

Effect of climate change scenarios on yield and water balance components in rice-wheat cropping system in Central Punjab, India

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ABSTRACT

The study focuses on simulating the effect of climate change under RCP4.5 scenario on irrigation requirements, crop yield, crop duration, and water use efficiency of rice-wheat cropping system with DSSAT v 4.6.1 model at Ludhiana. Model simulations predict reduction in irrigation requirements for rice crop and increase in irrigation requirements for wheat crop under RCP 4.5 scenarios. Also reductions in crop yields in future associated with shortening of growth period due to increased temperature were predicted by the model. Increased rainfall in future would decrease irrigation water requirement of crops but would not offset the adverse effect of increased temperature. Although evapotranspiration would decrease towards end of the century, yet relatively more decrease in yield would lower water use efficiency.

Keywords: Climate change scenarios, bias correction functions, DSSAT, rice-wheat cropping system

The changes in climate parameters are being felt globally in the form of changes in temperature and rainfall pattern. For Indian region, Chaturvedi *et al.*, (2012) projected mean warming ranging from of 2°C (RCP2.6) to 4.8°C (RCP8.5) from 1880s to 2080s through CPIMP5 model ensemble based projections. All India precipitation is projected to increase by 6, 10, 9 and 14 per cent under the scenarios RCP2.6, RCP4.5, RCP6.0 and RCP8.5 respectively, by 2080s relative to the 1961–1990 baseline, whereas much larger variability will be seen in the spatial distribution. The emerging scene of agriculture in Punjab is facing some serious concerns. Green revolution sustained till the eighties, after which the agricultural production in the state showed the signs of stagnation. This was largely attributed to continuous cultivation of rice wheat cropping system having negative implications for soil quality (nutrient balance), infestation of weeds and pests. The issue of overexploitation of groundwater is more concentrated mostly in central Punjab. Under climate change scenario daily weather data is generally derived from general circulation models (GCM) and/or regional climate models (RCM). Zacharias *et al.*, (2015) used the climatic outputs of an RCM–PRECIS (providing regional climates for impact studies) model to analyze baseline simulation daily weather data on temperature and precipitation patterns with the observed weather for the corresponding period (1960–1990) in order to find out the bias in the model. To study the impact of changing climate, numbers of crop models are available in the literature but the models like Decision Support System

for Agro Technology Transfer (DSSAT), InfoCrop and cropping system simulation (CropSyst) are widely used because these models assess the effects of CO₂ and weather parameters on crop growth, biomass, water balance, nitrogen balance on daily basis. The present study was undertaken with the objectives to (i) obtain climate data on maximum temperature (T_{max}), minimum temperature (T_{min}) and rainfall (RF) for baseline and future from HADGEM2-ES GCM model under RCP 4.5 and to (ii) assess the effect of climate change scenario on water requirements, productivity and water use efficiency of rice-wheat system in climatic conditions of Ludhiana Punjab, India.

MATERIALS AND METHODS

Study site and climate

The study was carried out for Ludhiana (75°52' E longitude and 30°56' N latitude) in the Punjab state of India. Past 46 years (1970–2015) daily weather data on rainfall (RF), T_{max} and T_{min} recorded at meteorological observatory were used. Climate change RCP 4.5 scenario data for T_{max} , T_{min} and RF was derived from HAD GEM2-ES- General circulation model on daily basis for Ludhiana for time period of 1970–2015 (baseline), 2020–2050 (mid-century) and 2060–2090 (end-century). Biases in T_{max} , T_{min} and RF data were evaluated for monthly trends and statistical parameters like mean, standard deviation and variance. The biases were minimized by applying correction functions developed from observed and modelled data of years from

Table 1: Statistical parameters of modelled and observed temperatures and rainfall

Statistical parameter	T _{max} (°C)		T _{min} (°C)		Rainfall, (mmday ⁻¹)	
	Modelled	Observed	Modelled	Observed	Modelled	Observed
Mean	31.7	30.0	17.8	17.6	2.8	2.0
SD	7.8	8.6	9.4	8.1	5.1	6.8
Variance	60.8	73.9	88.3	65.2	26.3	46.2

2010 to 2015, as it was producing the least error between the observed and modelled data after the application of correction functions and validated on the data for randomly selected two years. Linear scaling method for development of correction functions at monthly scale (Lenderink *et al.*, 2007) was used.

Crop simulation model

Simulations for irrigation requirements, yield, crop duration and water balance were run using DSSAT v 4.6.1 model (Hoogenboom *et al.*, 2015). This model had already been intensively parameterized with the experimental data observed at the Research Farm, Punjab Agricultural University, Ludhiana, (30°56'N, 75°52'E and 247 m above mean sea level) in central Punjab during year of 2005, 2011 and 2013 and the experimental details of treatments, soil conditions and management practices for these experiments are given elsewhere (Jalota *et al.*, 2006, 2009). Simulations were made for normal planting dates i.e. June 10 for rice (variety PR121) and November 5 for wheat (variety PBW 343). Validation and performance of the model have already been discussed elsewhere (Jalota *et al.*, 2012). Using baseline, mid-century (MC) and end-century (EC) daily weather data, crop growth durations (planting to physiological maturity), yields and water balance components were simulated for rice–wheat system with CO₂ levels for a given year and scenario as per (IPCC., 2013).

Water use efficiency (WUE) was calculated

$$\text{WUE (kg m}^{-3}\text{)} = \frac{\text{grain yield}}{\text{evapotranspiration}}$$

RESULTS AND DISCUSSION

Typical biases of HAD GEM2-ES

Monthly averages of 6 years (2010-2015) of the observed and GCM-HAD GEM2 ES modelled maximum temperature (T_{max}) and minimum temperature (T_{min}) for the location showed that the modelled temperature approximately represented the observed seasonal cycle. However, the modelled values of T_{max} were slightly higher than that of the observed (Table 1). The analysis of the

Table 2: Annual based climate predictions for the three time slices of the future weather for Ludhiana district under RCP 4.5

	Baseline (1970-2015)	Mid-century (2020-2050)	End century (2060-2090)
Annual T _{max} (°C)	29.7	31.0	33.1
Annual T _{min} (°C)	16.6	18.4	19.5
Mean (°C)	23.2	24.7	26.3
Rain (mm)	759.8	662.2	670.1

Table 3: Average duration for rice and wheat crop in baseline, mid-century (MC) and end century (EC) for Ludhiana district under RCP 4.5

Crop	Baseline (1970-2015)	Mid-century (2020-2050)	End century (2060-2090)
Rice	120	115	113
Wheat	167	161	158

statistical parameters i.e., annual mean, standard deviation (SD) and variance of T_{max} showed that the mean of the modelled T_{max} was 1.7°C more than that of the observed while as SD of modelled T_{max} was 0.8°C less than that of observed T_{max} data. In T_{min} mean of modelled and observed were comparable but T_{min} was 1.2°C more in the modelled data than observed T_{min}. In case of rainfall, mean of the modelled rainfall was 0.8 mm day⁻¹ more than that of the observed (Table 1).

Climate change scenarios

In the baseline the average ± standard deviation of RF was 759.8 ± 227.1 mm, which decreased to 662.2 ± 49.7 mm in MC and 670.1 ± 39.3 mm in EC under RCP 4.5. In case of T_{max} it was 29.7 ± 0.5°C for the baseline of the century and rose to 31.1 ± 0.4°C in MC and 33.1 ± 0.3°C in EC. Correspondingly, T_{min} of 16.6 ± 0.8°C of baseline would increase to 18.4 ± 0.3°C in MC and 19.5 ± 0.2°C in EC. This indicated that mean annual temperature would increase by 1.5°C in MC and 3.1°C in EC compared to that of the baseline period, respectively. The corresponding likely decrease in annual RF under RCP 4.5 is 97.6 mm and 89.7 mm, respectively (Table 2).

Table 4: Simulated yield, water balance components and use efficiency of rice and wheat crops as influenced by different time slices of the 21st century and soil texture under RCP 4.5

Time slice	Yield(kg ha ⁻¹)	Evapotranspiration (mm)	Irrigation (mm)	Rainfall (mm)	Drainage (mm)	WUE (kgm ⁻³)
Rice						
Baseline	6419	550.3	1495.3	595.6	1164.8	1.1
Mid century	6222	541.2	1367.2	541.5	949.5	1.1
End century	6316	592.9	1385.1	582.7	947.0	1.0
Wheat						
Baseline	5772	431.9	297.9	121.7	-	1.3
Mid century	5661	449.6	370.6	72.3	-	1.2
End century	5092	464.7	426.4	32.0	-	1.0

Crop yield and duration

Simulated crop yields and water balance components of rice and wheat crops in the baseline, MC and EC are presented in (Table 4). In baseline the resultant simulated yield was 6419 kg ha⁻¹ in rice and 5771 kg ha⁻¹ in wheat and was closer to the observed under field conditions (Jalota *et al.*, 2009, 2011). Under RCP 4.5, averaged across soil series, yield of rice in MC and EC was reduced by 197 kg ha⁻¹ and 103 kg ha⁻¹, respectively than that in the baseline. Yield of wheat in MC and EC was reduced by 110 kg ha⁻¹ and 680 kg ha⁻¹, respectively than that of baseline. Reduction in yields of rice and wheat crops in different time slices was found to be directly related to increased T_{max} and T_{min}. The resultant crop duration was shortened by 5 days and 7 days in rice; and 6 days and 9 days in wheat in MC and EC, respectively under RCP 4.5 (Table 3). These results bring out that inter year rotation information on crop yields in MC and EC can only be obtained using HAD GEM2-ES and like models, which provide daily weather data.

Irrigation requirements:

Under RCP 4.5, irrigation demand for rice in baseline, mid-century (MC) and end century (EC) indicated that irrigation demand was decreasing in all the three time periods due to more rainfall in these periods while in wheat crop less rainfall in these periods has led to increase in demand of irrigation. It was computed for Ludhiana district for rice crop that the annual water requirement would reduce to 1367.2 mm (8.6%) in MC and 1385.1 mm (7.4%) in EC from the 1495.3 mm in the baseline. In wheat crop the annual irrigation water requirements would increase to 370.6 mm (24.4%) in MC and 426.4 mm (43.1%) in EC from the irrigation

requirement of 297.9 mm in the baseline (Table 4). In the MC and EC, water balance components were changed as the crop duration was shortened and RF was decreased under RCP 4.5 compared to that of the baseline. In MC, the RF was decreased by 54 mm during rice and 49 mm during wheat crops. The corresponding values in EC were 13 mm and 90 mm, respectively. As a consequence of fluctuating behavior of rainfall, under this scenario the irrigation requirement in MC and EC was decreased by 128 and 110 mm in rice; and increased by 73 and 129 mm in wheat, respectively. Under RCP 4.5, in MC and EC, ET was decreased by 9 and increased 43 mm in rice; and increased by 18 and 33 mm in wheat, respectively. under elevated temperature (Table 4).

CONCLUSIONS

The present study of the effect of climate change on irrigation requirements, crop productivity and water use efficiency involved use of global climate model (HADGEM2-ES) data, its correction with suitable bias correction method and simulation of yield, crop duration and water balance with crop simulation model (DSSAT). The results from the present study conclude that in central Punjab temperature will increase by 1.5^a°C in mid and by 3.1^a°C in end of the 21st century under RCP 4.5. The increased temperature would decrease the demand for irrigation in rice crop however an increase in demand of irrigation for wheat crop was predicted by the model, which may be due different rainfall magnitudes during the growing periods of these two crops. The increased temperature reduced yields of rice and wheat crops by shortening their duration. With changed climate not only the irrigation requirements, crop yields would reduce but evapotranspiration and water use efficiency would also decrease.

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