IMPACT OF CLIMATE CHANGE ON INDIAN MUSTARD (*BRASSSICA JUNCEA*) IN CONTRASTING AGRO-ENVIRONMENTS OF THE TROPICS

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ABSTRACT:

The fourth assessment report of IPCC (Intergovernmental Panel on Climate Change) makes it clear that the global average temperature has been increased by 0.74^0C over the last 100 years and projected temperature increase is about 1.8 to 4^0C by 2100. It is very likely that all regions will experience either declines in net benefits or increases in net costs for increases in temperature greater than about 2-3^0C. The developing countries are expected to experience larger percentage losses, global mean losses could be 1-5% GDP for 4^0C of warming (IPCC, 2007).This paper presents the impact of climate change on Indian mustard (*Brassica juncea*) in contrasting agro-environments of the tropics by using InfoCrop (a dynamic crop simulation model) . Impact of projected climate change scenarios ($HadCM_3$ out put of A_2a scenario) was assessed by running the regional validated model for 2020, 2050 and 2080 at five locations of India which comprises of three in the IndoGangetic plains (IGP), comprising of Delhi in northern IGP, Lucknow in central IGP and Calcutta in eastern IGP. Other two locations are mustard growing region in western India (Sriganganagar in Rajasthan) and central India (Gwalior in Madhya Pradesh). Simulated results showed a spatial variation in yield among all five regions in both irrigated and rainfed mustard. Under irrigated condition the yield reduction in 2020, 2050 and 2080 would be highest in eastern-IGP region followed by central-IGP. This was due to maximum projected rise in temperature in eastern-IGP where maximum and minimum temperature would rise by 5.1° and 5.6°C in 2080. The reduction of irrigated mustard yield was least in northern-IGP under almost all scenarios. But in western India, yield reduction gradually increased from 2020 to 2080. In future climate change scenarios rainfall was projected to increase in 2050 irrespective of the locations. But in 2020 and 2080 rainfall would reduce in northern-IGP, western and central India. This was reflected in higher reduction rainfed mustard yield in these 3 locations. But maximum yield loss would occur in eastern-IGP in 2080 which might be attributed to maximum temperature rise in this region. 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 was observed from 2020, through 2050 till 2080. Yield of both irrigated and rainfed mustard was affected by the changing climate. Spatial variation was noticed in terms of its yield loss with western and northern India being more vulnerable in term of yield reduction of the crop.

1. INTRODUCTION

The diverse agro-ecological conditions in India are favorable for growing nine annual oilseeds, which include seven edible oilseed, *viz.*, groundnut, rapeseed-mustard, soybean, sunflower, sesame, safflower and niger and two non-edible oil sources *viz*., castor and linseed. Apart from this, a wide range of other minor oilseeds of horticultural and forest origin, including in particular coconut and oil palm are grown in the country. The country ranks first in the world in the production of castor, safflower, sesame and niger, second in groundnut and rapeseed, third in linseed and fifth in soybean and sunflower (Hedge, 2005). The oil seed scenario in the country has undergone a sea change in the last 18 years. India changed from net importer in 1980s to a net exporter status during early 1990s. Again, it is back to net importer status importing more than 40% of its annual edible oil needs. The main contributors to such transformation up to early nineties have been (i) availability of improved oilseeds production technology and its adoption (ii) expansion in cultivated area (iii) price support policy and (iv) institution support, particularly establishment of Technology Mission on Oilseed (TMO) in 1986. But there was decline and/or stagnation in yield causing negative growth rate from 1997 onwards due to unfavorable monsoon which create moisture stress (drought and excess rain fall), temperature increases etc. Mustard is very sensitive to climatic variables and hence climate 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 unfavorable monsoon which create moisture stress (drought and excess rain fall) 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 very recent paper, it has been shown that in coming decades fungicide treated oilseed rape crops will show an increase in yield of up to 0.5t/ha in Scotland while associated rising temperature will increase severity of stem canker disease which is likely to lead to decreased yields in southern England (Butterworth et al., 2009). A crop growth model was combined with a disease epidemic models and climate change forecasts for the 2020s and 2050s to derive these results. To

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quantify the impact of climate change on crops needs simulation model, because it provides a means to quantify the effects of climate, soil and management on crop growth, productivity and sustainability of agricultural production. These tools can reduce the expensive and time-consuming field experimentation as they can be used to extrapolate the results of research conducted in one season or location to other seasons, locations, or management.

Many crop simulation models have been evaluated and used as a research tool to assess risks associated with various management strategies, and to assist decision-making process. InfoCrop, a generic dynamic crop model, has been developed to meet these specific requirements. It provides integrated assessment of the effect of weather, variety, pests, soil and management practices on crop growth and yield, as well as on soil nitrogen and organic carbon dynamics in aerobic as well as anaerobic conditions, and greenhouse gas emissions. The model considers the key processes related to crop growth, effects of water deficit, flooding, nitrogen management, temperature and frost stresses, crop-pest interactions, soil water and nitrogen balance and (soil) organic carbon dynamics. Its general structure relating to basic crop growth and yield is largely based on several earlier models, especially SUCROS series, and is written in Fortran Simulation Environment (FSE) programming language. The model has been validated for dry matter and grain yields of several annual crops, losses due to multiple diseases and pests, and emissions of carbon dioxide, methane and nitrous oxide in a variety of agro-environments. 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.

2. MATERIALS AND METHODS

2.1. Model Description

InfoCrop is considering the processes such as of growth and development(phenology, photosynthesis, partitioning, leaf area growth, storage organ numbers, source: sink balance, transpiration, uptake, allocation and redistribution of nitrogen), effects of water, nitrogen, temperature, flooding and frost stresses on crop growth and development**,** crop-pest interactions (damage mechanisms of insects and diseases), soil water balance, soil nitrogen balance, soil organic carbon dynamics, emissions of green house gases and climate change module. The basic model is written in Fortran Simulation Translator programming language (FST/FSE; Graduate School of Production Ecology, Wageningen, The Netherlands), a language also adopted by the International Consortium for Agriculture Systems Application (ICSA) as one of the languages for systems simulation (Jones *et al*., 2001). Another version of the model has been developed to facilitate its greater applications in agricultural research and development by the stakeholders not familiar with programming. The user-interface of this software has been written using Microsoft. Net framework while the back-end has FSE models and databases in MS-Access. More details of the model are provided by Aggarwal *et al*. (2006a, b).

2.1.1 Model input requirements: Soil: For three soil layers depth (mm), organic carbon (%), soil texture (sand, silt, clay %), bulk density and NH_4-N and NO_3-N content is needed.

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

Daily weather: Minimum and maximum air temperature (^oC), solar radiation ($KJm^{-2}d^{-1}$) vapour pressure (kPa), wind speed (ms^{-1}) and rainfall (mm).

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

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

2.1.3 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 in I.A.R.I, research farm, New Delhi. 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 theses coefficients was done by the observations recorded from the field experiment conducted in 2006 -07. These coefficients were used in the subsequent validation and application.

2.2. Impact Assessment

The impact of projected climate change scenarios were assessed by running the regional validated model for 2020, 2050 and 2080. The projected climate change scenarios for maximum and minimum temperature, rainfall were identified for 2020, 2050 & 2080. The scenarios were put into the model through mathematical function. Separate functions were drawn for different agro-ecological zones under study. The functions were from the output of the $HadCM_3$ model for A_2a scenario. A2 scenario is characterized by continuous population rise along with regionally oriented economic development. The projected CO_2 concentration for 2020, 2050 and 2080 scenarios were also put into the model. The projected CO_2 concentrations used in this study were 414, 522 and 682ppm at 2020, 2050 and 2080 respectively.

3. RESULTS AND DISCUSSION

3.1. Irrigated Mustard

Model has been calibrated and validated with field experiments and the Statistical evaluation of the model is given in Table 1. 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 0.75-0.92 (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.

Statistical Estimates	Days to Anthesis (Days)	Days to maturity (Days)	Leaf Area Index	Dry Matter Production ($t\ ha^{-1}$)	Seed Yield ($t\ ha^{-1}$)
R^2 value	0.87	0.83	0.75	0.96	0.86
RMSE	2.11	4.37	0.46	0.49	0.26
D - index	0.96	0.95	0.93	0.98	0.96
CRM	0.004	0.002	0.06	- 0.13	- 0.05
EF	0.86	0.82	0.75	0.92	0.83

Table 1: Statistical Estimates for the Comparison of Observed and Simulated Parameters

From the statistical estimates it is conformed 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 co-efficients. After that the model has been used for climate change impact assessment. In future climate change scenarios projected yield is likely to reduce in both irrigated and rainfed crop. Simulated data showed a spatial variation in yield among all five regions. Yield reduction in future climate change scenarios in different locations of India was primarily attributed to reduction in crop growth period with rise in temperature in irrigated mustard. Under irrigated condition (Fig 1) the yield reduction in 2020, 2050 and 2080 would be highest in eastern-IGP (9.9%, 37.4%, 63.1%) region followed by central-IGP. This was due to maximum projected rise in mean temperature in 2080 in eastern-IGP in A1 and A2 scenarios where temperature would rise by 5.7° and 5.3°C respectively (Table 2). Increased temperature in future scenarios caused early flowering resulting in reduced seed yield in this region. In 2080 yield reduction in irrigated mustard was least (11.8% in A1, 8.3% in A2 and 8.6% in B2) in northern-IGP. Temperature during the crop growth period is lower in northern-IGP, which might have caused less yield loss in this region. Central and western India, showed moderate yield reduction in 2080 with values simulated as 14.7% and 15.7% respectively.

Location	2020	2050	2080
Northern IGP	1.4	2.6	4.4
Central IGP	1.1	2.6	4.3
Eastern IGP	1.0	3.0	5.3
Central India	1.3	2.5	4.5
Western India	1.5	2.7	4.7

Table 2: Projected Mean Temperature Rise (°C) During Mustard Growing Season in A_2a Scenario

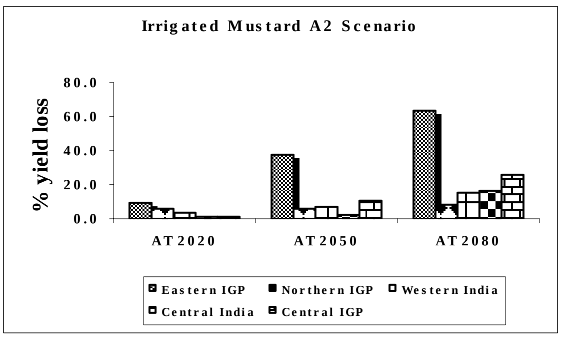

Figure 1. Percentage Yield Reduction of Irrigated Mustard due to Climate Change in India

3.2. Rainfed Mustard

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. In future climate change scenarios rainfall was projected to increase in 2050 irrespective of the locations. But in 2020 and 2080 rainfall would reduce in northern-IGP, western and central India. This was reflected in yield loss of rainfed mustard in these 3 locations where yield loss in 2080 will be 53.4%, 40.3%, 48.2% (Fig 2). But maximum yield loss would occur in eastern-IGP (57%) in 2080, which might be attributed to maximum temperature rise in this region. Yield of rainfed mustard was least affected in central-IGP, which is due to the fact that projected rainfall would increase in this region irrespective of the scenarios. 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 was observed from 2020, through 2050 till 2080. Yield of both irrigated and rainfed mustard was affected by the changing climate. Spatial variation was noticed in terms of its yield loss with western and northern India being more vulnerable in term of yield reduction of the crop.

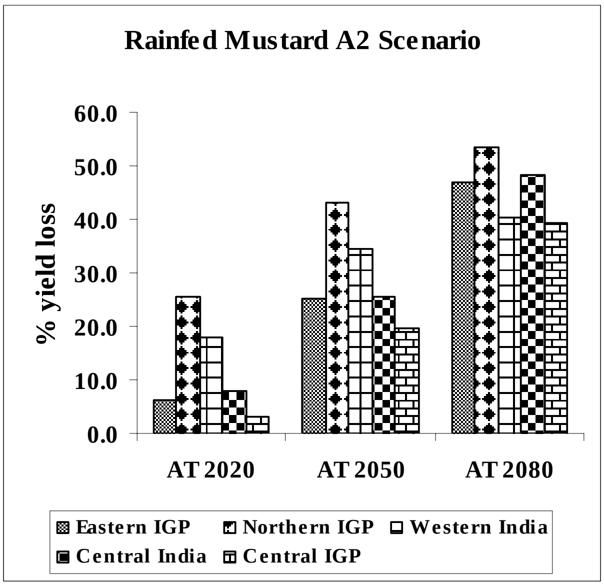

Figure 2. Percentage Yield Reduction of Rainfed Mustard due to Climate Change in India

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 support 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 deciding factor in regulating crop production. It is envisaged that the increase in temperature, if any, may be compensated by increase in rainfall.

4. SUMMARY AND CONCLUSION

Results from this simulation study support the adverse impacts of future anticipated climate change on mustard growth and yield. An overall negative impact on India's mustard farming was observed from 2020, through 2050 till 2080. Yield of both irrigated and rainfed mustard was affected by the changing climate. Spatial variation was noticed in terms of its yield loss with western and northern India being more vulnerable in term of yield reduction of the crop. The potential adaptation strategies have to be identified to overcome the detrimental impacts of climate change on mustard yield, thereby nullifying the pressure on food demand. In future climate change studies, the uncertainties and limitations are to be considered in the crop simulation modeling and climate change scenarios. The assessment of climate change on Indian agriculture can be more precise and provide sound basis for regional policy planning.

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