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Impacts of Carbon Dioxide Emission and Subsequent Rise of Temperature on Rice Production in Bangladesh: Implications for Food Security

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Abstract

This article provides a long run perspective of climate change impacts mainly due to CO_2 emission and subsequent rise of temperature on food security in Bangladesh. The trends of changes in food demand and production was estimated considering five different climatic scenarios (A, B, C, D and E) based on Intergovernmental Panel on Climate Change (IPCC). These scenarios were accounted from the base year of 2008 to 2050, 2070 and 2100. Based on these scenarios the probable yield of winter rice variety BR3 was estimated for the year 2050, 2070 and 2100 using Decision Support System for Agrotechnology Transfer (DSSAT) model. The outcome of DSSAT model reveals that if the present trend of the population expansion and economic development continues, the future food security situation would be aggravated by the end of this century. Besides, the study suggests that the condition of future food security would be more vulnerable under the five climatic changes scenarios. It was estimated that the shortage of rice might be 58 million tons, 55 million tons and 48 million tons for scenarios C, D and E respectively which might lead to the expansion of food seeking (attributed to rice) community up to 45.90%, 43.85% and 38.25% by the year 2100. Furthermore, study suggests some policy recommendations to meet the challenges of future food security under climatic variability considering the gap between demand and supply.

Keywords: Bangladesh, *Boro* rice, climate change, DSSAT model, food security.

Introduction

Agriculture always suffers from the adverse impacts of weather and climatic conditions. The global climatic conditions are changing evidently and it is observed that the average surface temperature has increased 0.74^0C in the 100 year from 1906 to 2005[1]. However, the increase of mean temperature is even faster during this century. For example, yearly-average maximum and minimum temperature in Bangladesh has increased by about 0.6^0C and 0.5^0C, respectively for only 30 year period from 1976 to 2005[2]. Primarily, the emission of CO_2 into the atmosphere due to the accelerated rate of socio-economic activities is identified one of the most causes of increase of global mean temperature through green house effect.

Climate change has a significant negative impact on crop production as because during the cultivation period, mean and sum temperature, diurnal range and changes of temperature, distribution pattern, or a combination of these factors are highly correlated with crop production[3]. For instance, a study of Yoshida[4] shows that the growth of rice plant has nine growing stages (e.g., germination, seedling emergence, rooting, leaf elongation, tillering, initiation of panicle primordia, panicle differentiation, anthesis and ripening) in three separate growth phases. He also explained that, every stage has an optimum range of temperature for its proper growth but differs with crop variety and physiological condition[4]. Change of temperature patterns, cause damage to the rice plant where high temperatures are a constraint to rice production and cause a significant crop reduction. Crops often respond negatively with a steep decline in net growth and yield, if temperatures exceed the optimal level of biological processes[5].

An estimation of Intergovernmental Panel on Climate Change (IPPC)[1], due to change in rainfall patterns associated with increasing temperatures, flooding, prolonged droughts and salinity by sea level rise could cause decline in rice production in Bangladesh by 8% and wheat by 32% in the year of 2050 against 1990 as the base year[6]. At the country level, studies using crop models with various assumptions about temperature and CO_2 level shows that a decline in rice production in all seasons in the year of 2050 compared to the base year of 1990[7].

Due to effect of high temperature, the crop production of two most important rice varieties (*Aus* and *Aman*) will decline by 1.5-25.8% for *Aus* variety, and 0.4-5.3% for *Aman* variety (*Aus* and *Aman* rice varieties are cultivated during monsoon season in Bangladesh) respectively in the year of 2050[8]. Basak et al. also estimated a significant reduction in production (reduction of 20% and 50% have been predicted for the year of 2050 and 2070 respectively) of some varieties of *boro* rice (rice which is cultivated in winter season) due to climate change[9]. Besides, climatic eventualities (believed to be increase of frequency due to climate change) like prolong drought spell, floods, changes in rainfall pattern, cyclones, and salinity intrusion pose serious threat to the overall food production. FAO/GIEWS Global Watch reported at the time of the passage of cyclone SIDR, about 70% of the annual production of *aman* rice in the most affected areas, are partially or sometimes fully damaged[10]. Salinity also decreases the terminative energy and germination rate of some crop plants[11, 12]. Due to salinity effect, rice yield reduced about 23% during the period of 1985 to 2005 and 69% for shrimp culture[13].

Therefore, it is imperative to assess the future food demand in advance so that necessary actions could be taken up to overcome the food security challenge. The objective of this study is to assess the impact of climate change mainly due to carbon dioxide emission and subsequent rise of temperature on *boro* rice production as well as food security in Bangladesh considering five climatic scenarios. Furthermore, the study has attempted to suggest some recommendations to meet the challenges of future food security under varying climatic conditions considering the gap between demand and supply.

Material and Methods

Study sites: For the study, six major rice growing districts (Rajshahi, Mymensingh, Satkhira, Barisal, Comilla and Sylhet) from six divisional areas in Bangladesh under five different climatic scenarios were selected (figure-1). These locations covered High Ganges River Floodplain Agro-Ecological Zones (AEZ-11) for Rajshahi, Eastern Surma-Kushyara Floodplain (AEZ-20) for Sylhet, Young Meghna Estuarine Floodplain (AEZ-18) for Barisal, Ganges Tidal Flood Plain (AEZ-13) for Satkhira, Old Brahmaputra Flood Plain (AEZ-9) for Mymensingh and Old Meghna Estuarine Floodplain (AEZ-19) for Comilla region.

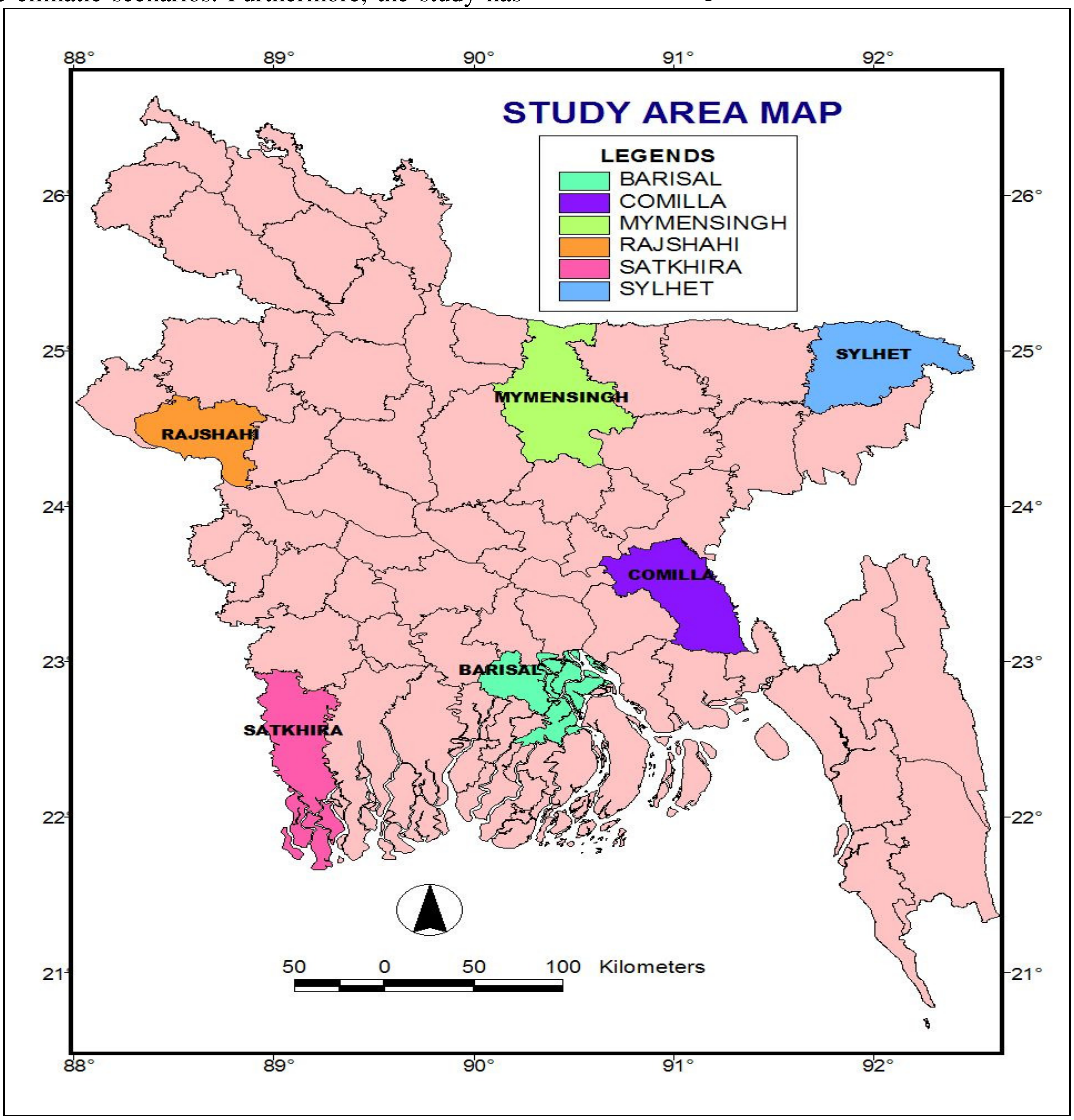

Figure-1
Map of Bangladesh indicating location of the study sites

Methods: For the study, 47 years' (1961-2007) data of agricultural land and production along with considering the population growth rate, per capita consumption were used for making prediction of the probable population, food demand and production in future. The targeted years were estimated assessing demand-production gap and identifying the food situations. Therefore, twenty agricultural crops of Bangladesh were selected on the basis of ranking in production and consumption to understand the pattern of growth in production. Agricultural land and production data for 47 years (1961-2007) were collected from the Food and Agricultural Organization (FAO)[14] and population data from Bangladesh Bureau of Statistics (BBS)[15]. Per capita rice consumption data was collected from preliminary report on Household Income and Expenditure Survey (HIES)[16]. A simulation exercise has been conducted to estimate the future rice demand. The projection of future population was estimated based on exponential population growth model.

$$P_t = P_0\, e^{rt}$$

Where P_0 = Population of the previous year, P_t = Population of the present year, t = Time interval between previous and present years, r = Annual growth rate of the population.

The demand of rice was calculated by multiplying the population and consumption data for those specified years. Rice consumption rate was calculated from preliminary report on HIES, 1995-96 to 2010. Average value of rice consumption is used in this study to calculate rice demand for the targeted years. Future production of rice has been estimated from the data of 47 years (1961-2007) rice production trend.

Crop model and soil and crop management inputs: Decision Support System for Agrotechnology Transfer (DSSAT) modeling system is an advanced physiologically-based rice crop growth simulation model that has been widely applied to understanding the relationship between rice yield, development phases and its environment. DSSAT uses a detailed set of crop specific genetic coefficients, which allows the model to respond to diverse weather and management conditions[17,18]. The *boro* rice variety BR3 has been selected for the present study because genetic coefficients for this variety are available in the DSSAT modeling system. Moreover, the model requires a quite detailed set of input data on soil and hydrologic characteristics (i.e., pedological and hydrological data), and crop management. Input data related to soil characteristics include soil texture, number of layers in soil profile, soil layer depth, pH of soil for each depth, clay, silt and sand contents, organic matter, cation exchange capacity, etc. were collected from Soil Resources Development Institute and Bangladesh Rice Research Institute (BRRI). Moreover, crop management data required by the model include planting method, transplanting date, planting distribution, plant population at seedling, plant population at emergence, row spacing, plant per hill, fertilizer application dose and irrigation application and frequency were collected from BRRI.

Weather data: Data of daily average maximum and minimum temperature, precipitation, CO_2, and solar radiation in 2008 were collected from Bangladesh Meteorological Department. Initially, the simulation study was conducted to predict the average rice yield for Bangladesh under the year of 2008 (considered as a base year for this study) climatic parameters by using DSSAT model. Then five different climatic scenarios were set up to find out the rice yield for targeted years (table-1). A2, B2, A1, and B1 are four families of socio-economic development and associated emission scenarios considered by IPCC as well as atmospheric CO_2 concentrations. Depending on the SRES emission scenario, the atmospheric CO_2 concentration is projected to increase ≈379 to >550 ppm by 2100 in SRES B1 to >800 ppm in SRES A1FI. For the present study, considered increasing CO_2 at a level of 50 ppm, 100 ppm and 200 ppm with 379 ppm (the value reported for the year 2005 in the fourth assessment report of IPCC) to see their combined effect on rice production. The average yield reduction predicted by DSSAT model for the selected regions has been used to find out the climate change impacts on rice production as well as food security in future.

Table-1
Studied climatic scenarios

Assumptions	Predicted year	Scenario
Increased Tmax 2^0C+ Tmin 2^0C+50 ppm CO_2	2050	A
Increased Tmax 2^0C+ Tmin 2^0C+100 ppm CO_2	2050	B
Increased Tmax 4^0C+ Tmin 4^0C+50 ppm CO_2	2070, 2100	C
Increased Tmax 4^0C+ Tmin 4^0C+100 ppm CO_2	2070, 2100	D
Increased Tmax 4^0C+ Tmin 4^0C+200 ppm CO_2	2070, 2100	E

Results and Discussion

Trends of agricultural land and production: A trend analysis of 1961–2007 years data predicted that the agricultural production per person was gradually increasing and in 2007, it reached 0.411 tons per person. After 1980, food production increased at a significant rate in Bangladesh, primarily due to cultivation of high yielding crop varieties, application of modern technologies including innovation of new management and harvesting practices (figure-2a). The availability of agricultural land for food production is continuously decreasing and it has been reduced by two folds in the last 47 years. From the analysis, it was found that in 1961, one metric ton food was produced from 0.406 ha of land, whereas the same production was achieved in 2007 from the land below 0.140 ha (figure-2b). Moreover, the allocation of agricultural land per person was continuously decreasing (figure-2c). Allocation of agricultural land per person in 1961 was 0.17 ha, whereas it was only 0.06 ha in 2007. High population growth rate and low-level of economic conditions are the main reasons for the reduction by 2.83 times land per person in the period between 1961 and 2007. The decreasing rate of agricultural land with increasing food demand for a huge population may put food security in more vulnerable condition in future.

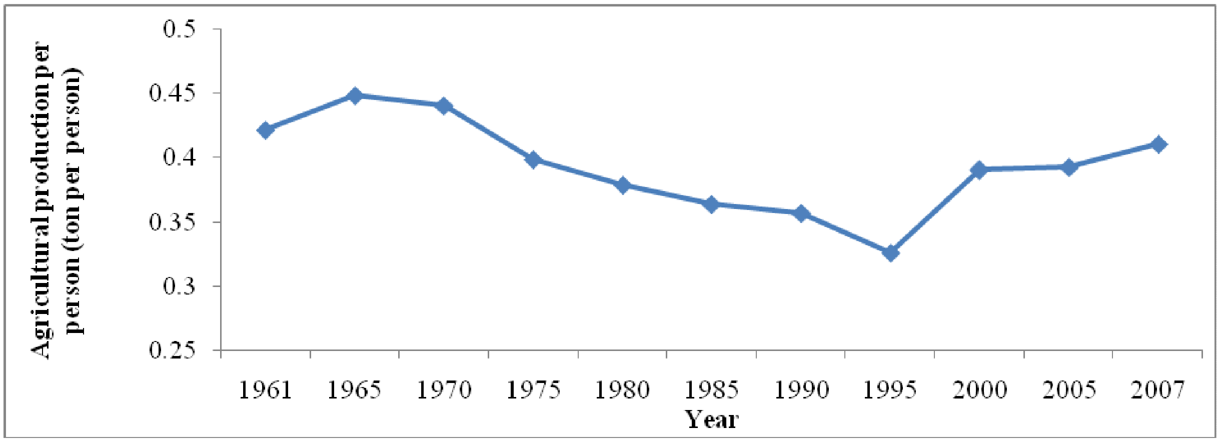

Figure- 2a
Yearly agricultural production for every person

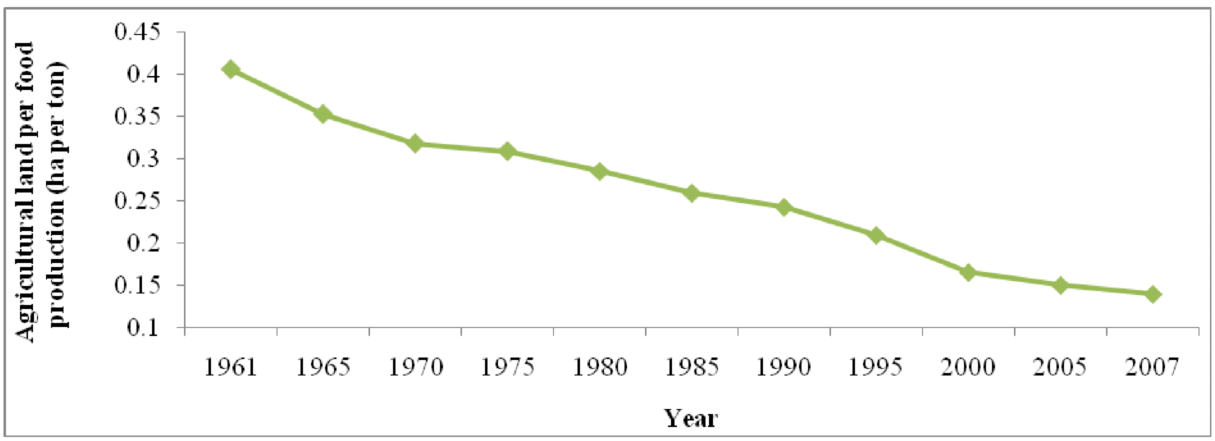

Figure-2b
Yearly agricultural land for food production

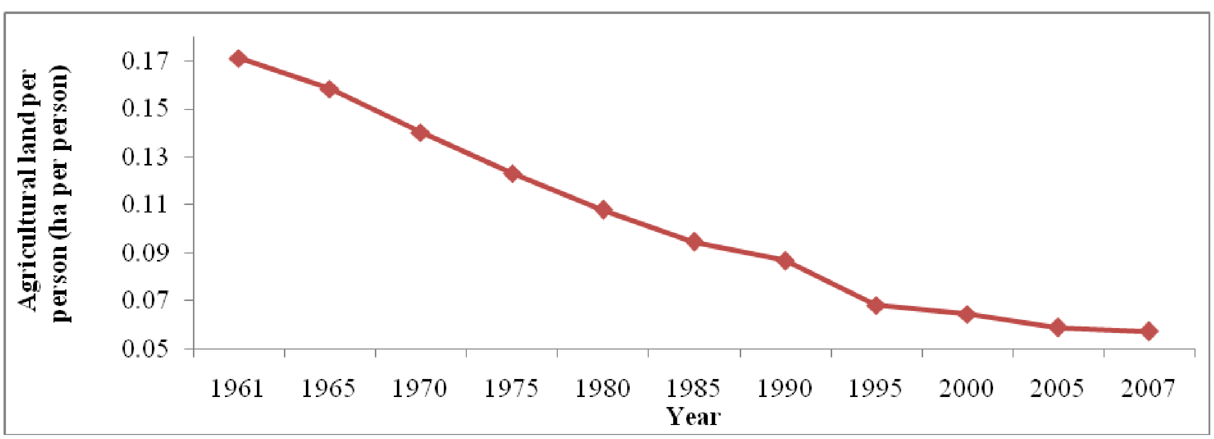

Figure-2c
Yearly agricultural land for every person

Future population and food demand in Bangladesh: As the population continues to grow, a huge pressure is being placed to ensure the provision of an adequate supply of food while maintaining the integrity of ecosystem. From the analysis of population data of 47 years (1961-2007), it was found that population increased 2.85 times. If the annual population growth rate (1.34 percent per year[15]) continues at a business as usual rate based on the year of 2011 (152.518 million), estimates suggest that the total population might be 172.53 million in 2020, 260.23 million in 2050, 342.26 million in 2070, and 516.24 million in 2100 in Bangladesh. In 2100, under business as usual scenario, the population could be more than half billion. Therefore, a huge amount of food will be necessary for the future generation to meet their food demand.

The per capita consumption of rice in Bangladesh is 162.30 kg per person per year and it is the highest rate among all South Asian countries. The exponential population growth model predicted that if the production goes at business as usual rates, Bangladesh may face food shortage in 2050. The projection undertaken for the current study shows that the gap between rice production and demand (table-2). For 2050, the rice shortage has been estimated to be 2.46 million tons. As a result, more than 10 million populations may face rice shortage in 2050, which is equivalent to 3.85 percent of the projected population of that particular point of time. Therefore, a considerable level of population might face a remarkable amount of rice shortage which is calculated to be 35.68 million tons for 2100. Consequently, more than 145.63 million people possibly will face rice shortage problem which is estimated to be more than 28.20 percent of the projected population in 2100.

Table-2
Paddy rice demand and production (million ton)

Year	Demand	Production
2020	42.30	44.10
2050	63.76	61.30
2070	83.85	72.30
2100	126.48	90.80

Level of significance below 90%

Future food security condition under different scenarios in Bangladesh: The study has found a significant demand production gap of rice during 2050, 2070 and 2100 under five scenarios (A, B, C, D and E) which may cause food security situation more vulnerable for the corresponding years in Bangladesh.

DSSAT model predicted that rice yield may be reduced (on average for the selected six regions in Bangladesh) 8.28 percent for scenario A, 4.95 percent for B, 24.66 percent for C, 21.79 percent for D and 14 percent for E. This amount of yield reductions might have significant negative impact on food security situation in Bangladesh.

It is estimated that if the current trend of production persists, on an average 7.54 million tons and 5.49 million tons of rice may remain shortage than that of demand in 2050 under scenarios A and B, respectively. As a result, more than 30 million and 22 million people may face rice shortage, which is equivalent to 11.80 percent and 8.80 percent of the projected population in 2050 for respective scenarios (figure-3a).

Similarly, the amount of shortage of rice in 2070 might be 29.38 million tons, 27.30 million tons and 21.67 million tons on average under scenarios C, D and E respectively. The number of population might face such rice shortage amounts more than 119 million, 111 million and 88 million, equivalent to 35.04 percent, 32.56 percent and 25.96 percent of the projected population under above mentioned three scenarios (figure-3b).

The gap between demand and production of rice might increase further in 2100. Continuation of prevailing trend might witness the demand production gap of rice at 58.07 million tons, 55.47 million tons and 48.39 million tons under scenarios C, D and E respectively. Consequently, 45.90 percent (273.02 million), 43.85 percent (226.40 million) and 38.25 percent (197.50 million) of the projected population may face difficulty in seeking rice in 2100 (figure-3d). Rice shortage due to the huge population pressure and to the impact of climate change along with population growth is shown in figure-3c.

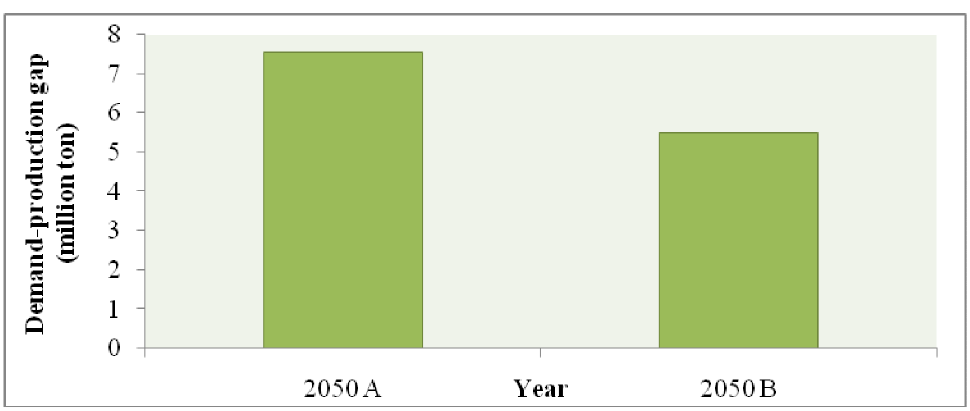

Figure-3a
Demand-production gap of rice for 2050

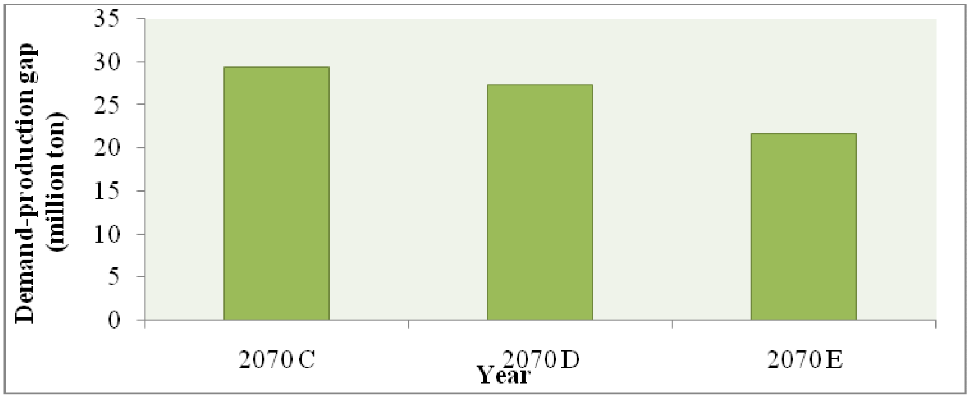

Figure-3b
Demand-production gap of rice for 2070

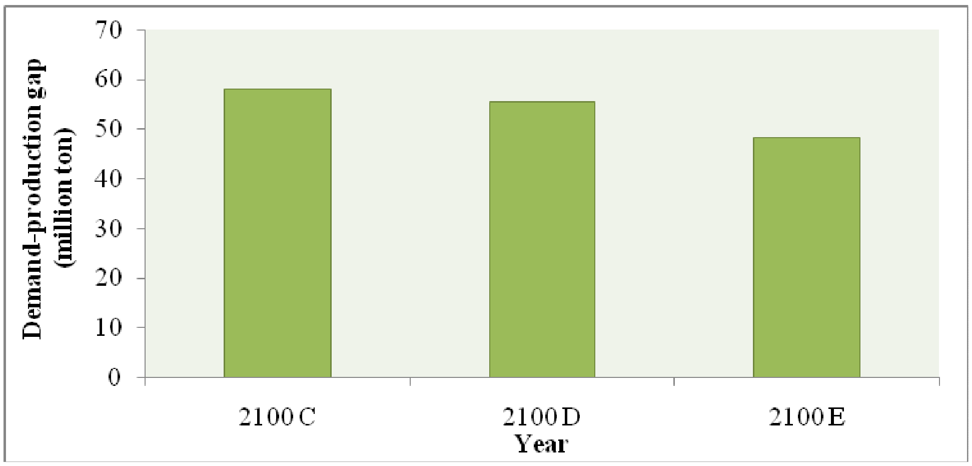

Figure-3c
Demand-production gap of rice

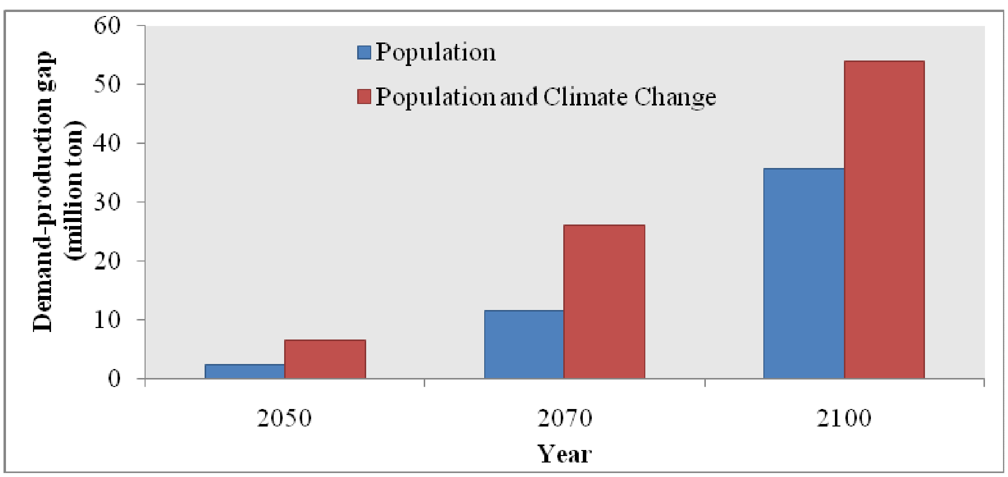

Figure-3d
Demand-production gap of rice for 2100

Discussion: Food security is the major sustainable development issue that linked with social, health, economic development as well as environment. The status of food security of a country needs to be assessed at three levels: availability of food at national level on sustainable basis, physical and economic access of all households to food and the utilization of available food by individuals[19]. This study has focused on the potential effects of increasing population growth and changing climatic conditions mainly due to CO_2 emission and subsequent rise of temperature on rice production as well as food security situation in Bangladesh. Trend line analysis of 47 years data (1961-2007) on agriculture land, population and production shows that food production increased at a significant rate, whereas land per person and land for food production decreased by two times during the same period. The decreasing trend of agricultural land with increasing food demand for a huge population might create food security situation vulnerable. The study estimated that, a clear deficiency of rice e.g., 2.46 million tons and 35.68 million tons may be due to high population growth at the current rate. Consequently, 4 percent and 28 percent of the projected population may face difficulty in seeking rice in 2050 and 2100 respectively. Furthermore, changing climatic parameters during growing period for a particular crop have a significant impact on its yield. Some other studies have been carried out in Bangladesh to assess the negative impacts of climate change and variability on food grain production[2,7,20-24]. However, those studies have predicted lower yield of crops under different climate change scenarios only.

A recent study in India discusses the impacts of climate change on water resources that have consequences on the food security of India. Study predicted that, India is expected to become water stressed country by the years 2020-2025 with per capita water availability falling to 1341m^3/person/year by 2025[25]. Consequently, agricultural growth, economic development and food security issues should be addressed in a timely and systematic manner[26]. In a study of International Rice Research Institute (IRRI) predicted that the world rice production will decrease by 10% for every 1°C increase in temperature[27] moreover IPCC also estimated that rice production in Asia could decline by 3.8% by the end of the 21st century[28]. In Bangladesh, rice and wheat production might decrease by 8% and 32% respectively by the year of 2050[19, 29]. The findings of the current study show that about 10 percent, 31 percent and 43 percent of the projected population may face rice shortage in 2050, 2070 and 2100 respectively for increasing temperature and CO_2 concentration along with population growth. Therefore, a huge amount of rice will be required to meet the demand of food and thereby need a long term strategy to achieve food security for all based on indigenous efforts.

Conclusion

Although currently the BR3 rice variety is not widely grown, the present study provides a useful insight into the potential effects of climate change on *boro* rice yield as well as food security along with population growth in Bangladesh. A simulation exercise based on exponential population growth model shows that rice shortage would be 35.68 million tons in 2100 and as a result 28 percent of the projected population could face rice shortage. Moreover, vulnerability to climate change under the climatic scenarios and its effects on production system has also been estimated. The crop model simulation results suggest that if the rate of temperature increases in future, this may in turn, cause significant reduction in rice production. In order to assess the effect of climate change on rice varieties currently being grown in Bangladesh, it is necessary to determine their genetic coefficients through carefully controlled experiments. It is also necessary to develop temperature and salt resistant rice varieties and modify management practices to offset the adverse effects of climate change. Moreover, public awareness of the impact of climate change on the agricultural production systems deserves priority consideration, and mitigating technologies must be developed, which will require increased public and private investment. In addition, due to climate change, the dependency on rice may further increase and create more pressure on food security. In this context, the issue of food security not only put the existing policies at questions but also requires a region wide comprehensive intervention and steps.

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References

1. IPCC, Synthesis Report, Contribution of Working Groups I, II and III to the Fourth Assessment Report of IPCC. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK **(2007)**

2. Basak J.K., Rahman M.M., Das R., Rahman T. and Ali M.A., Assessment of changes in temperature and precipitation patterns in Bangladesh. Proceedings of the international conference on climate change impacts and adaptation strategies for Bangladesh. International Training Network, BUET, Dhaka, 18-20 February 2009 **(2009)**

3. BRRI, Annual Report for July 2005-June 2006. Plant Breeding Division, Bangladesh Rice Research Institute, Gazipur, Bangladesh **(2006)**

4. Yoshida S., Fundamentals of Rice Crop Science (Ed.). International Rice Research Institute, Los Banos, Philippines, 56-90 **(1981)**

5. Rosenzweig C. and Parry M.L., Potential impact of climate change on world food supply, *Nature* **367**, 133-138 **(1994)**

6. MoEF, Bangladesh climate change strategy and action plan-2009, Ministry of Environment and Forests, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh **(2009)**

7. Karim Z., Hussain S.G. and Ahmed M., Assessing impacts of climatic variations on foodgrain production in Bangladesh, *Water Air Soil Poll.*, **92(1& 2)**, 53-62 **(1996)**

8. Hussain S.G. Assessing impact of climate change on cereal production and food security in Bangladesh. Paper presented at the international conference on global climate change and its effect, Dhaka, 25-30 August 2008 **(2008)**

9. Basak J.K., Ali M.A., Islam M.N. and Rashid M.A., Assessment of the effect of climate change on *Boro* rice production in Bangladesh using DSSAT Model, *J. Civil Eng. IEB*, **38(2)**, 95-108 **(2010)**

10. FAO/GIEWS Global Watch, Livelihood of over 8.9 million people adversely affected by Cyclone Sidr in Bangladesh. Available online at: http://www.fao.org/giews/english/shortnews/bangladesh071221.htm (Accessed 31 August, 2012). Last updated 21 December **(2007)**

11. Rashid M.M., Hoque A.K.F. and Iftekhar M.S., Salt tolerances of some multipurpose tree species as determined by seed germination, *J. Biol. Sci.*, **4(3)**, 288-292 **(2004)**

12. Ashraf M.Y., Sarwar G., Ashraf M., Afaf R. and Sattar A., Salinity induced changes in *α*-anylase activity during germination and early cotton seedling growth, *Biol. Plant.*, **45(4)**, 589-591 **(2002)**

13. Ali A.M.S., Rice to shrimp: Land use/ land cover changes and soil degradation in Southwestern Bangladesh, *Land Use Policy*, **23(4)**, 421-436 **(2006)**

14. FAO, Statistics Division of Food and Agriculture Organization. Available online at: http://faostat.fao.org/default.aspx (accessed 30 August, 2012), Rome, Italy **(2009)**

15. BBS, Population and Housing Census. Bangladesh Bureau of Statistics, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh **(2011)**

16. HIES, Preliminary Report on Household Income and Expenditure Survey (HIES) 2010. Bangladesh Bureau of Statistics, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh **(2011)**

17. Ritchie J.T., Alocilja E.C., Singh U. and Uehara G., IBSNAT and the CERES-Rice model. Proceedings of the international workshop on the impact of weather parameter on growth and yield of rice. International Rice Research Institute, Manila7-10 April, 1986. Philippines **(1987)**

18. Hoogenboom G., Jones J.W., Porter C.H., Wilkens P.W., Boote K.J., Batchelor W.D., Hunt L.A. and Tsuji G.Y. (Eds.)., Decision Support System for Agrotechnology Transfer Version 4.0. (volume 1: Overview). University of Hawaii, Honolulu, USA **(2003)**

19. Sayan B., Dhrubajyoti C. and Aniruddha M., Changing dimensions of food security in a globalized world: a review of the perspectives for environment, economy and health, *Int. Res. J. Environ. Sci.,* **2(3)**, 67-73 **(2013)**

20. Titumir R.A.M. and Basak J.K., A long run perspective on food security and sustainable agriculture in South Asia, *Dhaka Uni. J. Develop. Studies*, **1(1)**, 2072-9545 **(2010)**

21. Quadir D.A., Hussain M.A., Hossian M.A. and Ahasan M.N., Deficit and Excess Rainfall Conditions over Bangladesh, Proceedings of the SAARC Seminar on Agricultural Applications of Meteorology, Dhaka, 23-24 December 2003, 25-32 **(2004)**

22. Nooruddin M., Forecasting of rice yield using agro-meteorological variables at Rajshahi district in Bangladesh, Proceedings of the SAARC Seminar on Agricultural Applications of Meteorology, Dhaka, 23-24 December 2003 **(2004)**

23. Mahmood R., Meo M., Legates D.R. and Morrissey M.L., The CERES-Rice model-based estimates of potential monsoon season rainfed rice productivity in Bangladesh, *The Profess. Geographer*, **55(2)**, 259–273 **(2003)**

24. Mahmood R., Air temperature variations and rice productivity in Bangladesh: a comparative study of the performance of the YIELD and CERES-Rice models, *Ecol. Model.*, **106(1-3)**, 201-212 **(1998)**

25. Manoj K. and Kumar P.P., Climate change, water resources and food production: some highlights from India's standpoint, *Int. Res. J. Environ. Sci.,* **2(1)**, 79-87 **(2013)**

26. Hiremath D.B. and Shiyani R.L., Adapting Gujarat to climatic vulnerabilities: the road ahead, *Res. J. Recent Sci.,* **1(5)**, 38-45 **(2012)**

27. Peng S., Huang J., Sheehy J.E., Laza R.C., Visperas R.M., Zhong X., Centeno G.S., Khush G.S. and Cassman K.G., Rice yields decline with higher night temperature from global warming, *Proc. National Acad. Sci.,* **101(27)**, 9971-9975 **(2004)**

28. IPCC, Climate Change 2007: Impacts, adaptation and vulnerability, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK **(2007)**

29. Faisal I.M. and Parveen S., Food security in the face of climate change, population growth and resource constraints: implications for Bangladesh, *Environ. Manag.,* **34(4)**, 487-498 **(2004)**