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Assessing the vulnerability of Indian mustard to climate change

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ABSTRACT

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 (CO_2) 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

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Table 1
Input requirements for InfoCrop model.

Soil	Plant	Weather (daily)	Crop management
Three soil layers depth (mm), organic carbon (%), soil texture (sand, silt, clay%), bulk density, initial soil NH_4–N and NO_3 content	Seed rate, specific leaf area and test grain weight (g)	Maximum and minimum temperature (°C), solar radiation (kJ m^{-2} d^{-1}), vapour pressure (kPa), wind speed (ms^{-1}), and rainfall (mm)	Date of sowing, dates and amount of irrigation and fertilizer application

decline in the agricultural production with climate change. Winter crops are especially vulnerable to high temperature during reproductive 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 rainfall. On the other hand, global warming impact was likely offset to some extent by increased CO_2 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 CO_2 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 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 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 temperature 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 models 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 models 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 CO_2 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 CO_2 in the model is given here. The model simulated the effect of higher CO_2 on net assimilation 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 CO_2, linearly increasing to 1.15 as CO_2 increased to 550 ppm and to 1.23 until CO_2 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 CO_2 environments are mediated through their effects on leaf area growth and hence radiation absorption. Evapotranspiration in the model also responds to increased CO_2 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 (Hebbar 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 quantified 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 thermal time, which is modified by day and night temperatures and nitrogen and water stress experienced by the crop. Optimum temperature 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 flowering 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 seeding rate. A seed rate of 5 kg ha^{-1} was used as an input in the model. Growth rate of the crop was calculated 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 partitioned 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.