dry matter yield ranged from 0.28 to 7.22 Mg ha$^{-1}$.

3.2.2.3. Yield. InfoCrop model was validated for simulating mustard yield for different locations using wide range of yield data for different agronomic management practices (dates of sowing, N level) for both irrigated and rainfed crop. Observed grain yield of mustard varied from 0.25 to 2.87 t ha$^{-1}$ while simulated values ranged from 0.26 to 3.14 Mg ha$^{-1}$. The simulated and observed values showed a good agreement (slope = 0.9346; intercept = 0.19; $R^2 = 0.85$) and the estimation error was within the acceptable limits. The least yield was observed in Akola (Maharashtra) under rainfed condition without any fertilizer application. Maximum yield was observed in Kanpur (Uttar Pradesh) with 120 kg N application under irrigated condition. Model simulated grain yield was satis-

![Fig. 2. Effect of CO$_2$ and temperature on simulated yield of irrigated and rainfed mustard in different locations in India.](image-url)
factory at all the regions, barring some variation in few treatments at Ludhiana, Hisar and Kanpur. Statistical evaluation of the model is given in Table 5. High $R^2$ values (0.75–0.96) indicate good linear agreement between observed and simulated data. In all the cases, $D$-index value was found to be closer to 1. This showed a good simulation by the model. Model efficacy values ranged from 0.75 to 0.92 (closer to 1) showing good performance of the model. CRM values ranged from −0.13 to 0.06 showing slight error of under and over estimation. From the statistical estimates, it is confirmed that InfoCrop-mustard model can be used to predict phenology (days to 50% flowering and days to maturity), growth (leaf area index, total dry matter production) and grain yield, effectively after calibration of the model defined cultivar specific coefficients.

3.3. Impact assessment

Simulated yield showed that the mustard crop is much sensitive to rise in temperature and CO2. In all three regions, increasing temperature reduced mustard grain yield, while increase in CO2 concentration increased crop yield. Increase in CO2 from 369 to 550 ppm with no change in temperature has resulted in 15.8–31% increase in yield of irrigated mustard across different regions. Positive yield response of mustard to elevated carbon dioxide was due to, increased photosynthetic activity resulting in increased specific leaf area, leaf weight, biomass production and grain number. But the positive effect of increase in CO2 concentration was nullified by temperature rise. Under irrigated condition, the grain yield dropped steeply with rise in temperature in eastern India. In this region, yield reduction was maximum (86.6%) with 5°C rise in temperature. Rise in temperature coupled with rise in CO2 to 450 and 550 ppm decreased yield reduction to 82.4 and 79.4% respectively. Yield reduction of mustard was moderate in northern part of the country (Fig. 2). In north India, temperature rise by 5°C, with no rise in CO2 reduced mustard yield by 34.7%. Rise in CO2 along with temperature caused less yield reduction of mustard in this region. Mustard crop grown in central part of the country was also vulnerable to temperature rise, where substantial yield loss was observed. Temperature rise would be most harmful for the crop in eastern region, followed by central India, where winter season temperature is comparatively higher than northern region. Further rise in temperature in these locations would cause substantial yield reduction in this crop.

Under rainfed condition, temperature increase also caused substantial yield loss in mustard crop. Similar to irrigated crop, rainfed mustard would be most affected by temperature rise in eastern India with yield loss of 78.4% with 5°C rise in temperature (Fig. 2). Substantial yield loss would also occur in central India with a loss of 40.2% yield. Rainfed mustard was less vulnerable to temperature rise in northern India as compared to other two locations. Thus, rise in temperature by 5°C caused yield reduction by 20.9% which got reduced to 8.5 and 7.3% with increase in CO2 level to 450 and 550 ppm respectively. Rise in CO2 coupled with rise in temperature caused less yield reduction due to the beneficial effect of CO2 on crop growth and yield. Rise in atmospheric temperature reduced leaf area index, grain number as well as weight of grains which was in turn reflected in yield of the crop. The sensitivity response of the model to CO2 and temperature changes followed the various experimental results obtained from climate change studies in mustard.
Similar results were reported by earlier workers (Kimball, 1983; Mishra et al., 1999; Upreti et al., 2003) who found that increase in CO₂ concentration leads to changes in crop physiological processes thus affecting crop yield. According to Rottet and Van de Geijn (1999) and Jacobs and DeBruin (1992) rise in CO₂ accompanied by temperature increase might decrease plant growth and increase transpiration rate causing crop yield reduction. Aggarwal et al. (2006b) also reported that yield reduction in rice and wheat crop is attributed to reduction in leaf area index and grain number with rise in temperature. According to Morrison and Stewart (2002), increased temperature during bolting to flowering period reduced yield of all Brassica spp.

Under future climate change scenarios, the projected yield is likely to reduce in both irrigated and rainfed crop. Simulated data showed a spatial variation in yield among all the three regions (Figs. 3 and 4). Yield reduction in future climate change scenarios at different locations of India were primarily attributed to reduction in crop growth period due to rise in temperature in irrigated mustard. Under irrigated condition the yield reduction in 2020, 2050 and 2080 would be highest in eastern India. Under the all three climate change scenarios yield reduction of mustard was maximum in eastern part of the country. In 2080 maximum yield loss (67%) was observed in eastern India under A1 climate change emission scenario followed by A2 emission scenario where yield loss was 63% (Fig. 3). This is due to maximum projected rise in mean temperature in 2080 in eastern India in A1 emission scenario where temperature would rise by 5.7 °C while in A2 emission scenario, the projected rise would be 5.3 °C (Table 3). Increased temperature in future scenarios caused early flowering resulting in reduced seed yield in this region. In central India moderate yield reduction is observed with values ranging between 13.3 and 14.7% in 2080 in three different scenarios. The predicted yield loss of irrigated mustard, in northern part of the country is 21.4, 15.7 and 11.2% in A1, A2 and B2 emission scenarios respectively. Under A1 emission scenario predicted temperature rise is maximum in 2080 (5.6 °C), which caused maximum yield reduction. Temperature during the crop growth period is lower in northern India, which might have caused less yield loss in this region as compared to eastern region.

Rainfed mustard would also suffer from yield loss in future climate change scenarios. Impact of variation in rainfall in future scenarios was observed in simulated yield of rainfed mustard. Similar to irrigated mustard maximum yield loss in rainfed crop would also occur in eastern India in 2080. Predicted yield loss in rainfed mustard was higher than irrigated mustard in all the locations except eastern India. Due to increase in rainfall in eastern region irrespective of all scenarios, the rainfed yield reduction would be same like irrigated conditions. In northern and central India, rainfall is projected to decrease in 2020, 2050 and 2080 irrespective of the climate change scenarios. This caused substantial yield reduction in rainfed mustard in this region. In 2080 yield loss is projected between 29.8–40.4% in northern India and 31–42.5% in central India and maximum yield loss would occur in eastern India (57%) (Fig. 4).

Increasing temperature lowered days to flowering and days to maturity, which in turn lowered total crop duration. In plants, warmer temperature accelerates growth and development leading to less time for carbon fixation and biomass accumulation before seed set resulting in poor yield (Rawson, 1992; Morrison, 1996). Simulated results also confirmed reduction in leaf area index with climate change which in turn lowered the radiation use efficiency (RUE) of the crop. Less leaf area together with low RUE has lowered net photosynthesis and finally reducing total dry matter production of mustard crop. Pidgeon et al. (2001) also reported that changes in climate affect crop radiation use efficiency (RUE). Spatial variation in temperature as well as rainfall and its distribution led to spatial variation in yield reduction. This study supports the recent report of the IPCC and a few other global studies which indicate a probability of 10–40% loss in crop production in India with increase in temperature by 2080–2100 (Fischer et al., 2002; Parry et al., 2004; IPCC, 2007). Simulation study conducted by Singh et al. (2008) also revealed that with rise in temperature, rain becomes the deciding factor in regulating crop production. It is envisaged that the increase in temperature, if any, may be compensated by increase in rainfall.

Five adaptation strategies were tested to improve the mustard yield against climate change. Among that the three adaptation strategies such as 50% increasing recommended fertilizer (120 kg ha⁻¹) as basal as well as split dose (basal, 30 and 60 DAS) and increasing one more irrigation (1, 30, 60 DAS) and increasing one more irrigation (1, 30, 60 DAS) did not help in improving mustard yield in future climate change scenarios. Then, it should be clearly stated that such adaptation strategies, which will certainly be adopted by farmers in a yield decline situation due to climate change, will not be useful for sustenance of the crop production.

Another two adaptation strategies, (S1 – late sowing by 7 days and S2 – long-duration variety) were tested to study their effect on yield loss of irrigated mustard. Both the adaptation measures are found to prevent yield loss to certain extent irrespective of the climate change scenarios. Yield loss would be less with adaptation measures in central and northern India in all the future scenarios (Table 6). In eastern region, adoption of adaptation measures could prevent yield loss in 2020 and 2050, while in 2080 they could not prove to be beneficial. The adaptation strategy of sowing late could be able to increase yield by 1% compared to current in northern India in 2020, while in 2050 and 2080 it decreased mustard yield loss considerably. Under climate change scenarios temperature rise has caused reduced grain number in mustard which was ultimately reflected in its yield. But temperature during anthesis period of late sown mustard was less than that of normal sown mustard. This has reduced yield loss of mustard in future climate change scenarios. Rise in temperature in future climate change scenarios has caused early maturity of the crop which has resulted in fewer yields. This happened for both normal as well as long-duration variety. But in long-duration variety maturity occurred later than that of the existing variety. So yield loss was also less than the existing one. This shows that adoption of these two adaptation measures would cause less yield loss in mustard crop.

4. Conclusions

Results from this simulation study revealed that InfoCrop model can successfully simulate growth and yield of mustard crop across different locations in India. Simulated yield of mustard was found to be sensitive to changes in atmospheric CO₂ and temperature. Yield of mustard increased with elevated CO₂ concentration, while the positive effect of increased CO₂ was nullified by temperature rise.

### Table 6

<table>
<thead>
<tr>
<th>Region</th>
<th>Year</th>
<th>S1</th>
<th>S2</th>
<th>S1</th>
<th>S2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern India</td>
<td>2020</td>
<td>–3.2</td>
<td>–3.0</td>
<td>–6.6</td>
<td>–3.6</td>
</tr>
<tr>
<td>Central India</td>
<td>2020</td>
<td>–1.4</td>
<td>–0.5</td>
<td>–2.1</td>
<td>–1.1</td>
</tr>
<tr>
<td>Eastern India</td>
<td>2020</td>
<td>–9.9</td>
<td>–3.6</td>
<td>–37.4</td>
<td>–31.4</td>
</tr>
<tr>
<td>Current</td>
<td>2050</td>
<td>1.0</td>
<td>–0.4</td>
<td>–2.6</td>
<td>–6.6</td>
</tr>
<tr>
<td>Current</td>
<td>2080</td>
<td>–3.0</td>
<td>–2.6</td>
<td>–9.4</td>
<td>–8.6</td>
</tr>
<tr>
<td>Current</td>
<td>2020</td>
<td>–3.0</td>
<td>–2.6</td>
<td>–9.4</td>
<td>–8.6</td>
</tr>
<tr>
<td>Current</td>
<td>2050</td>
<td>–3.0</td>
<td>–2.6</td>
<td>–9.4</td>
<td>–8.6</td>
</tr>
<tr>
<td>Current</td>
<td>2080</td>
<td>–3.0</td>
<td>–2.6</td>
<td>–9.4</td>
<td>–8.6</td>
</tr>
</tbody>
</table>

S1 – late sowing by 7 days and S2 – long-duration variety.
The above result supports the adverse impacts of future anticipated climate change on mustard growth and yield. An overall negative impact on India’s mustard farming is observed from 2020, through 2050 till 2080. Yield of both irrigated and rainfed mustard would be affected in the changing climate. Spatial variation was noticed in terms of its yield loss with eastern India being more vulnerable in term of yield reduction of the crop. Adaptation strategies like late sowing and growing longer duration variety would be helpful in preventing yield loss of irrigated mustard crop in different locations. But other adaptation strategies such as 50% increase in recommended fertilizer as basal as well as split dose and increasing one more irrigation did not help in improving mustard yield in future climate change scenarios. Further the assessment of climate change on Indian agriculture can be more precise and provide sound basis for regional policy planning.

Acknowledgement

We wish to acknowledge the University Grants Commission (UGC) of India for providing financial support for this research.

References


