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Effect of projected climate change on mustard (*Brassica juncea)*

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ABSTRACT

Mustard is one of the most important *rabi* season oilseed crops and contribute about 30 per cent of total oilseed production. It is very sensitive to weather variable. The likely climate change may have varying effect on mustard production. Info Crop a process based crop simulation model was calibrated and validated with experimental crop data of 2003-04 to 2006-07 *rabi* seasons with different dates of sowing at IARI, New Delhi. PRECIS downscaled, baseline weather data for period 1961-1990 and projected A2a scenario data for the period 2071 to 2100 for the grid covering experimental site were used for computing magnitude of climate change and the same was used for computation of weather data for period of 2071 to 2100 using actual observed data of baseline period. Annual maximum temperature is likely to rise by 5.25°C with maximum of 7.55° for November and minimum 3.21°C for May. Similarly minimum temperature is also likely to rise by 4.83°C with highest increase of 6.34°C during February. Crop simulation suggests no or little change in mustard production under unlimited soil moisture and nitrogen conditions, but higher coefficients of variation (33%) shows unstable crop performance. Under rainfed condition which is marked by either one pre-sowing irrigation or sowing on favourable residual moisture mostly practiced in significant part of mustard growing area, crop yield is likely to reduce by 81% and crop performance is highly unlikely to be stable (116 % CV). Crop duration is also likely to reduce by 25 to 30 days, mainly due to fast accumulation of thermal unit (GDD) required for crop maturity.

Key words: Mustard, Climate change, Baseline, Projected period, Adaptation.

Mustard is grown in more than 50 countries worldwide in subtropical and temperate climates. It requires a relatively cool temperature, a fair supply of moisture in growing season and relatively dry harvest period. India, with a contribution of about 15-19 per cent of the world total rapeseed and mustard production, ranks at third position in world after china and Canada. There has been a phenomenal increase in production and productivity of mustard in last two decades. Production of rapeseed and mustard increased from 2.68 million tonnes in 1985-86 to about 7.2 million tonnes in 2008-09 where as the productivity increased from about 650 kg ha^{-1} to 1022 kg ha^{-1} during the same period. As per the fourth advance estimates, rapeseed and mustard production for 2009-10 is 6.4 million tonnes (India current affairs, 2010)

Mustard is considerably sensitive to weather as evidenced from the variable response to different dates of sowing (Singh and Singh, 1999; Kar and Chakravarty, 2000; Angadi *et al.*, 2000; Singh *et al.*, 2004 and Kumar *et al.*, 2007). One month delay in sowing from mid of October resulted loss of 40.6% in seed yield (Lallu, *et al., 2010).* In general mustard suffers from exposure of low temperature during vegetative and early pod filling stage and relatively higher temperature during grain filling and maturity. Biomass production depends on rate of growing degree day (GDD) accumulation. Exposure to higher temperatures leads to fast accumulation of GDD that means fulfilment of thermal requirement without producing sufficient biomass or economic yield (Aggarwal *et al., 2004*; Kumar *et al.*, 2007 and Adak *el al., 2010*). As per fourth assessment report of Intergovernmental Panel on Climate Change (IPCC), global average temperature has increased by 0.7^0C over the last 100 years and projected temperature increase is about 1.8 to 4°C by 2100. Global losses may account for 1 to 5% of GDP but developing countries with tropical and subtropical climate are likely to suffer more (IPCC, 2007). The likely increase in average annual temperature in Northern Indo-Gangetic Plains (IGP) by 2020, 2050 and 2080 is 1.4°, 2.6°, and 4.4°C under A2a scenario (characterized by continuous population rise along with regionally oriented economic development) (Boomiraj *et al.*, 2010). The other main change rather main cause of climate change, CO_2 concentration is likely to increase to the level of 682 ppm under A2a scenario (IPCC, 2007) by 2080. An increase in CO_2 would increase photosynthetic rate, and water use efficiency (Baker *et al.*, 1990) but increased temperature would negate it by increasing respiration (Penning de Vries, 1993)

There are different views and opinions about climate change but limited study has been done to assess the impact of climate change on mustard crop grown in India. It is difficult to generate artificial field conditions accommodating different parameters of projected change altogether and hence crop simulation models are being used to study the effect of climate change. The paper presents the effect of projected climate change on performance of mustard under northern Indo Gangatic Plain using Info Crop, a crop simulation model developed by Aggrawal *et al.,* (2006) considering different coefficients under Indian conditions.

MATERIALS AND METHODS

Info Crop, a process based model that considers growth and development (phrenology, 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**,** crop-pest interactions, soil water, nitrogen, organic carbon dynamics, emissions of green house gases as well as climate change module was used for climate change impact study.

For calibration and validation of Info Crop model, observed weather data of all required parameter were obtained from Agromet Observatory near the experimental field at IARI New Delhi. Vapour pressure data were computed from daily temperature and relative humidity data using FAO sheet for computing reference evapotranspiration (Allen *et al*., 1998). Priestley-Taylor method for computing reference evapotranspiration that do not require vapour pressure or wind speed data was used as option in model.

Dew point vapour (E_{dew}) pressure was used in model as required input and were computed as follows

$$E_{dew} = RH_{mean} / ((50/Es \text{ at } T_{min}) + (50/Es \text{ at } T_{max})$$

Es (kpa) at temperature T = 0.618* EXP ((17.27*T / (T + 237.3))

where, Es = saturation vapour pressure; T_{max} = maximum temperature; T_{min} = minimum temperature; RH_{mean} = mean relative humidity (%)

For climate change impact study, two set of weather data, one representing baseline period (1961-1990) and another representing future projection (2071-2100) are required. The base line weather data for the period of 1961 to 1990 and projected weather data for the period of 2071 to 2100 of A2a scenario were derived from PRECIS downscaled model prepared by IITM, Pune. There are gross differences between PRECIS base line data and observed weather data for the same period (Tripathi *et al.,* 2009). With assumption that the difference between PRECIS baseline (1961-1990) and projected (2071-2100) data is to be relied for climate change, thirty year monthly average of daily weather parameters of baseline data was subtracted from corresponding projected A2a scenario data and the difference obtained were used for computing projected data from actual observed data. In case of rainfall, percentage difference between projected and baseline of monthly sum of 30 year average data were used as correction factor.

For baseline period (1961-1990), actual observed weather data were used where as for computation of daily weather data of A2a scenario for projected period, the methodology is described by Kumar *et al* (2010) in this issue.

Calibration and validation of model

Field data were generated for variety Pusa Jaikisan, through experiments conducted at IARI for two crop seasons (2004-05 and 2005-06) with two dates of sowing (15^{th} Oct and 30^{th} Oct) on sandy clay loam soils. Crop phenological data from field experiments with ten dates of sowing; during 2003-04 (under NATP project) were mainly used for calibration along with the inbuilt coefficients for the variety Pusa Jaikisan, in the model. Published data for the year 2006-07 (Adak, *et al.,* 2009; Boomiraj *et al.,* 2010) for the experiment conducted at same/adjacent field along with the experimental datasets for year 2004-05 and 2005-06 of phenology, leaf area, dry matter partitioning, and yield were used for validation.

Climate change impact assessment

Thirty years weather data for projected period obtained through the method discussed in the manuscript along with 30 year actual observed data suitably adjusted to the baseline period (1961-1900) were used for impact study. CO_2 concentration for A2a scenario was taken as 682 ppm. Different realistic hypothetical set of management were also used to get comprehensive picture of impact of climate change.

RESULTS AND DISCUSSION

Parameters after calibration were: base temperature for all stages: 5°C, GDD from sowing to germination, germination to 50% flowering and from 50% flowering to maturity were 110, 650 and 980 days °C respectively. 50% flowering stage is subjective as it suffers from individual judgement, the parameter was subjected to change for calibration. Relative growth rates of leaf area were taken as 0.008 *i.e.,* almost conservative in nature for mustard crop. Specific leaf area ($dm^2 mg^{-1}$) was taken as 0.0033, and radiation use efficiency was taken as 2.8 (observed in field experiment). Rest of the

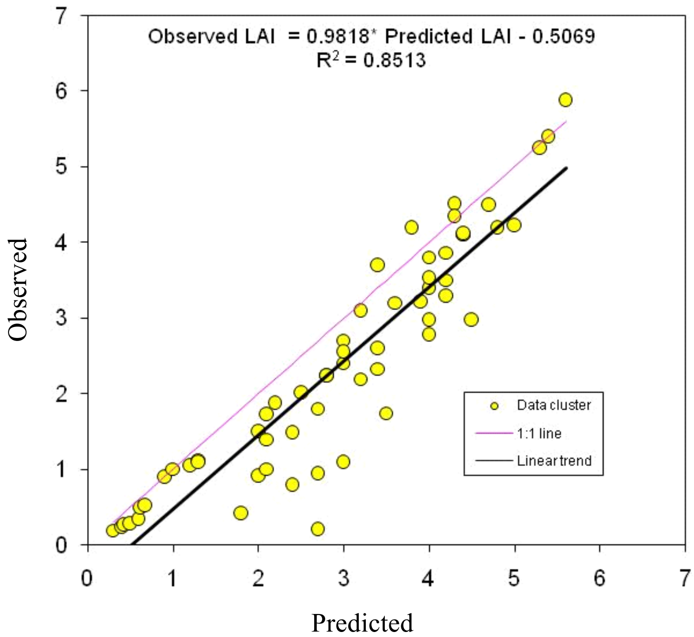

Fig.1 : Comparison of observed and simulated leaf area index (LAI) for model validation

parameters subjected to calibration were retained as such *i.e.,* inbuilt value in the model as it is a highly specific parameter not measured in routine.

Model validation

Weekly observed leaf area index for four sets (two year and two date of sowing) was subjected to validation (Fig. 1). Leaf area index was satisfactorily (R^2 =0.85) simulated by model. The Nash-sutcliffe Model efficiency (ME) is well represented with value calculated to be 0.713. Higher R^2 and ME show that the 'InfoCrop' model adequately confirmed to observed trend in LAI estimation and in good agreement (RMSE=0.591). In all crop seasons (subjected to validation) there were overestimation of LAI towards the end of crop season, with coefficients of residual mass (CRM) of -0.234. This may be because the model considers green pod area also in green area that contributes in intercepting solar radiation while observed data is only for leaf area.

Out of six cases, model over-estimated yield in four cases to the extent of 4 to 26 %. It may be because of the nature and extent of biotic stress that could not be captured by model as no data were provided for the controlled conditions. Higher value (26%) over overestimation observed in one case is because of frost damage that could not be captured by model. Simulation of LAI as well as yield with reasonable accuracy established model's capability to capture crop growth process.

Climate change impact study

A2a scenario is marked by continuous population rise along with regionally oriented economic development. The CO_2 concentration is likely to reach to 682 ppm by 2080 and taken as representative for the period of 30 year *i.e.*, 2071 to 2100. Annual maximum temperature is likely to rise by 5.25°C with maximum of 7.55^0 for November and minimum 3.21^{0}C for May. Similarly, minimum temperature is also likely to rise by 4.83°C with highest increase of 6.34°C during February. Solar radiation, vapour pressure and wind speed are also likely to increase (Table1). Rainfall is likely to decrease slightly *i.e.*, by 3% (25 mm).

Simulations were done for 30 year base line period (1961-1990) and 30 year projected period (2071-2100) using the weather data prepared as discussed above for Delhi conditions. Since the weather data prepared are not meant for daily or weekly or even monthly analysis as it is climatic representative, yield of individual year were not put to statistical analysis. Percentage changes in yield under three different management conditions are sown in Table 2.

In case of unlimited supply of soil moisture and nitrogen, there is no difference of crop yield between baseline and projected scenario. The respiration loss due to increase in temperature is compensated by increased photosynthesis under elevated CO_2. The crop performance is more stable during projected period as evidenced from lower coefficient

Table 1: Climate change (difference of projected and baseline) parameter for Delhi condition, (“T_{max}, “T_{min}, “Srad, “VP, “WS, “ppt* are change in daily maximum temperature, minimum temperature, solar radiation, vapour pressure wind speed and monthly rainfall (*: monthly sum).

Months	ΔT_{max} (°C)	ΔT_{min} (°C)	ΔSrad ($kJm^{-2}d^{-1}$)	ΔVP (kPa)	ΔWS (ms^{-1})	Δppt* (mm)
Jan	6.22	5.40	303.3	-0.01	-0.09	-2.02
Feb	5.90	6.34	-454.5	0.06	-0.09	1.25
Mar	4.61	5.96	-617.8	0.16	0.03	2.51
April	3.71	4.88	-621.2	0.27	-0.02	1.36
May	3.21	4.37	-763.8	0.57	-0.2	4.30
June	4.91	3.84	887.8	0.23	0.51	-14.04
July	4.58	3.62	1124.1	0.39	0.49	-2.40
Aug	4.32	3.80	1029.0	0.45	0.43	7.03
Sept	5.09	4.33	1490.4	0.46	0.63	-17.85
Oct	6.07	4.99	1625.2	0.46	-0.05	3.06
Nov	7.55	5.10	2115.9	0.22	0.05	-4.48
Dec	6.80	5.38	464.8	0.09	-0.28	-3.32
Average	5.25	4.83	548.6	0.28	0.15	-24.61*

Table 2: Relative performance of crop under different adaptation/management condition for projected A2a scenario (2071-2100) as compared to baseline period (1961-1990).

Adaptation/management condition	%change in yield
No limitation of water and nitrogen	negligible
Irrigation practice (one pre sowing and two during crop season)	13.4
Rainfed with sowing on suitable moisture	- 80.7

*Frequent Crop failure

of variation (13.2) as compared to baseline period (1961-1990). Daily maximum temperatures for projected period were frequently reaching beyond maximum temperature limit (40°C) for crop growth and simulation were not advancing. The maximum limit for crop growing was then set to 42°C and is subjected to the study of plant response under elevated temperature beyond 40°C. No limitation of soil moisture and nitrogen under two conditions needs further description to get comprehensive picture and cost benefit scenario.

For existing practice under irrigated condition *i.e.,* one pre-sowing irrigation and two irrigation in standing crop, the response of climate change is slightly positive that is evidenced from 13.4% higher yield under projected scenario. Crop performance under projected scenarios are uncertain (CV; 59%) as compared to baseline period (CV; 33%) that is marked by crop failure on couple of occasion in simulation study but bumper yield in the year of favourable weather was probably enough to compensate. Enhanced performance under projected scenario of limited irrigation is beyond the comprehension of author and it differs from recent report of decrease of yield by about 10% under similar management (Boomiraj *et al.,* 2010). The higher water use efficiency under elevated CO_2 and compensation during favourable year may be one of the reasons.

Under rainfed a condition which is marked by either one pre-sowing irrigation or sowing on favourable residual moisture mostly practiced in main mustard growing area, crop response under projected scenario is considerably poor and marked by frequent crop failure. Crop yield is likely to reduce by 81% and crop performance is highly unstable (CV; 116 %). Crop duration reduced by 25 to 30 days, mainly due to fast accumulation of thermal units (GDD) required for phonological changes.

Existing timely sowing (15th Oct) is likely to become early sowing under projected scenario because early (at present timely) sowing is much likely to suffer due to maximum temperature crossing upper limit of temperature for crop growth leading to crop damage at very early stage. Period from 25th Oct to 10th November is found to be normal range of date of sowing with average highest performance of 28th Oct sown crop. The results of most practised management were in order of the report of global study i.e. 10-40% losses in crop production in India with increase in temperature by 2071-2100 (Fischer *et al.* 2002; IPCC, 2007). Singh *et al*., (2008) also revealed that with rise in temperature, rain/water becomes deciding factor in regulating crop production. It is envisaged that the increase in temperature, if any, may be compensated by increase in rainfall/irrigation.

CONCLUSION

Crop simulation model can be used in climate change impact and adaption strategy. Though there was no or marginal effect of climate change on mustard crop under non limiting condition of water and nitrogen or highly irrigated condition, the availability of water in changed climate is in question because of likely increase in evapotranspiration under high temperature coupled with slight decrease (3%) in rainfall in northern IGP. The majority of area of mustard grown on residual moisture is likely to suffer badly in terms of yield reduction of 80 % and frequent crop failure (CV: 116%) due to climate change. Likely shift in optimal sowing date (by 10 to 12 days) and reduced crop growing period (25-30 days) reveals narrow window of crop management.

Though InfoCrop model could satisfactorily simulate the process of crop growth for baseline period as model has been developed and using coefficients for current climatic condition, it needs to be relooked and modified for coefficient under elevated CO_2 and temperature condition.

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