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CLIMATE CHANGE AND CROP PRODUCTION CHALLENGES: AN OVERVIEW

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ABSTRACT

Climate change has heterogeneous effect on crop production. Potential yield of some crops were found to be decreasing in different simulation models. High temperature, drought, salinity, excessive rain fall are the major stresses faced by crops in a changing climatic condition. Coastal areas of Bangladesh are highly vulnerable to climate change. It was found that a total of 1,405.57 MT yield are lost in different crops. Data shows the production trends of many crops remaining in a steady state or their increase is very slow compared to elapse of time. Some possible adaptation measures such as sorjan system, floating bed agriculture, growing crops in raised beds, harvesting rain water, cultivation of salt and flood tolerant crop varieties etc. were suggested to reduce possible climate change risk and to cope up with the current situation.

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INTRODUCTION

Climate change and crop production are interrelated processes, both of which take place on a global scale. It describes how weather patterns will be affected around the globe. On the other hand, global warming describes an average temperature increase of the earth over time. These changes could be manifested in changes in climate averages as well as changes in extremes of temperatures and precipitation. It is likely that the changes will vary depending on region. Global warming is projected to have significant impacts on conditions affecting agriculture, including temperature, carbon dioxide, glacial run-off, precipitation and the interaction of these elements. These conditions determine the carrying capacity of the biosphere to produce enough food for the human population and domesticated animals. The overall effect of climate change on agriculture will depend on the balance of these effects.

At the same time, agriculture has been shown to produce significant effects on climate change, primarily through the production and release of greenhouse gases such as carbon dioxide, methane, and nitrous oxide, but also by altering the earth's land cover, which can change its ability to absorb or reflect heat and light, thus contributing to radiative forcing. Land use change such as deforestation and desertification, together with use of fossil fuels, are the major anthropogenic sources of carbon dioxide; agriculture itself is the major contributor to increasing methane and nitrous oxide concentrations in earth's atmosphere. Despite technological advances, such as improved varieties, genetically modified organisms, and irrigation systems, weather is still a key factor in agricultural productivity, as well as soil properties and natural communities. The effect of climate on agriculture is related to variabilities in local climates rather than in global climate patterns. The earth's average surface temperature has increased by 1.5°F (0.83°C) since 1880 (Anonymous, 2012). There is unequivocal evidence that the global climate is warming because of an increased concentration of greenhouse gases (GHG) in the earth atmosphere. According to the IPCC 4th assessment report (2007), continued GHG emission at or above current rates would cause further warming and induce changes in global climate system during the 21st century that would very likely be larger than those observed during the 20th century. A 0.1 to 0.5 m rise in sea-level by the middle of this century (as predicted by most of the estimate) will pose a great threat to the livelihoods and agriculture in low-lying coastal areas of the world including about 1/5th of the total land area of Bangladesh. With a population of about 148 million, it is one of the poorest and most vulnerable countries in the world to disaster and climate change impacts. Different types of natural hazards including floods(e.g. river flood, urban flood and flash flood), cyclone and storm surges, tidal surges/intrusion of saline water, salinity, water-logging/submergence, drought, river bank erosion, tornadoes etc affect the country almost every year (Rahman, 2013). These catastrophic events significantly hinder the crop production systems. In Bangladesh, over 30 % of the net cultivable area is in the coastal region. Out of 2.85 million hectares of the coastal and off-shore areas about 0.828 million hectares of the arable lands, which constitutes about 52.5 percent of the net cultivable area in 64 upazilas of 13 districts (Miah, 2010*)*. But these vast cultivable areas is under great threat of vulnerabilities of the climate change and crop production is rapidly declining due to climate risk factors. Saline water intrusion, sea level rise, water logging, cyclone and storm surges are climatic hazards affecting the low lying coastal areas. Impacts of climate change and sea-level rise should have real consequences on the livelihoods of the coastal people as it would be affected by salinity intrusion, flooding, drainage congestion, cyclones, heavy storms and erosion of the land masses (WB, 2000; Agarwala et al., 2003).

The climate of Bangladesh is influenced by monsoon climate and characterized by high temperature, heavy rainfall, often-excessive humidity and marked seasonal variations. Although more than half of the area is north of the tropics, the effect of the Himalayan mountain chain is such as to make the climate more or less tropical throughout the year. The climate is controlled primarily by summer and winter winds, and partly by pre-monsoon (March to May) and post-monsoon (late October to November) circulation. The southwest monsoon originates over the Indian ocean, and carries warm, moist and unstable air. The easterly trade winds are also warm, but relatively drier. The northeast monsoon comes from the Siberian desert, retaining most of its pristine cold, and blows over the country, usually in gusts, during dry winter months.

Environmental stress is the primary cause of crop losses worldwide, reducing average yields for most major crops by more than 50% (Bray et al., 2000). The tropical crop production environment is a mixture of conditions that varies with season and region. Climatic changes will influence the severity of environmental stress imposed on crops. Moreover, increasing temperatures, reduced irrigation water availability, flooding, and salinity will be major limiting factors in sustaining and increasing vegetable productivity. Extreme climatic conditions will also negatively impact soil fertility and increase soil erosion. Thus, additional fertilizer application or improved nutrient-use efficiency of crops will be needed to maintain productivity or harness the potential for enhanced crop growth due to increased atmospheric CO_2. The response of plants to environmental stresses depends on the plant developmental stage and the length and severity of the stress (Bray, 2002). Plants may respond similarly to avoid one or more stresses through morphological or biochemical mechanisms (Capiati et al., 2006). Environmental interactions may make the stress response of plants more complex or influence the degree of impact of climate change. Temperature limits the range and production of many crops. In the tropics, high temperature conditions are often prevalent during the growing season and, with a changing climate, crops in this area will be subjected to increased temperature stress.

Drought, a slow onset disaster is the single most important factor affecting world food security and the catalyst of the great famines of the past (CGIAR 2003). The world's water supply is fixed, thus increasing population pressure and competition for water resources will make the effect of successive droughts more severe (McWilliam, 1986). Inefficient water usage all over the world and inefficient distribution systems in developing countries further decreases water availability. Water availability is expected to be highly sensitive to climate change and severe water stress conditions will affect crop productivity, Crop production is threatened by increasing soil salinity particularly in irrigated cropland which provide 40% of the world's food (FAO 2004). Excessive soil salinity reduces productivity of many agricultural crops, including most vegetables which are particularly sensitive throughout the ontogeny of the plant. Vegetable production occurs in both dry and wet seasons in the tropics. However, production is often limited during the rainy season due to excessive moisture brought about by heavy rain. For instance, most vegetables are highly sensitive to flooding.

MATERIALS AND METHODS

Scientific approach requires a close understanding of the subject matter. This paper mainly depends on the secondary data. Different published reports of different journals and reports mainly supported in providing data in this paper. This paper is completely a review paper. Therefore no specific method has been followed in preparing this paper. It has been prepared by Internet search, comprehensive studies of various articles published in different journals, books and proceedings available in the libraries of BSMRAU, BARI, BRRI and BARC. Valuable information has been collected through personal contact with respective resource personnel to enrich the paper. It compiled the all related information to prepare this paper.

RESULTS AND DISCUSSION

The impacts of climate change on crop production are expected to be widespread across the globe, although studies suggest that African agriculture is likely to be most affected due to heavy reliance on low-input rainfed agriculture and due to its low adaptive capacity (Mertz et al., 2009). Broadly speaking, climate change is likely to impact crop productivity directly through changes in the growing environment, but also indirectly through shifts in the geography and prevalence of agricultural pests and diseases, associated impacts on soil fertility and biological function, and associated agricultural biodiversity. While many impact predictions tend towards the negative, increased CO_2 will also contribute to enhanced fertilization, although there is significant debate as to the extent to which this may increase plant growth. The Inter-governmental Panel on Climate Change (IPCC, 2007) concluded that 'in mid- to high latitude regions, moderate warming benefits crop and pasture yields, but even slight warming decreases yields in seasonally dry and low-latitude regions (medium confidence)'. In IPCC language, moderate warming is in the range of 1–3°C. Smallholder and subsistence farmers, pastoralists and artisanal fisher-folk will suffer complex, localized impacts of climate change (high confidence). Food and forestry trades are projected to increase in response to climate change with increased dependence on food imports for most developing countries (medium to low confidence). Warming beyond 2–3°C will likely result in yield declines in all areas.

IPCC (2009) indicates that rising temperatures, drought, floods, desertification and weather extremes will severely affect crop production, especially in the developing world. Developing countries will be affected most for three reasons:

I. Climate change will have its most negative effects in tropical and subtropical regions;
II. Most of the predicted population growth to 2030 will occur in the developing world (United Nations Population Division DoEaSA, 2009); and
III. More than half of the overall work force in the developing world is involved in agriculture (FAO, 2005).

While anthropogenic effects on climate have been apparent for several decades, modeling future climate change is not an exact science due to the complexity and incomplete understanding of atmospheric processes. None the less, there is broad agreement that, in addition to increased temperatures, climate change will bring about regionally dependent increases or decreases in rainfall, an increase in cloud cover and increases in sea level. Extreme climate events will also increase in intensity or frequency, such as higher maximum temperatures, more intense precipitation events, increased risk and duration of drought, and increased peak wind intensities of cyclones. Predictions in sea level rise indicate that this will continue for centuries after temperatures stabilize, causing flooding of coastal lands and salinization of soils and subsurface water in coastal regions.

Models of crop response to climate change mainly consider temperature, soil moisture and increased carbon dioxide. However, many other processes not easily incorporated into models could potentially have significant effects including: pests and diseases, brief exposures of crops to very high temperatures, elevated ozone, loss of irrigation water, and increase in inter-annual climate variability associated with monsoons and phenomena like El Niño. The model outputs, while encompassing a wide range of potential outcomes, tend to have the following in common:

- The yield potential of staple foods will decline in most production environments and commodity prices will rise
- While projections for a few countries with northerly latitudes indicate net positive impacts of climate change, projections for most developing countries are negative.
- Only 'best-case' scenarios predict no net effect of climate change on global cereal yields by 2030 but predictions beyond that time frame are much more pessimistic.

A. Simulation Models

Models are a mathematical representation of a real world system. The use of models is very common in other disciplines, including the airplane industry, automobile industry, civil, industrial and chemical engineering etc. The use of models in agriculture and environmental sciences is not very common.

Crop simulation models integrate current scientific knowledge from many different disciplines, including crop physiology, plant breeding, agronomy, agro meteorology, soil physics, soil chemistry, pathology and entomology. Crop simulation models in general calculate or predict crop yield as a function of weather conditions, soil conditions and crop management scenarios

SRES (Special Report Emissions Scenarios)

It is a report by IPCC that was published in 2000. The greenhouse gas emissions scenarios described in the report have been used to make projections of possible future climate change.

GCM (Global Circulation Models)

GCMs and global climate models are widely applied for weather forecasting, understanding the climate, and projecting climate change.

RCM (Regional Climate Models)

This modeling technique consists of using initial conditions, time-dependent lateral meteorological conditions and surface boundary conditions to drive high-resolution RCMs. The driving data is derived from GCMs (or analyses of observations) and can include GHG and aerosol forcing. One of the primary advantages of these techniques is that they are computationally inexpensive, and thus can easily be applied to output from different GCM experiments. Another advantage is that they can be used to provide local information, which can be most needed in many climate change impact applications.

PRECIS (Providing Regional Climate for Impacts Studies)

It is a regional climate modeling system designed to run on a Linux based PC. PRECIS can be applied to any area of the globe to generate detailed climate change projections.

VAR (Vector Auto Regression)

It is a statistical model used to capture the linear interdependencies among multiple time series. VAR models generalize the univariate auto regression (AR) models. All the variables in a VAR are treated symmetrically; each variable has an equation explaining its evolution based on its own lags and the lags of all the other variables in the model. It does not require expert knowledge.

DSSAT (Decision Support System for Agro technology Transfer)

The DSSAT-CSM simulates growth, development and yield of a crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil water, carbon, and nitrogen that take place under the cropping system over time. The DSSAT-CSM is. The DSSAT helps decision makers by reducing the time and human resources required for analyzing complex alternative decisions (Tsuji et al., 1998).

APSIM (Agricultural Production Systems Simulator)

It is used to simulate biophysical processes in farming systems, particularly to the economic and ecological outcomes of management practices in the face of climate risk.

Data Sets Required for Model Calibration and Validation

Daily weather data: Rainfall, max and min temperatures, solar radiation or sunshine hours.

Soil profile characterization data (one time activity—data to be collected from soil survey reports): Soil texture by horizon, bulk density, fraction stones, organic carbon, soil pH (water), horizon thickness and depth, root growth distribution, surface characteristics such as soil color, slope, permeability, drainage class, soil series name.

Management data: Crop, cultivar, planting date, seedling rate, plant spacing, row spacing, planting depth, irrigation (dates, amounts, type and method of irrigation), fertilizer applied (dates, amounts, type of material, method of application), chemical application (date, amount, type, method of application), tillage/ intercultural operations (dates, depth, equipment used), organic fertilizer (date, amount, type and method of application), thinning and weeding (date and method).

Initial soils data (to be collected at sowing of a crop): Initial soil water measurements up to maximum soil depth (1.5 m) and soil sampling at 30 cm depth intervals, Initial soil fertility up to 1.5 m at 30 cm depth intervals. Soil samples should be analyzed for NH_4, NO_3, P, K, pH and organic C and N, Soil surface residue, amount and composition (N and C content).

Soil water measurements: At every 10 to 15 day interval up to maximum soil depth (1.5 m) at 30 cm depth interval using gravimetric method if others not available

Vegetative and reproductive development (crop-specific visual observations only): Observations taken at every 2 or 3 days. Emergence date, vegetation stages (V_1, V_2, V_3 ---------- V_n) and reproductive stages (R_1, R_3, R_5, R_6 -------- R_8).

Crop growth analysis (crop-specific, could change with crop): Plants sampled every two weeks and sample harvested area is determined (1 m2), no. of plant sampled, total above ground biomass, weights of leaf, petioles, pods and seeds; leaf area (can be done on a sub-sample), no. of pods, no. of seeds and nitrogen concentration (optional) etc. data are collected.

Yield and yield components at harvest (crop specific, could change with crop): Harvest date, harvest density (plants/m2), harvest area, total above ground biomass, pod yield (seed + shell), seed yield, 1000 seed weight, 1000 pod weight recorded.

B. Climatic change scenarios

The climate in Bangladesh is changing and it is becoming more unpredictable every year. The impacts of higher temperatures, more variable precipitation, more extreme weather events, and sea level rise are already felt in Bangladesh and will continue to intensify. Climate change poses now-a-days severe threat mostly in crop sector and food security among all other affected sectors. Crop yields are predicted to fall by up to 30%, creating a very high risk of hunger and only sustainable climate-resilient crop production is the key to enabling farmers to adapt and increase food security (Climate Change Cell, 2007). The coastal area of Bangladesh is naturally susceptible to disaster.

Table 1. Climate change scenario for Bangladesh

Model	Year	Temperature change (°C) Mean (standard deviation)			Precipitation change (%) Mean (standard deviation)			Sea Level Rise (cm)
		Annual	DJF	JJA	Annual	DJF	JJA	
GCM	2030	1.0	1.1	0.8	5	-2	6	
PRECIS	2030 (Max)	0.3	-0.02	1.3*	4	-8.7	3.8	14
	2030 (Min)	1.18	0.65	1.78*				
GCM	2050	1.4	1.6	1.1	6	-5	8	
PRECIS	2050 (Max)	0.2	0.07	0.89*	2.3	-4.7	3.0	32
	2050 (Min)	1.24	0.59	1.65*				

Note: * JJAS (June, July, August, September); DJF= December January February, JJA= June July August.
(Source: Miah, 2010)

Drought

Unpredictable drought is the single most important factor affecting world food security and the catalyst of the great famines of the past (CGIAR 2003). The world's water supply is fixed, thus increasing population pressure and competition for water resources will make the effect of successive droughts more severe (McWilliam 1986). Inefficient water usage all over the world and inefficient distribution systems in developing countries further decreases water availability. Water availability is expected to be highly sensitive to climate change and severe water stress conditions will affect crop productivity, particularly that of vegetables. In combination with elevated temperatures, decreased precipitation could cause reduction of irrigation water availability and increase in evapotranspiration, leading to severe crop water-stress conditions (IPCC 2001). Vegetables, being succulent products by definition, generally consist of greater than 90% water (AVRDC 1990). Thus, water greatly influences the yield and quality of crops; drought conditions drastically reduce crop productivity. Drought stress causes an increase of solute concentration in the environment (soil), leading to an osmotic flow of water out of plant cells. This leads to an increase of the solute concentration in plant cells, thereby lowering the water potential and disrupting membranes and cell processes such as photosynthesis. The timing, intensity, and duration of drought spells determine the magnitude of the effect of drought.

Table 2. Drought prone areas (in mha) of Bangladesh

Drought Class	**Rabi**	**Pre-Kharif**	**Kharif**
Very Severe	0.446	0.403	0.344
Severe	1.71	1.15	0.74
Moderate	2.95	4.76	3.17
Slight	4.21	4.09	2.90
No Drought	3.17	2.09	0.68
Non-T. aman			4.71

Source: Drought Manual, BARC, 2003

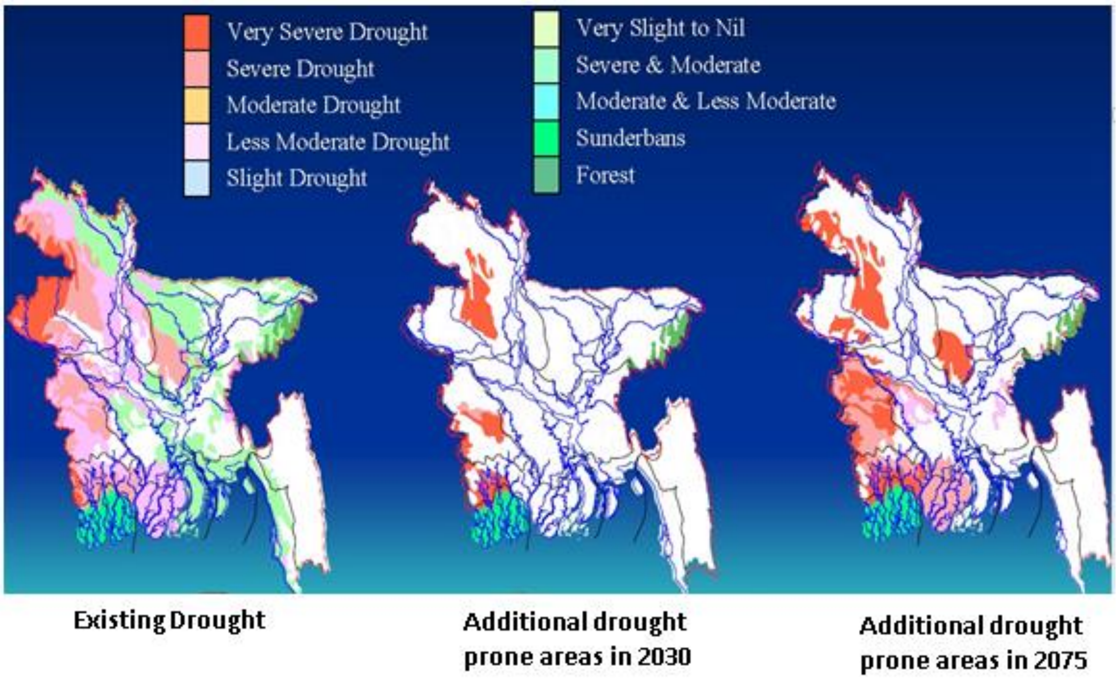


Figure 1. Maps showing existing drought and drought in the year 2030 and 2075. (Source: Sultana *et. al.,* 2008)

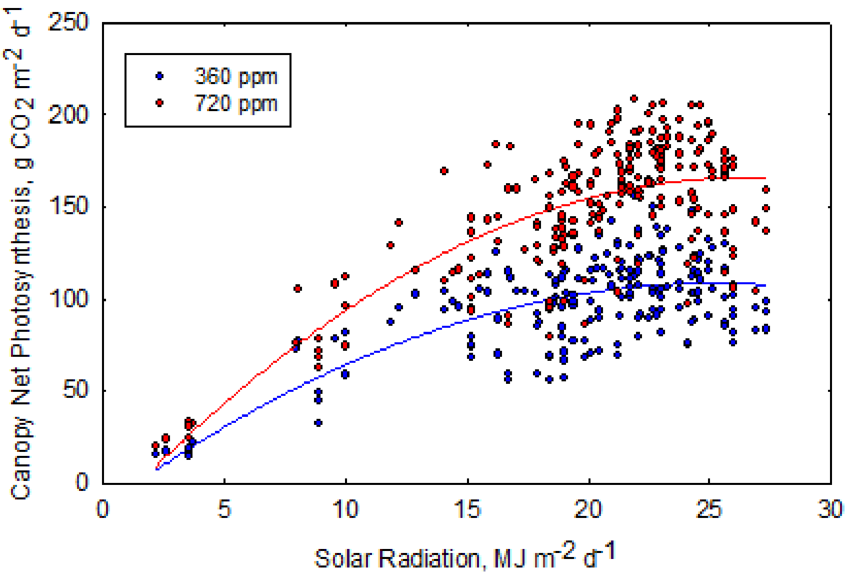


Figure 2. Cotton photosynthesis-solar radiation.
(Source: Baker and Allen, 1993)

High temperatures

Temperature limits the range and production of many crops. In the tropics, high temperature conditions are often prevalent during the growing season and, with a changing climate, crops in this area will be subjected to increased temperature stress. Analysis of climate trends in tomato growing locations suggests that temperatures are rising and the severity and frequency of above optimal temperature episodes will increase in the coming decades (Bell et al., 2000). Vegetative and reproductive processes are strongly modified by temperature alone or in conjunction with other environmental factors (Abdalla and Verkerk, 1968).

High temperature stress disrupts the biochemical reactions fundamental for normal cell function in plants. It primarily affects the photosynthetic functions of higher plants (Weis and Berry, 1988). High temperatures can cause significant losses in productivity due to reduced fruit set, and smaller and lower quality fruits (Stevens and Rudich, 1978). Pre-anthesis temperature stress is associated with developmental changes in the anthers, particularly irregularities in the epidermis and endothesium, lack of opening of the stromium, and poor pollen formation (Sato et al., 2002). In pepper, high temperature exposure at the pre-anthesis stage did not affect pistil or stamen viability, but high post-pollination temperatures inhibited fruit set, suggesting that fertilization is sensitive to high temperature stress (Erickson and Markhart, 2002). Hazra et al., (2007) summarized the symptoms causing fruit set failure at high temperatures in tomato; this includes bud drop, abnormal flower development, poor pollen production, dehiscence, and viability, ovule abortion and poor viability, reduced carbohydrate availability, and other reproductive abnormalities. In addition, significant inhibition of photosynthesis occurs at temperatures above optimum, resulting in considerable loss of potential productivity.

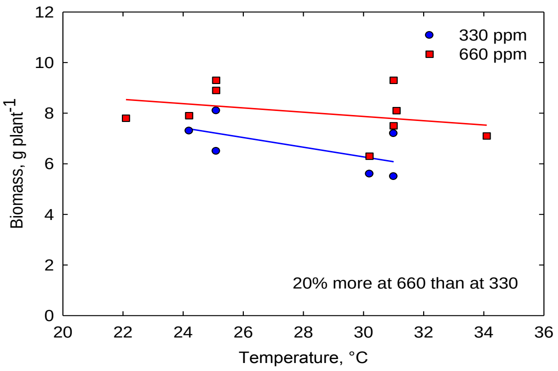


Figure 3. Rice growth in different temperature and CO_2 concentration.

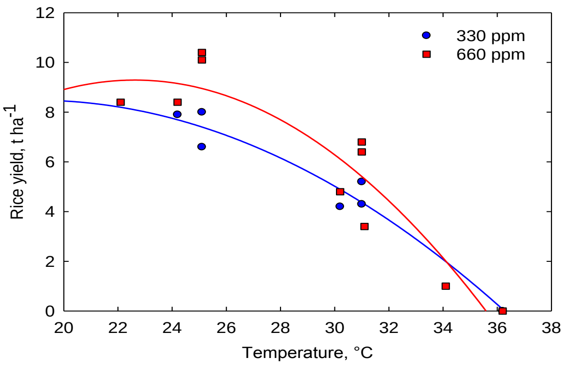


Figure 4. Variation in rice yield in different CO_2 concentration.

(Source: Baker and Allen, 1993)

Effect of climate change on biomass and grain yield of wheat

Without the direct effect of CO_2 the model predicted that all three climate change scenarios significantly increases biomass production compared to the baseline (Table 3), with A1B increasing the most (28%) followed by B1 (16%) and A2 (12%). The combined effect (climate and CO_2) increased biomass production much more, with A1B increasing the most (74%) and A2 (55%) and B1 (41%) being similar. Increased CO_2 concentrations of 220 and 120 ppm resulted in increased biomass production of 43-45% and 25%, respectively. The effect of the climate change scenarios on grain yield shows the same trend as biomass with a slightly higher increase rate.

Table 3. Effects of climate change on biomass and grain production of wheat

Scenario	CO2 ppm	Biomass (Kg/ha)	Grain Yield (Kh/ha)
Baseline	330	5039f	2467f
A1B	330	6463d	3167d
A1B	550	8753a	4349a
A2	330	5651e	2834e
A2	550	7813b	3978b
B1	330	5856e	2880e
B1	450	7104c	3520c

Note: Baseline= 1961-1990, A1B = 3.2^{0}C, A2= 3.6^{0}C, B1= 2.7^{0}C more than the baseline temperature

(Source: Wang et. al., 2011)

Table 4. Rice and wheat production under different climate change scenarios

Simulation	HYV Aus		HYV Aman		HYV Boro		Wheat	
	('000' tones)	Percent Change	('000' tones)	Percent Change	('000' tones)	Percent Change	('000' tones	Percent Change
Baseline (1994-95)	702	0	4,484	0	6,200	0	890	0
CCCM	512	-27	4,170	-7	6,014	-3	712	-20
GFDL	512	-27	3,901	-13	5,766	-7	347	-61
330 ppmv CO_2+20^{0}C	569	-19	3,901	-13	5,952	-4	561	-37
330 ppmv CO_2+40^{0}C	435	-38	3,363	-25	5,766	-7	285	-68
580 ppmv CO2+00^{0}C	920	31	5,605	-25	7,626	23	1,228	38
580 ppmv CO_2+20^{0}C	793	13	4,977	11	7,440	20	881	-1
580 ppmv CO_2+40^{0}C	660	-6	4,529	1	7,192	16	534	-40
660 ppmv CO_2+00^{0}C	983	40	5,964	33	8,060	30	1,317	48
660 ppmv CO_2+20^{0}C	856	22	5,336	19	7,874	27	970	9
660 ppmv CO_2+40^{0}C	730	4	4,888	9	7,626	23	614	-31

CCCM= Canadian Climate Centre Model. (Source: Karim et al., 1998)
GFDL= Geophysical Fluid Dynamics laboratory.

Table 5. Temperature effects on crop yield

Crop	T opt, °C	T max, °C	Yield at T opt, (t/ha)	Yield at 28 °C, (t/ha)	Yield at 32°C (t/ha)	% decrease (28 to 32 °C)
Rice	25	36	7.55	6.31	2.93	54
Soybean	28	39	3.41	3.41	3.06	10
Dry bean	22	32	2.87	1.39	0.00	100
Peanut	25	40	3.38	3.22	2.58	20
Grain sorghum	26	35	12.24	11.75	6.95	41

Source: Reddy et. al., 2005

Table 6. Climate change responses of sorghum (Location: Parbhani, Maharashtra)

Variety: CSH 15			**Rainfall: 790 mm**		
Mean seasonal temperature: 29^{0}C			**AWC of soil: 120 mm**		
Scenarios	**Crop duration (days)**	**Grain Yield** t ha^{-1}	% Change	CV (%)	HI (%)
Control	94	4.12	0	11	35
+ Temp.	82	2.90	-27	18	33
+ Temp.+RF	82	3.05	-26	16	33

Data period: 1969-2007 Source: Singh et. al., 2009

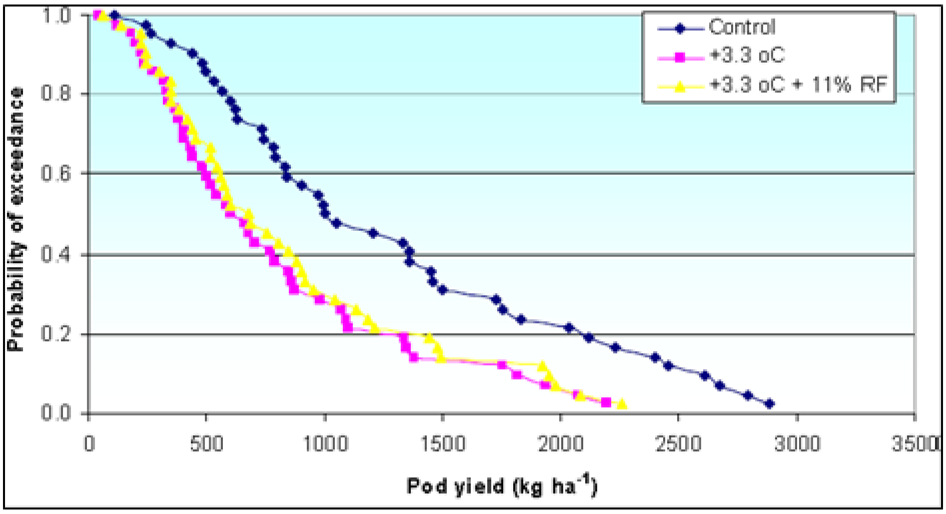


Figure 5. Probability distribution of yield under climate change (Groundnut - Anantapur). (Source: Singh et. al., 2009)

Table 7. Simulated effect of climate changeon ICRISAT crops

Crop	% change in grain yield		
	+Temp.	+ CO_2	Net change
Sorghum	- (27 to 55%)	+ (0 to 10%)	- (22 to 50%)
P. millet	- (38 to 56%)	+ (0 to 10%)	- (33 to 51%)
Groundnut	- (38 to 44%)	+ (10 to 20%)	- (23 to 29%)
Pigeon pea	- (23 to 26%)	+ (10 to 20%)	- (8 to 11%)
Chick pea	- (22 to 24%)	+ (10 to 20%)	- (7 to 9%)

Source: Tubiello et al., 2007

When adaptation is not considered, most of the major potato producing countries would suffer great losses in potential potato yield. Bolivia is the only country where potential yield would increase without adaptation, and with adaptation it is predicted to increase a staggering 77%. In most other major potato producing countries, adaptation mitigates a large part of the climate change induced yield loss. In Iran, for example, yield loss decreases from 48% to 13%. China, Peru, Russia, and the USA are other notable examples of countries where adaptation could mitigate much of the negative effects of global warming. When considering adaptation, Bangladesh, Brazil, Colombia, and Ukraine have the largest decrease in potential yield (more than 20% in 2040-59). The percentage of area with yield increase (Table 8) reflects the possibility to mitigate the effect of climate change by shifting the location of production with existing potato growing regions. It is particularly high (>30%) in Argentina, Canada, China, Japan, UK, Russia, and Spain.

Effect of climate change on rice production in Bangladesh

Tables 9 and 10 show predicted yields of BR3 and BR14 boro rice varieties, respectively at 12 locations of Bangladesh in the years 2008, 2030, 2050 and 2070. These predictions have been made using a fixed concentration of atmospheric CO_2 of 379 ppm (the value reported for the year 2005 in the fourth assessment report of IPCC) and for planting date of 15 January. The tables show significant reduction in rice yield in the future due to predicted changes in climatic condition. Compared to 2008, predicted average reductions of BR3 variety for the 12 selected locations are about 11% for the year 2030, 21% for 2050 and 54% for 2070. The corresponding reductions for BR14 variety are about 14%, 25% and 58% for the years 2030, 2050 and 2070, respectively. Some regional variation could also be observed in the predictions, with somewhat higher reductions predicted for central, southern and south-western regions.

Table 8. Potato area and changes in potential potato yield induced by climate change in the 2040-59 and the percentage of the potato area in a country where potential potato yield will increase

Country	Potato area (1000 ha)	Change in potential yield (%)		Areas with yield increase (% of cells)	
		Without Adaptation	With Adaptation	Without Adaptation	With Adaptation
China	3430	-22.2	-2.5	8.5	30.7
Russia	3289	-24.0	-8.8	12.4	48.4
Ukraine	1534	-30.3	-24.8	0.0	2.7
Poland	1290	-19.0	-16.1	0.0	2.4
India	1253	-23.1	-22.1	0.4	2.0
Belarus	692	-18.8	-16.6	0.0	0.0
United States	548	-32.8	-5.9	1.4	20.1
Germany	300	-19.6	-15.5	0.0	0.0
Peru	263	-5.7	5.8	8.3	13.9
Romania	262	-26.0	-9.9	0.0	19.2
Turkey	207	-36.7	-17.1	0.0	10.4
Netherlands	181	-20.0	-10.9	0.0	0.0
Brazil	177	-23.2	-22.7	0.0	0.0
United Kingdom	169	-6.2	8.1	50.0	57.1
France	168	-18.7	-6.9	4.5	29.9
Colombia	167	-32.5	-30.6	4.5	4.5
Kazakhstan	165	-38.4	-12.4	2.3	9.4
Iran	161	-48.3	-13.3	0.0	21.4
Canada	155	-15.7	4.6	17.9	55.5
Spain	142	-31.4	-6.6	0.0	37.5
Bangladesh	140	-25.8	-24.0	0.0	0.0
Bolivia	131	8.4	76.8	22.6	29.0
Lithuania	126	-13.7	-9.2	0.0	0.0
Argentina	115	-12.9	0.5	11.4	35.2
Nepal	115	-18.3	-13.8	0.0	16.7
Japan	102	-17.4	-0.9	8.8	41.2

Source: Hijmans, 2003

Table 9. Predicted yield of BR 3 variety of boro rice (kg ha^{-1}) at 12 selected locations for the years 2008, 2030, 2050 and 2070

Station Name	Cultivar	2008	2030	2050	2070	% change in yield for 2030	% change in yield for 2050	% change in yield for 2070
Rajshahi	BR3	3063	4083	3265	1785	33.3	6.59	-41.7
Bogra	BR3	5741	5119	4070	2036	-10.8	-29.1	-64.5
Dinajpur	BR3	6848	4824	4364	2692	-29.6	-36.3	-60.7
Mymensingh	BR3	5995	5275	4455	2739	-12.0	-25.7	-54.3
Tangail	BR3	5487	5160	3874	1938	-5.95	-29.4	-64.7
Jessore	BR3	5571	4432	4583	1997	-20.4	-17.7	-64.2
Satkhira	BR3	4700	4364	3603	2066	-7.14	-23.3	-56.0
Barisal	BR3	6043	4006	3971	2091	-33.7	-34.3	-65.4
adaripur	BR3	4582	4017	3647	2186	-12.3	-20.4	-52.3
Chandpur	BR3	5975	5455	4039	2772	-8.70	-32.4	-53.6
Comilla	BR3	6115	5987	4456	3075	-2.09	-27.1	-49.7
Sylhet	BR3	5960	5117	5750	3595	-14.1	-3.52	-39.7

Source: Basak et.al., 2010

Table 10. Predicted yield of BR 14 variety of boro rice (kg ha^{-1}) at 12 selected locations for the years 2008, 2030, 2050 and 2070

Station Name	Cultivar	2008	2030	2050	2070	% change in yield for 2030	% change in yield for 2050	% change in yield for 2070
Rajshahi	BR14	2334	2771	2392	1148	18.7	2.48	-50.8
Bogra	BR14	4306	3668	2637	1398	-14.8	-38.8	-67.5
Dinajpur	BR14	5047	3374	3023	1656	-33.1	-40.1	-67.2
Mymensingh	BR14	4353	3790	3186	1873	-12.9	-26.8	-57.0
Tangail	BR14	4104	3883	2565	1297	-5.38	-37.5	-68.4
Jessore	BR14	4032	3160	3153	1305	-21.6	-21.8	-67.6
Satkhira	BR14	3153	3171	2434	1377	0.57	-22.8	-56.3
Barisal	BR14	4397	2889	2705	1457	-34.3	-38.5	-66.9
Madaripur	BR14	3229	2606	2578	1491	-19.3	-20.2	-53.8
Chandpur	BR14	4389	3981	2801	1842	-9.29	-36.2	-58.0
Comilla	BR14	4678	4368	3063	1978	-6.62	-34.5	-57.7
Sylhet	BR14	4596	3764	4240	2378	-18.1	-7.74	-48.3

Source: Basak et.al., 2010

Flooding

Crop production is often limited during the rainy season due to excessive moisture brought about by heavy rain. Most crops are highly sensitive to flooding and genetic variation with respect to this character is limited. In general, damage to crops by flooding is due to the reduction of oxygen in the root zone which inhibits aerobic processes. Flooded crop plants accumulate endogenous ethylene that causes damage to the plants (Drew 1979). Low oxygen levels stimulate an increased production of an ethylene precursor, 1-aminocyclopropane-1-carboxylic acid (ACC), in the roots. The rapid development of epinastic growth of leaves is a characteristic response to water-logged conditions and the role of ethylene accumulation has been implicated (Kawase 1981). The severity of flooding symptoms increases with rising temperatures; rapid wilting and death of tomato plants is usually observed following a short period of flooding at high temperatures (Kuo et al., 1982).

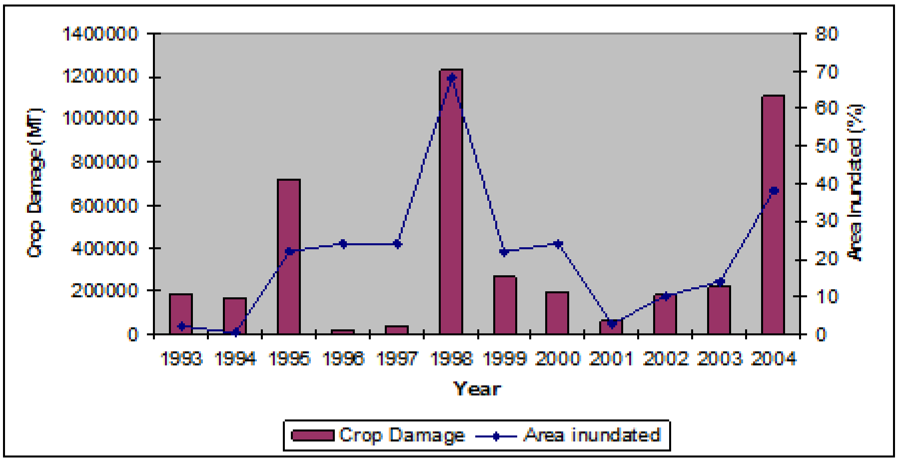


Figure 6. Crop damage (MT) due to historical flood in Bangladesh
(Source: Madhu, 2009)

Salinity

Crop production is threatened by increasing soil salinity particularly in irrigated croplands which provide 40% of the world's food (FAO 2002). Excessive soil salinity reduces productivity of many agricultural crops, including most vegetables which are particularly sensitive throughout the ontogeny of the plant. Onions are sensitive to saline soils, while cucumbers, eggplants, peppers, and tomatoes are moderately sensitive. In hot and dry environments, high evapotranspiration results in substantial water loss, thus leaving salt around the plant roots which interferes with the plant's ability to uptake water. Physiologically, salinity imposes an initial water deficit that results from the relatively high solute concentrations in the soil, causes ion-specific stresses resulting from altered K^+/Na^+ ratios, and leads to a build up in Na^+ and Cl^- concentrations that are detrimental to plants (Yamaguchi and Blumwald 2005). Plant sensitivity to salt stress is reflected in loss of turgor, growth reduction, wilting, leaf curling and epinasty, leaf abscission, decreased photosynthesis, respiratory changes, loss of cellular integrity, tissue necrosis, and potentially death of the plant (Jones, 1986; Cheeseman, 1988). Salinity also affects agriculture in coastal regions which are impacted by low-quality and high-saline irrigation water due to contamination of the groundwater and intrusion of saline water due to natural or man-made events. Salinity fluctuates with season, being generally high in the dry season and low during rainy season when freshwater flushing is prevalent. Furthermore, coastal areas are threatened by specific, saline natural disasters which can make agricultural lands unproductive, such as tsunamis which may inundate low-lying areas with seawater. Although the seawater rapidly recedes, the groundwater contamination and subsequent osmotic stress causes crop losses and affects soil fertility. In the inland areas, traditional water wells are commonly used for irrigation water in many countries. The bedrock deposit contains salts and the water from these wells are becoming more saline, thus affecting irrigated vegetable production in these areas.

Table 11. Influence of salinity on total dry matter production (g/10 plants) of rice cultivars and their classification to salinity tolerance

Variety	**Salinity level (ds m-1)**			
	0	**4**	**6**	**12**
IR 20	0.068	0.054	0.045	0.027
Pokkali	0.133	0.083	0.054	0.035
MR 33	0.069	0.058	0.039	0.021
MR68	0.060	0.044	0.028	0.018
MR 84	0.094	0.048	0.033	0.024
MR 52	0.075	0.057	0.040	0.028
MR 211	0.081	0.065	0.049	0.035
MR 219	0.066	0.052	0.038	0.024
MR 220	0.101	0.052	0.026	0.014
MR 232	0.077	0.054	0.040	0.031
BR 29	0.053	0.040	0.018	0.004
BR 40	0.075	0.054	0.039	0.023

(Source: Hakim et al., 2010)

Table 12. Tuber yield and harvest index for seven diploid potato clones and the tetraploid cultivar 'Norland' exposed to control conditions or 150 mM salt stress for 7 days at tuber initiation

Clones	Tuber yield (g)	
	Control	Stress
Norland	266.2	98.7
10908-05	241.4	71.5
10909-18	265.8	167.5
F20-ID	74.7	45.9
9506-04	100.0	137.2
11374-01	225.0	59.2
10602-02	70.5	51.3
9788-03	12.5	29.7
Mean	157.0	82.6

(Source: Shaterian et.al., 2008)

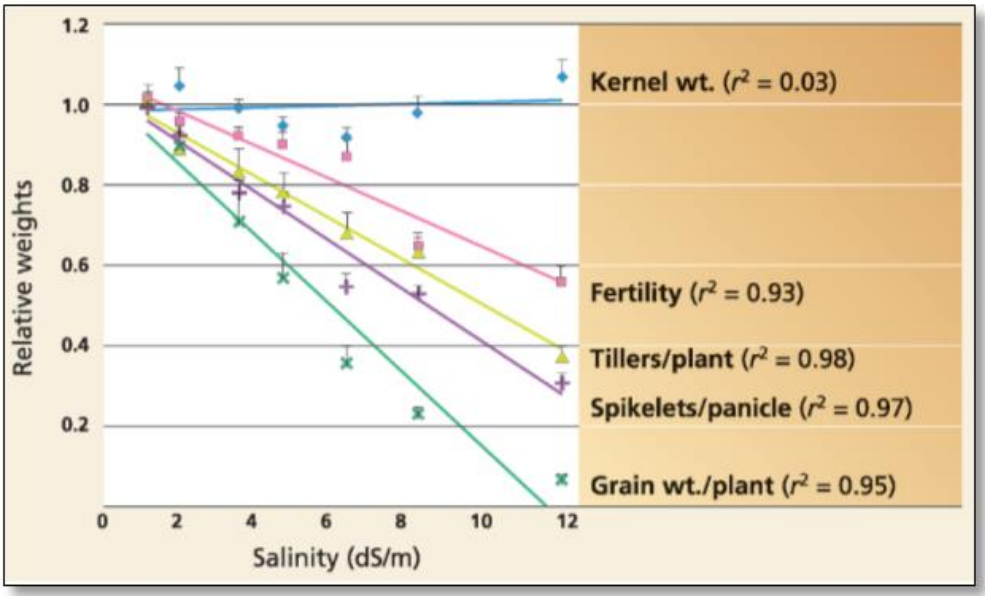


Figure 7. Relationship between salinity and various yield components of rice (*Oryza sativa* L. cv M202). (Source: Zeng and Shanon, 2002)

From estimates it is seen that the main reasons of yield reduction (20-40 % yield loss) in T.Aman crop are erratic rainfall, increased intensity and frequency of drought, increased salinity, tidal surges, floods, cyclone, use of local varieties, increased incidences of pests and diseases etc in the context of climate change. Total yield loss of T.Aman crop has been estimated to about 6.93 lakh ton per year in 450,320 hectares based on last 5-10 years climate change scenarios. Similarly, average yield level of HYV Boro is being affected (30-40 % yield loss) by high temperature (causing sterility) and increased salinity and that of T.Aus/Aus crop is being affected (20-40 % yield loss) by tidal surges. Vegetables, pulses, oil seed crops and fruit crops are being affected (20-40 % yield loss) by drought, increased salinity, soil wetness, excessive rainfall and water-logging and tidal surges in most coastal districts. From the study, total crop loss for major crops (viz. cereals, potato, pulses, oil seeds, vegetables, spices and fruit crops) due to different climate risks has been estimated to about 14.05 lakh tons per year based on last 5-10 years of climate change scenarios in ten districts. But the people are to live with these climatic vulnerabilities and risks in the coastal region.

Climate change scenarios on the coastal regions of Bangladesh

Table 13. Crop loss/yield reduction due to climate risk factors

Crop	% yield reduction	District	Total areas (in ha) affected	Total yield loss '000' MT	Major Climatic Risks
T. Aman	40-60	Cox's Bazar	35,500	71.00	Drought, flash floods, salinity, erosion, tidal surges, pests & diseases
	20-40	Patuakhali	76,200	114.30	Drought, water-logging, tidal floods, pests and diseases
	20-40	Baraguna	27,500	41.25	Drought, flood, pests & diseases
	20-40	Pirojpur	25,600	38.40	Flood, drought, tidal surge, pests
	20-40	Barisal	57,700	86.62	Flood, water-logging, drought, pests & diseases
	20-40	Noakhali	59,950	89.93	Drought, flood, water, logging, pests & diseases
	20-40	Satkhira	35,700	53.55	Drought, water-logging, erosion, pests
	20-40	Khulna	28,850	43.27	Cyclone, water-logging, salinity, pests
	20-40	Bagerhat	61,270	91.90	Drought, flood, river erosion, pests
	20-40	Bhola	42,000	63.00	Drought, tidal flood, cyclone, pests
T. Aus	20-40	All districts	75,000	112.50	Submergence, drought, salinity, Fe toxicity, river & ground water salinity, cyclone, pests & diseases
HYV Boro	20-40	All districts	150,000	300.00	Drought, salinity, Fe toxicity, river & ground water salinity, cyclone
Potato, Sweet Potato	40-60	All districts	28,055	140.25	Short winter, clayey soils, salinity, fogginess. Average yield = 10-12 t/ha
Pulses (Khesari, M.bean)	20-40	All districts	201,850	60.55	Untimely rainfall, soil wetness, drought, salinity, Pests & diseases
Oilseed Crops (Mustard,sesame, G.nut)	20-40	All districts	63,750	19.12	Late/short winter, salinity, clayey soils, Pests & diseases
Spice Crops (Chilli, Onion, Garlic)	20-40	All districts	53,630	26.81	Early rainfall, soil wetness, salinity, pests and diseases.
Fruit crops (banana,papaya, water melon, amra, guava, amra etc)	20-40	All districts	10,625	53.12	Erratic rain, drought, high temperature, salinity, tidal flood, water-logging, pests & diseases and cyclone
			Total	**1,405.57**	

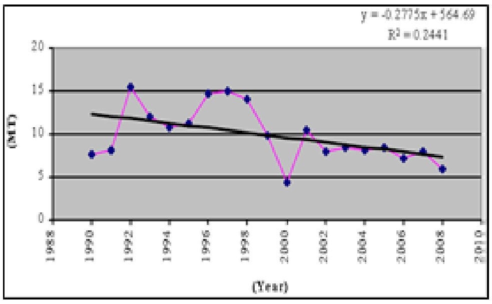
All districts= Khulna, Bagerhat, Satkhira, Barisal, Bhola, Barguna, Pirojpur, Patuakhali, Cox's Bazar and Noakhali.
(Source: Miah, 2010)

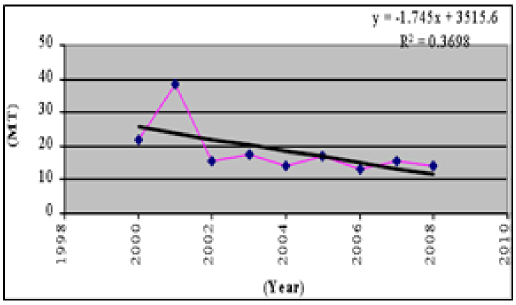
Table 14. Adaptation practices for sustainable crop production in the context of climate change

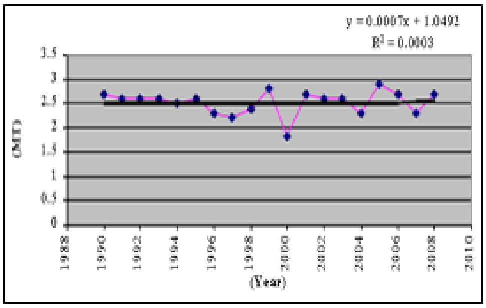
District	Recommended adaptation practices
1. Cox's bazaar	Sorjan system of cultivating year round vegetables, spices and fruits on raised beds and creeper vegetables on bed edges, Fish culture in ditches during wet months, Introduction of salt tolerant crop varieties, Encourage fruits and vegetables gardening Introduction of high value vegetable crop varieties (hybrid cucumber, ladies finger, chillis etc) as relay cropping in vegetable growing areas. Embankment repair and introduction of late T.Aman variety
2. Noakhali	Excavation of canals ponds for saline free water and introduction of salt tolerant varieties, Promote introduction of salt-tolerant pulses and oil seed crops (viz. cowpea, soybean, mungbean, ground nut etc.) Introduce floating bed agriculture in water-logged areas. Drainage improvement, introduce short duration and salt-tolerant crop varieties. Introduce standing water (submergence var.) boro cultivation Making high embankment and introduce salt tolerant varieties
3. Barisal	Sorjan system of cultivating year round vegetables, spices and fruits on raised beds and creeper vegetables on bed edges and cultivation of fish in ditches during wet months. Introduce submergence tolerant rice varieties (BRRIdhan-51,52, BINAdhan-11,12) Popularize floating bed agriculture. Zero tillage (potato, maize) and floating bed agriculture. Introduce submergence tolerant rice varieties
4. Barguna	Introduction of salt tolerant pulse crops (mungbean, cowpea, soybean, ground nut, sweet potato, chilli) Sorjan system of cultivating year round vegetables, spices & fruits on raised beds and creeper vegetables on bed edges and cultivation of fish in ditches during wet months. Introduction of drought and salt-tolerant crop varieties creating facilities of irrigation in fallow lands. Introduction of zero tillage (potato) Digging ponds and canals for rain water harvest.
5. Satkhira	Introduction of salt-tolerant crop varieties in salt affected areas - rice crops (BRRIdhan- 44,47 BINAdhan-8,10) -Utilization of fallow bunds under gher areas for year round vegetable cultivation, Popularization of zero tillage (potato, maize) Sorjan system of cultivating year round vegetables, spices and fruits on raised beds and creeper vegetables on bed edges and cultivation of fish in ditches during wet months, Floating bed agriculture in water-logged areas.

Source: Miah, 2010

Trends of Crop production per hectare (Satkhira district) due to climate change are shown graphically below: (Figures 8-11)







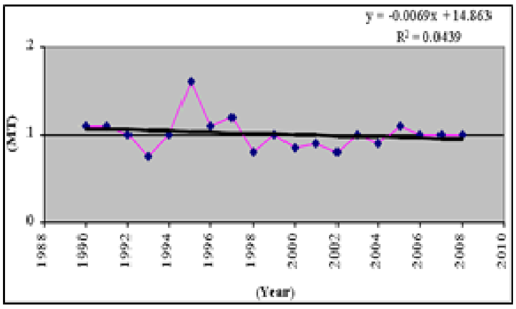


Figure 8. Trend of T Aman (HYV) production.

Figure 9. Trend of sesame (HYV) production.

Figure 10. Trend of Onion production.

Figure 11. Trend of Winter vegetables production.

(Source: Miah, 2010)

CONCLUSION

Climate change can boost up certain crop's production and also can decrease particulars yield. Therefore it is advised to cultivate stress tolerant crops and change production technology in vulnerable areas such as coastal region and flood prone areas. Bangladesh is not responsible for climate change or global warming, but is severely affected. To cope with the present situation of climate change in crop sector of Bangladesh, research should be conducted for introducing of salinity and flood tolerant variety of crops. Otherwise, the food security will be hampered in the near future.

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