

Climate Change Impacts on Rice and Wheat Production in Mymensingh and Dinajpur

M.A. Munnaf¹, F.Y. Ruma² and B.K. Bala³

Abstract

Climate factors such as temperature, rainfall, atmospheric carbon dioxide, solar radiation relative humidity are closely linked with agricultural production. Production of rice and wheat has become major concern in recent years for changing climatic conditions. A simulation study was conducted to assess the climate change impacts on rice and wheat production in Bangladesh using infocrop. The model simulated the yields of rice and wheat for the climate change scenarios of temperature, rainfall and CO₂ concentration. The effect of temperature on rice and wheat production is negative while that of CO₂ is positive, but temperature plays dominant role. The climate change impacts on rice and wheat production for both scenarios of historical and IPCC trends are negative, but the impacts are more prominent for wheat. Mymensingh is more vulnerable to climate change in comparison to Dinajpur.

Key words: Climate change, Infocrop model, Simulation, Crop yield

1. Introduction

Climate changes include both rapid changes in climatic variables such as temperature, radiation and precipitation, as well as changes in the atmospheric concentration of greenhouse gases, soil water and nutrient cycling. Climate changes affect food security, supply of fishes and forest ecosystems (Bala, 2010).

Bangladesh is an agricultural country with 76% of total population is living in the rural areas and 90% of rural population directly related with agriculture. Agriculture plays a significant role in supporting rural livelihoods and economic growth of Bangladesh. The agro-economic contribution is 14.09% of the Gross Domestic product (Bangladesh economics review, 2012).

Our major problem is a large number of populations with a growth rate of 1.34% (Bangladesh economics review, 2012). In addition, agriculture is facing numerous problems due to unfavorable weather events and climate change. Now-a-days major concern is to feed the rapidly increased population. Despite impressive success in increasing the food production in Bangladesh the ability to sustain the increasing population is still a major concern.

Tubiello *et al.* (2000) investigated the effects of climate change and elevated CO₂ on cropping systems at two Italian locations and the results suggest that the combined effects of elevated atmospheric CO₂ and climate change at both sites would depress crop yields if current management practices were not modified.

Tao *et al.* (2009) reported that food security presenting a covariant relationship between changes in cereal productivity due to climate change and the cereal harvest area required to satisfy China's food demand.

Rosenzweig *et al.* (2010) reported the effects of climate change on rice production in Bangladesh and this study shows that *aus* production is not strongly affected. *Aman* crop simulations projected highly consistent production increase.

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Bala (2010) reported the effects of climate change on rice and wheat in the Hill Tracts of Chittagong in Bangladesh and this study shows that there is almost no change in food security at Upazila level for the historical climate change scenario, but there is small change in the food security at Upazila level for IPCC climate change scenario.

Bala *et al.* (2011) predicted the climate change impacts on the yields of rice, wheat and maize in Bangladesh. There is almost no change in the yields of rice and maize for the historical climate change scenario in the Hill Tracts of Chittagong, but there is a comparatively higher decrease in the yields of rice and maize for IPCC climate change scenario.

In the last two decades, there has been rapid development of crop models that can simulate the response of crop production to a variety of environment and management factors (Bala, 2010). With such models, it is feasible to assess the variations in yields for different crops or management options under given climatic change.

For proper implementations of the plans and programs of the adaptation strategies of the climate change impacts, the systems must be modeled and simulated. Simulation models can assist in examining the effect of different scenarios of future development and climate change impacts on crop production.

The agricultural sectors require systematic integration of environmental and economic development measures for a sustainable agricultural growth. The objective of the study is to predict the climate change impacts on rice and wheat production in Mymensingh and Dinajpur using InfoCrop.

2. Methodology

Mymensingh and Dinajpur districts were selected for conducting the simulation study. Crop data required for simulation study using InfoCrop model were planting method, transplanting date, planting distribution, plant population at seedling, plant population at emergence, row spacing, and plant per hill, fertilizer application dose, irrigation application and frequency. Physico chemical properties of soil data used in the climate change impacts assessments using InfoCrop are shown in Table 1.

Weather data including daily average maximum and minimum temperature, daily precipitation and carbon dioxide concentration in 2009 were collected from weather station at BAU campus, Mymensingh and Wheat Research Institute, Dinajpur. The simulation study was conducted with the following treatments shown in Table 2.

Table 1. Physico chemical properties of soil

Clay, %	20
Silt, %	26
Sand, %	54
Organic carbon, %	0.17
pH	8
Cation Exchange, ds/m	0.3
Field capacity	0.15
Saturation fraction	0.3
Wilting point fraction	0.15
Saturation hydraulic conductivity, mm/day	0.05
Bulk density, g/cm ³	1.46
EC, ds/m	0.3

(Source: InfoCrop model, 2006)

Table 2. Treatments

Treatment No.	Temperature change, °C		CO ₂ level, ppm
	Maximum	Minimum	
Base	0	0	Base
1	1	1	1
2	2	2	2
3	3	3	3

2.1 Modeling of climate change impacts

Computation of canopy photosynthesis from the incoming photosynthetically active radiations forms the central part of the crop growth simulation models. The growth rate of the crop is calculated as a function of radiation use efficiency, photosynthetically active radiation, total leaf area index and a crop/cultivar specific extinction coefficient. The crop model used for climate impacts assessment of several crop development and growth processes and the relationships among them are shown in Fig. 1 (Bala, 2010). These development and growth processes are dry matter production, dry matter partitioning, leaf area growth and phenology.

2.1.1 Dry matter production

Several models including SUCROS, MACROS, WTGROWS and ORYZA calculate dry matter production as a function of gross canopy photosynthesis, depending on the detailed calculations of the distribution of light within the canopies, the radiation absorbed by the canopy, and photosynthesis light response curve of leaves (Bouman *et al.*, 2000). More or less similar results can generally be obtained under normal radiation situations by calculating the net dry matter production as a function of the radiation use efficiency. This approach was utilized in the present model as follows:

$$GCROP = RUE * (1 - EXP (-KDF * LAI)) \tag{1}$$

Where, GCROP = net crop growth rate
 RUE = radiation use efficiency
 KDF = extinction coefficient
 LAI = leaf area index

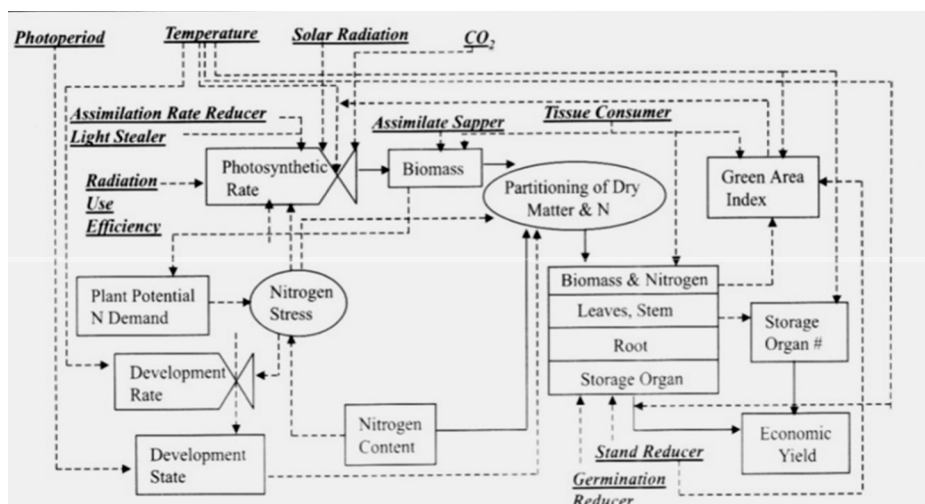


Fig. 1. Crop growth model

2.1.2 Dry matter partitioning

The net dry matter available each day for crop growth was partitioned into roots, leaves, stems, and storage organs as a crop-specific function of development stage. The net growth rates of leaves, stems, roots and storage organs were calculated based on the growth rate of the crop, fractions allocated, death due to senescence, and losses due to pests and during transplanting if any. The weights of green leaves, dead leaves, stem, roots and storage organs were updated everyday based on their initial weights at seedling emergence and the daily growth rates were calculated. The net weight of the storage organs was adjusted for their energy content (Penning de Vries *et al.*, 1989). Allocation to leaves is computed as:

$$RWLVG = GCROP * FSV * FLV - (DLV + SUCKLV) \quad (2)$$

Where, RWLVG = net growth rates of leave
 GCROP = net crop growth rate
 FSH = fraction allocated to shoots
 FLV = fraction allocated to leaves
 DLV = losses in weight due to dead leaves
 SUCKLV = losses in weight due to senescence
 Similar procedure is adopted for stems and roots.

2.1.3 Leaf area growth

The leaf area growth was calculated based on initial leaf area index and its growth rate. The latter was obtained by multiplying the increment in leaf weight by the specific leaf area. During initial stages, there is a greater control over the area formation, and hence for this period net growth rate is calculated based on a thermal time-dependent relative growth rate of leaf area index (Kropff *et al.*, 1994). Net effective leaf area for photosynthesis and transpiration are thus the sum of the leaf areas and non-lamina green area after subtracting all losses due to senescence and insect feeding.

$$RLAI = LAII + GLAI - DLAI - LALOSS \quad (3)$$

Where, RLAI = net leaf area growth rate
 LAII = initial leaf area index
 GLAI = leaf area growth rate
 DLAI = death rate of leaf area index
 LALOSS = net loss of leaf area index due to pests

2.1.4 Phenology

The total development of a crop has been quantified based on development stages (DS), a dimensionless variable having a value of 0 at sowing, 0.1 at seedling emergence, 1.0 at flowering and 2.0 at maturity. This was calculated by integrating the temperature-driven development rates of the phases from sowing to seedling emergence, seedling emergence to anthesis and storage organ filling phases. The rate of crop development is therefore, accelerated depending upon the crop/intensity of stress.

$$DRV = HUVG * \frac{DAYLC}{TTVG} \quad (4)$$

Where, DRV = rate of development during vegetative phase
 HUVG = thermal time of the day
 DAYLC = correction factor for the photoperiod-dependent thermal time
 TTVG = thermal time required for entire phase

2.2 Model Simulations

The basic scenario was simulated using a fixed concentration of CO₂ of 370 ppm, without water and fertilizer stress for the weather data in 2009. Climate data were varied for different treatments of temperature and CO₂ for assessment of rice and wheat production for two locations. Then the climate change impacts on production of rice and wheat for historical and IPCC climate change scenarios were simulated.

3. Results and Discussion

3.1 Model Validation

Model must be validated to build up confidence in the model prediction. The model has been extensively validated against experimental data and sensitivity of this prediction has also been analyzed (Aggarwal *et al.*, 2006 a and b).

3.2 Climate change impacts

3.2.1 Impacts of temperature on rice and wheat yield

The model was simulated to assess the impacts of temperature increase of 1, 2 and 3°C for rice and wheat in Mymensingh and Dinajpur and the simulated results are shown in Fig. 2. The simulated results showed that 3°C increase of temperature reduced rice yield from 5856.7 to 3911.4 kg/ha and wheat yield from 3607.8 to 1484.4 kg/ha in Mymensingh while rice yield firstly increased from 5974.5 to 6144.2 kg/ha for 1°C increase in temperature and then it reduced to 4848.5 kg/ha for 3°C temperature increase in Dinajpur and wheat yield decreased from 3914.2 to 1756.8 kg/ha in Dinajpur.

In comparison with the base line treatment, for 3°C increase in temperature rice yield reduced up to 33% and wheat yield reduced up to 58% in Mymensingh. On the other hand for 3°C temperature increase rice yield reduced up to 25% and wheat yield reduced up to 55% in Dinajpur.

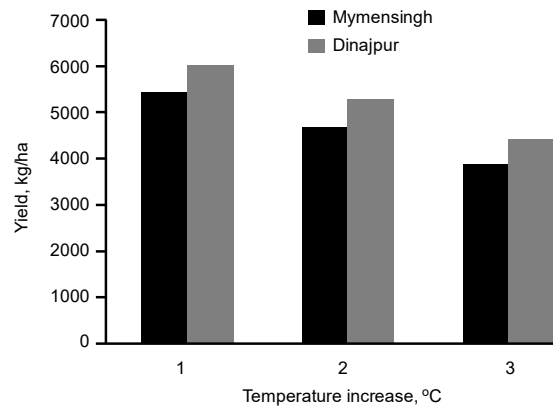


Fig. 2a. Impact of temperature on rice yield

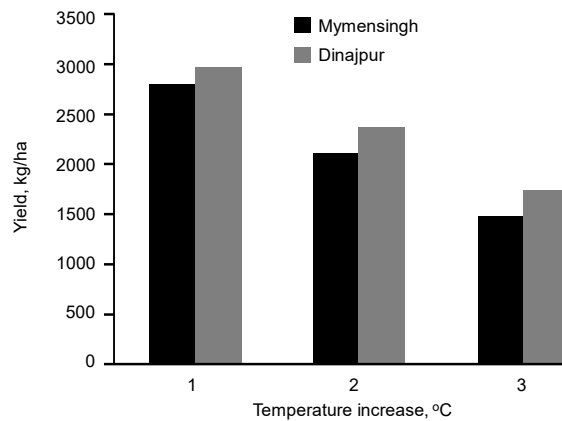


Fig. 2b. Impact of temperature on wheat yield

Results showed that the temperature had the most negative impact on rice and wheat yields in Mymensingh district for 1, 2 and 3°C increase in temperature than those of Dinajpur district.

3.2.2 Impacts of carbon dioxide on rice and wheat yield

The model also simulated the effects of CO₂ changes of 390, 410 and 430 ppm on the yields of rice and wheat in Mymensingh and Dinajpur and the simulated results are shown in Fig. 3.

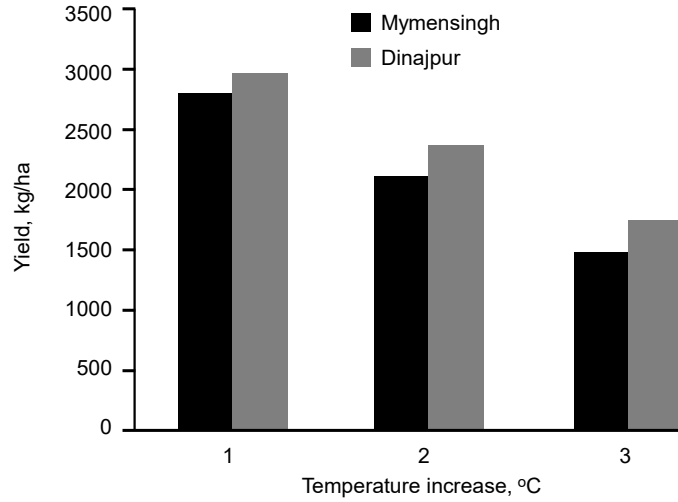


Fig. 3a. Impact of CO₂ on rice yield

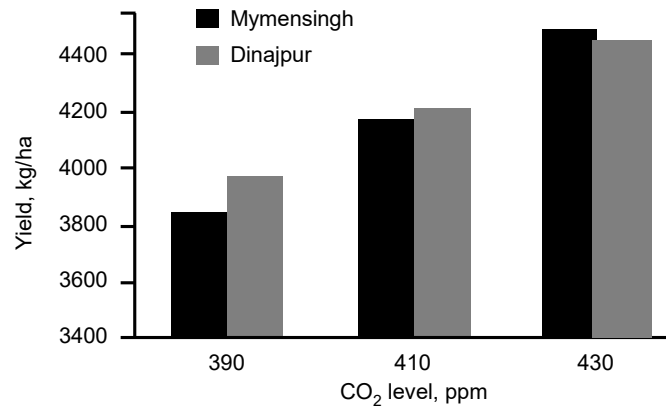


Fig. 3b. Impact of CO₂ on wheat yield

Predictions had been made using fixed concentration of atmospheric CO₂ of 370 ppm and then it was increased at a level of 390, 410 and 430 ppm. Simulated results showed that the increase in CO₂ concentration from 370 to 430 ppm increased rice yield from 5856.7 to 6372.7 kg/ha and wheat yield from 3607.8 to 4009.6 kg/ha in Mymensingh while the increase in CO₂ concentration from 370 to 430 ppm increased rice yield from 5974.5 to 6349.6 kg/ha and wheat yield from 3914.2 to 4321.3 kg/ha in Dinajpur. Increase in CO₂ concentration has positive impacts on the yields of rice and wheat. The most positive effect of increase in CO₂ had been found in Mymensingh district.

3.2.3 Combined impacts of temperature and carbon dioxide (CO₂) on rice and wheat yield

The simulation study was conducted to predict the yields of rice and wheat under different climatic scenarios of temperature and carbon dioxide concentration. Combined impacts of temperature and carbon dioxide change on the yields of rice and wheat are shown in Table 3.

Fig. 4 showed the climate change impacts on the yields of rice and wheat for three different treatments. All of the scenarios showed the negative impacts on rice and wheat yield in Mymensingh and Dinajpur districts.

Table 3. Combined impacts of temperature and carbon dioxide change on rice and wheat yield

Treatment no	Yield, kg/ha in Mymensingh		Yield, kg/ha in Dinajpur	
	Rice	Wheat	Rice	Wheat
Base	5856.7	3607.8	5974.5	3914.2
1	5641.5	2923.5	6144.2	3090.3
2	4995.4	2297	5570.3	2574.9
3	4340.9	1721	4848.5	2019.7

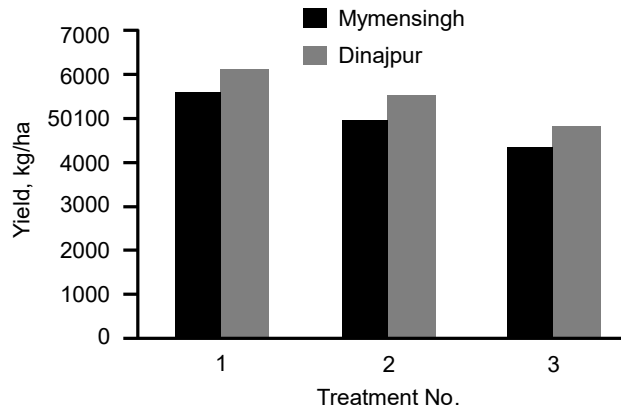


Fig. 4a. Impact on rice yield

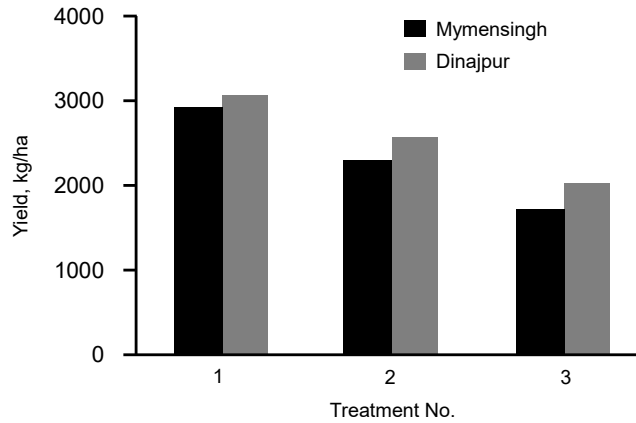


Fig. 4b. Impact on wheat yield

From prediction of the rice and wheat yields under different scenarios, it was evidenced that temperature is the most dominant climatic factor and its impact is very high.

3.2.4 Climate change scenarios for both historical data and IPCC assumptions

Simulation study was conducted for the locations of Dinajpur and Mymensingh for 2020, 2030, 2040 and 2050 for both historical data and IPCC assumptions as shown in Table 4. From the trend line analysis of the historical data over the last 30 years (1976-2005), it has found that the monthly average maximum and minimum temperatures increase 0.02°C per year and if this trend line is extended up to 2020, 2030, 2040 and 2050, temperature increases are by 0.3, 0.5, 0.7 and 0.9°C respectively. Temperature is projected to rise in a range from 1.8°C (with a range from 1.1 to 2.9°C for SRES B1) to 4.0°C (with a range from 2.4 to 6.4°C for A1) by 2100 under IPCC trend. On the basis of the IPCC report temperature will increase at a rate of 0.042°C per year and total increase may be 0.67, 1.09, 1.51 and 1.93°C in 2020, 2030, 2040 and 2050 respectively. Concentration of CO₂ increases at a rate of 1.9 ppm per year and if this rate of increase in CO₂ concentration is constant for the future, CO₂ concentration would be 409, 428, 447 and 466 ppm for the years of 2020, 2030, 2040 and 2050 respectively (simple trend line analysis).

Table 4. Year wise assumptions of CO₂ concentrations and temperature data

Year	Historical data analysis		IPCC	CO ₂
	Max: Temp:	Mini: Temp:	Ave: Temp:	379, ppm in 2005
2008 (Base)	0.02°C/yr	0.02°C/yr	0.042°C/yr	1.9 ppm/yr
2020	0.3	0.3	0.67	409
2030	0.5	0.5	1.09	428
2040	0.7	0.7	1.51	447
2050	0.9	0.9	1.93	466

3.2.5 Rice and wheat yields under historical and IPCC trends in Mymensingh and Dinajpur

The simulated climate change impacts on the yields of rice and wheat for historical and IPCC trends of both the temperature and CO₂ changes for a period of 2020-2050 are shown in Fig. 5(a) and Fig. 5(b), respectively. There was almost no change in the yields of rice and wheat for the historical climate change scenario, but there was small decrease in the yields of rice for IPCC climate change scenario.

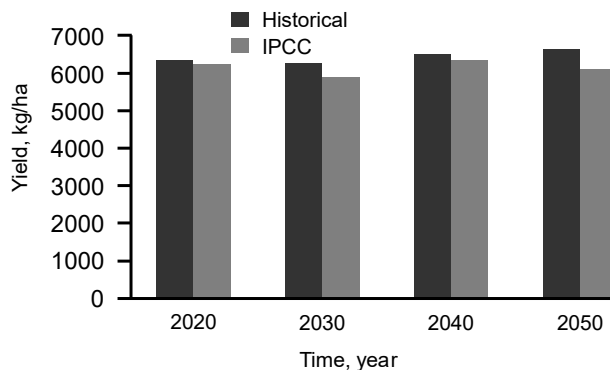


Fig. 5a. Changes in the yields of rice & wheat for historical & IPCC climatic scenarios (Mymensingh)

Rice yield decreased from 5780.9 to 5449.3 kg/ha and from 6222.1 to 6110.8 kg/ha in Mymensingh and Dinajpur, respectively while wheat yield decreased from 3263.8 kg/ha to 2648 kg/ha and 3573.9 kg/ha to 2933 kg/ha in Mymensingh and Dinajpur, respectively.

In IPCC assumptions, temperature increasing trend is two times greater than that of historical analysis, but the year wise CO₂ concentrations are same for both historical and IPCC scenarios. As a result, yield reductions are higher for IPCC climatic scenario.

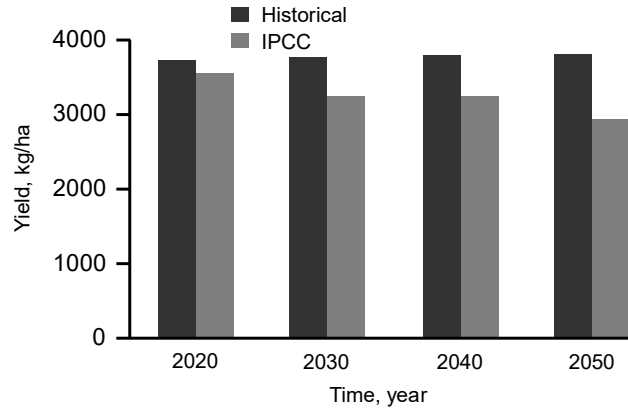


Fig. 5b. Changes in the yields of rice & wheat for historical & IPCC climatic scenarios (Dinajpur)

4. Conclusions

Temperature has negative impact on rice and wheat yields while CO₂ has positive impact on rice and wheat yields. Over all impacts of the increase in temperature and CO₂ on the yields of rice and wheat are negative.

Historical climate change scenario has little or no negative impacts on rice and wheat yields, but IPCC climate change scenario has higher negative impacts. IPCC climate change scenario shows more negative impacts for wheat yields than those of rice yield, and rice and wheat productions in Mymensingh are more vulnerable to climate change in comparison to Dinajpur.

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