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InfoCrop – a crop simulation model for assessing the climate change impacts on crops

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ABSTRACT

This study presents results of evaluation in terms of its validation and impact of climate change on Indian mustard (*Brassica juncea*), sorghum (*Sorghum vulgare*) and maize (*Zea mays*) by using the crop simulation model, '*InfoCrop'*. Simulated results of mustard model showed a spatial variation in yield among all five regions in both irrigated and rainfed mustard. Under irrigated conditions, the yield reduction in 2020, 2050 and 2080 would be highest in Eastern-IGP (Indo-Gangetic Plain) 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, the rainfall would be 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 higher yield reduction in rainfed mustard in these three locations. In sorghum, the future climate change scenario analysis showed that the yields (CSH 16 and CSV 15) are likely to reduce at Akola, Anantpur, Coimbatore and Bijapur. But yield of CSH 16 will increase slightly in Gwalior (0.1%) at 2020 and thereafter it will decline. At Kota the sorghum yield is likely to increase in 2020 (3.3 and 1.7 % in CSH 16 and CSV 15 respectively) with no change in 2050 and yields will be reduced at 2080 in both varieties. Maize trend is similar from the sorghum impact except in the UIGP where rainfall could be projected to increase in the future. In MIGP and SP(Southern Plateau), expected reduction would be 5%, 13%, 17% and 21%, 35%, 35% in 2020, 2050 and 2080 respectively from the current level.

Key Words**:** Climate change, *InfoCrop*, validation, simulation, scenario

Climate is usually defined as the average weather or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The climate change refers to a statistically significant variation in either the mean stage of the climate or in its variability, persisting for an extended period. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Constant increase in greenhouse gases concentrations, since pre-industrial times, has led to positive radiative forcing of the climate, tending to warm the surface.

The fourth assessment report of IPCC (Intergovernmental Panel on Climate Change) confirmed the rise in atmospheric temperature by 0.74 ^{0}C over the last 100 years due to global warming and projected a temperature increase of 1.8 to 4 ^{0}C by 2100. Global warming induces events such as frequent occurrence of warmest year, heavy intensity rainfall, flash flood, frost, etc., posing potential threat to ecosystems especially, agricultural production and productivity throughout the world. Agricultural production is the most sensitive and vulnerable to climate change, as climate is the primary determinant of agricultural productivity (Watson *et al.,* 1996). Crop productivity is projected to decrease for the increase of local temperature (1-2 ^{0}C) at lower latitudes, especially in seasonal dry and tropical regions of the world (IPCC, 2007).

The crop simulation models are useful tools for considering the complex interactions between a range of factors that affect crop performance, including weather, soil properties and crop management (Shamim *et al.,* 2012). ***InfoCrop***- a crop simulation model is used to study the impact and adaptation of climate change on mustard, sorghum and maize to climate change in India. 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.

MATERIALS AND METHODS

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 adapted 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*. (2006 a and b).

Calibration and validation of model

The field experiments dealing with water and nitrogen level, dates of sowing, mustard aphid population and their interactions on mustard growth and yield were used to calibrate and validate the model. The field experimental data from different mustard growing regions of India (Hisar, Ludhiana, Kanpur, Sriganganagar, Delhi, Gwalior, Pantnagar, Akola and Varanasi) was used for the validation of the *Info Crop* model for mustard crop. Weather and agronomic management practices vary considerably in different parts of India, which influences crop growth and yield. Hence, five locations were identified for the study in mustard growing tract of the country. Among the five locations three are situated in the Indo Gangetic Plains (IGP), comprising of Delhi in northern IGP, Lucknow in central IGP and Calcutta in eastern IGP. Other two locations are mustard growing regions in western India (Sriganganagar in Rajasthan) and Central India (Gwalior in Madhya Pradesh).

For sorghum simulation study, data from All India Coordinated Research trials conducted at various sorghum growing regions of the country (Palem, Dharwad, Akola, Indore, Coimbatore and Kanpur) was used. Management practices relating to date of sowing, time and amount of application of irrigation and nitrogen as measured in the different treatments were given as inputs for validation of *InfoCrop* sorghum model. The validated model was further used for climate change impact assessment of sorghum at Akola, Anantpur, Bijapur, Coimbatore, Gwalior and Kota.

For maize simulation experiment, model was calibrated and validated using data sets of experiments from different sources. The data sets accumulated on phenology, Leaf Area Index (LAI), Total Dry Matter (TDM) and grain yield from experiments conducted at various locations of India through All India Co-ordinated Research Project at Varanasi, Pantnagar, Ludhiana, Kanpur, Karnal, Hyderabad and Patna. Validated model was further used for impact assessment for Upper-Indo gangetic plain (Delhi), Mid- Indo gangetic plain (Patna), Southern Plateau (Hyderabad).

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 and 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 HadCM3 model for A1, A2 and B2 scenarios. A1 scenario is characterized by rapid economic growth with population increase till 2050. A2 scenario has continuous population rise along with regionally oriented economic development, while in B2 scenario rate of population growth is less than A2. 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 418, 522 and 639 ppm for A1, 414, 522 and 682 ppm for A2 and 406, 473 and 552 ppm for B2 at 2020, 2050 and 2080 respectively.

RESULTS AND DISCUSSION

In future climate change scenarios projected yield is likely to reduce in both irrigated and rainfed crop. Simulated data showed a spatial variation in Indian mustard 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 (Table 1) the yield reduction in 2020, 2050 and 2080 would be highest in eastern-IGP (19.8%, 50.2%, 67.3% in A_1, 9.9%, 37.4%, 63.1% in A2 and 20.3%, 49.6% and 55.3% in B2) 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°C 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.

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 45%, 27.5%, 41.9% in A1 53.4%, 40.3%, 48.2% in A2 and 39.6%, 29.9% , 31.3% in B2 , respectively (Table 3).

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.

The maize *InfoCrop* model analysis indicates that in Upper Indo-Gangetic plain (UIGP) region climate change is

Table 1 : Yield reduction (percentage loss) of irrigated mustard due to climate change in India

Scenarios	**A1**			**A2**			**B2**		
Regions	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Eastern IGP	20	50	67	10	37	63	20	50	55
Northern IGP	2	6	12	6	6	8	3	5	9
Eatern India	1	7	21	3	7	16	1	11	11
Central India	1	2	14	1	2	16	1	4	13
Central IGP	5	10	28	1	11	26	4	11	14

Table 2 : Projected mean temperature rise (°C) during mustard growing season in A1, A2 and B2 scenarios

Location	**2020**			**2050**			**2080**		
	A1	**A2**	**B2**	**A1**	**A2**	**B2**	**A1**	**A2**	**B2**
Northern IGP	1.5	1.4	1.4	2.5	2.6	3.0	4.8	4.4	3.4
Central IGP	1.6	1.1	1.3	2.3	2.6	2.9	4.6	4.3	3.2
Eastern IGP	1.5	1.0	1.3	3.5	3.0	3.0	5.7	5.3	3.8
Central India	1.5	1.3	1.5	2.3	2.5	2.9	4.8	4.5	3.4
Western India	1.3	1.5	1.4	3.2	2.7	3.1	4.6	4.7	4.0

Table 3 : Yield reduction (percentage loss) of rainfed mustard due to climate change in India

Scenarios	**A1**			**A2**			**B2**		
Regions	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Eastern IGP	20	50	67	6	25	57	7	34	54
Northern IGP	2	6	12	25	43	53	10	31	45
Eatern India	1	7	21	18	34	40	4	20	27
Central India	1	2	14	8	26	48	0.1	23	42
Central IGP	5	10	28	3	20	39	0.4	2	11

projected to insignificantly affect the productivity of monsoon maize crop in 2020, 2050 and 2080 scenarios (Fig. 1). This is mainly due to projected increase in rainfall during crop season, which will provide scope for improved dry matter production and increase in grain number. This implies that the maize crop may benefit from additional availability of water in spite of increase in temperature and related reduction in crop duration by 3-4 days. On the other hand, in Middle and lower Indo-Gangetic Plain (MIGP), maize is likely to suffer yield loss in future scenarios. The loss from current yields is projected to be ~5%, ~13%, ~17% in 2020, 2050 and 2080, respectively. In Southern Plateau (SP), monsoon season crop is projected to lose grain yield by 21% from current yields due to climate change by 2020 and 35% by 2050 and later. Projected rise in day time temperature during monsoon is higher in SP and MIGP as compared to UIGP region, even though minimum temperatures are projected to rise almost similarly at these locations. Apart from this, rainfall is projected to increase in UIGP while it is likely to change in MIGP. Thus, the spatial and temporal variation in existing climatic conditions and projected changes in temperature and rainfall would bring about differential impacts on monsoon maize crop in India.

Sorghum crop was also found to be sensitive to changes in carbon dioxide and temperature. Future climate change scenario analysis showed that sorghum yields (CSH 16 and CSV 15) are likely to reduce at Akola, Anantpur, Coimbatore and Bijapur. But yield of CSH 16 will increase little at Gwalior (0.1%) at 2020 and thereafter it will reduce. At Kota the sorghum yield is likely to increase at 2020 (3.3 & 1.7 % in CSH 16 and CSV 15 respectively) and no change at 2050 and yields will reduce at 2080 in both varieties. The increase in yield at Gwalior and Kota at 2020 would be due to reduction in maximum temperature and increase in rainfall from current (Fig. 2).

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.

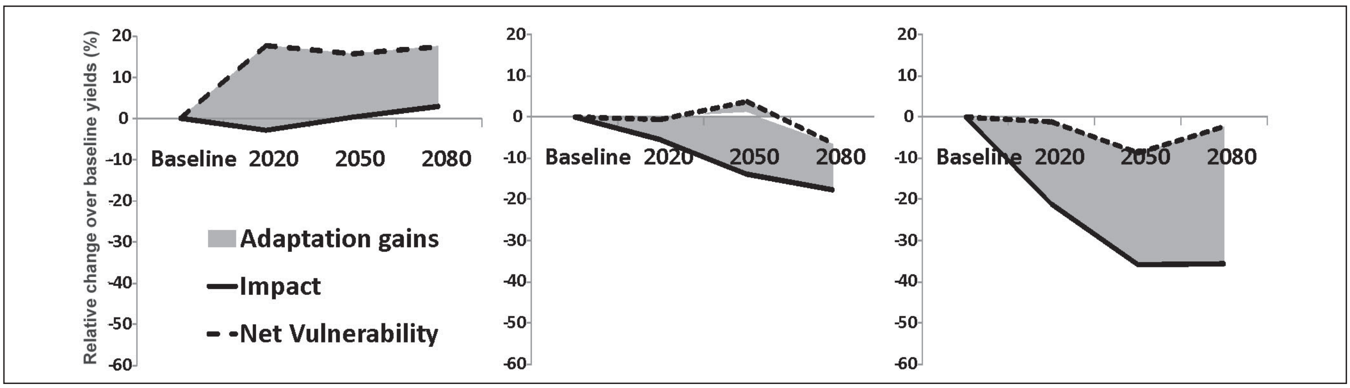

Fig. 1: Impact, adaptation and net vulnerability of monsoon maize yield to 2020, 2050 an 2080 HadCM3 scenarios (UIGP –Upper Indo-Gangetic plain; MIGP :- Middle and lower Indo-Gangetic Plain; SP:- Southern Plateau)

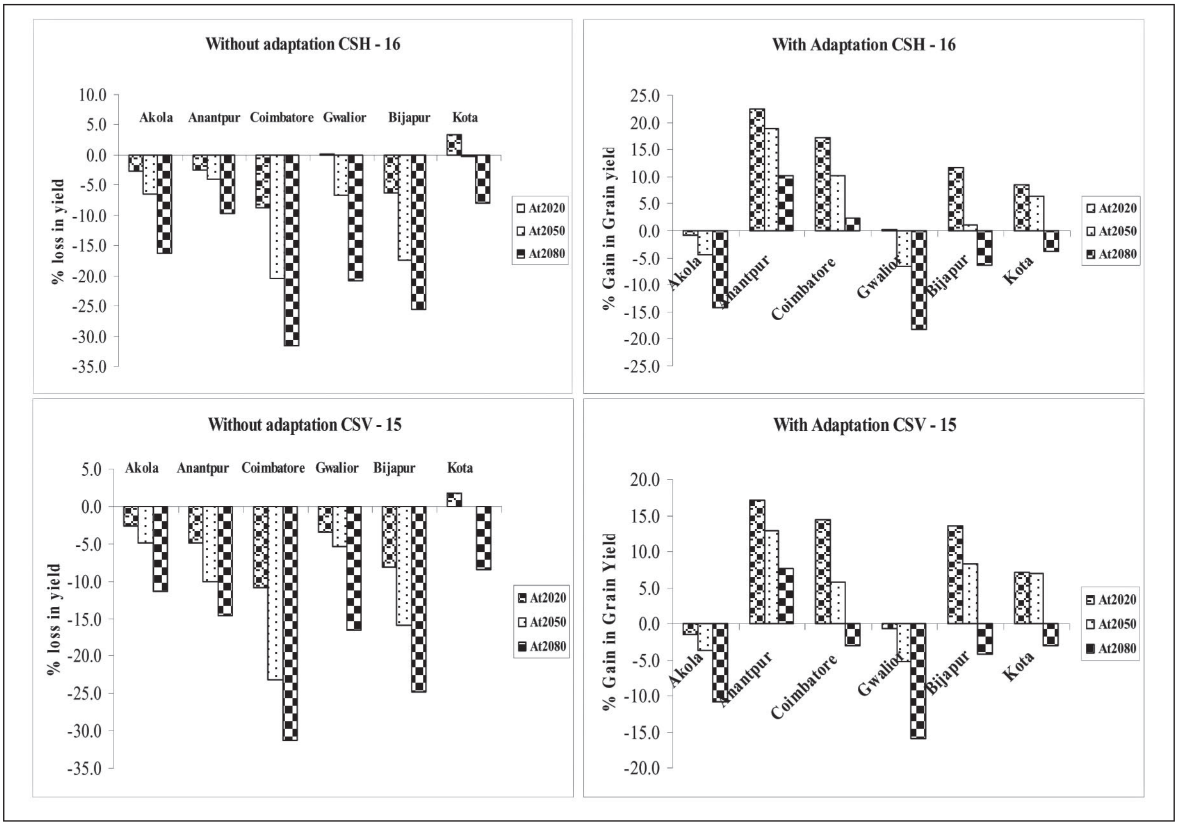

Fig. 2: Simulated percent change in yields CSH 16 and CSV 15 in HadCM3 – A2a scenarios of climate change without and with adaptation

CONCLUSIONS

Results from this simulation study support the adverse impacts of future anticipated climate change on mustard, maize and sorghum growth and yield. In mustard 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. In maize projected rise in day time temperature during monsoon is higher in SP and MIGP as compared to UIGP region, even though minimum temperatures are projected to rise almost similarly in these locations. Apart from this, rainfall is projected to increase in UIGP, while it is likely to change in MIGP. Thus, the spatio-temporal variation in existing climatic conditions and projected changes in temperature and rainfall would bring about differential impacts on monsoon maize crop in India. Likewise, sorghum crop also showed the mixed response, except Kota (increase in rainfall in future) other regions the yield reduction may occur in the future. But at the same time the yield gap among all crops in India is wider. Bridging the yield gap through available technology, the climate change effect could be nullified to ensure the food security in India. Future climate change studies should consider the uncertainties and limitations for crop simulation modeling and climate change scenarios. The assessment of climate change on Indian agriculture need to be more precise and provide sound basis for regional policy planning.

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