EFFECTS OF CLIMATE CHANGE ON BORO CULTIVATION IN BANGLADESH

A THESIS

BY

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Jayanta Kumar Basak

ABSTRACT

In this study, trends of changes in temperature and precipitation patterns in dry season (December-May) in Bangladesh has been assessed through analysis of data on temperature and precipitation for the period 1976-2005 for 34 meteorological stations all over the country. The climate trends were assessed in terms of changes in maximum and minimum temperatures and changes in precipitation patterns. Analysis of monthly average maximum and minimum temperature show increasing trend for all months of the year except January; the increasing trend was particularly significant for the months of February, April and May. On an average, monthly-average maximum temperatures of each of these months increased by about 1 °C during the 30 year period from 1976-2005 and in monthly average minimum temperature increased by about 0.80 °C during the same period (i.e., 1976 to 2005). The magnitude of increase in monthly average maximum and minimum temperatures during the 30-year period from 1976 to 2005 is quite significant. Eighteen stations (out of 32) show increasing trend in number of "hot" days per year, while 13 stations (out of 31) show decreasing trend in the number of "cold" days per year; however, most of these trends are not statistically significant. Analysis of precipitation data during 1976-2005 show that for a large majority of stations, the total rainfall show decreasing trend for the winter (December to February), and pre-monsoon (March to May) rainfall did not show any significant change. In general, these trends are consistent with the general climate change predictions. These observations are particularly significant in the context of Bangladesh where agriculture is heavily dependent on temperature and rainfall patterns.

An agro-climatic study was conducted to assess the vulnerability of boro production in Bangladesh to potential climate change. Effect of climate change on yield of two varieties of boro rice has been assessed using the DSSAT (v4) modeling system. The yield of BR3 and BR14 boro varieties for the years 2008, 2030, 2050 and 2070 have been simulated for 12 locations (districts) of Bangladesh, which were selected from among the major rice growing areas in different regions of Bangladesh. The DSSAT model uses a detailed set of crop specific genetic coefficients for predicting yield and the BR3 and BR14 were selected in the present study because "genetic coefficients" for these varieties are available in the DSSAT modeling system. Available data on soil and hydrologic characteristics of these locations, and typical crop management practice for boro rice were used in the simulations. The weather data required for the model (daily maximum and minimum temperatures, daily solar radiation and daily precipitation) were generated for the selected years and for the selected locations using the regional climate model PRECIS. The model predicted significant reduction in yield of both varieties of boro rice due to climate change; yield reductions of over 20% and 50% have been predicted for both rice varieties for the years 2050 and 2070, respectively. However, BR14 appears to be slightly more vulnerable to climate change pheromones compared to BR3. Increases in daily maximum and minimum temperatures have been found to be primarily responsible for reduction in yield. Increases in incoming solar radiation and atmospheric carbon-di-oxide concentration increases rice yield to some extent, but their effect is not significant compared to the negative effects of temperature. Variations in rainfall pattern over the growing period have also been found to affect rice yield and water requirement. Increasing temperatures and solar radiation have been found to reduce the duration of physiological maturity of the rice varieties. Model results also suggest that in addition to reducing yield, climate change may also make rice yield more vulnerable to transplanting date, predicting significant reduction in yield as transplanting date is delayed, especially beyond 15 January. DSSAT modeling system could be a useful tool for assessing possible impacts of climate change and management practices on different varieties rice and other crops.

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Chapter 1

INTRODUCTION

1.1 General

The global issue of climate change encompasses significant challenge to the survival of all living entities on earth. The global warming and its consequent effect of climate change are attributed directly or indirectly to human activities that alters the composition of global atmosphere. Despite contributing insignificantly to the causes of climate change, developing countries are expected to be the worst victims. Due to its geographically location, Bangladesh is one of the most disaster-prone countries in the world and due to adverse impact of climate change natural calamities are predicted to be even more intense and frequent in the coming years. Demographic and socio-economic condition of the country makes the situation more precarious.

Global climate has been changing due to natural forcings as well as anthropogenic activities, especially emissions of greenhouse gases and aerosols, and land use changes in recent decades. Observational evidences demonstrate that composition of global atmosphere is changing, e.g., increasing atmospheric concentrations of greenhouse gases, such as carbon-di-oxide (379 ppm recorded in 2005), methane (1774 ppb recorded in 2005) and nitrous oxide (319 ppb recorded in 2005) (IPPC, 2007). Observational evidences also suggest changes in earth's climate, e.g., recent recorded changes in temperature, precipitation, sea level, arctic ice temperature, mountain glacier and snow cover, and in some regions extreme events including heat waves, heavy precipitation events and droughts. Continuing emissions of greenhouse gases and other anthropogenic factors are likely to result in significant changes in mean climate and its intra-seasonal and inter-annual variability in the Asian region. Bangladesh, being in South Asia, is one of the most vulnerable countries regarding the impacts of climate change.

General Circulation Models (GCMs) predicted that the average increase in temperature would be 1.3^{0}C and 2.6^{0}C for the years 2030 and 2070, respectively. It was found that there would be a seasonal variation in changed temperature: 1.4^{0}C change in the winter and 0.7^{0}C in the monsoon months in 2030. For 2070, the variation would be 2.1^{0}C and 1.7^{0}C for winter and monsoon, respectively. For precipitation it was found that the winter precipitation would decrease to a negligible rate in 2030, while in 2075 there would not be any appreciable rainfall in winter at all. On the other hand, monsoon precipitation would increase at a rate of 12% and 27% for the two projection years, respectively (Nishat et al., 2009).

Agriculture is always vulnerable to unfavorable weather events and climate conditions. Despite technological advance such as improved crop varieties and irrigation systems, weather and climate are still key factors in agriculture productivity. Often the linkage between these key factors and production losses are obvious, but sometimes the linkages are less direct. The impacts of climate change on food production are global concerns, and they are very important for Bangladesh. Agriculture is the single most and largest sector of Bangladesh's economy, which accounts for about 35% of the GDP and about 70% of the labor force (Ahmed et al., 2000). Agriculture in Bangladesh is already under pressure both from huge and increasing demands for food, and from problems of agricultural land and water resources depletion. In 2006/07, the total food (rice) requirement in Bangladesh was 29.77 million ton and production during this period was 27.32 million ton (BRRI, 2007). So food shortage was 2.45 million ton. The yield of modern varieties (MV) of boro rice increased up to 1.80% during the 1990s implying that it has contributed much to accelerate the overall rice production in Bangladesh. However, the adoption of MV rice in Bangladesh so far reached 73%, contributing nearly 85% to the total rice production (BBS, 2006). Area devoted to rice production by season can be viewed in Table 1.1 and Fig. 1.1. It is evident that area under boro production was quite low in 1971/72, but afterwards, there has been an increasing trend of area devotion to boro rice production over the years (Table 1.2). This is directly related to the expansion of shallow tubewell irrigation in Bangladesh.

Table 1.1: Area devoted to rice production in Bangladesh (1971/72-2006/07)

Fiscal Year	Aus million ha.	Aman million ha.	Boro million ha.	Total Rice area million ha.
1971/72	3.00	5.41	0.86	9.28
1975/76	3.41	5.75	1.14	10.32
1979/80	3.03	5.72	1.14	9.89
1984/85	2.93	5.71	1.57	10.22
1989/90	2.25	5.70	2.45	10.41
1995/96	1.54	5.65	2.75	9.94
1999/2000	1.35	5.70	3.65	10.71
2006/07	1.01	5.42	4.05	10.48

Source: BBS, 2008.

Table 1.2: Average yield of rice in Bangladesh (1971/72-2006/07)

Fiscal Year	Aus ton/ha	Aman ton/ha	Boro ton/ha	Total rice Average ton/ha
1971/72	0.78	1.15	2.01	1.05
1975/76	0.94	1.34	1.99	1.22
1979/80	0.93	1.33	2.11	1.23
1984/85	0.95	1.49	2.48	1.43
1989/90	1.10	1.71	2.46	1.70
1995/96	1.09	1.66	2.62	1.78
1999/2000	1.28	1.92	3.02	2.15
2006/07	1.70	2.05	3.65	2.68

Source: BBS, 2008.

Table 1.3: Level of rice production in Bangladesh (1971/72-2006/07)

Fiscal Year	Aus million ton	Aman million ton	Boro million ton	Total rice million ton
1971/72	2.34	5.70	1.73	9.77
1975/76	3.22	7.04	2.29	12.56
1979/80	2.80	7.30	2.43	12.53
1984/85	2.78	7.93	3.91	14.62
1989/90	2.47	9.20	6.03	17.71
1995/96	1.68	8.79	7.22	17.68
1999/2000	1.73	10.31	11.03	25.09
2006/07	1.51	10.84	14.96	27.32

Source: BBS, 2008.

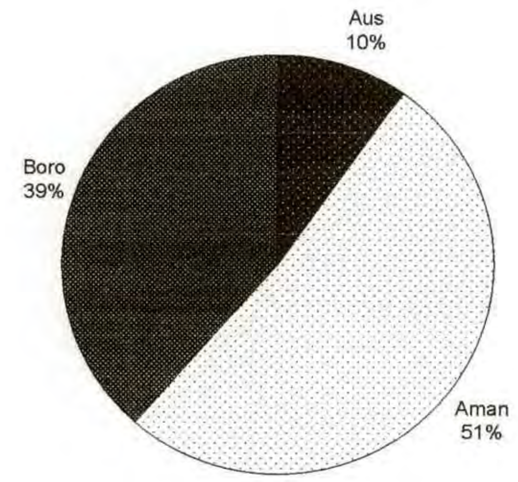

Figure1.1: Area devoted to rice production in Bangladesh in 2006/2007

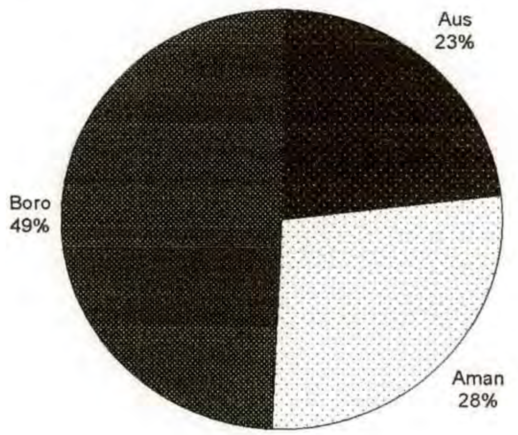

Figure 1.2: Average yield of rice in 2006/2007

Data on rice production are summarized in the above Table 1.3 and it shows that the quantity of rice produced in 2006/07 was about three times that produced in 1971/72. This is primarily due to expansion of cultivated area and introduction of high yield varieties of rice. IPCC impact assessments identify Bangladesh as one of the most 'susceptible countries' of the world to the negative impacts of climate change. These impacts range from an overall increase in sea level, atmospheric temperature, and rainfall to more intense natural disasters in the form of floods, cyclones, storm surges and drought (IPCC, 2007). The largest impact of global warming will be felt in the water resources of Bangladesh. Many projections suggest greater variability in future monsoon patterns, with severe impacts upon agriculture and other sectors due to either excess flow or severely low flows and draughts in other years (Nishat et al., 2009).

Table 1.4: Total food grain production and share of rice

Year	Rice million ton	Wheat million ton	Maize million ton	Total million ton	Share of rice to total food grain (%)
1971/72	9.77	0.113	-	9.88	98
1975/76	12.56	0.215	-	12.78	98
1979/80	12.53	0.827	-	13.36	93
1984/85	14.62	1.48	-	15.64	90
1989/90	17.71	0.89	-	16.56	95
1995/96	17.69	0.137	-	19.06	93
1999/2000	23.06	0.184	-	24.907	92
2005/06	27.55	0.0735	0.0522	27.787	96

Source: Economic review 2007,

Bangladesh needs to increase the rice yield in order to meet the growing demand for food emanating from population growth. Irrigated rice or boro rice is a potential area for increasing rice yield, which currently accounts for about 50% of total rice production in the country. However, climate change is a potential threat toward attaining this objective. It is therefore very important to understand the effect of climate change on rice production, especially boro production.

1.2 Objectives

The primary objective of the study is to assess the effects of climate change for boro cultivation in Bangladesh. Specific objectives include-

(a) Generation of climate scenarios (e.g., temperature, rainfall, solar radiation) for the years 2008, 2030, 2050, and 2070 predicted, using Regional Climate Change Model (PRECIS) for assessing impact on boro cultivation.

(b) Assessment of changes in temperature and rainfall patterns in Bangladesh in the dry season (i.e. boro season) through analyses of historical data (1976 to 2005) and projections of temperature and rainfall for the years 2030, 2050, 2070 for comparison with model (PRECIS) predictions.

(c) Qualitative assessment of the changing temperature and rainfall patterns (due to climate change) on different growth phases (vegetative, reproductive, ripening) for boro rice.

(d) Assessment of possible change in yield of selected boro rice varieties (for which genetic coefficients are available, e.g. BR3 and BR14) due to climate change using DSSAT 4 crop model system (utilizing CERES-Rice).

(e) Assessment of the effect of climate change on physiological maturity and irrigation requirement of boro rice, using DSSAT 4 crop model system.

1.3 Organization of the Thesis

The study has been presented in five chapters.

Chapter 1 presents background and objectives of the study.

Chapter 2 presents literature review on important climatic parameters and then observed and predicted changes, effect of climatic and other parameters on boro rice production and use of crop model for predicting rice yield.

Chapter 3 presents and assessments of the climate change trends in Bangladesh based on available data on temperature and precipitation.

Chapter 4 presents and assessments of the effect of climate change on yield of selected varieties of boro rice. Effects of climate change on physiological maturity and water requirement have also been predicted.

Chapter 5 presents the major conclusion from the present study and recommendations for further study in this area.

Chapter 2

REVIEW OF LITERATURE

2.1 General

Weather and climate have a profound influence on life on Earth. They are part of the daily experience of human beings and are essential for health, food production and well being. Many consider the prospect of human-induced climate change as a matter of concern. The IPCC Third Assessment Report (IPCC, 2001) presented scientific evidence that human activities may already be influencing the climate. If one wishes to understand, detect and eventually predict the human influence on climate, one need to understand the system and determines the climate of the Earth and of the processes that lead to climate change. Crop production depends on various factors such as soil, climate, irrigation, pesticide, seeds and other parameters. The available climate as a resource, should therefore, be thoroughly understood and crop-weather relationships using different climatic parameters like rainfall, temperature, humidity, sunshine hour etc. need to be established to identify potential areas and at the same time to characterize the adverse areas with emphasis on research needs for varietals improvement and improved cultural practices. The information related to the present study existing in the literatures were reviewed and presented below.

2.2 Important Climate Parameters and their Changes

Weather is one of the most important factor to have a profound on food availability and socio-economic conditions of the people in general and farming community in particular. The average conditions of the atmosphere near the earth's surface over a long period of time, taking into account temperature, precipitation, humidity, wind, cloud etc. Geographical location and physical settings govern the climate of any country (Attri, 2004).

Climate is not invariant in greater or less degree, it is ever changing. In all points of the world, one-year, one decade, one country differs from another. Temperature variations from year to year and from epoch to epoch generally increase towards high latitudes. Rainfall variations are greatest in low latitudes, where the heaviest individual falls occur, rain and snowfall varies most in and near the warm and cold deserts of the tropics and Polar Regions (WMO, 1999).

The year to year variation of crop yield is mainly due to the fluctuations in weather. The most important component of weather is the amount of rainfall and its distribution during the life span of plant growth. Islam (1996) also found a minor change in plant life and/or climatic environment also carried a large change in plant life and plant communities. Food security in south Asia is now threatened by yield stagnation, and possibly decline in rice yields, in the face of continuing population growth. Added to this are current threats to sustainability including overexploitation of ground and surface waters, water logging and salinity, declining soil organic matter, water and atmospheric pollution, and global climate change (Hobbs and Gupta, 2003). The sustainability of irrigated agriculture in the rice-growing areas of southern Australia is also threatened by reduced availability and increasing price of water and by secondary salinisation and global climate change.

2.2.1 Temperature

Bangladesh has a tropical monsoon type climate, with a hot and rainy summer and a pronounced dry season in the cooler month. January is the coolest month of the year, with the temperature ranging 13.5^{0}C to 26.5^{0}C, and April the warmest month, with the temperature ranging 33^{0}C and 36^{0}C. In rare cases the temperature goes down less than 5^{0}C but never touches freezing point. The climate is one of the wettest in the world; most places receive 1525 mm (60 in) of rain a year, areas near the hills receive 5080 mm (200 in) (Karim et al., 1990).

According to the Third Assessment Report (TAR), for the range of scenarios developed in the IPCC Special Report on Emission Scenarios (SRES), the globally averaged surface air temperature is projected to rise by 0.8-2.6°C by 2050 and by 1.4-5.8°C by 2100, relative to 1990 as shown in table 2.1.

Table 2.1: Global temperature change :(IPCC, 2001)

Year	Global Temperature Change(^{0}C)[a]
1990	0
2000	0.2
2050	0.8-2.6
2100	1.4-5.8

[a] Change in global mean annual temperature relative to 1990 averaged across simple climate model runs emulating results of seven AOGCMs with an average climate sensitivity of 2.8°C for the range of 35 fully quantified SRES emissions scenarios

Besides, projections of changes in surface air temperature have also been made for some Asian regions (under IS92a emission scenarios) and these are presented in Table 2.2. The projection considered the time periods around 2020s (2010-2029), the 2050s (2040-2069), and the 2080s (2070-2099), and changes in surface air temperature have been projected relative to 1961-1990. The projected area-averaged annual mean warming is 1.6±0.2°C in the 2020s, 3.1±0.3°C in the 2050s, and 4.6±0.4°C in the 2080s over land regions of Asia as a result of increases in the atmospheric concentrations of GHGs. Under the combined influence of GHGs and sulfate aerosols, surface warming will be restricted to 1.4±0.3°C in the 2020s, 2.5±0.4°C in the 2050s, and 3.8±0.5°C in the 2080s. The area-averaged increase in surface air temperature is likely to be most pronounced over boreal Asia and least in Southeast Asia in all seasons. The annual changes for South East Asia, where Bangladesh lies are, 1.36, 2.69, and 3.84°C, respectively. The projections also conclude that rise in temperature during winter is higher compared to that during the summer even though aerosol forcing reduces surface warming. Table 2.2 also shows that rise in temperature during winter is higher compared to that during the summer. It is also evident from Table 2.2 that even though aerosol forcing reduces surface warming, the magnitude of projected warming is still considerable and could substantially impact the Asian region.

Table 2.2: Plausible changes in area-averaged surface air temperature as a result of future increases in greenhouse gases (IPCC, 2001)

Regions	2020s			2050s			2080s		
	Temperature Change (°C)			Temperature Change (°C)			Temperature Change (°C)		
	Annual	Winter	Summer	Annual	Winter	Summer	Annual	Winter	Summer
Asia	1.58 (1.36)	1.71 (1.52)	1.45 (1.23)	3.14 (2.49)	3.43 (2.77)	2.87 (2.23)	4.61 (3.78)	5.07 (4.05)	4.23 (3.49)
South Asia	1.36 (1.06)	1.62 (1.19)	1.13 (0.97)	2.69 (1.92)	3.25 (2.08)	2.19 (1.81)	3.84 (2.98)	4.52 (3.25)	3.20 (2.67)
South-East Asia	1.05 (0.96)	1.12 (0.94)	1.01 (0.96)	2.15 (1.72)	2.28 (1.73)	2.01 (1.61)	3.03 (2.49)	3.23 (2.51)	2.82 (2.34)

Note: Numbers in parenthesis are area-averaged changes when direct effects of sulfate aerosols are included

Modeling studies by Huq et al., (1999) indicated that the average increase in temperature would be 1.3 °C and 2.6 °C for the projection years, 2030 and 2075, respectively. Similar to IPCC projections, the rise in winter temperature in Bangladesh was predicted to be higher by Huq et al., (1999), probably due to significant increase in monsoon precipitation, which could also cause severe flooding in the future. The projected changes were: 1.4 °C change in the winter and 0.7 °C in the monsoon months in 2030. For 2075, the variation would be 2.1 °C and 1.7°C for winter and monsoon, respectively (Tables 2.4, 2.5). Temperature increases reported in World Bank (2000) are: by 2030, a 0.7° C temperature rise in monsoon, and a 1.3 ° C rise in winter temperature, and by 2050, 1.1° C rise in monsoon, and 1.8° C rise in winter. The projected increases in surface air temperature by Huq et al., (1999) and World Bank (2000) were somewhat lower those projected for south Asian regions by IPCC (2001).

SAARC Meteorological Research Centre (SMRC) has studied surface climatological data on monthly and annual mean maximum and minimum temperature, and monthly and annual rainfall for the period of 1961-90. The study showed an increasing trend of mean maximum and minimum temperature in some seasons and decreasing trend in some other seasons. Overall the trend of the annual mean maximum temperature has shown a significant increase in annual mean maximum temperature over the period of 1961-90 (Karmakar and Shrestha, 2000). The study has also projected climatic changes up to 2050 and 2100 using a 5 years running average, and actual values. Based on a 5-year running average, it is found that the annual mean maximum temperature is likely to rise by 0.48^0C and 0.88^0C in 2050 and 2100, respectively. It is also found that the annual mean minimum temperature is likely to decrease by 0.06^0C and 0.11^0C by 2050 and 2100 respectively. The overall annual mean temperature is likely to increase by 0.21^0C and 0.39^0C by 2050 and 2100, respectively. The most important finding of the study is the seasonal variation of future temperature and rainfall. It is found that in the pre-monsoon season the mean maximum temperature is likely to decrease by 0.44^0C and 0.80^0C by 2050 and 2100, respectively. Conversely in the southwest monsoon season the maximum temperature is likely to increase by 0.90^0C and 1.65^0C by 2050 and 2100, respectively and the increasing trend is statistically significant (Karmakar and Shrestha, 2000).

Chowdhury and Debsarma (1992) observed the increasing tendency of the lowest minimum temperature over Bangladesh. Warrick et al., (1994) studied the variation of temperature and rainfall over Bangladesh. In this study, mean-annual temperatures have been expressed as departures from the reference period 1951-1980. It is evident that, on this time scale, Bangladesh region has been getting warmer. Since the later part of the last century, there has been, on average, an overall increase in temperature by 0.5^0C which was comparable in magnitude to the observed global warming. Karmaker and Nessa, (1997) studied climate change and its impacts on natural disasters and southwest-monsoon in Bangladesh and the Bay of Bengal. They found that the decadal mean annual temperature over Bangladesh have shown increasing tendency especially after 1961-1970.

2.2.2 Rainfall

Water that is considered from the aqueous vapor in the atmosphere and falls in drops from sky to the earth is called rain; and the total amount of rain that falls in a particular area within a certain time is called rainfall. The rainfall in Bangladesh varies seasonally and place to place. Among the climatic parameters the most important one is rainfall.

Rainfall varies not only with time but also with geographical area and altitude in space and is a continuous random variable (Ali et al., 1994).

Rainfall is the single most important climatic parameter influencing agriculture of our country since some 75 to 80% of the cultivated land is non-irrigated. This is the free source of water directly and most uniformly available to a crop and the foliage. But it can be utilized most efficiently by reducing its harmful effect and increasing beneficial outcomes, which requires planning of agricultural activities in such a way that beneficial effect of the rainfall is maximized and harmful effect minimized (Khan et al., 1991).

Hargreaves and Prassad (1985) stated that rainfall was erratic, uncertain and unevenly distributed. Although irrigation facilities in the country rapidly expanding, but it was a costly input in crop production. Out of the total cultivable areas available in the country about 85% of the cultivated areas were under rain-fed agriculture (Handa and Srenath, 1983).

Patterns of Rainfall

Instrumental records of land-surface precipitation continue to show an increase of 0.5 to 1% per decade in much of the Northern Hemisphere mid- and high latitudes. A notable exception includes parts of eastern Russia. In contrast, over much of the sub-tropical land areas rainfall has decreased during the 20th century (by –0.3% per decade), but this trend has weakened in recent decades. Other precipitation indicators suggest that large parts of the tropical oceans have had more precipitation in recent decades, and that precipitation has significantly increased over tropical land areas during the 20th century (2.4% per century). The increase in precipitation over the tropics is not evident during the past few decades. In the Southern Hemisphere, the pattern of island rainfall in parts of the South Pacific has changed since the mid-1970s, associated with the more frequent occurrence of the warm phase of the El Niño-Southern Oscillation (ENSO).

In the IPCC third assessment report, projections of changes in precipitation in different Asian regions have also been made (under IS92a emission scenarios) and these are presented in Table 2.3. The projections considered time periods around 2020s (2010-2029), the 2050s (2040-2069), and the 2080s (2070-2099), and changes in precipitation have been projected relative to 1961-1990. In general, all models simulate an enhanced hydrological cycle and increase in annual mean rainfall over most of Asia. Projected increases are more pronounced under the combined influence of GHGs and sulfate aerosols, compared to those under the influence of GHGs alone. The models show high uncertainty in projections of future winter and summer precipitation over south Asia (with or without direct aerosol forcing). The effect of sulfate aerosol on Indian summer monsoon precipitation is to dampen the strength of the monsoon compared to that seen with GHGs only. Table 2.3 shows increases in summer precipitation for projected years, especially under the influence of GHGs alone. On the other hand, it shows a reduction in winter precipitation (especially with consideration of sulfate aerosols).

Table 2.3: Plausible changes in precipitation over Asia and its sub regions as a result of future increases in greenhouse gases (IPCC, 2001)

Regions	2020s			2050s			2080s		
	Precipitation Change (%)			**Precipitation Change (%)**			**Precipitation Change (%)**		
	Annual	Winter	Summer	Annual	Winter	Summer	Annual	Winter	Summer
Asia	3.6 (2.3)	5.6 (4.3)	2.4 (1.8)	7.1 (2.9)	10.9 (6.5)	4.1 (1.5)	11.3 (7.0)	18.0 (12.1)	5.5 (3.5)
South Asia	2.9 (1.0)	2.7 (-10.1)	2.5 (2.8)	6.8 (-2.4)	-2.1 (-14.8)	6.6 (0.1)	11.0 (-0.1)	5.3 (-11.2)	7.9 (2.5)
South-East Asia	2.4 (1.7)	1.4 (3.3)	2.1 (1.2)	4.6 (1.0)	3.5 (2.9)	3.4 (2.6)	8.5 (5.1)	7.3 (5.9)	6.1 (4.9)

Note: Numbers in parenthesis are area-averaged changes when direct effects of sulfate aerosols are included

The results of modeling studies on Bangladesh presented by Huq et al. (1999) and World Bank (2000) follow a trend similar to those presented in Tables 2.3 and 2.4. Huq et al. (1999) predicted (see Tables 2.4, 2.5) that winter precipitation would decrease at a negligible rate in 2030, while in 2075 there would not be any appreciable rainfall in winter. On the other hand, monsoon precipitation would increase at a rate of 11 percent and 28 percent for the years 2030 and 2075, respectively. This may cause sever drought conditions in some parts of the country putting pressure on both domestic and irrigation water supplies.

Table 2.4 shows that compared to 1990 values, average evaporation would be almost similar in 2030 and slightly higher in 2075. But in winter months (December to March), evaporation for 2075 would be much higher owing to less precipitation, which would decrease moisture availability in dry months. Even in monsoon months evaporation would be much higher in 2075. All these results suggest that there would be extreme events in monsoon and winter, while the average annual change in evaporation would be insignificant (Huq et al., 1999).

Table 2.4: Climate change scenarios for Bangladesh in 2030 and 2050 (Haq et al., 1999 and World Bank, 2000)

Year	Average Temperature			Temperature Increase[1]			Average Precipitation			Precipitation Increase[2]		
	W	M	Ave	W	M	Ave	W	M	Ave	W	M	Ave
	°C			°C			mm/month			mm/month		
Base 1990	19.9	28.7	25.7	0.0	0.0	0.0	12	418	179	0	0	0
2030	21.4	29.4	27.0	1.3	0.7	1.3	18	465	189	+6	47	10
2075	22.0	30.4	28.3	2.1	1.7	2.6	00	530	207	-12	112	28

W stands for winter, M stands for monsoon, and Ave stands for average.

Notes: 1) Estimated values obtained by correlating model output data with the observed data.

2) Estimated based on model output data regarding rate of temperature change

Table 2.5: The fluctuations of values of parameters considered by Huq et al. (1999) with respect to their values under base-year (1990) situation (Huq et al., 1999)

Parameter	**2030**		**2075**	
	Winter	**Monsoon**	**Winter**	**Monsoon**
Temperature (°C)	2	0.65	3	1.5
Evaporation (%)	10	2	16	5
Precipitation (%)	-3	11	-37	28
Discharge (%)	-5	20	-67	51
Watershed development (%)	60		100	
Sea level rise (cm)	30		70	

The SAARC Meteorological Research Council (SMRC) carried out a study on recent relative sea level rise in the Bangladesh coast. The study has used 22 years historical tidal data of the three coastal stations. The study revealed that the rate of sea level rise during the last 22 years is many fold higher than the mean rate of global sea level rise over 100 years, which shown the important effect of the regional tectonic subsidence. Variation among the stations was also found.

General Circulation Model used by the US Climate Change Study team for Bangladesh reported that the average increase in temperature would be 1.3°C and 2.6°C for the years 2030 and 2070, respectively. It was found that there would be a seasonal variation in changed temperature: 1.4°C change in the winter and 0.7°C in the monsoon months in 2030. For 2070 the variation would be 2.1°C and 1.7°C for winter and monsoon, respectively. For precipitation it was found that the winter precipitation would decrease at a negligible rate in 2030, while in 2075 there would not be any appreciable rainfall in winter. On the other hand, monsoon precipitation would increase at a rate of 12 per cent and 27 per cent for the two projection years, respectively (Ahmed and Alam, 1999).

Availability of Rainfall

Murshid (1987) presented the year to year variation of crop yield was mainly due to the fluctuation in weather. The most important component of weather was the amount of rainfall and its distribution during the life span of a crop. Karmakar (2004) studied the monthly country averaged rainfall had interannual variation and it had increasing linear trends during the pre-monsoon season. The rates of increase of country-averaged rainfall were 1.3359 mm/year, 1.0909 mm/year and 1.1189 mm/year in March, April and May, respectively. The variation of monthly country averaged rainfall over Bangladesh maintained a similar pattern of variation with 11-13 year cycle. Quadir et al., (2003) reported that the average annual of rainfall over Bangladesh varies from 1429-4338mm. About 75% of the annual precipitation occurred during the monsoon period, about 15% in the pre-monsoon and the rest 10% occurred in winter and post-monsoon season. In Bangladesh monsoon, average rainfall varied from 1994 to 3454 mm (BBS, 2002).

The average annual rainfall in the country was 2486 mm. They also found that the average monsoon rainfall in every year was found to be 66.76%. About 70 to 80% of the rainfall occurred during the month from June to September. Leaving the most productive dry season (November to March), there is extremely inadequate rainfall for crop growth (Ali et al., 1994).

Talukder et al. (1988) studied the average annual rainfall in Bangladesh was 2047mm the contribution of the month of June, July, August and September were 416, 415, 342, and 269 mm, respectively. The annual rainfall in the country ranges from 1400 to 5800mm, but its distribution is uneven. Amin et al., (2004) analyzed the period between May to October was surplus period (rainfall>PET), and generally no problem with agricultural and other water-based activities in Bangladesh. The months from November to March, and in some instant up to April was deficit period (rainfall<PET). Individually months of May-October there is no aridity in Bangladesh. Only for individual months of November, December, January and February Bangladesh falls in aridity condition. In March, except sylhet, Rangamati, Chittagong, Cox's Bazar whole country falls in arid zone. In April month, only Rajshahi, Bogra, Dinajpur, Rangpur, Jessore, Satkhira, Cox'x Bazar falls in arid zone (Quadir et al., 2003).

Islam et al., (2002) described ascent and descent of severity of droughts mostly depended on fluctuation in rainfall distribution. Higher fluctuation was responsible for higher drought; while less varied distribution causes somewhat lower drought. Rainfall at 50% and 80% probability with respect to crop demand was almost scarce throughout the crop season. Specially, at the beginning of ripening stage availability of rainfall was nearly zero. The irrigation requirement during different months of the crop growing period is a function of rainfall deficits in those months for planting an irrigation water supply system. Thus, rainfall deficit information for different areas and periods can greatly help in determine optimal water release from a reservoir in accordance with demand, when rainfall exceeds evaporation, soil moistures reserves are recharged till filed capacity is reached and any further rainfall is termed as surplus. When rainfall is less than evaporation, soil moisture is utilized and rainfall deficit conditions occurred. The rainfall deficits are functions of time (Talukder et al., 1994).

2.2.3 Solar Radiation

Solar radiation is radiant energy from the sun, measured as a total amount (direct beam solar radiation plus sky radiation) expressed in calories per cm^2 per hour ($cal/cm^2/hr$) or MJ per m^2 per day ($MJ/m^2/day$). Only the "visible" part (380-720 nm) of the total solar energy is important for photosynthesis. During the ripening period of the crop in the monsoonal tropics, the intensity of solar radiation during an average day is about 350 cal/cm^2 per day, which is similar to the values reported during the rice growing season in temperate Asia such as in Japan (Munakata et al., 1969) and Korea (IRRI, 1972). Fukui (1971) reported that in the temperate Asian countries, solar radiation during the main cropping season is nearly the same as that for the rainy season in humid tropical regions, that is, 400 cal/cm^2 per day.

In the rice-growing areas in the Mediterranean countries, the United States, and southern Australia, average solar energy for the rice-growing season is about 100 cal/ cm^2 per day greater in either Asian temperate or monsoon tropical countries. Solar energy during the ripening period of rice in the southern Australia is 100 cal/ cm^2 per day more than in Asian temperate or monsoon tropical condition (Fukui, 1971). At least 700 cal/ cm^2 per day are recorded in some rice growing regions in Portugal and the United States.

2.2.4 Relative Humidity

Relative humidity refers to water vapor, exclusive of condensed water, in the atmosphere. It is the ratio, expressed as a percentage, vapor pressure (e) to saturation vapor pressure (em) at the existing temperature. March and April are the least humind months over most of the western part of the country. The lowest average relative humidity (57%) has been recorded in Dinajpur in the month of March. The least humind months in the eastern areas are January to March. Here the lowest monthly average of 58.5% has been recorded at Brahmanbaria in March. The relative humidity is everywhere over 80% during June through September. The average relative humidity for the whole year ranges from 78.1% at Cox's Bazar to 70.5% at Pabna (Banglapedia, 2004).

2.2.5 Sunshine Hour (Day Length)

The natural day length, or photoperiod, which affects growth of the rice plants, consists of the length of the period of daylight and the duration of the civil twilight. Day length is the interval between sunrise and sunset. Civil twilight is the interval between is the interval between sunrise or sunset and the time when the position of the center of the sun is 6^0 below the horizon. The day length (including civil twilight) pattern during the main rice cropping season varies most in high latitudes such as in Sapporo, Japan, and least near the equator such as in Bogor, Indonesia. Similarly, the day length patterns of selected upland rice-growing areas in some countries show that greater changes take place in Uberaba, Brazil, than in Ibradan, Nigeria (De Datta and Vergara, 1975).

2.2.6 Carbon di oxide (CO_2)

The atmospheric CO_2 concentration has risen dramatically since pre-industrial times, and it might be doubled by end of the century (IPCC, 2001). As a result of enhanced rate of trapping of infrared radiation by the increased levels of CO_2 and other trace gases in the atmosphere. The elevated CO_2, together with higher temperatures, could have a large impact on future agricultural productivity at the time when the larger global population will demand more food to be produced from the smaller land area that is available for agriculture. According to UNEP, CO_2 induced warming is expected to land to rises in sea level as a result of thermal expansion of the oceans and partial melting of glaciers and ice caps and its most severe effects on agriculture are likely to stem directly from inundation. South-east Asia would be most affected because of with a 1.5 m sea-level rise, about 15 percent of all land area in Bangladesh would be inundated and a further 6 percent would become more prone to frequent flooding. Altogether 21 percent of agricultural production could be lost.

The predicted temperature increase in the low latitudes is expected to be even smaller than the global average. Modest increases of less than 1-3.5^{0}C will be deleterious but manageable. Further, adaptation and carbon fertilization are expected to mitigate most of these effects. Current predictions suggest impacts in most developing countries that range from losses to small gains. In order to cast some light on these predictions, a low, medium and high climate scenario of 1, 2, 3.5^{0}C global temperatures increase. This range of temperatures is partly due to range of possible CO_2 concentrations. The 1^{0}C scenario has a 2100 CO_2 concentration of 700 ppmv, the 2^{0}C scenario is 800 ppmv and 3.5^0 C scenario involves a 1000 ppmv concentration. Country-specific changes in temperature and precipitation are predicted using UIUC 11 (Schelesinger and Andronova, 1995; Schelesinger and Verbitsky, 1996) for each of these three climate scenarios. Agricultural impacts are then predicted using country-specific future agricultural projections along with two climate sensitivities.

A pessimistic prediction is taken from agronomic-economic results and an optimistic prediction is taken from cross-sectional results (Mendelsohn and Schelesinger, 1999). Developed countries are likely to benefit in every scenario as carbon fertilization effects are expected to more than compensate for climate effects. The agricultural GDP in the OECD is expected to increase 4% to 11% by 2100 from global warming. The biggest winners are Eastern Europe and the former Soviet Union which are expected to gain between 9% and 48% of agricultural GDP. Developing countries, however, may experience losses. The range of effects for developing counties is between gains of 4 % of agricultural GDP.

2.3 Effect of Climatic Parameters on Rice Production

To delineate the effects of climate on rice production, understanding of both weather and climate is essential. Weather, which depends upon the heating and cooling of the earth's atmosphere, is a condition of the atmosphere at a given moment; climate is the condition of atmosphere over a period of time. Climatic differences must be carefully considered when comparing the performance of a rice crop or a variety grown at different sites.

According to Quadir et al., (2004) production of crops depends on different types of weather parameters and phenomenon. Crop failure may sometimes occur due to excess and deficit rainfall conditions or flood or drought of the country comes as a significant strain to its socio-economic structure. Nooruddin (2004) mentioned that the yield levels of both local and high yielding rice crops were significantly different between seasons in Bangladesh. It is highest during boro and lowest during aus season.

According to BINA (2004) crop grew under rain-fed condition when short duration and low water demand crop varieties could be chosen. In addition, the areas where usually occurred excessive depletion of the groundwater (e.g. Rajshahi) and problems like arsenic contamination has been started; the dry-land crops might be produced instead of winter rice (boro) for as sustainable and environment safe agricultural production. The effect of climate on the environment for the rice crop is major. Basic to understanding climate is knowledge of its elements, especially temperature, rainfall, solar radiation, relative humidity, sunshine hour and CO_2.

2.3.1 Effect of Temperature on Rice Production

The tropical and subtropical countries will be more vulnerable to the potential impact of global warming through the effect on crops, soils, insects, weeds and diseases. Bangladesh is in the subtropical region. Therefore, the agriculture of this country will be affected. The effects of climate change are already evident in the agro-ecosystem of the country. Agriculture is strongly interrelated with climate factors. Temperature, which is one of the main factors of climate, is close associated with agricultural production. In agricultural, rice production is affected by deviation in temperature. Climate change will increase the temperature which will bring changes in rice farming activities and affect crop yield. Temperature regime greatly influences not only the growth duration but also the growth pattern of the rice plant. During the growing season, the mean temperature, and the temperature sum, range, distribution pattern, and diurnal changes, or a combination of these, may be highly correlated with grain yields (Moomaw and Vergara, 1965).

A boro crop encountering critical low temperature is appeared to suffer from cool injury. The extent of cool injury depends on the nature and duration of low temperature and diurnal change of low temperature and diurnal change of low (night) and high (day) temperature. The critical low temperature for a rice crop at agronomic panicle initiation (API), reduction division (RD) and anthesis are 18^0C, 19^0C and 22^0C, respectively. The probability of experiencing stage-wise critical temperature approaches to 100% for established and short duration crop (Biswas, 2009). In Bangladesh low temperature i.e. cold problem occurs in winter season usually during November to February when minimum temperature remains often below 20^0C. Sometimes minimum temperature occur bellow 20^0C in March and April in some parts of the country.

Injury of rice plants by low temperature occurs in temperate and tropical regions. Kaneda (1972) reported 20 counties, mainly in lower-latitude areas, where cold injury in rice was confirmed. Those countries included Australia, Bangladesh, Colombia, Indonesia, India (Kashmir), Nepal, Peru, Sri Lanka, China and the United States. In Nepal, 15-20% of 1.3 million hectares of rice land are in a temperate region. Large areas of that land area are at altitude of 1000-2000 m and cold damage to rice is common. The highest altitude at which rice is grown is in Nepal's Jumla Valley (2621 m) in the far western Himalayas (Shahi and Heu 1979). In temperate regions, cold injury is the main constraint limiting the rice growing area and length of growing season. In Korea, low temperature often causes low rice yields (Chung 1979). In the Beijing area of China, where the temperature can go as low as 5^0C, rice seedlings have to protected from cold injury. In California, two major types of cold problems have been cited since rice became a commercial crop about 1912:

1. Seedling vigor and establishment in cool water (18^0C or below).
2. Sterility caused by cool night temperatures (below 15^0C) 10-14 days before heading (Rutger and Peterson, 1979).

Two factors cause cold injury to rice-cool weather and cold irrigation water. The common types of symptoms caused by low temperature are (Keneda and Beachell, 1974)

1. Poor germination
2. Slow growth and discoloration of seedlings
3. Stunted vegetative growth characterized by reduced height and tillering
4. Delayed heading
5. Incomplete panicle exsertion
6. Prolonged flowering period because of irregular heading
7. Degeneration of spikelets
8. Irregular maturity
9. Sterility
10. Formation of abnormal grains

Islam et al., (1995) studied that the higher minimum temperature during the ripening phase also affected the grain yield significantly. In one study, multiple regressions between grain yield and temperature and solar radiation revealed that higher mean temperature at vegetative stage affected grain yield. He reported that cold temperature during boro season often reduced the rice production. In Bangladesh, in many areas, early planting of short duration varieties suffered from cold temperature during boro season. It was found that boro season crops often suffered from cold at the seedling stage and sometime at reproductive phase particularly for early planting with short duration rice varieties (Islam and Morison, 1992). In 1990 boro field observations revealed very high grain sterility (40-90%) due to unusual fall of temperature in March resulting crop failure in several regions of Bangladesh (Haque et al., 1992).

When temperatures exceed the optimal for biological processes, crops often respond negatively with a steep drop in net growth and yield. If night time temperature minimum rise more than day time maximum, heat stress during the day may be less severe than otherwise, but increased night time respiration may also reduce potential yields. High temperature is accelerated physiological development, resulting in hastened maturation and reduced yield (Cynthia Rosenzweig and Daniel Hillel, 1995). Karim et al., (1996) reported that higher temperature reduced the yields in almost all locations in Bangladesh and it was particularly pronounced with 4^0C increase. The production of boro rice decreases 4% and 7% for temperature increases of 2^0C and 4^0C, respectively. The increased production over baseline varied between 16 and 30% for combinations of increased temperature and CO_2. In generally, though, the 4^0C increase was more detrimental that the 2^0C increase, despite of the level of CO_2.

Yoshida (1981) conducted experiments at the International Rice Research Institute (IRRI) in the Philippines showed that when rice was exposed to air temperature higher than 35^0C, heat injuries occurred. Varietals differences were observed for higher temperatures at different growth stages. The rice appeared to be the most sensitive to high temperatures at flowering. High temperatures during anthesis induced high percentage of spikelet sterility, which was attributed to disturbed pollen shedding and impaired pollen germination. Early morning anthesis was considered one way of avoiding high temperature stress. Studies showed that heat tolerance had a fairly high heritability, and that most genetic variation was additive. Amin et al., (2004) studied that temperature regulated respiration and translocation. Plant respiration rate increased with temperature. The optimum temperature for the ripening of rice was 21-22^0C. At temperature below 21^0C translocation was usually decelerated, while at temperature above 22^0C the respiration rate was accelerated and the grain-filling period shortened.

Satake and Yoshida (1978) reported the heading stage at which the rice plant is most sensitive to high temperature. Fertility of spikelets was 75% for plants held at 35^0C for 4 hours, about 55% at 38^0C for 4 hours and about 15% at 41^0C for 2 hours. It is common to have maximum daily temperatures from 35-41^{0}C or higher in semiarid regions and during hot months in tropical Asia. In these areas, a heat susceptible variety may suffer from a high percentage of sterility induced by high percentage of sterility induced by high temperature (Satake and Yoshida, 1977). According to Satake and Yoshida (1978), spikelet sterility from high temperature is induced largely on the day of flowering. Within the flowering day, high percentage just before anthesis was second most detrimental and high temperature after anthesis had little effect on spikelet fertility. Two important characteristics for heat tolerance of rice varieties at flowering are good pollen shedding and early morning anthesis.

Change of temperature would also have an effect on moisture available for crop growth, whether or not levels of rainfall remained unchanged. In general, and mid latitudes, evaporation increases by about 5 percent for each ^{0}C of mean annual temperature. Thus if mean temperature were to increase in the east of England by 2^{0}C potential evaporation would increase by about 9 percent (Rowntree et al., 1989).

Most agricultural diseases have greater potential to reach severe levels under warmer conditions. Fungal and bacterial pathogens are also likely to increase in severity in areas where precipitation increases. Under warmer and more humid conditions cereals would be more prone to diseases such as Septoria (Beresford et al., 1989). Zhao et al., (1988) indicated drier soil moisture conditions will exist in South Asia (including Bangladesh) during boro rice growing under global warming conditions. Air temperature is the critical variable that influences the dry season boro rice productivity (when water supply is not a major issue), inclusion of the variations in the weather variables is not necessary.

2.3.2 Effect of Rainfall on Rice Production

Variability in the amount and distribution of rainfall is the most important factor limiting yields of rainfed rice, which constitutes about 80% of the rice grown in South and Southeast Asia. For the same amount of rainfall, the coefficient of variability of the rainfall is higher in the tropics than in the temperate areas. In low-rainfall areas, variability is high regardless of latitude (De Datta, 1970). Unfortunately, the world's two largest rice growing countries, India and China, have many areas that receive less than 1200-1500 mm of rainfall. India, with the largest rice growing in the world, often has inadequate or excessive rainfall during the rainy season. As a result, drought or flood, and sometimes both, cause substantial damage to rainfed rice production.

Variability of rainfall affects the rice crop at different times. If the variability is associated with the onset of the rain, stand establishment and the growth duration of rice are affected. If variability is associated with an untimely cessation at the reproductive or ripening stage of the rice crop, yield reduction is severe (Moomaw and Vergara, 1965). Rainfall variability is more critical for upland rice-growing than for lowland rice. Moisture stress can damage, or even kill, plants in an area that receives as much as 200 mm of precipitation in a day and then receives no rainfall for the next 20 days. An evenly distributed precipitation of 100 mm/month is preferable to 200 mm/month that fall in 2 or 3 days.

The irrigation requirement during different months of the crop growing period is a function of rainfall deficits in those months for planting an irrigation water supply system. Thus, rainfall deficit information for different areas and periods can greatly help in determine optimal water release from a reservoir in accordance with demand, when rainfall exceeds evaporation, soil moistures reserves are recharged till filed capacity is reached and any further rainfall is termed as surplus. When rainfall is less than evaporation, soil moisture is utilized and rainfall deficit conditions occurred. The rainfall deficits are functions of time (Talukder et al., 1994).

Nooruddin (2004) mentioned that rainfall would supply water that was very essential for rice growth particularly the rain-feed rice cultivation. Adequate water will support the plant growth particularly during vegetative until the middle of reproductive stages, from nursery until about 75 days after seedling. Soil can hold the water for some times depending on the soil texture. The lighter the soils texture the lower capacity in holding the water. He also found that the yield levels of both local and high yielding rice crops were significantly different between seasons in Bangladesh. It is highest during boro and lowest during aus season.

Karim et al., (1999) reported that a little rainfall in early February helped the standing boro cultivation to a significant extent while local rainfall may lead to severe floods in late August, resulting into significant decline in area suitable for aman cultivation. Soil moisture depletes rapidly in the later part of crop growth if there is scantly or no rainfall during the wheat crop growing period. Soil moisture stress is reported to be adversely affecting wheat yield (Islam, 1990).

Ingram et al., (1993) and Islam et al., (1994) observed that yield losses resulting from water deficit were particularly severe when drought strikes at booting stage. Effects on yield, however, are small as compared to drought stress at reproductive stages, which irreversibly reduces the number of fertile spikelets. Hargreaves and Prassad (1985) stated that rainfall was erratic, uncertain and unevenly distributed. Although irrigation facilities in the country rapidly expanding, but it was a costly input in crop production. Out of the total cultivable areas available in the country about 85% of the cultivated areas were under rain-fed agriculture (Handa and Srenath, 1983).

2.3.3 Effect of Solar Radiation on Rice Production

The absorption of solar radiation by a plant canopy is a major factor determining its rate of photosynthesis, and therefore also its rate of growth and development. The photosynthesis mechanisms as well as the water demand and canopy microclimate are influenced by light penetration (Blad and Lemur, 1979). It was stated that arrangement, shape and number of leaves in plant canopy affect the penetration interception, distribution and reflection of light.

The importance of solar energy in tropical agriculture was recognized only after World War II (Best, 1962). Calculated by De Wit's(1958) method, the average daily solar radiation available in the temperate rice-growing regions such as the Po Valley, Italy, Australia or Davis, Calfornia. But, because of his dependence on rainfall, the farmer of rainfed rice in the tropics must grow his crops when there is low sunlight intensity. On the other hand, where irrigation water is available, rice can be grown in the dry season and the grain yield will be higher than in the wet season because of the higher intensity of solar radiation.

Solar radiation at soil surface increased rapidly at nearly 9.00 h to till on and exceeded the peak values of global radiation (Ham et al., 1991), because of extra radiation reflected from the canopy towards the sensors (Baten et al., 1997). Marani and Ephrath (1985) conducted an experiment to investigate the penetration radiation into canopies. Photo-synthetically active radiation (PAR) above and below the canopy was also measured. A high correlation was found between plant height and leaf area index (LAI), and both were highly correlated with radiation penetration.

Based on experiments in Texas, Stansel et al., (1965) and Stansel (1975) suggest that the rice plant's most critical period of solar energy requirement is from panicle initiation until about 10 days before maturity. In the tropics, the correlation between solar radiation for 45-days period before harvest (from panicle initiation to crop maturity) and grain yield, plotted by harvest month was highly significant (De Datta and Zarate, 1970). Earlier experiments indicated a strong correlation between grain yield and solar radiation during the last 30 days of growth (Moomaw et al., 1967). Subsequent IRRI research indicated that the increase in dry matter between panicle initiation and harvest was highly correlated with grain yield (De Datta et al., 1968). These results indicate the amount of solar energy received from as early as panicle initiation until crop maturation is important for the accumulation of dry matter during that period. This may be explained from the results obtained by Murata (1966), which showed that the accumulation of starch in the leaves and culms begins about 10 days before heading. Starch accumulates markedly in the grain during the 30-day period following heading (Murata 1966, Yoshida and Ahn 1968) and the total period of 40 days before maturity may be considered as the period of grain production.

With irrigation, the dry-season rice yields in the tropics (11 t/ha reported at IRRI) should be similar to those reported by Best (1962) for the temperate region (12.5 t/ha). However, the grain yield obtained during the wet season is lower than those in the dry season because of the lower level of solar radiation received during the crops' grain-filling and ripening stages (De Datta and Zarate, 1970).

The solar radiation requirement of a rice crop differs from one growth stage to another (Islam and Morison, 1992). Shading during the vegetative phase only slightly affected yield and yield components. In contras, shading during the reproductive and ripening phase caused significant reductions in yield by reducing panicle number, final spikelet number, grain weight etc. Kumar and Tripati, (1991) reported that direct sun under drought condition reduced leaf water potential and influences canopy temperature of wheat.

Yoshida (1977) has shown that critical stage in rice was the 25-day period before flowering when the number of spikelets is determined solar radiation is especially important. The spikelet number accounts for 60% of the yield variation. Solar radiation affects many physiological processes, particularly photosynthesis. The light requirement varies with plant species. There are critical stages of plant growth when solar radiation is especially important. For the same amount of daily solar radiation, the photosynthesis rate increase with day length.

2.3.4 Effect of Relative Humidity on Rice Production

The effects of relative humidity in the tropics are generally confused with the effects of solar energy and temperature. The average relative humidity before harvest follows a trend opposite that of the solar radiation values for the same period. Therefore, no importance is attributed to the high negative correlation between relative humidity and grain yield. However, a long dew period often causes increased incidence of blast disease in rice. In such cases, the effects of high relative humidity are often confounded by the night temperature regime, which cause a long dew period.

Relative humidity may affect grain formation after milk stage, ripening and disease incidence in rice. High relative humidity favours crop growth through the vegetation stage. During grain formation, low humidity may cause grain to shrink, but high humidity favours disease, particularly in rainfed rice (Amin et al., 2004).

2.3.5 Effect of Sunshine hour on Rice Production

Rice is generally a short-day plant and sensitive to photoperiod. Thus, long days can prevent or considerably delay flowering (Vergara and Chang, 1976). In lowland rainfed rice culture, delay in transplanting photoperiod-sensitive varieties because of delayed rains does not usually affect the grain yields. It is because of that flexibility at the seedling stage that photoperiod-sensitive varieties have traditionally been grown in monsoonal Asia (Vergara, 1976). The photoperiod-sensitive traditional varieties have provided stability in rice production even though their yield levels have been low. Those varieties produced some yield levels have been low. Those varieties produced some yields levels regardless of lodging, typhoon damage, or inadequate management practices such as no fertilizer or no weeding (Vergara et al., 1966). In some areas, the need to delay harvesting until monsoon-season floodwater has receded makes it essential to grow varieties with long growth duration. This is possible only by using photoperiod-sensitive varieties. But day length or photoperiod-insensitive rice varieties enable the farmer in the tropics and subtropics to plant rice at any time of the year without great change in growth duration (Chang and Vergara, 1972). In irrigated areas, and in rainfed areas where flooding is limited to a maximum water depth of 15-20 cm, improved photoperiod-insensitive varieties have partially replaced photoperiod-sensitive varieties. Thus, it is obvious that insensitivity to day length is essential in one situation and a liability in another. Amin et al., (2004) studied the months from November to March, and in some instant up to April is deficit period (rainfall<PET). But from the viewpoint of availability of bright sunshine hour, this period is best suited for crop production.

Yoshida (1981) described that grain yield in rice was comparatively low due to inadequate light intensity but showed positive correlation with solar radiation, especially during later stages of crop growth. Drought has some impact on the early stage of aus rice but its greater influence could be visualized during the anthesis and milk stages. According to Chang (1981) photoperiod is important in crop development. It can cause crop failure and hinder the introduction of new varieties.

2.3.6 Effect of Carbon di oxide (CO_2) on Rice Production

Plants grow through the well-known process of photosynthesis, utilizing the energy of sunlight to convert water from soil and carbon dioxide from the air into sugar, starches, and cellulose. CO_2 enters a plant through its leaves. Greater atmospheric concentrations trend to increase the difference in partial pressure between the air outside and inside the plant leaves, and as a result more CO_2 is absorbed and converted to carbohydrates. Crop species vary in their response to CO_2. Wheat, rice, and soybeans belong to a physiological class (called C3 plants) that responds readily to increased CO_2 levels. Higher levels of atmospheric CO_2 induce plants to close the small leaf openings through which CO_2 is absorbed and water vapor is released. Thus, under CO_2 enrichment crops may use less water even while they produce more carbohydrates (Cynthia Rosenzweig and Daniel Hillel, 1995).

Higher air temperatures will also be felt in the soil, where warmer conditions are likely to speed the natural decomposition of organic matter and to increase the rates of other soil processes that affect soil fertility. Additional application of fertilizer may be needed to counteract these processes and to take advantage of the potential for enhanced crop growth that can result from increased atmospheric CO_2 (Cynthia Rosenzweig and Daniel Hillel, 1995). Higher temperature reduced the yields in almost all locations in Bangladesh and it was particularly pronounced with 4^0C increase. The production of boro rice decreases 4% and 7% for temperature increases of 2^0C and 4^0C, respectively. The increased production over baseline varied between 16 and 30% for combinations of increased temperature and CO_2. In generally, though, the 4^0C increase was more detrimental was more detrimental that the 2^0C increase, despite of the level of CO_2 (Karim et al., 1996).

Singh and Padilla (1995) studied the effect of climate change on rice yield and adaptive management practices in the Philippines. They reported that, under current temperature regime, there would be beneficial effects of CO_2 from current (330 ppm) to high (660 ppm) concentrations in terms of grain yield, reduced transpiration, increased water-use efficiency, increased radiation use efficiency, reduced N losses, and higher N-use efficiency. The trends would be reversed for all the above parameters for each ^{0}C increase in temperature from 0 to 5^0C at each CO_2 level. The increase in grain yield with high N at 660 ppm concentration was much greater than at 330 ppm concentration. At zero N, crop response to temperature was similar, but response to an increase in CO_2 concentration was very low, suggesting that the benefits of higher concentration would be more pronounced in high input irrigated rice. Further, some of negative effects of temperature increase in warmer regions could be offset by the use of rice cultivars tolerant to high temperature-induced spikelet sterility, and by planting cultivars with longer growth duration, particularly longer grain-filling duration.

Karim et al., (1994) studied the impact of climate change on rice production at two contrasting locations (Mymensingh and Barisal) in Bangladesh. At both sites, simulated rice yield decreased significantly with temperature increases but this was offset by the physiological effects of CO_2. The study concluded that if CO_2 concentrations did not increase, or if the fertilization effects of CO_2 were less than predicted, then rice production in Bangladesh could be negatively affected and the country's food security for the increasing population would be threatened from climate change.

The agronomic results cited above do not include carbon fertilization or efficient adaptation. The agronomic-economic studies suggest that including adaptation would reduce the magnitude of losses. The experiments in laboratories and the field suggest that elevated carbon dioxide levels will also have a dramatic positive effect. The IPCC estimates that doubling carbon dioxide will roughly increase farm productivity by 30% for most crops (Reilly et al., 1996).

2.4 Response of Soil Parameters on Rice Production

Rice is grown from the equator to 50^0N and from sea level to 2500 m. It is grown in the hot, wet valleys of Assam and in the irrigated deserts of Pakistan. The soils on which rice grows are as varied as the climatic regime to which the crop is exposed: texture ranges from sand to clay, pH from 3 to 10; organic matter content from 1 to 50%; salt content from almost 0 to 1%, and nutrient availability from acute deficiencies to surplus. Productivity of land used for growing rice is to a large extent determined by soil and water conditions. Rice is the only major annual food crop (with the exception of aroids) that thrives on land that is water saturated, or even submerged, during part or all of its growth cycle. Rice is grown on a variety of soils ranging from water logged and poorly drained to well drained. It is also grown under many different climatic and hydrologic conditions. Adequate water supply is a key to optimum rice growth and grain yield. Because of the characteristic shrinkage and the accompanying changes in physical properties that occur, drying paddies are likely to pose conditions that will restrict root development for sensitive plants cultivated under upland conditions, which is also the case when an upland crop is grown in rotation with lowland rice. The nature of soil impedance to root growth takes cognizance not only of the role of water content as it affects mechanical resistance but also to the characteristics of the growing root tip.

Understanding of clay minerals is important for management of rice soils. Both clay content, as expressed by texture, and clay mineralogical characteristics have great bearing on the productivity of soils. In Japan, and in most tropical Asian countries, soils with montmorillonitic clay have higher fertility and higher yield potential than soils with allophone (amorphous silicates) as the major clay constituents (Kawaguchi and Kyuma, 1969). Clay minerals play a significant role in physical and chemical properties of rice soils. Soil pH, before and after flooding lowland fields, are important determinant in evaluating fertility and management of rice soils. The pH values of lowland rice soils vary greatly from country to country. Example of the range of pH values of paddy soils in some South and Southeast Asian countries are, given in Table 2.6.

Table 2.6: pH of Plow layer soils of the Paddy Fields in selected Countries (In a water suspension of Air Dried Soil) (Adapted from Kawaguchi, 1973)

Country	**pH**	**Country**	**pH**
Thailand	5.2	India	7.0
Malaysia	4.7	Philippines	6.4
Sri Lanka	5.9	Indonesia (Java)	6.6
Bangladesh	6.1	Japan	5.5

With regard to mineral composition, many Indonesian soils contain low silica and high iron, aluminum, and manganese. Soils from Thailand and Kampuchea have extremely low phosphorus content. Soils from Sri Lanka are highly siliceous and low in iron oxide, reflecting their sandy texture. Soils from India, Bangladesh and Burma have intermediate levels of minerals (Kyuma, 1978).

Rice generally reported as a moderately salt-tolerant crop but no rice variety can withstand high salinity throughout its growth cycle. Soil solutions high in sodium chloride with specific conductance values 6-10 mS/cm are harmful to rice plants and cause as much as 50% decrease in rice yield. In tidal areas, the specifics conductance values change from day to day depending on tidal regime. Inland saline soils generally have a pH>7. They are low in nitrogen, low in available phosphorus, but well supplied with potassium. Coastal saline soils may be eutric (fertile), dystric (infertile), calcaric (calcareous), thionic (sulfidic and sulfaticc), or histic (organic). Saline-sodic soils and calcaric saline soils are deficient in available zinc; thionic saline soils may have problems of aluminum toxicity and iron toxicity as well as phosphorus deficiency; histic saline soils are deficient in major nutrients as well as copper and zinc, and have other soil problems. Hydrology and relief are important in determining the suitability of saline lands for rice production (Ponnamperuma and Bandyopadhya, 1980).

2.5 Response of Planting Date on Rice Production

The gradually decrease in duration of the life cycle of different varieties occurs because of the change in the vegetative phase at different dates of planting in the winter season. The duration of the vegetative phase was the longest in January planting and the shortest in March planting. Such variation was due to the number of days exposed to minimum temperature below 20^0C. The minimum temperature in January is usually the lowest and it gradually rises towards March/April. Similarly tillering duration at January planting was the longest, followed by February and March planting. The higher the tillering duration, the higher percentage of productive tillers. The smaller percentage of productive tillers in the warm season was probably due to presence of a high number of underdeveloped tillers. Thus, the long tillering duration as affected by the prevailing temperature in the winter-season rice crop is one of the key factors for the achieving higher yield (S.Peng and B.Hardy, 2001).

The vegetative phase of rice is extended due to low temperature (Vergara and Chang, 1985). In November planting of BR3 when the temperature was cool, the vegetative phase was extended by 50 d and the relative tillering rate reached its peak at 40 to 50 d after transplanting. In contrast, with planting in July when temperature was high, the relative tillering rate reached the highest value within 15 to 25 d after transplanting. In most cases, tillering rate decreases because of low temperature (Kondo, 1954). Planting time or sowing time is very important to obtain higher grain yield and the same time to increase the land productivity. So, it is essential to screen advanced breeding lines that have potential as future rice variety. An experiment was conducted at the BRRI farm, Gazipur in the T,Aman season 2005. The lines BR6592-4-6-5, BR6592-4-6-4 and IR70175-54-1-1-2-3-HR2 were tested and compared with BR11 and BRRI dhan32 (ck). Thirty-day-old seedlings were transplanted during 15 July to 1 October at 15 days intervals. The promising lines BR6592-4-6-5 and BR6592-4-6-4 gave more than 4.00 t/ha yield up to 1 September planting. However, these two lines gave more than 3.92 t/ha yield up to 15 September. Although grain yields of these two promising lines were greater than check varieties irrespective of planting dates, they required about 7 days more for maturation compared to BRRI dhan32. Moreover, grain yield drastically reduced during 1 October planting, which was related with water stress in the flowering stage. Thus, BR6592-4-6-5 and BR6592-4-6-4 could supplement BR11 and BRRI dhan32 for obtaining more than 3.92 t/ha grain yield planted up to 15 September (BRRI annual report, 2005-06).

The time seeding had contrasting effects on the two components of water productivity of boro rice grown in the South Western coast of Bangladesh. Seeding before November resulted in very low yields due to cold stress at the critical reproductive stages of boro rice. Late-seeding required more water to be taken from the limited storage capacity of the canal network, and therefore will reduce the area that can be irrigated. With the optimum dates of seeding around 1-10 November and proper water management, 15% of the rice land can be planted after the Aman season. The percentage can be increased to 40% with some investments to improving the conditions of the canals (Abul et al., 2006).

2.6 Water Requirement for Rice Production

Water is indispensable to plant life. A plant's water content varies by species and within various plant structures and also diurnally during the entire growth period. The formative water for the plant is obtained mainly from soil through absorption by the plant roots. The plant uses less than 5% of the water absorbed. The rest is lost to the atmosphere through transpiration from the plant leaves.

Karmer (1969) summarized the functions of water for a plant:

1. It is a vital constituent of cell protoplasm.
2. It is a reactant or reagent in chemical reactions.
3. It is solvent for organic and inorganic solutes and gases facilitating their translocation within the plant.
4. It gives mechanical strength to the plant by producing turgidity.

Water affects the physical character of the rice plant, the nutrient and physical status of the soils, and the nature and extent of weed growth. The height of the rice related to the depth of water in the paddy; the plant height generally increases with increasing water depth. Tiller number of a rice plant, on the other hand, appears inversely related to water depth, at least over a relatively wide range of moisture conditions. With progressive drying of the soil, tiller number decreases, and much more sharply than under the influence of increased water depth. Culm strength of the rice plant, and therefore lodging resistance, decreases as the plant height increases. Thus, culm strength decreases if culms elongate as water depth increases. There is no evidence that grain-straw ratio is affected by water management practice in the rice field. Senewiratne and Mikkelsen, (1961) compared growth of rice plants in submerged and upland soil. At the early growth stage of rice, plants grew larger in the non submerged upland soil than on the submerged soil. But later there were more increases in tiller number, plant height, and leaf area in the submerged soil than in the non submerged soil.

One benefit of submerging rice soils is that it increases the availability of many nutrients, particularly phosphorus, potassium, calcium, silicon, and iron. But if the soil is highly permeable, nutrients will be leached downward from the root zone. Flooding a soil causes chemical reduction of iron and manganese, as well as other elements in the soil. Various organic acids such as acetic and butyric, and gases such as carbon dioxide, methane, and hydrogen sulfide are produced. All except methane, when present in large amounts, may retard root development, inhibit nutrient absorption, and cause root rot (usually between the seedling and panicle initiation stages). These toxic effects are variously identified as physiological diseases, such as Akiochi (degraded paddy soils) in Japan and bronzing in Sri Lanka. Toxicity is most often noticed when oxygen in the soil is depleted due to the rapid decomposition of large quantities of organic matter.

High and low water temperature have adverse effects on growth and grain yield of rice. High water temperatures have been reported to reduce rice yield, reduced uptake silicon, potassium (sometimes resulting in brown spot caused by Helminthosporium oryzae), reduced tiller number, and increased percentage of unfilled spikelet. At low water temperature some indica varieties grow poorly, usually with reduced tillering. At the later stages of rice growth, low water temperature delays panicle initiation, decreases panicle size, and increases sterility. Nutrient uptake is adversely affected by low (15^0C) water temperature (Bhattacharyya and De Datta, 1977).

Emergence of weeds and the type of weeds in a weed population are closely related to the moisture content of the soil and the water depth in the rice field. Conditions that favor weed growth also make weed control difficult. Moist, but unflooded soil, warmer temperature, and adequate light favor growth of grass. Water control during the early stages of crop has a major effect on weed control. As weed become established, it much more difficult to control them through water management. For transplanted rice, proper management can substantially substitute for weeding. Grasses can be completely eliminated if continuous flooding to a 16 cm depth is maintained throughout crop growth. Even with 5 cm of continuous standing water, grasses are substantially controlled (De Datta et al., 1973). Continuous flowing irrigation has the potential to produce optimum rice yields. In an experiment at Japan's Niigata Agricultural Experiment Station, flowing irrigation practiced (3-5 cm depth) from 35 days before heading o maturity gave about 7% increase in yield over that from continuous static submerged plots (5 cm depth). There was, however, 8% reduction in grain yield if flowing irrigation was practiced throughout crop growth, indicating the period of flowing irrigation may be critical (Matsubayashi et al., 1963).

In the Asia tropics rice is primarily transplanted for stand establishment. However, in most of Sri Lanka, and in parts of India, and Bangladesh, rice is broadcast-seeded either in the dry soil or wet or moist soil. Seeding into standing is not common in the tropics because lack of proper water control and low oxygen concentration in water under the high temperatures that occur in the tropics lead to poor establishment. In an experiment by De Datta et al. (1973), as the water depth was increased for direct-seeded flooded rice, crop establishment or number of plants per square meter was decreased. A brief drainage period at the maximum tillering and panicle initiation stages reduced lodging but increased weed populations.

It is important to determine water quality before the water is used for irrigation. It is equally important to monitor water quality periodically against the potential hazards of crop damage by poor irrigation water. For example, some parts of IRRI's experiment station had the soil pH increased to 7.9, the electrical conductance to 12 mS/ cm (12 mmho/ cm), and the available boron content to 13 ppm as a result of irrigation with alkaline, slightly-saline, deep-well water high in bicarbonates of calcium and magnesium, boron, and silicon. The high pH, deposition of calcium and magnesium carbonate, and the accumulation of silicon depressed the availability of zinc (Ponnamperuma, IRRI 1980). In Arkansas, United States, many of the irrigation wells produce water containing high concentrations of calcium and magnesium carbonates. In parts of southwest and southeast Arkanass, the groundwater contains high levels of sodium. Contained application of such poor-quality water on a rice field may cause chlorosis and sometimes death seedlings.

In California, Finfrock et al., (1960) described good rice irrigation water as that with:

1. Specific conductance less than 0.75 mS/ cm (0.75 mmho/ cm).
2. Boron contents of less than 1 ppm.
3. Sodium adsorption ratio (SAR) index (tendency to from alkaline soil) less than 10.

When high sodium water is used regularly each growing season, it may deflocculate the soil so that thickness, compactness, and impermeability increase. The deflocculated soil makes tillage difficult and usually produces low yields.

2.7 Growth Duration of Rice production

In temperate Asia, the growth duration of rice can be manipulated in a limited was by manipulating cultural practices. For example, in Japan where rice is mostly machine transplanted, seedbed technology has been considerably improved. Farmers in Japan extend the rice season by the use of temperature-protected seedbeds. This led to use of longer-duration varieties and to significant yield increase (Ishizuka et al., 1973). Rice yields in Japan have increased steadily due to improvements in variety and cultural practices. The rice growing season has been shifted to earlier in the spring by using nonseasonal varieties. Transplanting is done when temperature is lower.

In tropics, where temperature is favorable for the year-round rice culture, there appears to be optimum growth duration for high grain yields. The growth period of short-duration plants (of less than 100-day maturity) grown under normal field conditions usually do not permit the production of sufficient leaf area to result in production of larger number of panicles with well filled spikelets. Results of tests by Vergara (1970) indicate that under certain environmental conditions (4^0N), the best yields are from varieties that mature in 130-140 days. Optimum growth duration could be attained earlier by closer spacing or higher nitrogen levels. With increased emphasis on increased cropping intensity in both irrigated and rainfed areas, there is a considerable demand for rice with growth duration around 100 days. With the use of those shorter duration varieties, it is possible to raise the productivity per hectare per day even if the individual crop yield is somewhat lower than for varieties with 130 days or longer. Thus, growth manipulation should be designed to efficiently use given resources such as water, fertilizer, solar radiation, and temperature.

2.8 Effect of Fertilizer Application on Rice production

Development of a rational method of fertilizer application requires knowledge of the mineral nutrition of the rice plant at the different growth stages. It is also essential to know the contributions of the nutrients absorbed to grain yield. A dynamic insight into the physiological condition of the plant at any stage of the growth requires analytical studies of every part of the plant. The characteristics of various plant organs are greatly influenced by environmental factors of which one of the most important is mineral nutrition.

For rice, 16 elements are essential- carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), zinc (Zn), iron (Fe), copper (Cu), molybdenum (Mo), boron (B), manganese (Mn) and chlorine (Cl). These are divided into major and minor elements. The major elements, C, H, O, N, P, K, Ca, Mg and S are needed by plants in relatively higher amounts than the minor elements, Fe, Mn, Cu, Zn, Mo, B and Cl. All essential elements must be present in optimum amounts and in forms usable by rice plants. Nitrogen, phosphorus, zinc and potassium are nutrient elements most commonly applied by rice farmers (De Datta, 1981).

Rice plants require a large amount of nitrogen at the early and mid tillering stages to maximize the number of panicles. Nitrogen absorbed at the panicle initiation stage may increase spikelet number per panicle, size of leaves and grain and protein content in the grains (Yoshida, 1975). The rate of dry matter production of the rice plant, the proportionate weight of each plant part, and the mineral content of a given plant part change as the plant develops. The causes are changes in physiological status of the plant with the development of growth phases and changes in environmental conditions, such as temperature, availability of each nutrient in the soil and so on, during growth and development. The accumulation of nitrogen in the vegetative organs is high during the early growth stages and decrease with growth. After flowering, translocation of nitrogen from the vegetative organs to the grains becomes significant. There is some translocation of carbohydrates from the vegetative plant parts to the grains. Accumulation of carbohydrates in the vegetative organs is negligible during the vegetative phase, and after flowering a large amount of carbohydrates accumulates in the grains (Ishizuka, 1965).

Fertilizer use efficiency is the output of any crop per unit of fertilizer nutrient applied under a specific set of soil and climatic conditions. Barber (1977) defined fertilizer efficiency as the increase in yield of the harvested portion of the crop per unit of fertilizer nutrient applied. The highest fertilizer efficiency is obtained with the first increment of fertilizer and the size of the yield increase decreases successively with each additional increment of fertilizer added. Therefore, the lowest rate of fertilizer would give the highest efficiency but the yield obtained may be low and unprofitable. Another approach to defining fertilizer efficiency is based on plant uptake with the least amount of fertilizer needed to match plant use with maximum grain yield as the most efficient rate of fertilizer application. Bartholomew (1972) classified nitrogen need according to plant use-good use efficiency, average use efficiency, poor use efficiency and pollution range. There are two possible reasons for not reaching expected yield levels:

1. The fertilizer nutrients are not taken up by the plants because they are applied at the wrong time or in the wrong place, or transformation of nutrients has made them unavailable.
2. Although taken up by the crop, the nutrients are not used for grain production due to other growth-limiting factors such as in sufficient water or light or lack of other mineral elements.

For India, Mahapatra et al., (1974) summarized fertilizer efficiency in cereals as dry-season rice > wet-season > wheat > maize > millet > sorghum. In all those crops, a well planned and well executed program of field research would help identify nutrient deficiencies and determine yield responses from low, as well as high, rates of fertilizer application. Nitrogen is generally needed in most rice soils, particularly in places where nitrogen-responsive modern rice varieties are grown with improved cultural practices. Low nitrogen use efficiency, the widespread need for nitrogen for food production, the anticipated world shortage of petroleum products.

Numerous nitrogen-response experiments have shown that the recovery of the fertilizer applied to the rice crop is seldom more than 30-40%. Even with the best agronomic practices and strictly controlled conditions the recovery seldom exceeds 60-65% (De Datta et al., 1968). Ironically, the soil and climatic conditions that favor rice growth adversely affect the recovery of nitrogen from the soil and are responsible for its rapid loss. Nitrogen may be lost from plants through root exudation, the flushing action of dew or rain and natural or mechanical loss of plants parts. Even considering all these possibilities, a portion of the applied nitrogen is not accounted for. Recent research indicates that there is a relationship between gaseous nitrogen loss and efficiency of nitrogen utilization by rice plants. These losses may need to be considered to determine nitrogen fertilizer effectivness in rice (da Silva and Stutte, 1979).

2.9 DSSAT/CERES-Model for Production of Rice Yield

Both rice and wheat are important crops in south Asia and Australia, and are grown together in sequence in large areas. The sustainability of rice-wheat cropping systems is a serious concern for food security in south Asia, and for viable regional communities in Australia. Issues facing both regions include reduced availability of water for irrigation, ability to farm profitably, and shallow water tables and salinity. Therefore there is much interest in technologies that increase water use efficiency, productivity and profitability of rice-based systems.

Crop models are useful tools for considering the complex interactions between a range of factors that affect crop performance, including weather, soil properties and management. Where pests and diseases are controlled, water and nitrogen fertilizer management are the main factors influencing yield for a given environment. The CERES Rice and Wheat models simulate crop growth, development and yield taking into account the effects of weather, genetics, and soil water, carbon and nitrogen, and planting, irrigation and nitrogen fertilizer management. The rice and wheat models can also be run in sequence under the DSSAT framework. Therefore DSSAT/CERES Rice-Wheat offers the ability to evaluate options for increasing yield and water and nitrogen use efficiency of rice-wheat systems.

Ritche et al., (1987) reported that the CERES-Rice model assumes nine stages of rice plant growth: pre-sowing, germination, emergence, juvenile, floral induction, heading, flowering, grain filling, and harvesting. Completion of these growth stages is determined by accumulation of degree-days.

The phenology components of CERES Wheat and CERES Rice have been described by Singh (1994) and Ritchie et al., (1998). The models describe the progress through the crop life cycle using degree-day accumulation (heat sum). The duration of growth stages in response to temperature and photoperiod varies between species and cultivars, and genetic coefficients to describe these differences. The phenology component also simulates the effect of water or N deficit on the rate of life cycle progress (Singh et al., 1999). These effects may vary with life cycle phase; for example, water deficit may slow the onset of reproductive growth but accelerate reproductive growth after the beginning of grain filling.

In the sub-tropical environment of Kherala, India, Saseendran et al., (1998) reported that grain yields of Jaya and IR8 were within 3% and straw yields within 27% of measured yields, and that grain weight and grain number per m^2 were also predicted closely by CERES model. In the same state, Rao et al., (2002) also observed very good agreement between simulated and observed yields of Jaya, Jyothi and Triveni for all transplanting dates in one year (0-2% of observed values). In a year in which heavy rains which caused high sterility, the simulated yields were 5-10% greater than the observed yields. Timsina et al. (1995) reported that for experiments at Pantnagar in northwest India, simulated grain yields of Pant-4 were generally within 1-15% of observed yields, but in some cases, the simulated yields were out by up to 40%, mainly due to the fact the model didn't accurately predict the phenological events. In northern Bangladesh, simulated yields of BR14 and BR11 were either over or underestimated relative to observed yields. The model undoubtedly yields at zero N (Timsina et al., 1998). However, some of the discrepancy between simulated and observed yields was due to insect damage and lodging at high N rates, which resulted in lower yields.

Timsina et al., (1995) tested the sensitivity of the CERES Rice and Wheat for a range of variables (moisture regimes, planting dates, weather years, and N application rates) that influence the productivity and sustainability of rice-wheat systems in the rainfed and irrigated ecosystems on a fertile and an infertile soil in a subtropical environment at Pantnagar, India. In the infertile soil, the simulated rice yields increased with increasing level of fertilizer N while in the fertile soil, yields leveled off for application rates higher than 90 kg/ha. These results suggest that both models were sensitive to a number of management related variables. Buresh et al., (1991) used CERES Rice to assess year to year variability in response to N application for two transplanting dates (15 January and 15 July) in Philippines. The model consistently predicted higher N response with the January than July transplanting and greater NH_3 loss for July than January transplanting. At Pantnagar, India, CERES wheat predicted a small response to applied N in fertile soil but a large response in fertile soil.

Timsina et al., (1998) calibrated and validated the CERES Rice and Wheat models and established the long-term yield trends for wheat systems at Nashipur in northern Bangladesh. Using the minimum soil, crop, and weather data, they then predicted the long-term yield trends two rice (BR14 and BR11) and two wheat (Kanchan and Sowgat) cultivars for low (zero N, rainfed) and high (120 kg-N/ha, irrigated) input systems for three sites in north (Dinajpur District), northwest (Jessore District) and central (Gazipur District) Bangladesh. Across sites, years, moisture and N regimes, BR11 rice always out yielded BR14, consistent with experimental results. Wheat yields across sites and years were highest at Nashipur due to lower minimum temperature and higher solar radiation during the growing season. Conversely, yields were lowest at Gazipur due to higher temperatures and lower solar radiation.

Hundal and Karu, (1996) used CERES models to study the effects of climate change on rice, wheat, maize and groundnut in Ludhiana, India. Scenarios included the effect of changes in each parameter separately and in combination, with daily increases in temperature (up to 3^0C above normal), solar radiation (up to 10%), precipitation (up to 50%) and CO_2 concentration (up to 600 ppm). Hundal et al., (1998) also studied the effect of climate change on the yields of rice cv. PR106 under various scenarious, also in Ludhiana. Increased temperatures advance wheat maturity, but delayed rice, and reduced leaf area, biomass and yield more in wheat than in rice. A 10% decrease in radiation decreased the maximum leaf area index (LAI) by 7.6% in wheat and 5.9% in rice, whilst a 10% increased LAI by 7.1 and 5.7%, respectively. Both Biomass and grain yields of rice and wheat increased with solar radiation, increasing CO_2 concentration to 660 ppm increased LAI, biomass, and grain yield of rice by 11, 7.7 and 8.7%, respectively. Decreased rainfall did not have any effect on rice and wheat yields as those crops were fully irrigated. The interaction between temperature and solar radiation did not have any effect on phenology. Negative effects on LAI, growth and yield of wheat were further intensified where both temperature and radiation were increased. In rice, however, the adverse effect of an increase in temperature by 1^0C on growth and yield was compensated for by increasing radiation by 5%. Increasing both temperature and CO_2 concentration reduced the maximum LAI, biomass and grain yield of rice.

Lal et al., (1998) predicted rice and wheat yields for various climate change scenarios (increase or decrease of maximum and minimum temperatures, CO_2 concentrations, and various water management levels) for Delhi, Hissar, and Ludhiana. Greater yields of both crops (15 and 28%, respectively) were predicted for doubling of CO_2 levels, but this was nearly cancelled out by 3^0C and 2^0C temperature rises during the wheat and rice seasons, respectively. While wheat yield was decreased by an increase maximum temperature, rice was affected by an increase in minimum temperature. With increasing CO_2 and maximum and minimum temperatures, wheat yields would increase by 21% while rice yields would increase by 4%.

Chapter 3

ASSESSMENT OF CLIMATE CHANGE TRENDS IN BANGLADESH

3.1 INTRODUCTION

The causes of climate change and variability and its impacts have been one of the most discussed agendas all over the world for the last couple of decades. The main factors behind the climate change can be classified into two broad categories as natural and anthropogenic factors. Natural factors are mainly greenhouse gases, plate tectonics, solar variation, orbital variation, volcanic activities, etc. Anthropogenic factors include burning of fossil fuel, aerosols, land use, irrigation, deforestation, agriculture, etc. Observational evidences demonstrate that composition of global atmosphere is changing [e.g., increasing atmospheric concentration of green house gases such as CO_2 and methane (CH_4)] as is the earth climate (e.g., temperature, precipitation, sea level, sea ice and in some regions extreme events including heat waves, heavy precipitation events and droughts). The world community faces many risks from climate change. Clearly, it is important to understand the nature of those risks, where natural and human systems are likely to be most vulnerable, and what may be achieved by adaptive responses.

According to IPCC, TAR, 2001, Southeast Asia is a highly vulnerable region regarding impacts of climate change on key sectors as food and fiber, biodiversity, water resources, coastal ecosystems, human health, settlement, etc. For a sea level rise of 45 cm only, Bangladesh will face a potential land loss of 15,668 km^2 (10.9%) and population exposure of 5.5 million (5%). Sea-level rise will affect mangrove ecosystems by eliminating their present habitats, loss of plant species, wild life, increase in salinity and creating new tidally inundated areas to which some mangrove species may shift. With a 1-m rise in sea level, the Sundarbans (the largest mangrove ecosystems) of Bangladesh will completely disappear. For the sea level rise of 45 cm or more, the extent of inundation will increase about 23-29% which will result in change in flood depth category and change in monsoon rice cropping pattern and reduction in rice yield. So the vulnerability is obvious.

Bangladesh is a part of humid tropics with Himalayas in the North and funnel shaped 710 km long coast touching the Bay of Bengal in the South. This peculiar geography of Bangladesh has to experience severe flood, monsoon, tornado, drought and catastrophic cyclones associated with severe storm surge. All these disasters are temperature related phenomena. Southwest monsoon is predominant here but there is a large variation of rainfall over different parts of the country. Climatologically, Northwestern part gets the least rainfall (1600-2000mm/year) and Northeastern and Southeastern region receive the maximum rainfall (2500-4000 mm/year) due to orographic and hill structures (Debsarma, 2003).

The IPPC (2001) projected certain climate change events during the 21st century with significant confidence, which included higher maximum temperature and more hot days, higher minimum temperature and fewer cold days, increased heat index and more intense precipitation events. A number of studies have been carried out on trends of change in climate parameters in the context of Bangladesh (Chowdhury and Debsarma, 1992; Warrick et al., 1994; Karmakar and Nessa, 1997; Karmakar and Shrestha, 2000; World Bank, 2000; Mia, 2003; Debsarma, 2003; Karmakar, 2003). Warrick et al., (1994), Karmakar and Shrestha (2000) and Debsarma (2003) provided assessment of changes in temperature and precipitation over Bangladesh, while Chowdhury and Debsarma (1992) and Mia (2003) reported changes in temperature based on analysis of historical data of some selected weather stations in Bangladesh. Karmakar and Nessa (1997) and Karmakar (2003) provided assessment of the effects of climate change on natural disasters. The present study provides an assessment of climate change and variability in Bangladesh based on analysis of historical data of temperature and rainfall recorded at 34 meteorological stations in Bangladesh. In particular assessments have been made of changes in maximum temperature, changes in minimum temperature, variations in number of hot days and cold days, and changes in precipitation pattern.

3.2 METHODOLOGY

In this study, different aspects of climate change in Bangladesh have been assessed through analysis of historical data on temperature and precipitation. Efforts were made to assess the phenomena that are likely to be observed as a result of climate change.

Table 3.1 Possible changes in climate and their confidence level (IPCC, 2001)

Confidence in observed change (latter half of the 20^{th} century)	Changes in Phenomena
Likely	Higher maximum temperature and more hot days nearly all land areas
Very likely	Higher minimum temperatures, fewer cold days and frost days over nearly all land areas
Likely, over many areas	Increase of heat Index over land areas
Likely, over many Northern Hemisphere mid to high latitude land areas	More intense precipitation events
Likely, in few areas	Increased summer continental drying and associated risk of drought

Climate change phenomena that could be assessed directly from precipitation and temperature data are presented in Table 3.1. In this study, efforts have been made to assess these changes through analysis of climatic data on precipitation and temperature. This Chapter describes the nature of data collected from the Bangladesh Meteorological Department (BMD), the methodology followed in the analysis of the data and results of the analysis.

3.2.1 Data Collection and Data range

Data on temperature and rainfall were collected from the Bangladesh Meteorological Department (BMD). There are a total of 34 meteorological stations all over Bangladesh. These 34 meteorological stations located at different representative regions and agro-ecological zones of Bangladesh were selected for study. These stations were namely: Rajshahi, Bogra, Dinajpur, Ishurdi, Rangpur, Sayedpur, Dhaka, Mymensingh, Tangail, Jessore, Chudanga, Satkhira, Khulna, Barisal, Madaripur, Faridpur, Bhola, Patuakhali, Khepupara, Chandpur, Comilla, Feni, Hatiya, Cox's Bazar, Chittagong, Kutubdia, Rangamati, Sandwip, Sitakunda, Teknaf, Majdu.Court, Mongla, Srimangal and Sylhet. Temperature data collected from BMD include daily, monthly average temperature and annual mean maximum and minimum temperature for the period 1948 to 2005 for 34 meteorological stations all over Bangladesh. Rainfall data include daily, monthly, seasonal and annual rainfall total at 34 stations for the period January 1948 through December 2005. Some previous studies used data range of 1948-2005; however, data for the period 1976-2005 have been used in the analysis because data for the period 1948-1975 are not considered reliable.

The average daily temperature data have been used for the trend analysis of hot and cold days. From monthly rainfall data, seasonal mean values have been computed for two seasons e.g., pre-monsoon (March-May) and winter (December-February). For the computation of mean rainfall values for the winter season, the data of December of one year and those of January and February of the following year were used. It should be noted that there are some missing data for some months at some stations, which have been excluded in the trend analysis. For calculation of yearly and monthly average maximum and minimum temperature, 4 stations (Chudanga, Mongla, Sayedpur and Tangail) temperature data could not be considered on account of limited data.

3.2.2 Higher Maximum Temperature and Hot Days

Monthly-average maximum temperature data for the period of 1976 to 2005 have been used to assess the possible changes in higher maximum temperature in dry season (December-May) in Bangladesh. These data were used to assess trend in yearly-average maximum temperature (calculated from monthly average values) as well as trends in monthly-average maximum temperature. These trends were assessed for each of the 34 stations. For assessment of trend, maximum temperature data for the period 1976-2005 were plotted and a linear trend line was then passed through the data. The nature (increasing or decreasing) and significance of trend was estimated from the R^2 value of the fit. To analyze the trend for hot days, the 85th Percentile average daily temperature for the period 1976-2005 has been taken as the cut-off point between regular and "hot" days. This value was found to be 29.3 ^{0}C and the days exceeding this temperature were taken as "hot" days. Number of hot days was then calculated for each year for the period 1976-2005, and the nature and significance of the trend of hot days was estimated.

3.2.3 Higher Minimum Temperatures and Cold Days

Monthly average minimum temperature data from the period of 1976 to 2005 have been used to assess the possible changes higher minimum temperature in dry season (December-May). From the monthly average, the yearly average temperature has been computed. Trends of yearly-average minimum temperature as well as trends in monthly-average minimum temperature were assessed.

To analyze the trend for cold days, the 15th Percentile average daily temperature for the period 1976-2005 has been taken as the cut-off point between regular and "cold" days. This value was found to be 20.10 ^{0}C and the days having temperature below this value were taken as "cold days" days. Number of cold days was then calculated for each year for the period 1976-2005, and the nature and significance of the trend of cold days was estimated.

3.2.4 Change in Precipitation Pattern

Analysis of "intense precipitation events" could not be made from the available data on precipitation. However, possible changes in precipitation pattern have been evaluated by assessing the changes in total yearly rainfall. The total rainfall trend for the two seasons, i.e., pre-monsoon (March-May) and winter (December-February) have been analyzed on a yearly basis for the period 1976 to 2005.

3.3 RESULTS AND DISCUSSION

In this study, possible climate change scenario in Bangladesh has been assessed through analysis of trends of different climate change phenomena: (a) Higher maximum temperature and hot days, (b) Higher minimum temperatures and cold days and (c) Change of precipitation events. These trends have been analyzed using precipitation and temperature data of 34 meteorological stations located all over Bangladesh for the period 1976-2005.

3.3.1 Higher Maximum Temperature and Hot Days

One of the important indications of climate change is the occurrence of higher maximum temperature, which is likely to be experienced over all land areas. In the study, efforts were made to assess if there is any trend in higher maximum temperatures in Bangladesh. For this purposes, trend analysis was carried out for yearly-averaged and monthly-averaged maximum temperatures in dry-season (December-May).

3.3.1.1 Trend of Yearly Average Maximum Temperature

The trend of variation of yearly average maximum temperature was analyzed graphically and the equations of the trend lines for each of the 34 stations are presented in Table 3.2 along with the correlation coefficients and nature of significance. The yearly average maximum temperature at Barisal (Fig. 3.1), Chittagong (Fig 3.2), Comilla, Cox's Bazar, Faridpur, Jessore, Khepupara, Khulna, Kutubdia, Mongla, Patuakhali, Rangamati, Sitakunda and Sylhet show increasing trend during the period of 1976-2005 with R^2 value above 0.215. In 14 stations, the maximum temperature has a very significant increasing trend at a significance level of 99% or above 99%. Temperature at M.Court has shown a sharp increasing trend with R^2=0.165. The value of R^2 during the period is significant at 95% level. Temperatures at Bhola, Chandpur, Dhaka, Dinajpur, Hatiya, Madaripur, Rajshahi, Rangpur, Sayedpur, Srimangal, Tangail, Teknaf and Ishurdi have

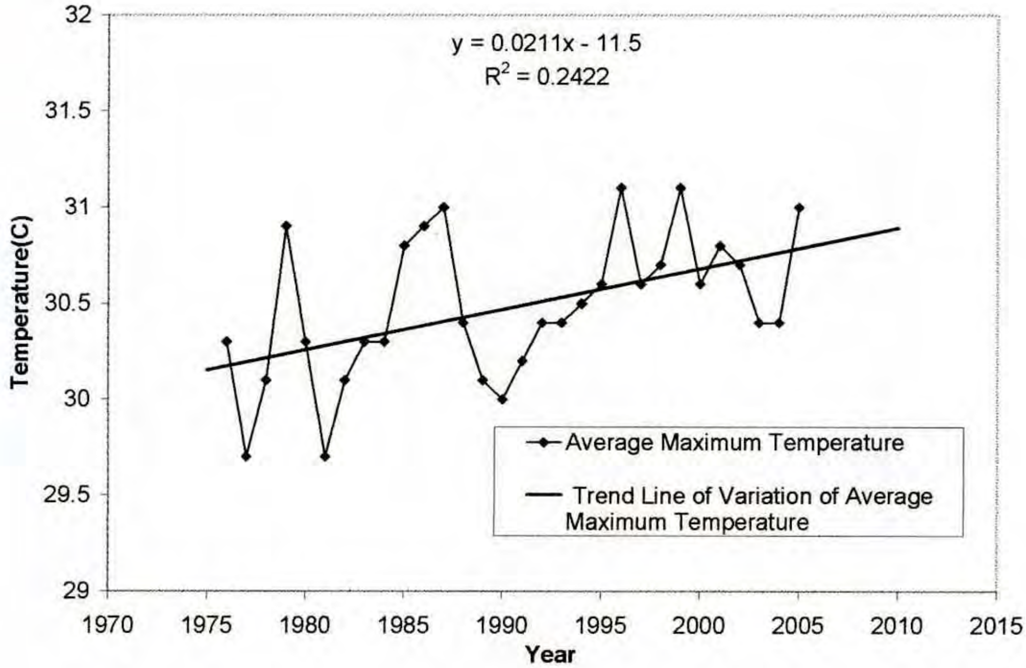

Figure 3.1 Variation of Annual Average Maximum Temperature at Barisal

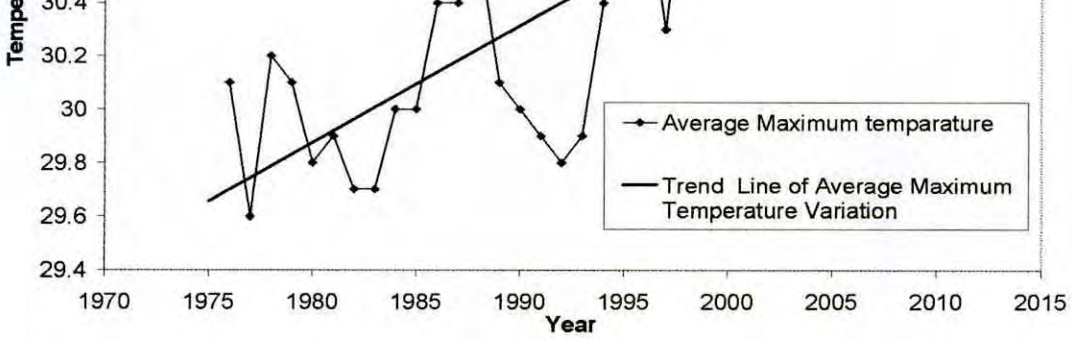

Figure 3.2: Variation of Annual Average Maximum Temperature at Chittagong

Table 3.2: Regression equation and correlation coefficient of average yearly maximum temperature for different stations for the period 1976-2005

Station	Trend Line Equation	Value of Correlation coefficient (r)	Significant/Insignificant
Barsial	Y=0.0211X-11.5	0.49214	99% significant
Bhola	Y=0.0106X+9.1524	0.27695	Below 90% significant
Bogra	Y=-0.0063X+43.19	-0.13856	Below 90% significant
Chandpur	Y=0.0097X+10.997	0.24678	Below 90% significant
Chittagong	Y=0.044X-57.21	0.78645	99.9% significant
Chuadanga	Y=-0.0081X+47.693	-0.1	Below 90% significant
Comilla	Y=0.0229X-15.473	0.50398	99% significant
Cox's Bazar	Y=0.064X-97.562	0.8708	99.9% significant
Dhaka	Y=0.0119X+7.0274	0.19209	Below 90% significant
Dinajpur	Y=0.0162X-2.4519	0.29597	Below 90% significant
Faridpur	Y=0.0211X-11.56	0.46379	99% significant
Feni	Y=-0.0038X+37.809	-0.09798	Below 90% significant
Hatiya	Y=0.0104X+8.8462	0.29325	Below 90% significant
Ishurdi	Y=0.0112X+8.5616	0.20881	Below 90% significant
Jessore	Y=0.0256X-19.492	0.59615	99% significant
Khepupara	Y=0.0214X-12.351	0.49101	99% significant
Khulna	Y=0.0256X-19.879	0.49528	99% significant
Kutubdia	Y=0.0451X-60.105	0.70121	99.9% significant
M.Court	Y=0.0262X-22.163	0.4062	95% significant
Madaripur	Y=0.0053X+20.205	0.11874	Below 90% significant
Mongla	Y=0.0488X-66.503	0.80443	99.9% significant
Mymensingh	Y=-0.0129X+55.426	-0.28496	Below 90% significant
Patuakhali	Y=0.028X-25.375	0.5748	99.9% significant
Rajshahi	Y=0.0022X+26.685	0.04898	Below 90% significant
Rangamati	Y=0.0531X-75.278	0.80685	99.9% significant
Rangpur	Y=0.021X-12.437	0.34395	90% significant
Sandwip	Y=-0.0001X+29.842	-0.00224	Below 90% significant
Satkhira	Y=-0.0076X+46.489	-0.12489	Below 90% significant
Sayedpur	Y=0.025X-20.143	0.27055	Below 90% significant
Sitakunda	Y=0.0571X-83.482	0.79353	99.9% significant
Srimangal	Y=0.0049X+20.653	0.08062	Below 90% significant
Sylhet	Y=0.0391X-48.082	0.65939	99.9% significant
Tangail	Y=0.0112X+7.9888	0.16703	Below 90% significant
Teknaf	Y=0.0112X+8.5616	0.20881	Below 90% significant

been found to be rising slowly with trend lines having R^2 values below 0.0871; though not statically significant at 95% level of significance. Only for six stations; Bogra, Chudanga, Feni, Mymensingh, Sandwip and Satkhira, the average maximum temperature has been found to have a slightly decreasing trend, with trend line having R^2 values below 0.0812, which however are not significant at a level of 90%. On an average (i.e., average of 30 stations) yearly average maximum temperature has been found to be increasing at a rate of 0.0193^{0}C per year for the period of 1976-2005.

3.3.1.2 Trend of Monthly Average Maximum Temperature

The trend of variation of monthly average maximum temperature was analyzed for the months of December-May and the equations of trend line for each of the stations are presented in Table 3.3 along with correlation coefficients and nature of significance. The correlation coefficients (r) are calculated from the value of R^2 using the sign of slope of the regression equations. Table 3.3 shows the trend variation for December month; the trends for the remaining 5 months are given in Appendix A (Tables A 3.1, A 3.2, A 3.3, A 3.4 and A 3.5).

The analysis of average maximum temperature in December has been performed for 34 stations; at 5 stations, Hatiya, Cox's Bazar, Chittagong (Fig. 3.3), Rangamati and Sitakunda, the records show sharp increasing trend with R^2 values above 0.4330, which are significant at 99.9%; at 8 stations (Barisal, Faridpur, Jessore, Khepupara, Kutubdia, Khulna, Rangpur and Sylhet) the data show significant increasing trend with R^2 values between 0.19589 to 0.26829, which are significant at 99%; at 16 stations, (Bhola, Bogra, Chandpur, Dhaka, Dinajpur, M.court, Madaripur, Feni, Mymensingh, Patuakhali, Rajshahi, Sandwip, Sayedpur, Srimangal, Tangail and Ishurdi) the data show a slight increasing trend with R^2 values below 0.0677, which are significant at below 90%. Only 2 stations showed a decreasing trend of temperature. The average temperature variation in December at Chuadanga and Satkhira show a slight decreasing trend with R^2 values below 0.01269, which are significant level at a below 90%. On an average, monthly average maximum temperature for December increased at a rate of 0.0355 ^{0}C per year during the period of 1976-2005.

Table 3.3: Regression equation and correlation coefficient of average maximum temperature for different stations in December month for the period 1976-2005

Station	Trend Line Equation	Value of Correlation coefficient (r)	Significant/Insignificant
Barisal	Y=0.0422X-57.279	0.51381	99% Significant
Bhola	Y=0.0195X-11987	0.23194	Below 90% Significant
Bogra	Y=0.0258X-24.889	0.21424	Below 90% Significant
Chandpur	Y=0.0163X-6.3544	0.19157	Below 90% Significant
Chittagong	Y=0.0762X-124.3	0.67104	99.9% Significant
Chuadanga	Y=-0.0074X+40.949	-0.04472	Below 90% Significant
Comilla	Y=0.0321X-37.28	0.37363	95% Significant
Tangail	Y=0.0416X-57.044	0.24819	Below 90% Significant
Cox's Bazar	Y=0.0796X-130.6	0.74706	99.9% Significant
Dhaka	Y=0.0178X-8.9117	0.18	Below 90% Significant
Dinajpur	Y=0.0315X-37.383	0.23173	Below 90% Significant
Faridpur	Y=0.0456X-65.093	0.45	99% Significant
Feni	Y=0.0078X+11.466	0.09695	Below 90% Significant
Sylhet	Y=0.0552X-83.436	0.51127	99% Significant
Hatiya	Y=0.0844X-140.53	0.74404	99.9% Significant
Ishurdi	Y=0.0104X+5.2701	0.11135	Below 90% Significant
Jessore	Y=0.0466X-66.098	0.46629	99% Significant
Khepupara	Y=0.0411X-54.989	0.4992	99% Significant
Khulna	Y=0.0438X-60.622	0.45265	99% Significant
Kutubdia	Y=0.0588X-90.211	0.51797	99% Significant
M. Court	Y=0.0108X+4.7488	0.1109	Below 90% Significant
Madaripur	Y=0.0077X+11.283	0.08124	Below 90% Significant
Mongla	Y=0.05X-73.274	0.38987	90% Significant
Mymensingh	Y=0.0157X-5.0334	0.14765	Below 90% Significant
Patuakhali	Y=0.0234X-19.886	0.2602	Below 90% Significant
Rajshahi	Y=0.0058X+14.268	0.06325	Below 90% Significant
Rangamati	Y=0.0681X-109.16	0.6581	99.9% Significant
Rangpur	Y=0.0543X-83.052	0.4426	99% Significant
Shandwip	Y=0.0237X-20.723	0.20297	Below 90% Significant
Satkhira	Y=-0.0112X+49.312	-0.11269	Below 90% Significant
Sayedpur	Y=0.0968X-168.07	0.40522	Below 90% Significant
Sitakunda	Y=0.0844X-140.53	0.74404	99.9% Significant
Srimangal	Y=0.0228X-18.767	0.16031	Below 90% Significant
Teknaf	Y=0.0252X-22.011	0.33166	90% Significant

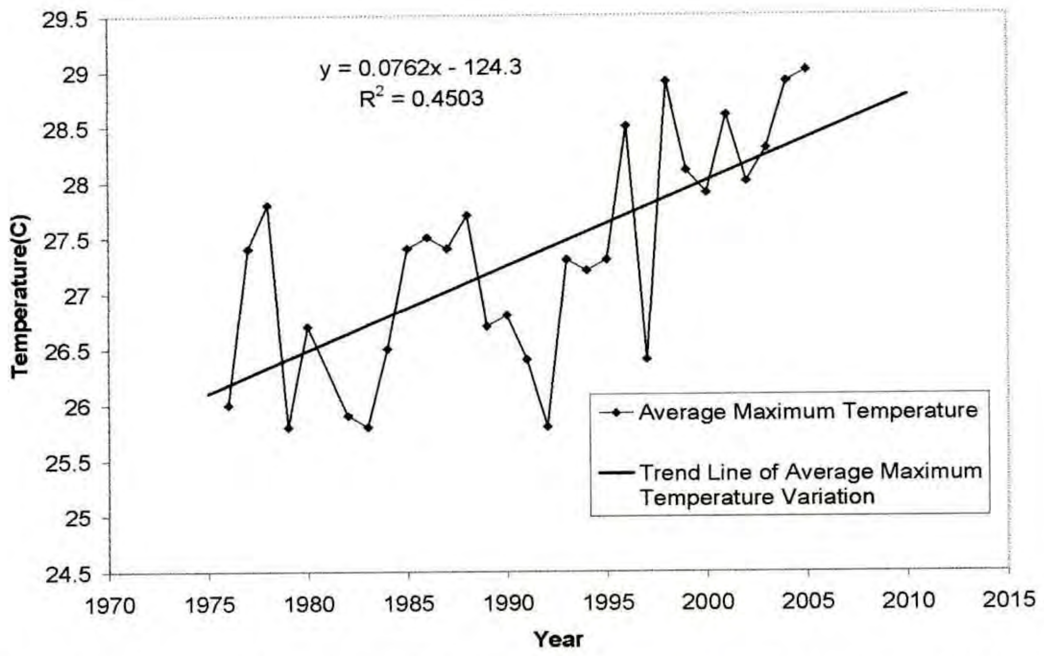

Figure 3.3: Variation of Average Maximum Temperature in December at Chittagong

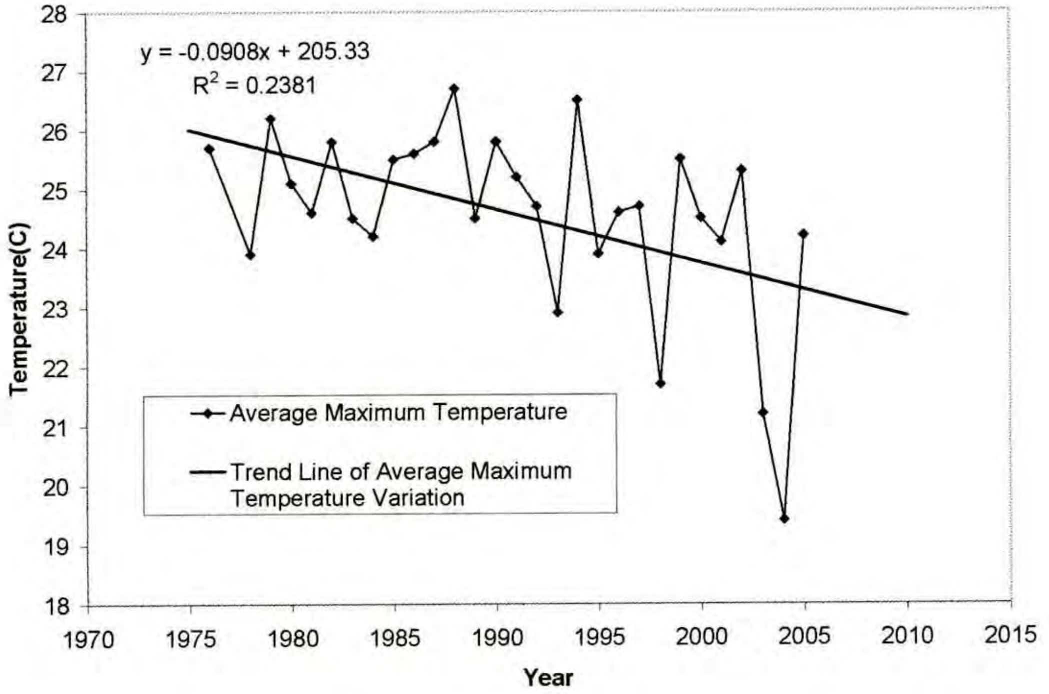

Figure 3.4: Variation of Average Maximum Temperature in January at Bogra

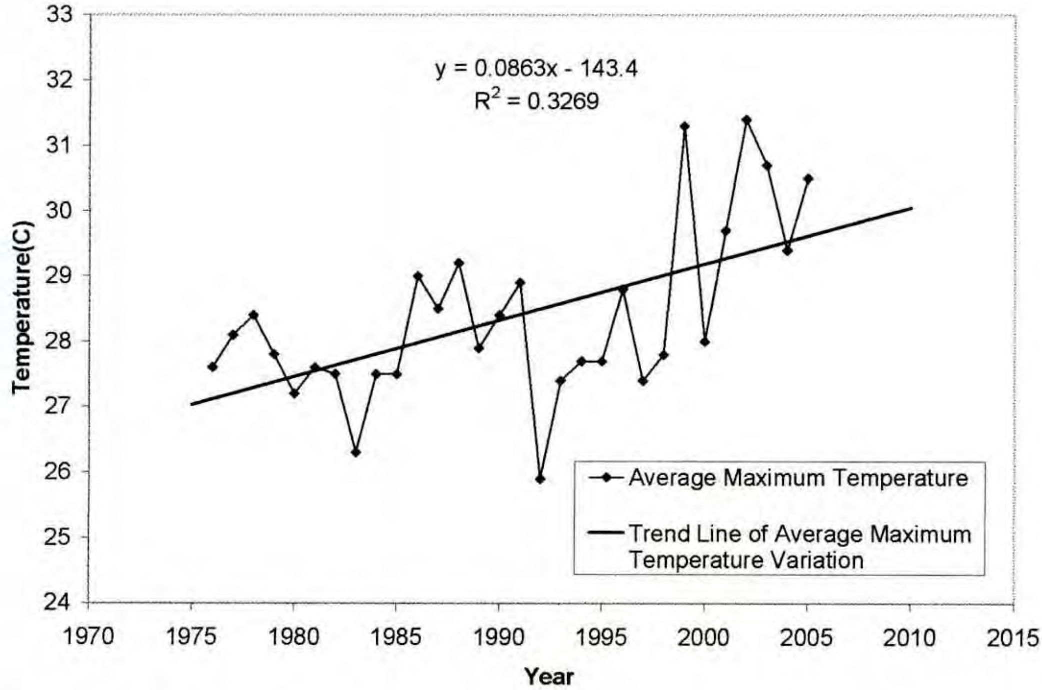

Figure 3.5: Variation of Average Maximum Temperature in February at Chittagong

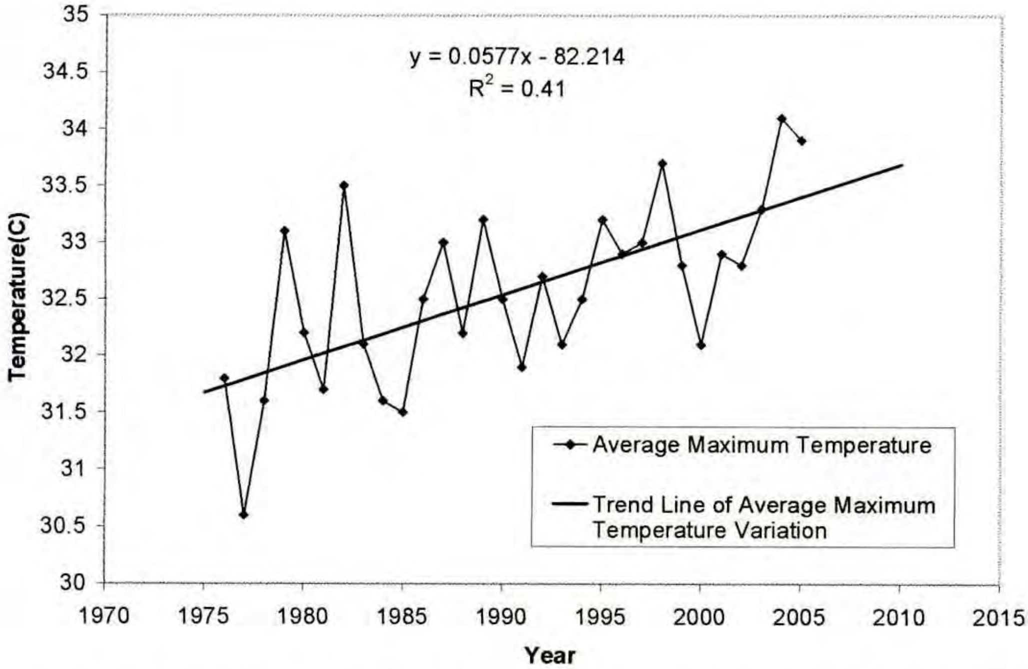

Figure 3.6: Variation of Average Maximum Temperature in May at Cox's Bazar

The analysis of average maximum temperature in January has been performed for 34 stations. Among these, 3 stations, Bogra (Fig. 3.4), Chandpur and Satkhira, show R^2 values above 0.23809, which are statically significant at 99% level of confidence; 11 stations (Cox's Bazar, Dhaka, Dinajpur, Feni, Hatiya, Ishurdi, Jessore, M.Court, Mymensingh, Rajshahi and Sitakunda) show R^2 values between 0.1381 to 0.1867, which are statically significant at 95% level of confidence; 15 stations (Barisal, Bhola, Faridpur, Khepupara, Khulna, Kutubdia, Madaripur, Mongla, Patuakhali, Rangpur, Srimangal, Sylhet, Sayedpur, Tangail and Teknaf) show R^2 values below 0.08, which are statically significant at below 90% level of confidence. It was also observed that among the 34 stations, 25 stations show decreasing trend, while 9 stations show increasing trend in average maximum temperature in January. On an average maximum temperature decreased in the month of January at a rate of 0.0233 ^{0}C per year for the period of 1976-2005.

Among 34 stations, the records show a sharper increasing trend of temperature at February with R^2=0.32689 and R^2=0.31770 at Chittagong (Fig. 3.5) and Cox's Bazar, respectively, which are significant at 99.9%; 5 stations (Barisal, Hatiya, Kutubdia, Khulna, and Rangamati) show significant increasing trend with R^2 values between 0.13459 to 0.21729, which are significant at 95%; 19 stations (Bhola, Chandpur, Chuadanga, Dhaka, Dinajpur, Feni, Ishurid, Jessore, Khepupara, M.Court, Madaripur Patuakhali, Rajshahi, Rangpur, Sandwip, Satkhira, Sayedpur, Tangail and Teknaf) show a slight increasing trend with R^2 values below 0.096, which are significant below at 90%. The average temperature variation in February at Bogra and Mymensingh show a slight decreasing trend with R^2 values 0.15239 and 0.01280, which are significant level 95% and 90%, respectively. Thus, an average maximum temperature in the month of February increased at a rate of 0.0394 ^{0}C per year for the period 1976-2005.

Monthly average maximum temperature data in March was analyzed for 34 selected stations in Bangladesh. Among these, the trend is statistically significant at 90 to 99.9 % confidence level for 6 stations only. Those stations are Mymensingh, Cox's Bazar, Sitakunda, Bogra, Teknaf and Chittagong. 17 stations out of 34 show increasing trend and 17 stations show decreasing trend. Temperature changes in March month is not significant. It has been found that maximum temperature changes in March are not so significant for the period of 1976-2005.

Among the 34 stations, the trend of changes in monthly average maximum temperature is statistically significant at 90 to 99% confidence level for 12 stations. These stations are Chuadanga, Rangamati, Patuakhali, M.Court, Kutubdia, Sayedpur, Sitakunda, Chittagong, Bogra, Teknaf, Mymensingh and Cox's Bazar. 17 stations (Bhola, Comilla, Rangamati, Patuakhali, Mongla, Chittagong, Barisal, Teknaf, Sitkunda, M.Court, Kutubdia, Chandpur, Sylhet, Faridpur, Dhaka, Cox's Bazar and Khepupara) show increasing trend and 17 stations (Rangpur, Chunadanga, Bogra, Sandwip, Madaripur, Jessore, Feni, Srimangal, Satkhira, Rajshahi, Mymensingh, Khulna, Ishurdi, Hatiya, Dinajpur, Tangail and Sayedpur) show decreasing trend. On an average, monthly average maximum temperature in April increased at a rate of 0.0325^0C per year for the period 1976-2005.

In May, the monthly average maximum temperature has a very sharp increasing trend at Cox's Bazar (Fig. 3.6) with R^2=0.40998 and Patuakhali R^2=0.25419, which are highly significant even at 99.9% level of significane. Jessore, Madaripur, Khulna, Sitakunda, and Chittagong stations show R^2 values between 0. 12869 to 0.17010 which are statically significant at 95% level of confidence. Chandpur, Feni, Ishurdi, Bhola, Dhaka, Hatiya, Chuadanga, M.Court, Mymensingh, Rajshahi, Shandwip, Sayedpur, Sylhet, Tangail, Bogra, Faridpur, Dinajpur, Rangpur, Satkhira, Srimangal and Kutubdia stations show R^2 values below 0.08889, which are not significant at 90% level. Among the 34 stations, 32 stations show increasing trend, while 2 stations show decreasing trend in average maximum temperature for May month. Maximum temperature increases in the month of May at rate of 0.0284^0 C per year for the period 1976-2005.

3.3.1.3 Trend of Annual Hot Days

Total number of days with the average temperature equal to or greater than 29.3^{0}C in a year is calculated at 32 different stations to asses one of the important climate change phenomena – occurrence of more hot days. The trend of variation in the number of annual hot days was analyzed graphically and the equations of the trend lines for each of 32 stations are presented in Table 3.4 along with the correlations coefficients. Figure 3.7 shows the trend of variation of number of hot days for one selected station (Dhaka). It was observed that among the 32 stations, 18 shows increasing trend, while 14 shows decreasing trend. Among the 18 stations showing increasing trend, the trend is statically significant at either 99% or 95% confidence level for 5 stations. Among the 14 stations showing decreasing trend, the trend is significant at 99% or 95% confidence level for also 5 stations.

Number of annual hot days in Chittagong (Fig 3.8) and Dhaka shows an increasing trend with coefficient of determination R^2=0.299 and R^2=0.1884, which are statically significant at 99% and 99.9% level of confidence, respectively. The trend lines in Cox's Bazar, Khulna and Rajshahi show that the numbers of hot days at these places are rising sharply; the R^2 values of the trend lines for these three stations are 0.1187, 0.14120 and 0.1210, all of which are statically significant at 95% significance. Hot days in Barisal, Bhola, Bogra, Chandpur, Feni, Hatiya, Jessore, Khepupara, Kutubdia, Sayedpur, Sylhet and M.Court have been found to be rising slowly with trend lines having R^2 values below 0.1200; through not statically significant at 95% level of significance. The annual number of hot days at Mymensingh, Dinajpur and Teknaf has a sharp decreasing trend having R^2 values are 0.237, 0.256 and 0.293, respectively; significant at a level of 99%. At Comilla, Faridpur, Madaripur, Mongla, Patuakhali, Rangamati, Srimangal, Tangail and Rangpur with R^2 values below 0.0523, the total number of annual hot days have slight decreasing trend (not statically significant). Decreasing trend line at Satkhira and Sitakunda with R^2=0.117 and R^2=0.178, respectively are significant at a level of 95%.

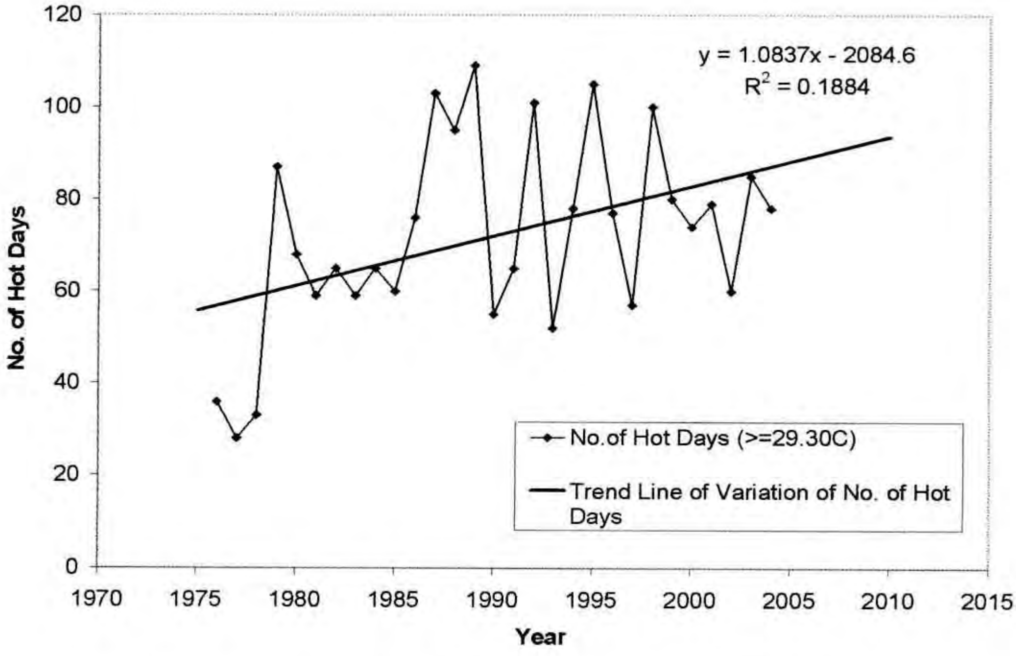

Figure 3.7: Annual Variation of number of Hot Days at Dhaka

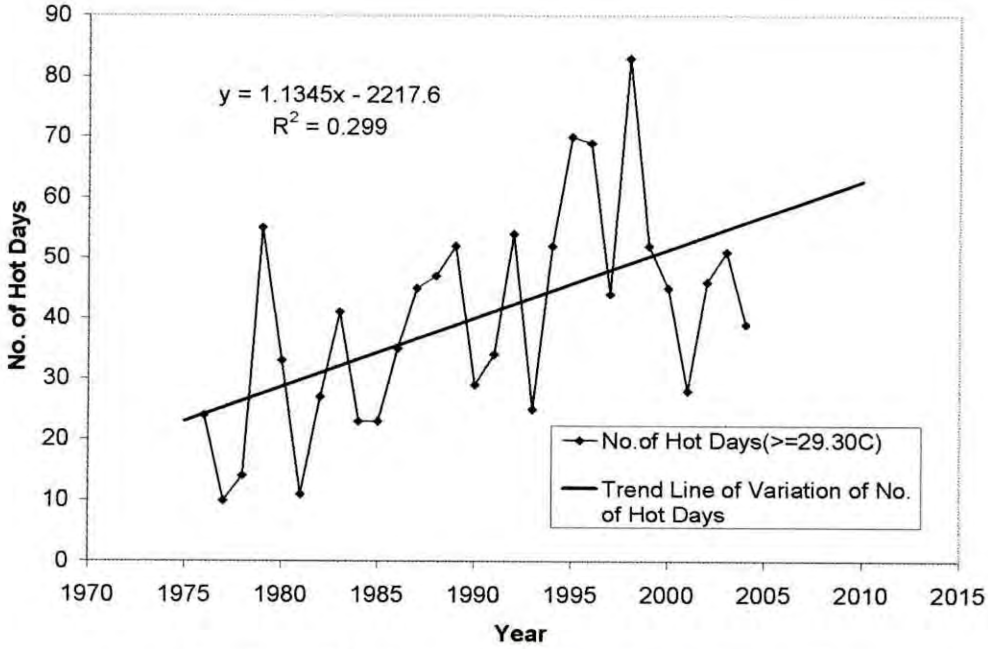

Figure 3.8: Annual Variation of number of Hot Days at Chittagong

Table 3.4: Regression equation and correlation coefficient of annual hot days for different stations for the period 1976-2005

Station	Trend Line Equation	Value of Correlation coefficient (r)	Significant/Insignificant
Barisal	Y=0.4498X-842.11	0.28249	Below 90% significant
Bhola	Y=0.2991X-555.64	0.22159	Below 90% significant
Bogra	Y=0.5329X-998.65	0.29866	Below 90% significant
Chandpur	Y=0.6908X-1317.8	0.34957	90% significant
Chittagong	Y=1.1345X-2217.6	0.54681	99.9% significant
Comilla	Y=-0.0586X+152.82	-0.04243	Below 90% significant
Cox's Bazar	Y=0.5522X-1068.4	0.34452	95% significant
Dhaka	Y=1.0837X-2084.6	0.43405	99% significant
Dinajpur	Y=-1.3309X+2719.7	-0.50606	99% significant
Faridpur	Y=-0.0961X+222.11	-0.034641	Below 90% significant
Feni	Y=0.13X-222.83	0.10583	Below 90% significant
Hatiya	Y=0.2052X-372.43	0.11783	Below 90% significant
Ishurdi	Y=0.6227X-1174.5	0.32741	Below 90% significant
Jessore	Y=0.3953X-704.1	0.23065	Below 90% significant
Khepupara	Y=0.1143X-160.29	0.065574	Below 90% significant
Khulna	Y=0.9291X-1765.3	0.37577	95% significant
Kutubdia	Y=0.8481X-1660.9	0.32093	Below 90% significant
M. Court	Y=0.5702X-1072.5	0.20199	Below 90% significant
Madaripur	Y=-0.7495X+1583.9	-0.16852	Below 90% significant
Mongla	Y=-0.4066X+894.81	-0.120416	Below 90% significant
Mymensingh	Y=-1.6222X+3285.6	-0.48672	99% significant
Patuakhali	Y=-0.1842X+431.42	-0.08246	Below 90% significant
Rajshahi	Y=0.6414X-1203.2	0.34785	95% significant
Rangamati	Y=-0.1399X+309.68	-0.07071	Below 90% significant
Rangpur	Y=-0.2473X+541.28	-0.15362	Below 90% significant
Satkhira	Y=-1.0409X+2178.6	-0.34249	95% significant
Sayedpur	Y=1.7X-3352	0.31827	Below 90% significant
Sitakunda	Y=-1.2898X+2609.8	-0.422611	95% significant
Srimangal	Y=-0.3904X+807.83	-0.13191	Below 90% significant
Sylhet	Y=0.2419X-457.95	0.27	Below 90% significant
Tangail	Y=-0.8153X+1682.8	-0.22869	Below 90% significant
Teknaf	Y=-1.4294X+2886.8	-0.54157	99% significant

3.3.2 Higher Minimum Temperatures and Cold Days

Another important indication of climate change is the occurrence of higher minimum temperature, which is likely to be experienced over all land areas, particularly at northern high latitudes during the cold season. Thus, efforts were made to assess if there is any trend in the higher minimum temperatures in Bangladesh. For this purpose, trend analysis was carried out for yearly-averaged and monthly-averaged (for dry-season) minimum temperatures.

3.3.2.1 Trend of Yearly Average Minimum Temperature

The trend of variation of yearly average minimum temperature was analyzed graphically and the equations of the trend lines for each of the 34 stations are presented in Table 3.4 along with the correlation coefficients. The correlation coefficients (r) are calculated from the value of R^2 using the sign of slope of the regression equations for each station.

From Table 3.5, it was observed that 27 out of 34 show an increasing trend of minimum temperature, which is consistent with the predictions made by IPCC. In Bhola (Fig. 3.9), Chandpur (Fig. 3.10), Chittagong, Cox's Bazar, Dhaka, Dinajpur, Ishurdi, M.Court, Madaripur and Teknaf, the average minimum temperatures have a sharp increasing trend with R^2 values above 0.1956 for the period 1976-2005 which are highly significant even at 99% or above 99% level of significance. The minimum temperature at Barisal, Churadanga, Patuakhali and Rangpur has shown an increasing trend with R^2 values 0.130, 0.266, 0.173 and 0.168, respectively. The values of R^2 during the period are significant at 95% level. The annual average minimum temperatures have a slight increasing trend at Comilla, Faridpur, Feni, Jessore, Khepupara, Khulna, Kutubdia, Mongla, Mymensingh, Rajshahi, Sayedpur, Sylhet and Bogra, which not significant even at 95% level of significance. Only for Rangamati, the average minimum temperature has been found to have a sharp decreasing trend, with the trend line having R^2= 0.4106, which is significant at a level of 99.9%. The trends of average minimum temperatures in Sandwip, Srimongal, Tangail and Satkhira show that average minimum temperature at these places are decreasing slowly; the R^2 values of the trend lines for these stations are below 0.101, none of which are statically significant even at 95% level of significance. From the analysis, it is found that on an average minimum temperature increased at a rate of 0.01519^{0}C per year for the period 1976-2005.

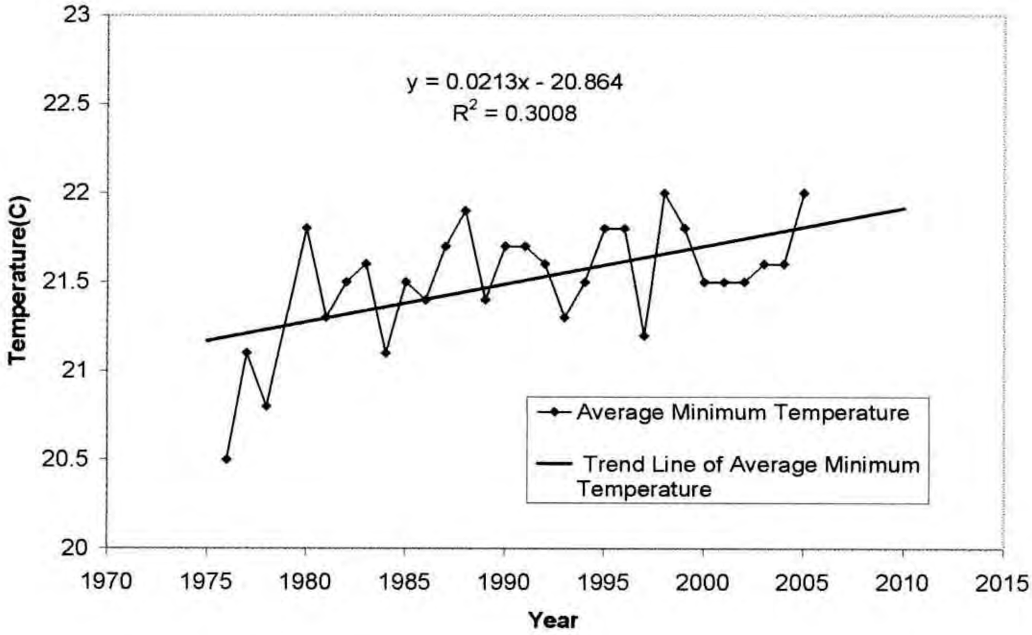

Figure 3.9: Variation of Annual Average Minimum Temperature at Bhola

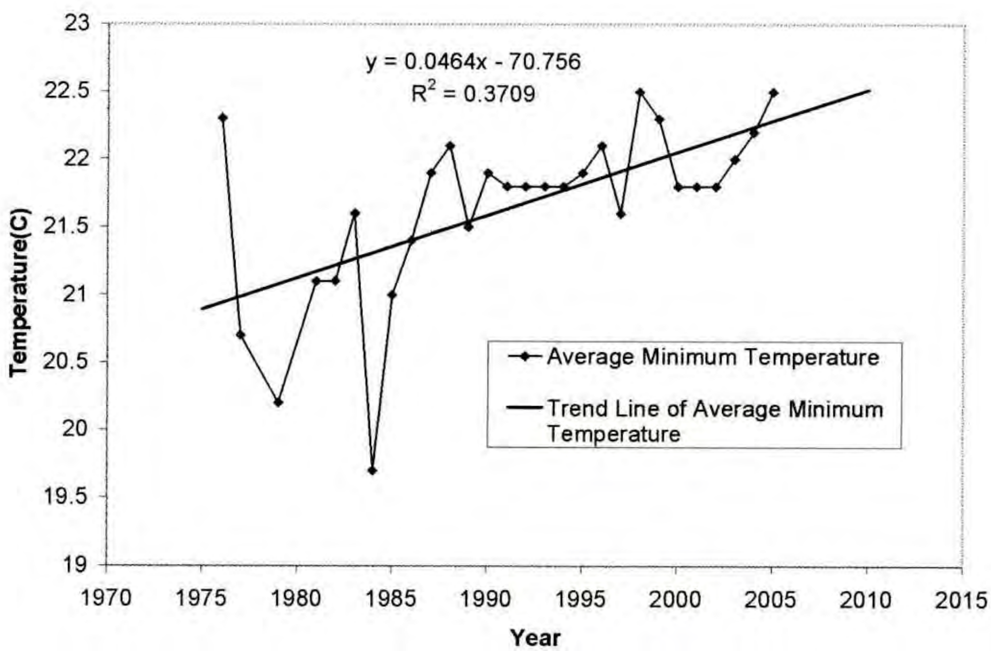

Figure 3.10: Variation of Annual Average Minimum Temperature at Chandpur

Table 3.5: Regression equation and correlation coefficient of average yearly minimum temperature for different stations in period 1976-2005

Station	Trend Line Equation	Value of Correlation coefficient (r)	Significant/Insignificant
Barisal	Y=0.013X-4.802	0.36166	95% Significant
Bhola	Y=0.0213X-20.864	0.54845	99.9% Significant
Bogra	Y=0.002X+17.016	0.03605	Below 90% Significant
Chandpur	Y=0.0464X-70.756	0.60902	99.9% Significant
Chittagong	Y=0.032X-42.139	0.59523	99.9% Significant
Chuadanga	Y=0.0338X-46.657	0.51536	95% Significant
Comilla	Y=0.004X+12.954	0.0098	Below 90% Significant
Tangail	Y=-0.0312X+83.226	-0.31875	Below 90% Significant
Cox's Bazar	Y=0.033X-43.69	0.65238	99.9% Significant
Dhaka	Y=0.0195X-17.171	0.44227	99% Significant
Dinajpur	Y=0.0629X-105.71	0.58703	99.9% Significant
Faridpur	Y=0.0178X-14.124	0.330757	90% Significant
Feni	Y=0.0103X+0.5186	0.22517	Below 90% Significant
Sylhet	Y=0.0419X-63.254	0.31177	90% Significant
Hatiya	Y=-0.022X+65.857	-0.40877	95% Significant
Ishurdi	Y=0.0345X-48.359	0.59674	99.9% Significant
Jessore	Y=0.0074X+6.1211	0.20099	Below 90% Significant
Khepupara	Y=0.0024X+17.398	0.03742	Below 90% Significant
Khulna	Y=0.0057X+10.312	0.10099	Below 90% Significant
Kutubdia	Y=0.0142X-6.079	0.195704	Below 90% Significant
M. Court	Y=0.0521X-81.922	0.663625	99.9% Significant
Madaripur	Y=0.0552X-88.719	0.71316	99.9% Significant
Mongla	Y=0.01X+2.3674	0.25807	Below 90% Significant
Mymensingh	Y=0.02X-19.037	0.23537	90% Significant
Patuakhali	Y=0.0334X-44.734	0.41641	95% Significant
Rajshahi	Y=0.0038X+12.953	0.074162	Below 90% Significant
Rangamati	Y=-0.0616X+143.84	-0.64078	99.9% Significant
Rangpur	Y=0.0284X-36.551	0.40988	95% Significant
Shandwip	Y=-0.0122X+46.396	-0.18055	Below 90% Significant
Satkhira	Y=-0.0007X+22.836	-0.01414	Below 90% Significant
Sayedpur	Y=0.0345X-48.45	0.40804	Below 90% Significant
Sitakunda	Y=-0.0239X+68.672	-0.41617	95% Significant
Srimangal	Y=-0.011X+41.419	-0.18166	Below 90% Significant
Teknaf	Y=0.026X-29.725	0.53675	99.9% Significant

3.3.2.2 Trend of Monthly Average Minimum Temperature

The trend of variation of monthly average minimum temperature was analyzed graphically for 34 selected stations for the month of December-May (dry season) and the equations of the trend lines for each of the stations are presented in Table 3.6 along with the correlation coefficients for only December are given in Table 3.6; others are presented in Appendix A (Tables A 3.6, A 3.7, A 3.8, A 3.9 and A 3.10).

In December among 34 stations, 2 stations Sylhet (Fig 3.11), and M.Court show sharp increasing trend of minimum temperature with R^2 values are 0.397 and 0.324, respectively, which are significant at 99.9%; 4 stations (Rangpur, Dhaka, Chandpur, and Madaripur) show significant increasing trend with R^2 value between 0.2048 to 0.2787, which are significant at 99%; 10 stations (Rajshahi, Mymensingh, Comilla, Jessore, Faridpur, Khulna, Sandwip, Chittagong, Kutubdia, and Tangail) show a slight increasing trend with R^2 values below 0.0767, which are significant below at 90%. The average minimum temperature variation in December at 8 stations (Srimangal, Satkhira, Hatiya, Sitakunda, Teknaf, Rangamati, Patuakhali, and Khepupara) show decreasing trend, which are significant at level below 90 to 99.9% level of confidence. Table 3.6 show that among the 34 stations, 26 stations show increasing trend, while 8 stations show decreasing trend in average minimum temperature in December. Average minimum temperature increased in the month of December at a rate of 0.0191^0 C per year for the period 1976-2005.

Among the 34 stations, the trend of monthly average minimum temperature in January was found to be statistically significant at 90 to 99% confidence level for 14 stations. These stations are Rajshahi (Fig 3.12), Sylhet, Dhaka, Chandpur, Madaripur, Khulna, Satkhira, M.Court, Hatiya, Sitakunda, Cox'x Bazar, Rangamati, Kutubdia and Khepupara. Sixteen stations (Bhola, Mongla, Chittagong, Barisal, Dinajpur, Rangpur, Sylhet, Srimangaol, Dhaka, Chandpur, Madaripur, M.court, Kutubdia, Cox's Bazar, Sayedpur, and Chudanga) show increasing trend and 18 stations (Rajshahi, Mymensingh, Bogra, Ishurdi, Comilla, Jessore, Faridpur, Khulna, Satkhira Feni, Hatiya, Sitakunda, Sandwip, Teknaf, Rangmati, Patuakhali, Khepupara and Tangail) show decreasing trend. Average minimum temperature decreased in the month of January at a rate of 0.0073^0 C per year for the period of 1976-2005.

Table 3.6: Regression equation and correlation coefficient of average minimum temperature for different stations in December for the period 1976-2005

Station	Trend line equation	Value of correlation co-efficient (r)	Significant/Insignificant
Barisal	Y=0.0344X-55.028	0.32403	90% significant
Bhola	Y=0.0289X-43.357	0.32878	90% significant
Bogra	Y=0.0335X-53.017	0.37175	95% significant
Chandpur	Y=0.0646X-113.39	0.50517	99% significant
Chittagong	Y=0.0296X-43.288	0.27694	Below 90% significant
Chuadanga	Y=0.0877X-162.57	0.54175	95% significant
Comilla	Y=0.0152X-16.917	0.11489	Below 90% significant
Cox's Bazar	Y=0.0463X-75.324	0.41121	95% significant
Dhaka	Y=0.071X-126.87	0.51097	99% significant
Dinajpur	Y=0.0516X-90.821	0.40509	95% significant
Faridpur	Y=0.0247X-35.129	0.21656	Below 90% significant
Feni	Y=0.0213X-28.022	0.02615	Below 90% significant
Hatiya	Y=-0.0479X+111.43	-0.44844	95% significant
Ishurdi	Y=0.0444X-76.08	0.35749	95% significant
Jessore	Y=0.0129X-12.941	0.1044	Below 90% significant
Khepupara	Y=-0.0128X+40.761	-0.16733	Below 90% significant
Khulna	Y=0.0062X+1.7428	0.0469	Below 90% significant
Kutubdia	Y=0.0256X-34.393	0.16462	Below 90% significant
M. Court	Y=0.0878X-159.18	0.56964	99.99% significant
Madaripur	Y=0.0676X-120.8	0.52792	99% significant
Mongla	Y=0.0586X-101.31	0.49578	95% significant
Mymensingh	Y=0.0258X-38.068	0.20904	Below 90% significant
Patuakhali	Y=-0.0146X+44.19	-0.15937	Below 90% significant
Rajshahi	Y=0.0145X-16.084	0.11575	Below 90% significant
Rangamati	Y=-0.1076X+229.96	-0.66272	99.99% significant
Rangpur	Y=0.0481X-82.82	0.45265	99% significant
Sandwip	Y=0.0047X+6.5241	0.03464	Below 90% significant
Satkhira	Y=-0.0129X+38.996	-0.10908	Below 90% significant
Sayedpur	Y=0.1018X-190.61	0.47423	95% significant
Sitakunda	Y=-0.0343X+82.246	-0.30248	90% significant
Srimongal	Y=-0.0149X+41.617	-0.08062	Below 90% significant
Sylhet	Y=0.0695X-124.11	0.63039	99.99% significant
Tangail	Y=0.0161X-18.779	0.1077	Below 90% significant
Teknaf	Y=-0.0113X+39.596	-0.09539	Below 90% significant

The analysis of average minimum temperature in February has been performed for 34 stations. Among 34 stations, 5 stations, (Ishurdi, Dhaka, Madaripur, Rangamati and Cox's Bazar) show R^2 values above 0.27839, which are statically significant at 99.9% level of confidence; 6 stations (Dinajpur, Rangpur, Chanpur, Faridpur, Barisal and

Sayedpur) show R^2 values between 0.12000 to 0.25589, which are statically significant at 95% level of confidence; 18 stations (Rajshahi, Srimangal, Comilla, Jessore, Khulna, Satkhira, Bhola, Feni, Hatiya, Sitakunda, Sandwip, Kutubdia, Teknaf, Patuakhali, Khepupara, Tangail, Mongla, and Chuadanga) show R^2 values below 0.084, which are statically significant at below 90% level of confidence. Thus, among the 34 stations, 29 show increasing trend, while 5 show decreasing trend in average minimum temperature in February. On an average, monthly average minimum temperature increased in the month of February at a rate of 0.0403^0 C per year for the period 1976-2005.

In March, the trend of monthly average minimum temperature was found to be level statistically significant at 90 to 99.9% confidence level for 9 stations only. These stations are Dinajpur (Fig. 3.13), Rangpur, Bogra, Mymensingh, Ishurdi, M.Court, Hatiya, Cox's Bazar and Rangamati. Among these stations, Dinajpur, Rangpur, Bogra, Mymensingh and Cox's Bazar show increasing trend with R^2 values above 0.1797, which are significant at a level of 99%. Two stations, Ishurdi (R^2=0.111) and M.Court (R^2=0.164) show a slightly increasing trend, with trend line significant at of 95% level of confidence. Significant decreasing trend at Rangamati (R^2=0.232) and Hatiya (R^2=0.1564) was observed, which are significant at a level of 99% and 95%, respectively. Twenty four stations (Dinajpur, Rangpur, Rajshahi, Bogra, Mymensingh, Sylhet, Ishurdi, Dhaka, Chandpur, Faridpur, Madaripur, Barisal, Bhola, M.Court, Sandwip, Chittagong, Cox's Bazar, Teknaf, Patuakhali, Khepupara, Sayedpur, Tangail, Mongla and Chuadanga) out of 34 show increasing trend and 10 stations (Srimangal, Comilla, Jessore, Khulna, Satkhira, Feni, Hatiya, Sitakunda, Kutubdia, and Rangamati) show decreasing trend. On an average, monthly average minimum temperature increased at a rate of 0.0167 ^{0}C per year for the period 1976-2005.

In April, the trend in the statistically significant at 90 to 95% confidence level for 6 stations only. These stations are Dinajpur, Ishurdi, Chandpur, Madaripur, Chittagong and Cox,s Bazar. Dinajpur, Chandpur, Madaripur and Chittagong show increasing trend having R^2 values above 0.1507, the trends are significant at a level of 95%. At Ishurdi with R^2=0.1092 and Cox's Bazar with R^2=0.0954 which are low significant at 90% level of significance. Twenty eight stations (Dinajpur, Rangpur, Rajshahi, Bogra, Mymensingh, Sylhet, Khulna, Srimangal, Ishurdi, Dhaka, Chandpur, Jessore, Faridpur, Madaripur, Barisal, Bhola, M.Court, Sandwip, Chittagong, Cox's Bazar, Teknaf, Patuakhali, Khepupara, Sayedpur, Tangail, Mongla, Chuadanga and Kutubdia) show increasing trend and 6 stations (Comilla, Satkhira, Feni, Hatiya, Sitakunda, and Rangamati) show decreasing trend (see Appendix A) shows that among the 34 stations, 28 shows increasing trend, while 6 shows decreasing trend in average minimum temperature in April month. On an average, monthly average minimum temperature increased in the month of April at rate of 0.0232^0 C per year for the period 1976-2005.

For May, 29 stations (Dinajpur, Rangpur, Rajshahi, Bogra, Mymensingh, Sylhet, Khulna, Srimangal, Ishurdi, Dhaka, Chandpur, Jessore, Comilla, Faridpur, Madaripur, Barisal, Bhola, M.Court, Chittagong, Cox's Bazar, Teknaf, Patuakhali, Satkhira, Khepupara, Feni, Tangail, Mongla and Kutubdia) out of 34 show increasing trend and 5 (Hatiya, Sandwip, Rangamati, Sayedpur and Chuadanga) show decreasing trend. In Madaripur (Fig. 3.14), the data show a very sharp increasing trend with R^2=0.36529 at 99.9% level of significance. Chandpur and Faridpur show increasing trend with R^2 values of 0.19729 and 0.17739, respectively, which are significant at level of 99%; Dinajpur, Rajshahi, Sylhet, Ishurdi, Jessore, Bhola, M.Court Chittagong and Bogra also show significant increasing trend with R^2 value between 0.11989 to 0.19048, which are significant at 95% level of significance. For the rest of the stations, R^2 values are below 0.0724, which are significant level at below 90%. On an average, monthly average minimum temperature increased in the month of May at rate of 0.02771 ^{0}C per year for the period 1976-2005.

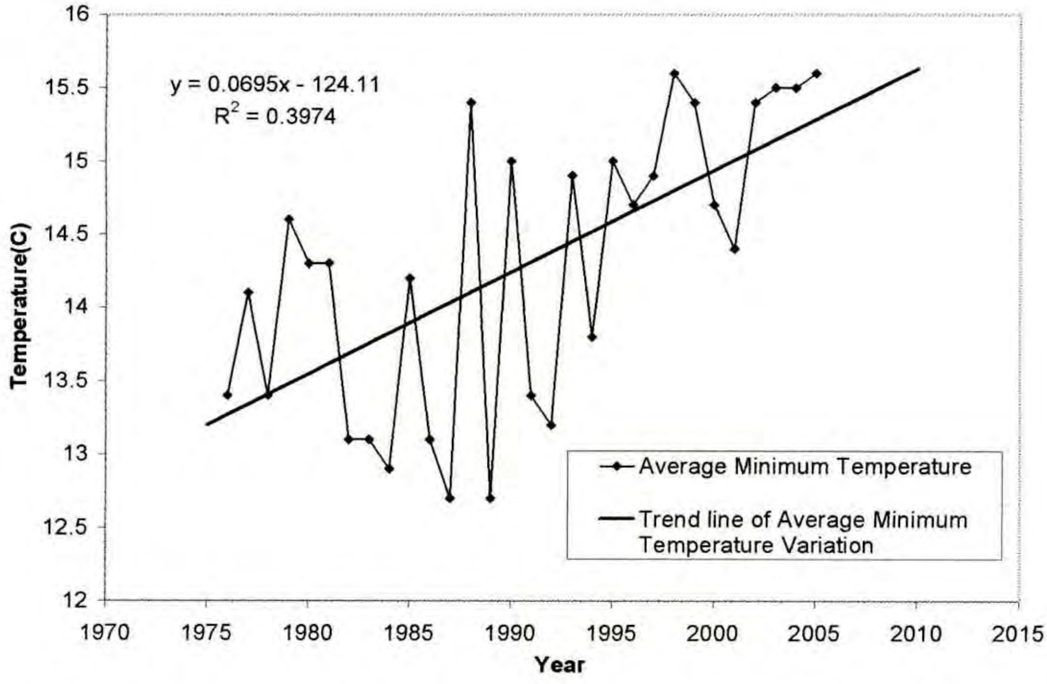

Figure 3.11: Variation of Average Minimum Temperature in December at Sylhet

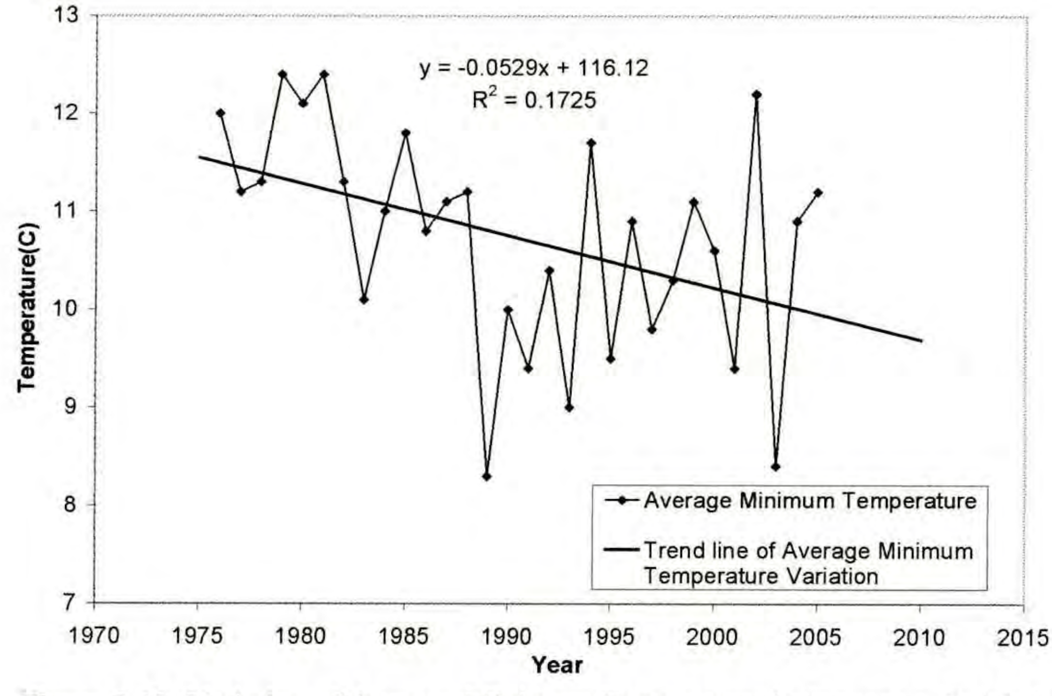

Figure 3.12: Variation of Average Minimum Temperature in January at Rajshahi

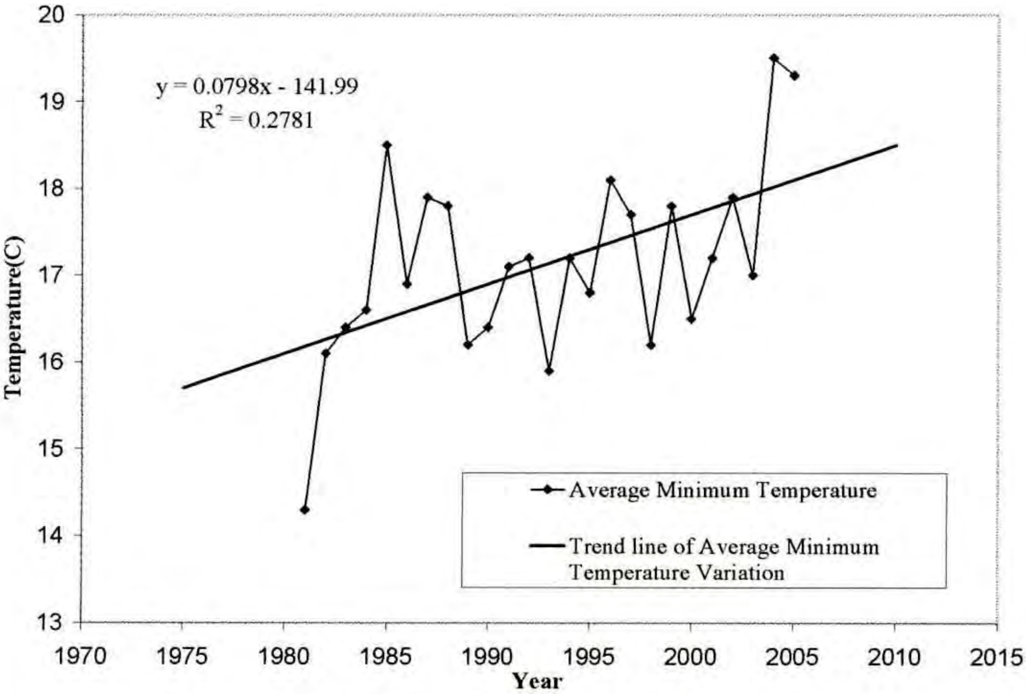

Figure 3.13: Variation of Average Minimum Temperature in March at Dinajpur

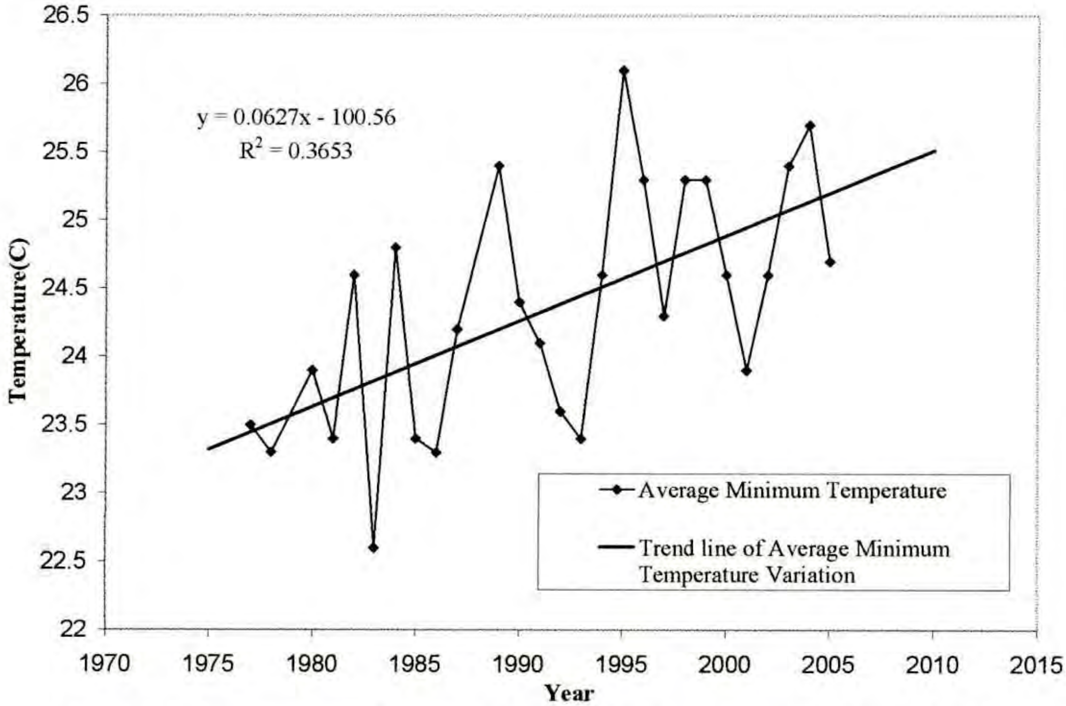

Figure 3.14: Variation of Average Minimum Temperature in May at Madaripur

3.3.2.3 Trend of Annual Cold Days

The trend of variation in the number of annual cold days was analyzed graphically and the equations of the trend lines for each of the 31 stations are presented in Table 3.7 along with the correlation coefficients.

Table 3.7: Regression equation and correlation coefficient of annual cold days for different stations for the period 1976-2005

Station	Trend Line Equation	Value of Correlation coefficient (r)	Significant/Insignificant
Barisal	Y=-0.1926X+441.47	-0.19748	Below 90% Significant
Bhola	Y=-0.0717X+197.73	-0.07348	Below 90% Significant
Bogra	Y=0.3416X-619.31	0.202237	Below 90% Significant
Chandpur	Y=-0.3204X+688.18	-0.22649	Below 90% Significant
Chittagong	Y=-0.5192X+1063.6	-0.38923	95% Significant
Chuadanga	Y=-1.3714X+2815.6	-0.27239	Below 90% Significant
Comilla	Y=0.1126X-167.69	0.07416	Below 90% Significant
Tangail	Y=0.6976X-1322.9	0.24433	Below 90% Significant
Cox's Bazar	Y=-0.2458X+508.41	-0.23259	Below 90% Significant
Dhaka	Y=-0.3985X+842.54	-0.26589	Below 90% Significant
Dinajpur	Y=1.1252X-2167.9	0.479769	99% Significant
Faridpur	Y=-0.2906X+639.31	-0.25099	Below 90% Significant
Feni	Y=0.1355X-219.55	0.11576	Below 90% Significant
Sylhet	Y=-0.432X+923.41	0.24758	Below 90% Significant
Hatiya	Y=0.5768X-1112.6	0.44091	95% Significant
Ishurdi	Y=-0.166X+407.19	-0.15779	Below 90% Significant
Jessore	Y=-0.0117X+85.532	-0.01	Below 90% Significant
Khepupara	Y=1.2025X-2360.5	0.74047	99.9% Significant
Khulna	Y=0.2911X-529.08	0.18303	Below 90% Significant
Kutubdia	Y=0.0917X-163.25	0.05196	Below 90% Significant
M. Court	Y=0.4731X-904.72	0.26153	Below 90% Significant
Madaripur	Y=0.9614X-1871.3	0.40559	95% Significant
Mongla	Y=-0.5738X+1181.5	-0.29866	Below 90% Significant
Mymensingh	Y=0.8695X-1675.3	0.38131	95% Significant
Patuakhali	Y=1.2025X-2360.5	0.74047	99.9% Significant
Rajshahi	Y=0.0951X-113.89	0.08	Below 90% Significant
Rangamati	Y=0.933X-1809.1	0.52182	99% Significant
Rangpur	Y=-0.8315X+1740.02	-0.46744	99% Significant
Satkhira	Y=1.1128X-2170.7	0.49719	99% Significant
Sitakunda	Y=1.5758X-3093.8	0.60349	99.9% Significant
Srimangal	Y=0.9864X-1891.3	0.43623	99% Significant
Teknaf	Y=0.5536X-1094.3	0.60382	99.9% Significant

Among the 31 stations, 13 showed a decreasing trend of the number of cold days (that is fewer cold days) for the period 1976-2005 and the remaining 18 stations showed increasing trend for the number of cold days. The number of cold days are found to be decreasing sharply at Rangpur with R^2=0.2185 (99% level of significance) (Fig. 3.15) and at Chittagong with R^2=0.1515 (95% level of significance) (Fig. 3.16). In Barisal, Bhola, Chandpur, Dhaka, Faridpur, Ishurdi, Jessore, Cox's Bazar, Chuadanga, Mongla and Sylhet, number of cold days also show a slight decreasing trend. Contrary to the general climate change predictions, the annual number of cold days at Dinajpur, Teknaf, Sitakunda, Rangamati, Patuakhali, Khepupara, Srimangal and Satkhira show steep increasing trend having R^2 values above 0.1903, which are highly significant even at a level of 99%. The annual variation of number of cold days at Mymensingh and Madaripur also have a significant increasing trend with R^2=0.1454 and R^2=0.1645 (significant at the level of 95%). The increasing trend obtained for Bogra, Khulna, Feni, M.Court, Kutubdia and Rajshahi, are statistically not significant.

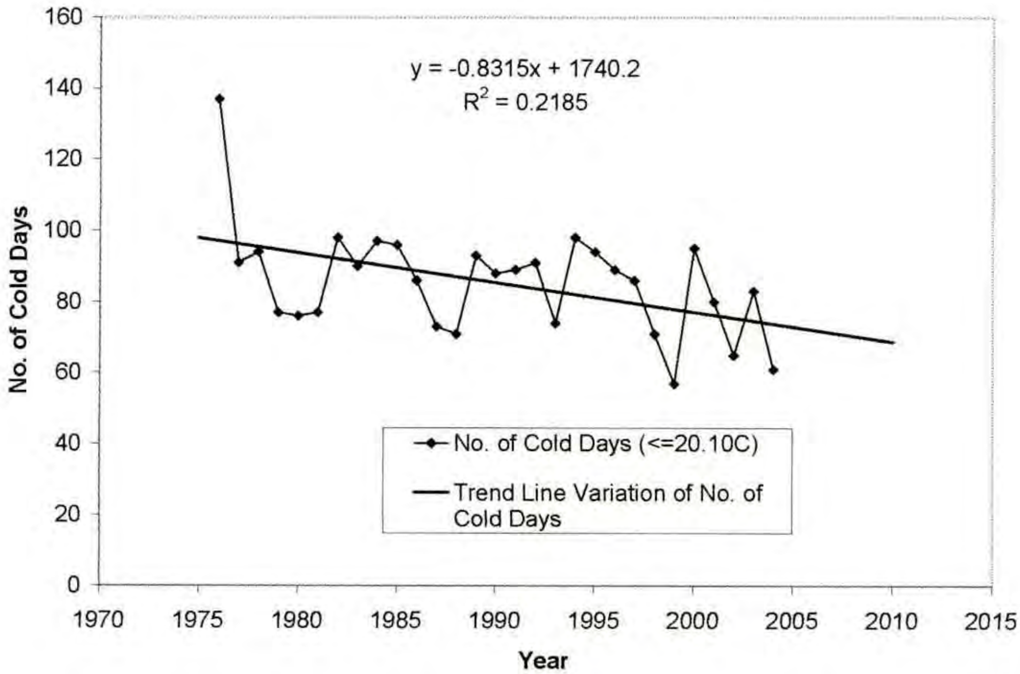

Figure 3.15: Annual Variation of number of Cold Days at Rangpur

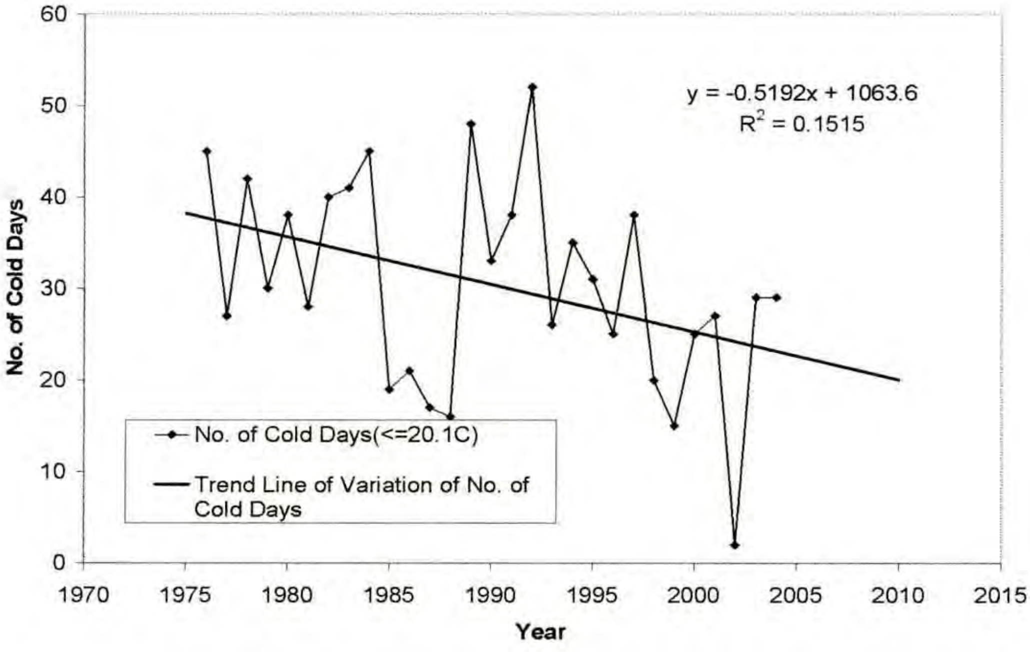

Figure 3.16: Annual Variation of number of Cold Days at Chittagong

3.3.3 Summary of Change in Annual Temperature

The trend of variation of yearly average maximum temperature was analyzed for each of the 34 stations and the results are summarized in Table 3.8. Table 3.8 shows that in 28 out of 34 stations, yearly average maximum temperatures show increasing trend. Out of these 28 stations, the increasing trends in 15 stations are significant at 99% confidence level; on the other hand, none of the decreasing trends observed for the 6 stations are statistically significant. Table 3.8 also shows that among the 34 stations, 27 showed increasing trends in yearly average minimum temperature; increasing trends in 14 stations are significant at 95% confidence level or higher. Among the 32 stations (for which data were available), 18 showed increasing trend in number of "hot" days per year; however, in only 5 stations these trends are significant at 95% confidence level or higher. On the other hand, 14 stations showed decreasing trend in number of "hot" days. Yearly number of cold days during 1976-2005 showed increasing trend for 18 out of 31 stations;

tends in 11 being significant at 95% confidence level or higher. On the other hand, decreasing trend was observed for 13 stations; however, none except 2 are statistically significant. Figure 3.17 shows the total change in yearly average temperature for the period 1976-2005.

Table 3.8: Summary of change in annual temperature pattern for the period 1976-2005

Climate Change Phenomena (annual)	No. of Station showing increasing Trend	No. of Station showing decreasing trend	Average Temp. changes per year °C /year	Increasing Trend (No. of Station)			Decreasing Trend (No. of Station)		
				95% LOS	99% LOS	NS	95% LOS	99% LOS	NS
Maximum Temperature	28	6	0.0193	1	15	12	0	0	6
Minimum Temperature	27	7	0.0152	4	10	13	2	1	4
Hot Days (32 stations)	18	14	-	3	2	13	2	3	8
Cold Days (31 Stations)	18	13	-	3	8	7	1	1	11

LOS: Level of Significance; NS: Not Significant

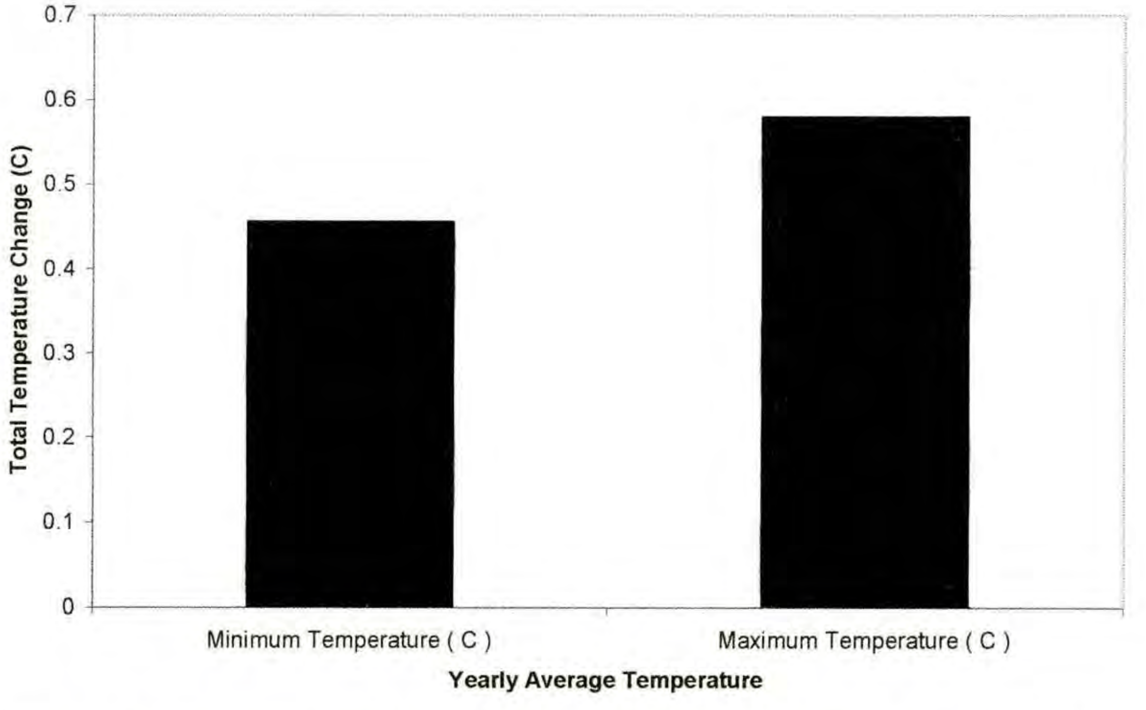

Figure 3.17: Total changes in yearly average temperature in Bangladesh during 1976-2005

3.3.4 Summary of Monthly Average Maximum and Minimum Temperature in Dry-Season (December-May)

Table 3.9 shows summary of analysis of monthly average maximum temperature for 34 weather stations. It shows that except for January, March and April, monthly average maximum temperature shows increasing trend for majority of the meteorological stations (Fig. 3.18). Increasing trend was particularly significant for the months of December, February and May. All but two stations showed increasing trend for the months of December, February and May. Only for January, more stations (25 out of 34) showed decreasing trend for monthly average maximum temperature.

Table 3.9: Summary of change in monthly average maximum temperature during 1976-2005

Month	No. of Station showing increasing trend	No. of Station showing decreasing Trend	Total Temp. change (°C) in 30 years from 1976 to 2005	Average Temp. changes per year °C /year	Increasing Trend (No. of Station)			Decreasing Trend (No. of Station)		
					95% LOS	99% LOS	NS	95% LOS	99% LOS	NS
January	9	25	-0.700	-0.023	3	0	6	8	3	14
February	32	2	1.182	0.039	5	3	24	1	0	1
March	17	17	0.064	0.002	1	1	15	1	1	15
April	17	17	0.975	0.032	7	1	9	2	0	15
May	32	2	0.852	0.028	5	2	25	0	0	2
December	32	2	1.065	0.035	1	13	18	0	0	2

LOS: Level of Significance; NS: Not Significant

Table 3.10: Summary of change in monthly average minimum temperature during 1976-2005

Month	No. of Station showing increasing trend	No. of Station showing decreasing Trend	Total Temp. change (°C) in 30 years from 1976 to 2005	Average Temp. changes per year °C /year	Increasing Trend (No. of Station)			Decreasing Trend (No. of Station)		
					95% LOS	99% LOS	NS	95% LOS	99% LOS	NS
January	16	18	-0.218	-0.007	1	3	12	2	4	12
February	29	5	1.210	0.040	6	9	14	0	1	4
March	24	10	0.500	0.016	5	2	17	1	1	8
April	28	6	0.695	0.023	4	0	24	0	0	6
May	29	5	0.831	0.027	9	3	17	0	0	5
December	26	8	0.571	0.019	7	5	14	1	2	5

LOS: Level of Significance; NS: Not Significant

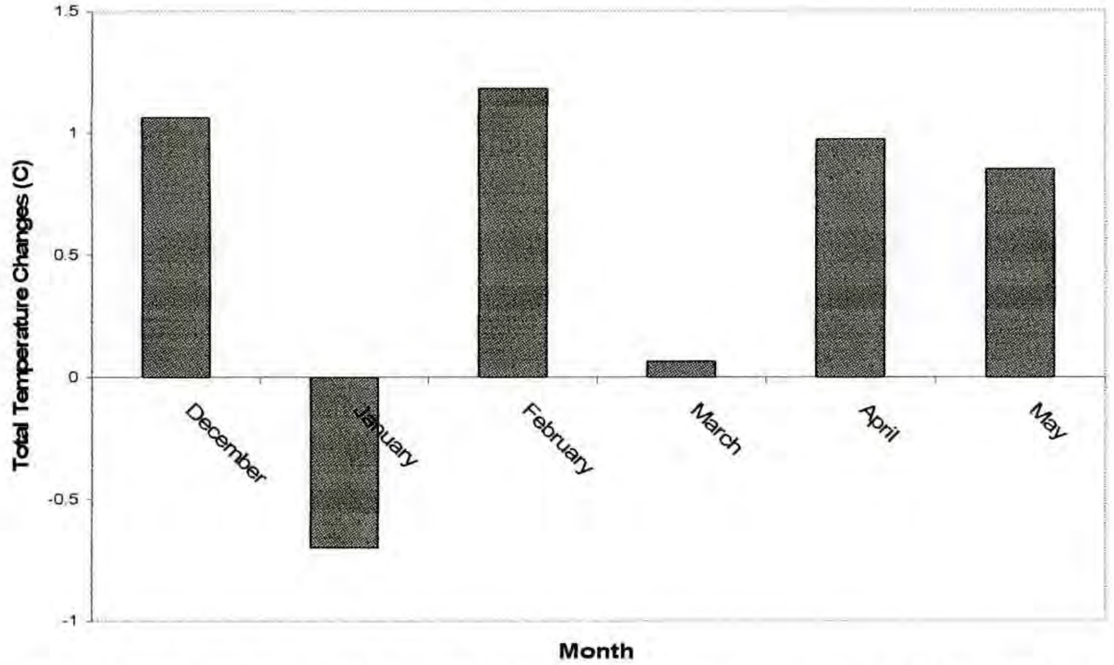

Figure 3.18: Total change in monthly average maximum temperature during 1976-2005 (dry-season)

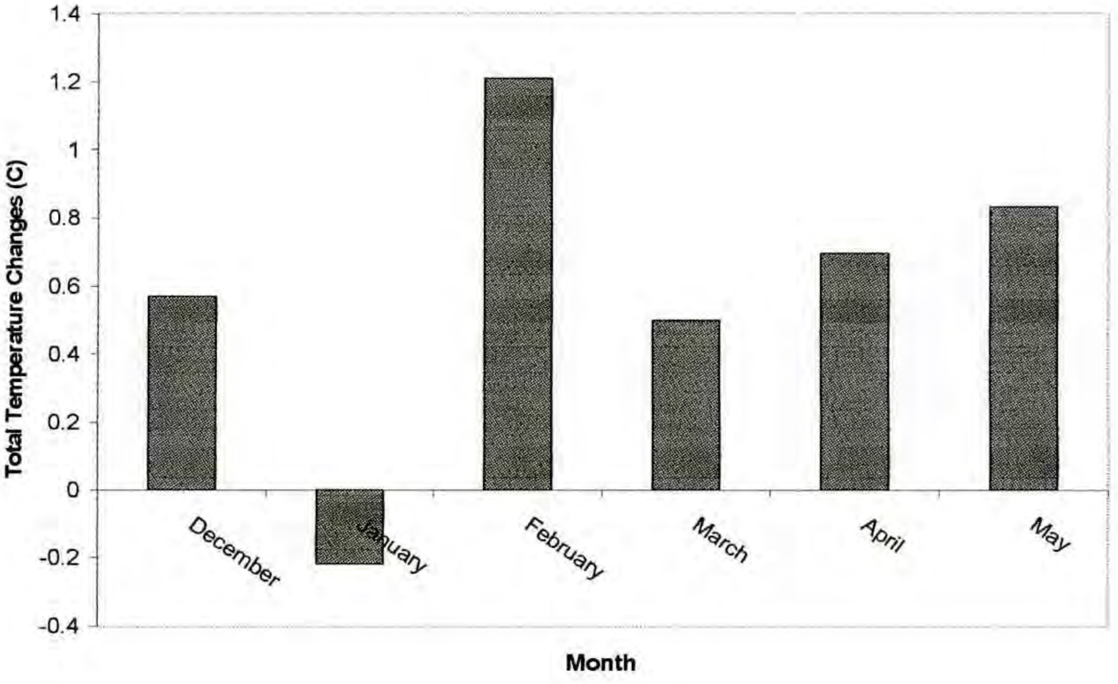

Figure 3.19: Total change in monthly average minimum temperature during 1976-2005 (dry-season)

Table 3.10 shows summary of analysis of monthly average minimum temperature for 34 weather stations during 1976-2005. Except for January, monthly average minimum temperature shows increasing trend for majority of the weather stations. The increasing trend was significant especially for the months of February and April. Calculated (from trend lines) total change during the 30-year period showed an increase in monthly average minimum temperature for all months of the year except January. For the 5 months (except January), average (i.e., average of 34 stations) total increase in monthly average minimum temperature was about 0.76 °C during the 30-year period, while for January, average decrease was about 0.218 °C during the same period (Fig. 3.19).

3.3.5 Trend of Dry-season Rainfall

The changes in rainfall pattern are important climate change phenomena, which are likely to be observed all over the land. In the study, efforts were made to assess if there is any significant change in trends of dry-season rainfall. For this purposes, trend analyses were carried out for total rainfall variation for two distinct seasons in Bangladesh Pre-monsoon (March-May) and Winter (December-February). The variation of dry-season rainfall for two seasons (Winter and Pre-monsoon) from 1976-2005 at 34 different meteorological stations in Bangladesh were carried out and trend lines for each station and each season were determined, along with the coefficient of determination (R^2) of each trend line. The following sections summarize the findings of the analysis.

3.3.5.1 Total Rainfall Variation in Pre-monsoon (March-May)

The variation of total rainfall during of pre-monsoon (March-May) was analyzed for 34 selected stations in Bangladesh are shown in Table 3.11. Twenty stations (Bogra, Chittagong, Comilla, Cox's Bazar, Chuadanga, Jessore, Kutubdia, Khepupara, Mongla, Patuakhali, Rangamati, Rangpur, sayedpur, Srimangal, Tangail, Teknaf, M.Court, Satkhira, Sitkaunda and Sandwip) out of 34 show increasing trend and 14 stations (Chandpur, Dhaka, Dinajpur, Ishurdi, Mymensingh, Rajshahi, Sylhet, Barisal, Bhola, Faridpur, Feni, Hatiya, Khulna and Madaripur) show decreasing trend. In Sayedpur, the records show a very sharp increasing trend with R^2=0.63220 at 99.9% level of significance. Increasing trend was also observed at Chudanga and Kutubdia (Fig 3.20) with R^2 values of 0.24129 and 0.20569, respectively, which are significant at level of 95%. Rangamati (R^2=0.08940) and Teknaf (R^2=0.1166) also show a significant increasing trend and Bhola (R^2=0.1110) shows, which are significant at 90% level of significance and the rest of the stations, R^2 values are below 0.08899 which are significant level at below at 90%.

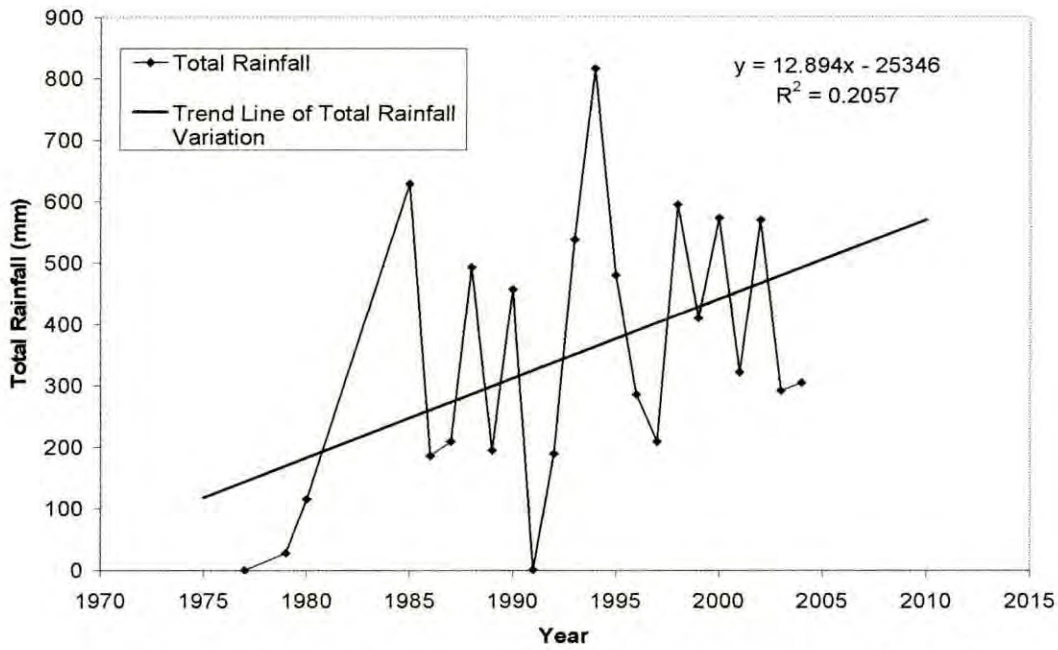

Figure 3.20: Variation of total Rainfall in Pre-monsoon at Kutubdia

3.3.5.2 Total Rainfall Variation in Winter (December-February) in 1976-2005

The variation of total rainfall during winter was analyzed for 34 stations (see Appendix A 3.11). Among the 34 stations, 16 show increasing trend, while 18 show decreasing trend in total rainfall in winter in Bangladesh. In Tangail, the records show a very sharp decreasing trend with R^2=0.3764 at 99.9% level of significance. Mongla and Sayedpur show decreasing trend with R^2 values are 0.25623 and 0.28536, respectively, which are significant at level of 99%. Jessore (R^2=0.10549) and Chudanga (R^2=0.10169) have a decreasing trend and Sitakunda (R^2=0.0967) show an increasing trend, which are significant at 90% level of significance. For the rest 28 stations; R^2 values are below 0.06789, which are significant level at below at 90% confidence level.

Table 3.11: Regression equation and correlation coefficient for variation of total rainfall in Pre-monsoon for different stations for the period 1976-2005

Station	Trend Line Equation	Value of correlation Coefficient (r)	Significant/Insignificant
Barisal	Y=-0.275X+932.26	-0.014142	Below 90% Significant
Bhola	Y=-7.525X+15436	-0.3332	90% Significant
Bogra	Y=0.9206X-1522.2	0.06245	Below 90% Significant
Chandpur	Y=-2.7935X+6040.2	-0.06855	Below 90% Significant
Chittagong	Y=4.269X-8021.6	0.1755	Below 90% Significant
Chuadanga	Y=10.494X-20727	0.49122	95% Significant
Comilla	Y=0.0916X+342.17	0.0007	Below 90% Significant
Tangail	Y=1.9422X-3423.7	0.07071	Below 90% Significant
Cox's Bazar	Y=6.8191X-13121	0.27349	Below 90% Significant
Dhaka	Y=-4.034X+8555.1	-0.1808	Below 90% Significant
Dinajpur	Y=-2.1252X+4543.5	-0.1044	Below 90% Significant
Faridpur	Y=-2.8191X+932.26	-0.15779	Below 90% Significant
Feni	Y=-1.7181X+4022.9	-0.06	Below 90% Significant
Sylhet	Y=-5.6994X+12401	-0.16462	Below 90% Significant
Hatiya	Y=-1.7922X+4029.2	-0.0728	Below 90% Significant
Ishurdi	Y=-2.068X+4413.1	-0.12409	Below 90% Significant
Jessore	Y=0.3321X-365.88	0.02236	Below 90% Significant
Khepupara	Y=3.3092X-6176.4	0.18708	Below 90% Significant
Khulna	Y=-1.3089X+2920.2	-0.07416	Below 90% Significant
Kutubdia	Y=12.894X-25346	0.45354	95% Significant
M. Court	Y=5.5129X-10430	0.203469	Below 90% Significant
Madaripur	Y=-6.6973X+13793	-0.29832	Below 90% Significant
Mongla	Y=5.978X-11634	0.21932	Below 90% Significant
Mymensingh	Y=-2.8852X+6269	-0.10677	Below 90% Significant
Patuakhali	Y=2.4214X-4431.1	0.086	Below 90% Significant
Rajshahi	Y=-1.8354X+3874.5	-0.14387	Below 90% Significant
Rangamati	Y=8.1971X-15802	0.299	90% Significant
Rangpur	Y=2.4681X-4494.4	0.13077	Below 90% Significant
Shandwip	Y=1.2049X-1851.9	0.03162	Below 90% Significant
Satkhira	Y=3.3041X-6294.7	0.236	Below 90% Significant
Sayedpur	Y=37.02X-73580	0.79511	99.9% Significant
Sitakunda	Y=8.1861X-15739	0.22804	Below 90% Significant
Srimangal	Y=7.7222X-14669	0.18894	Below 90% Significant
Teknaf	Y=8.1418X-15863	0.34146	90% Significant

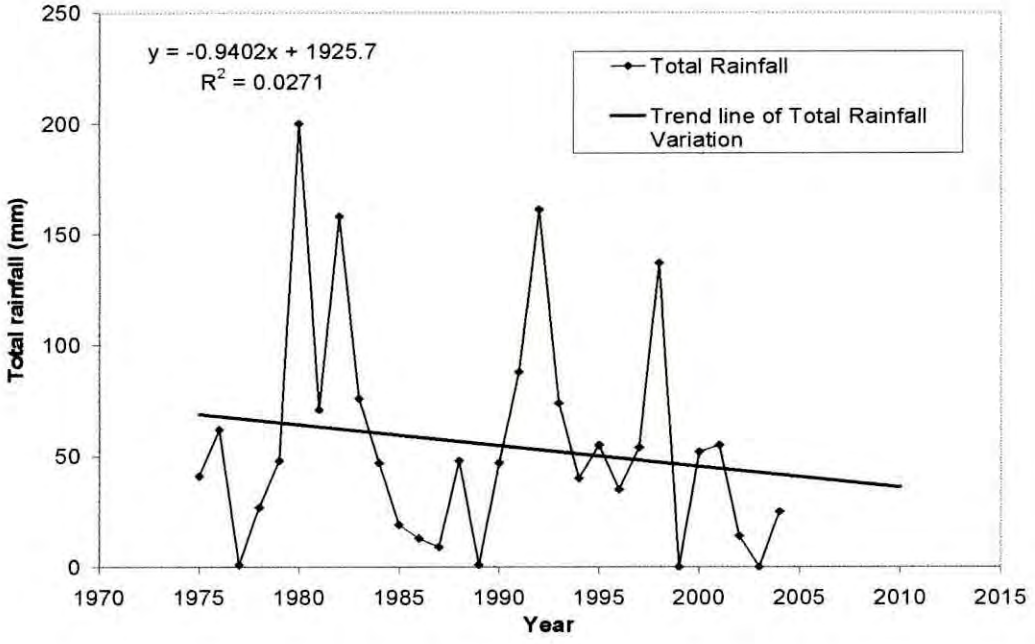

Figure 3.21: Variation of total Rainfall in Winter at Satkhira

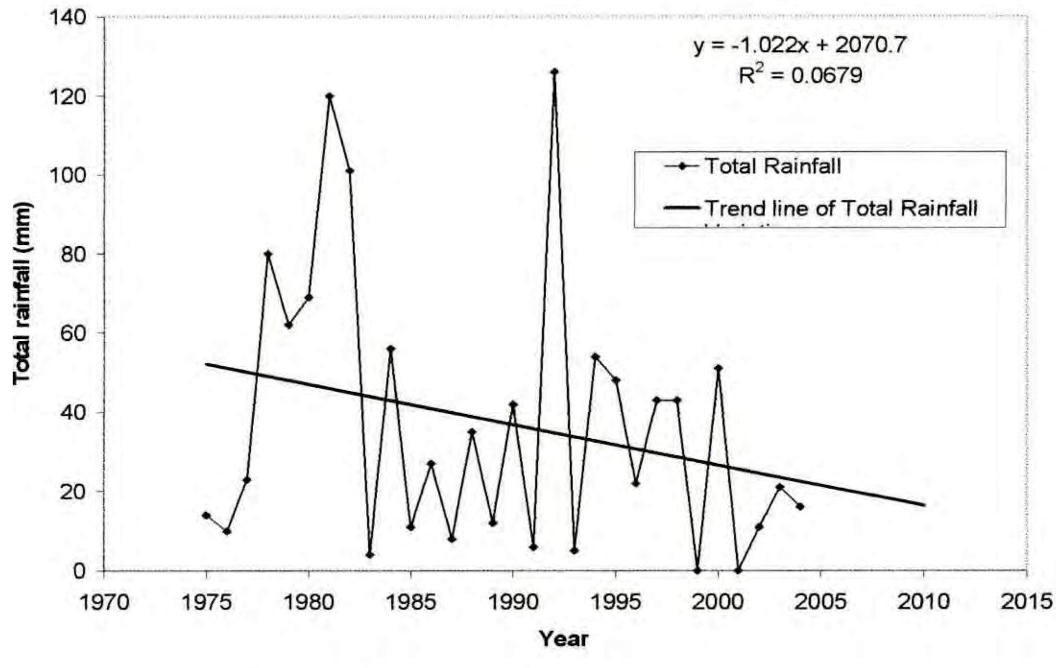

Figure 3.21: Variation of total Rainfall in Winter at Rajshahi

3.3.6 Trend of Seasonal Rainfall

Table 3.12 shows variation in total amount of rainfall in 2 seasons for all 34 meteorological stations during 1976-2005. It shows that the observed trends are not statistically significant in most cases. A significant number of stations showed decreasing trend of total rainfall during winter. These results are consistent with the general climate change predictions that wet periods would become wetter and dry periods would become drier. The Pre-monsoon (March-May) period shows an increasing trend in total rainfall for almost all stations.

Table 3.12: Summary of changes in total rainfall in 2 seasons during 1976-2005

Seasons	No. of Station showing increasing trend	No. of Station showing decreasing Trend	Increasing Trend (No. of Station)				Decreasing Trend (No. of Station)			
			90% LOS	95% LOS	99% LOS	NS	90% LOS	95% LOS	99% LOS	NS
Winter (Dec. to Feb.)	16	18	2	1	1	12	0	2	2	14
Pre-monsoon (Mar. to May)	20	14	2	2	1	15	1	0	0	13

LOS: Level of Significance; NS: Not Significant

Chapter 4

EFFECTS OF CLIMATE CHANGE ON BORO CULTIVATION IN BANGLADESH

4.1 INTRODUCTION

Global warming due to increasing concentrations of greenhouse gases poses a threat to human society by changing the living and working environment to which society has adapted over many generations. Agricultural impacts of climate change could have profound consequences in poor and developing countries. Bangladesh, a developing country in South Asia, is primarily a deltaic floodplain, and elevations in most of the country do not exceed 10 m. Rice in Bangladesh is grown under a diverse set of agro-environment varying in seasons, temperatures, rainfall, soil types, hydrology, varieties and input management. It is the staple food for a large majority of population. To meet the increasing demand of ever growing population, it is necessary to increase rice production in future.

The floodplains of Bangladesh are one of the regions where the rice plant was first domesticated around 5th millennium B.C. Bangladesh is also the place where rice production systems of various eco-seasonal characteristics evolved over centuries of rice farming experience and have been sustained. Rice is the staple food for the 140 million Bangladeshis who obtain more than 70% of their total calorie from rice. The per capita rice consumption in Bangladesh is higher than that in any other country where rice is the staple. Two-thirds of Bangladesh populations are engaged in livelihood activities related to rice. Most rice is grown by small-holder farmers who produce rice for family consumption and for marketing the marginal surplus (Bangladesh Rice Foundation, 2002).

World rice production must increase by 1% annually to meet the growing demand for food that will result from population growth and economic development. Most of the increase must come from greater yields on existing cropland to avoid environmental degradation, destruction of natural ecosystems and loss of biodiversity. Future crop yields will be influenced by complex interactions between the effects of increases in atmospheric concentrations of CO_2 and trace gases such as ozone as well as the effect of temperature increase brought about by climate change.

Change in global climate would significantly affect human health, natural aquatic and terrestrial ecosystems, and agricultural ecosystems. World-wide attention recently has turned to these issues and scientists from many countries are working to assess the potential magnitude and direction of the changes and the risks to the biota. Of great immediate concern to policy makers and scientists worldwide, are the potential effects of the changes on the world's agriculture. Whatever the magnitude of the global climate change mainly the predicted temperature changes, the pattern of temperature increases would vary over tropical rice producing areas depending on geographical factors. Rainfall patterns also would be expected to change depending on changes in temperature, which could have profound impacts on rice production.

A number of simulation studies have been carried out to assess impacts of climate change and variability on rice productivity in Bangladesh using the CERES-Rice model (e.g., Mahmood et al., 2003; Mahmood, 1998; Karim et al., 1996). These studies mainly focused on the effects of higher air temperature and atmospheric CO_2 concentration on rice yield. It may be noted that weather data requirement for DSSAT model include daily maximum and minimum air temperatures, daily precipitation and daily solar radiation, all of which could affect rice yield significantly. Therefore, in this study, future climate scenarios, including daily maximum and minimum temperatures, precipitation and solar radiation, for the selected locations of Bangladesh have been generated and used for predicting yield of boro rice. The yield of two boro varieties (BR3 and BR14) have been simulated in the present study for the years 2008 (representing present time), 2030, 2050 and 2070, using DSSAT (Decision Support System for Agrotechnology Transfer, version 4) modeling system. The future climate scenarios have been generated using the climate model named Providing REgional Climates for Impact Studies (PRECIS).

4.2 METHODOLOGY

In this study, different aspects of climate change in Bangladesh have been assessed through analysis of PRECIS-Model data on temperature, precipitation and solar radiation. Efforts were made to assess the phenomena that are likely to be observed as a result of climate change. A simulation study was also conducted to assess the vulnerability of boro production in Bangladesh to potential climate change. Simulations were made for high yield varieties of boro rice using the DSSATv4. In the present study, CERES-model has been used to estimate yield under normal and changed climate scenarios in Bangladesh for the period of 2008, 2030, 2050 and 2070. The minimum data requirements for operation, calibration and validation of rice models for irrigated crop (boro) were collected from various sources for 12 locations in Bangladesh. Those locations were selected from among the major crop growing areas in six regions in Bangladesh. The following sections discuss the methodology followed in this study in more details.

4.2.1 Selection of Simulation locations

The yield of two boro varieties BR3 and BR14 for the years 2008, 2030, 2050 and 2070 have been simulated for 12 districts of Bangladesh, which were selected from among the major rice growing areas in different regions of Bangladesh. Among them, Rajshahi, Bogra and Dinajpur were selected from northwestern region; Mymensingh and Tangail were selected from central region; Jessore and Satkhira from southwestern region; Barisal and Madaripur from southern region; Chandpur and Comilla from southeastern region; and Sylhet district from eastern regions. In addition to simulating yield for the selected years under the simulated climatic scenarios and the selected crop management conditions (described), potential yield (i.e., yield without any water and nitrogen stress) and vulnerability of the rice varieties under varying transplanting date was also assessed.

4.2.2 Selection of Rice Variety

The DSSAT model is variety-specific (e.g., BR3 boro) and is able to predict rice yield and rice plant response to various environmental conditions. In predicting crop growth and yield, the model takes into effect of weather, crop management, genetics, and soil water, C and N. The model uses a detailed set of crop specific genetic coefficients, which allows the model to respond to diverse weather and management conditions. Therefore, in order to get reliable results from model simulations, it is necessary to have the appropriate genetic coefficients for the selected cultivars. The two boro rice varieties BR3 and BR14 have been selected in the present study because genetic coefficients for these varieties are available in the DSSAT modeling system. Although these varieties are not widely used at present time, the effects of climate change and variability on these varieties provide insights into possible impact of climate change on rice yield in the future.

4.2.3 Crop management data

Crop management and experimental data were collected from Bangladesh Rice Research Institute (BRRI, 2006 and Rashid, 2008). Management data included planting date, planting density, row spacing, planting depth and irrigation and fertilizer practices. Experimental data included crop coefficient (K_C), crop growing period and soil water and fertility measurement.

The boro rice usually takes 3-6 months from germination to maturity, depending on variety and the environment under which it is grown. In this study two distinct varieties (BR3 and BR14) of boro rice were selected, grown during December to May. The selected varieties were BR3 and BR14. Using these inputs, the average (of 12 locations) yields of BR3 and BR14 for the year 2008, estimated by the model, were about 5500 kg ha^{-1} and 4050 kg ha^{-1}, respectively; these values are close to the reported yields of these varieties (BRRI, 2006). This total growing period, rice completes three distinct sequential growth phases, vegetative, reproductive and ripening. These phases are subdivided into various stages. Name of those stages and their growth duration are given in Table 4.1. Crop management data for boro rice such as planting method, planting distribution, planting population at seedling, planting population at emergence, row spacing, planting depth, transplant age, optimum temperature during transplanting and plant per hill are given in Table 4.2. Extreme temperatures are destructive to plant growth. The critical low and high temperatures, normally below 20^{0}C and above 30^{0}C, vary from one growth stage to another. These critical temperatures differ according to variety, duration of critical temperature, diurnal changes, and physiological status of the plant. The low, high and optimum temperature for different growth phases are given in Table 4.3.

Table 4.1: Growing period data

Growth Phase of Rice	Growth Stage of Rice	Duration(Days)
Vegetative Phase	Germination Stage	2-3
	Seedling Stage	40-45
	Initial and Maximum Tillering Stage	30-35
Reproductive Phase	Pancile Initiation Stage	8-10
	Booting Stage	10-12
	Heading Stage	5-7
	Flowering Stage	6-8
	Milking Stage	4-5
Ripening Phase	Soft Dough Stage	7-9
	Hard Dough Stage	6-8
	Ripening Stage	14-18

Table 4.2: Planting data

Planting Method	Transplant
Planting Distribution	Hill
Planting Population at Seeding, Plants/m^2	35
Planting Population at Emergence, Plants/m^2	32
Row Spacing, cm	15-20
Planting Depth, cm	3
Transplant Age, days	40-45
Temperature during Transplanting, ^{0}C	20-30
Plant per Hill, No.	2-3

Table 4.3: Temperature data

Growth Phase of Rice	Low (^{0}C)	High (^{0}C)	Optimum (^{0}C)
Vegetative Phase	10-12	40	20-30
Reproductive Phase	20	35	30-33
Ripening Phase	12-18	30	20-25

Like temperature, water requirement for boro rice also vary from one growth stage to another. This water requirement differs according to variety, climatic factors like temperature and solar radiation, physiological status of the plant and soil condition. Water requirement for heavy soil and light soil for different growth phases are given in Table 4.4. An adequate water supply is one of the most important factors in rice production. In many parts of tropical Asia, rice plants suffer from either too much or too little water because of irregular rainfall and landscape patterns. Irrigation requirement for boro rice in various phases are given in Table 4.5. Rice plants require a large amount of nitrogen at the early and mid-tillering stages to maximize the number of panicles. Nitrogen absorbed at the panicle initiation stage may increase spikelet number per panicle. Some nitrogen is also required at the ripening stage. The nitrogen requirement for boro rice is given in Table 4.6.

Table 4.4: Water requirement data

Growth Phase of Rice	**Heavy Soil (mm)**	**Light Soil (mm)**
Vegetative Phase	440	548
Reproductive Phase	240	343
Ripening Phase	153	208

Table 4.5: Irrigation data

Various Phases of Boro Rice	**Irrigation Interval (days)**
Vegetative Phase	5
Reproductive Phase	7
Ripening Phase	7

Month	**Irrigation Requirement (mm/day)**
January	8
February	9
March	10
April	10
May	10

Table 4.6: Fertilizer dose

Fertilizer Name	**Fertilizer Dose (kg/ha)**	**Fertilizer Application**
Urea (N) (3 times in total growing period)	100-120	Broadcast on Flooded
Triple Super Phosphate (P)	40-45	Broadcast on Flooded
Potassium Nitrate (K)	60-75	Broadcast on Flooded

4.2.4 Soil data

Rice is grown on a variety of soils ranging from waterlogged and poorly drained to well drained. It is also grown under many different climatic and hydrologic conditions. In this study, soil data were collected from Bangladesh Rice Research Institute (BRRI) and Soil Resources Development Institute (SRDI). The sources from where soil data were collected included Fertilizer Recommendation Guide-2005 (Bangladesh Agricultural Research Council, Dhaka), A Manual for the Determination of Soil Physical Parameters (Karim et al., 1988, Bangladesh Agricultural Research Council, Dhaka) and Metrika Beggan (Bhuya et al., 1985).

Soil data included upper and lower horizon depth, percentage of sand, silt, and clay, color, bulk density, organic carbon, permeability and drainage, pH in water. Some of the soil parameters used in this model is presented in Appendix B (Table B 4.1). As an example, the soil profile data used in the model for the North Eastern Barind Tract (i.e., Agro-Ecological Zone, AEZ-27) covering Dinajpur, Rangpur, Bogra, Gaibandha, and Joypurhat districts is presented in Table 4.7 and the Old Meghna Estuarine Floodplain (i.e., Agro-Ecological Zone, AEZ-19) covering Kishoregani, Habigang, Brakmanbaria, Comilla, Chandpur, Feni, Noakhali, Laksmipur, Narsingdi, Narayanganj, Dhaka, Shariatpur, Modaripur, Gopalganj and Barisal districts is presented in Table 4.8. Tables for the remaining regions are shown in Appendix B (Table B 4.2, B 4.3, B 4.4 B 4.5, B 4.6, B 4.7, B 4.8 and B 4.9).

Table 4.7: Soil profile data for North Eastern Barind Tract (AEZ-27)

Depth Bottom Cm	Clay %	Silt %	Stones %	Organic Carbon %	pH in Water	Cation Exchange Capacity meq/100gm	Total Nitrogen %
5	19	17.5	0	0.79	5.2	5.25	0.14
15	19	17.5	0	0.79	5.2	5.25	0.14
30	19	17.5	0	0.75	5.2	5.25	0.13
45	19	17.5	0	0.63	5.2	5.25	0.11

Soil Texture: Loamy

Table 4.8: Soil profile data for Old Meghna Estuarine Floodplain (AEZ-19)

Depth Bottom cm	Clay %	Silt %	Stones %	Organic Carbon %	pH in Water	Cation Exchange Capacity meq/100gm	Total Nitrogen %
5	13	38	0	1.51	5.6	11.3	0.14
15	13	38	0	1.51	5.6	11.3	0.14
30	13	38	0	1.43	5.6	11.3	0.13
45	13	38	0	1.22	5.6	11.3	0.11

Soil Texture: Silt Loam

4.2.5 Weather Data

The Hadley Centre of United Kingdom has developed the model named Providing REgional Climate for Impact Studies (PRECIS), a regional climate model (RCM), system which can be run to generate climate change scenarios. The aim of PRECIS is to allow developing countries, or groups of developing countries, to generate their own national scenarios of climate change to use in impacts studies. It is a hydrostatic, primitive equation grid point model containing 19 levels described by a hybrid vertical coordinate (Simmons and Burridge, 1981; Simon et al., 2004). In this study, a regional climate model named Providing REgional Climate for Impacts Studies (PRECIS) was used to generate daily weather data needed for running the DSSAT model (Islam. 2008). The special report on emission scenarios (SRES) A2 of ECHAM4 has been used as PRECIS input. In this study PRECIS runs with 50-km horizontal resolution for the present climate using baseline lateral boundary conditions (LBCs). The model domain was selected 65–103°E and 6–35°N to cover Bangladesh and its surroundings. In the next step PRECIS run was completed for the year 2030, 2050 and 2070 using ECHAM 4 SRES A2 as the model input. The PRECIS outputs that were used in the DSSAT model include daily maximum temperature (T_{max}), daily minimum temperature (T_{min}), daily incoming solar radiation (Srad), daily precipitation.

4.2.6 DSSAT Model

The Rice model of the DSSAT model system (v4) simulates crop growth, development and yield taking into account the effects of weather, management, genetics, and soil water, C and N. The simulation runs for rice was made by using Rice models of Decision Support System for Agrotechnology Transfer (DSSAT) version 4.0. The DSSAT Cropping System Model (CSM) simulates growth and development of a crop over time, as well as the soil water, carbon and nitrogen processes and management practices. These include:

1. A main driver program, which controls timing for each simulation,
2. A land unit module, which manages all simulation processes which affect a unit of land,
3. Primary modules that individually simulate the various processes that affect the land unit including weather, plant growth, soil processes, soil-plant-atmosphere interface and management practices.

Collectively, these components simulate the changes over time in the soil and plants that occur on a single land unit in response to weather and management practices. The DSSAT-CSM incorporates models of all crops within a single set of code. The design feature greatly simplifies the simulation of crop rotations since soil processes operate continuously, and different crops are planted, managed, and harvested according to cropping system information provided as inputs to the model.

4.2.6.1 Tools of DSSAT-Model

The "Tools" menu of the DSSAT model includes the Crop Management Data editor (XBuild), the Graphical Display Tool (GBuild), the Soil Data editor (SBuild) and the Experimental Data editor (ATCreate).

Crop Management Data Editor (XBuild)

XBuild was designed to help the users create experimental files easily to avoid major errors like types, format errors, errors with dates, etc. An important role of the program is to make it easy to select information default values and retrieved information from DSSAT4 files.

The Environment menu option allows users to make changes to (1) Field information, which includes daily weather variables, soil data, etc., (2) Soil Initial Condition which defines the initial soil water and nitrogen conditions at the start of simulation, (3) Soil Analysis, (4) Environmental Modification which allows one to make changes to weather variables such as daylength, daily total radiation, maximum temperature, minimum temperature, precipitation, CO_2, humidity, and wind. In the Management menu option, the user can (1) select the crop and Cultivar that will be simulated, (2) enter management inputs of Planting details which defines the planting date, plant density, row spacing and planting depth, (3) Irrigation and water management which defines the dates and amounts of irrigation applications, (4) Fertilizer which defines the dates, amount, and types of fertilizer applications, (5) residues and other Organic Amendments which defines initial residue from the previous crop present at the start of simulation, (6) Tillage, (7) Harvest which defines final harvest date and other harvest parameters, and (8) Chemical Applications.

The importance of the above sections depends on the treatment factor levels that one defines for an experiment. The Treatments section allows one to select combination of the factors on section entries for each treatment.

Soil Data Editor (SBuild)

The soil file (Soil.sol) contains data on the soil profile properties. These data are used in the soil water, nitrogen, phosphorus and root sections of the crop models. The purpose of SBuild is to provide an effective tool for creating and modifying the soil files. SBuild is a key-mouse driven windows program that allows the user to enter data into tables, freeing the user from possible formatting errors associated with entering data directly into an ASCII file. The program will also calculate missing data before saving.

Graphical Display Tool (GBuild)

GBuild is a mouse-menu-key-driven plotting tool for data visualization. It provides users with the capability to easily plot graphs that are routinely used during the development and validation of crop models. Different graphic options will give different views of the research results. GBuild lets one compare data from experimental measurements with results from simulation models. Additionally, GBuild calculates statistics based on experimental and simulated data. It also provides the possibility of exporting the data into an Excel spread sheet, or to a text file.

WeatherMan

Daily weather data are commonly used as input to mathematical models used in water related projects and agriculture. While the models expect the data to be complete and reliable, raw data from a weather station, or even a reliable secondary supplier of weather data, are often flawed. The WeatherMan program is designed to simplify or automate many of the tasks associated with handling, analyzing, and preparing weather data for use with crop models or other simulation software. WeatherMan has the ability to translate both the format and units of daily weather data files, check for errors on import, and fill-in missing or suspicious values on export. WeatherMan can also generate complete sets of weather data comprising solar radiation, maximum and minimum temperature, rainfall, and photosynthetically active radiation.

4.2.6.2 Data requirement for Rice model

There are several input requirements of these crop models. These inputs and how they were generated are described in this section.

Genetic coefficients

Rice model of DSSAT Model system uses as inputs coefficients that account for differences in growth and development among cultivars. These coefficients are referred to as genetic coefficients. Genetic coefficients allow the model to simulate performance of different varieties under diverse weather and management conditions. Therefore, to obtain reasonable outputs from the simulation models, it is necessary to have the appropriate genetic coefficients for the selected cultivars. Since the genetic coefficients for the varieties considered in this study were not available, they were estimated by using GENCALC of DSSAT v4.0, a computer software program that facilitates estimation of crop genetic coefficients (Hunt et al., 1993).

Table 4.9: Genetic coefficients for rice cultivars, grown in Bangladesh, determined for DSSAT Model

Rice	Cultivar	Coefficients								Source
		P1	P2R	P5	P2O	G1	G2	G3	G4	
Boro	BR3	650.0	90.0	400.0	13.0	65.0	0.025	1.0	1.0	DSSAT v4
	BR14	560.0	200.0	500.0	11.5	45.0	0.026	1.0	1.0	DSSAT v4

Soil data

Soil information is contained in a soil data file. The file contains information collected for the soil profile at a specified site along with supplement information extracted from soil survey reports for a soil with similar taxonomic classification. The file was created by maintaining the format required by the DSSAT v4.0 crop models. Soil data were collected for 12 locations mentioned in subsection 4.2.4 (Source and description of soil data).

Crop data

The required crop data on development and growth characteristics and cultural practices for the selected varieties were collected from BRRI (Table 4.10). The cultural practices information was used for creating different simulation experiments. The cultural practices are planting date, planting density, row spacing, planting depth and irrigation and fertilizer practices, crop growing period and soil water and fertility measurement. 15 January was selected for planting date for 12 locations all over in Bangladesh. In the simulation experiments, for selecting suitable planting date, 1, 5, 15 and 25 January were selected. For finding yield of boro rice in the period of 2008, 2030, 2050 and 2070 the following management data was considered. To observe the impact of climate change on boro production, it was necessary to maintain a similar interval of irrigation application date corresponding with planting date in all locations in Bangladesh. But when years were changed (2030, 2050 and 2070), at that time irrigation application date unchanged; only year was replaced with desirable year. It was also same as fertilizer application.

Table 4.10: Crop management data used in the model simulations

Parameter	**Input data**
Planting method	Transplant
Transplanting date	1, 5, 15 and 25 January
Planting distribution	Hill
Plant population at seedling	35 plants per m^2
Plant population at emergence	33 plants per m^2
Row spacing	20 cm
Planting depth	3 cm
Transplant age	35 days
Plant per Hill	2
Fertilizer (N) application • 18 days after transplanting • 38 days after transplanting • 56 days after transplanting	 30 kg ha^{-1} 70 kg ha^{-1} 30 kg ha^{-1}
Application of irrigation	855 mm in 14 applications

Weather data

Predicted weather data in the period of 2008, 2030, 2050 and 2070 for the 12 locations was obtained from SAARC Metrological Research Centre (Islam. 2008). The weather data included daily values for the following variables: rainfall (mm), maximum and minimum temperatures (^{0}C), and incoming solar radiation (MJ/m^2/day) (sec section 4.2.5 for details).

4.3 RESULTS AND DISCUSION

In this study, effect of climate change on two varieties of boro rice was assesed. Predicted climate scenarios for the years 2008, 2030, 2050 and 2070 were used to the assessment at first qualitative assessment of impact was made by comparing the predicted temperature with optimum temperatures for different growth phases of boro rice. Quantitative amount of the impact of climate change on boro rice was made using the DSSAT (v4.0) model. The section presents the results of both qualitative and quantitative assessment of the impact of climate change on boro cultivation on different regions of Bangladesh.

4.3.1 Qualitative Assessment of Temperature and Rainfall on Growth Phases of Boro Rice

4.3.1.1 Temperature

The rice plant usually takes 3-6 months from germination to maturity, depending on variety and the environment under which it is grown. During this total growing period, rice completes three distinct sequential growth phases, vegetative, reproductive and ripening.

The vegetative phase refers to a period from germination to the initiation of panicle primordia. It is characterized by active tillering, gradual increase in plant height and leaf emergence at regular intervals. All contribute to increasing the leaf area that receives sunlight. The low, high and optimum temperature ranges in vegetative phase are normally 10-12^{0}C, 40^{0}C and 20-30^{0}C and water requirement for heavy soil is 440 mm and for light soil 548 mm. These temperature ranges and water requirement in vegetative phase differ according to variety, duration of critical temperature, diurnal changes, and physiological status of the plant and soil condition. The vegetative phase is subdivided into germination, seedling and initial and maximum tillering stage. Germination starts when seed dormancy has been broken down, the seed absorbs adequate water, and is exposed to a temperature ranging from about 10 to 40^{0}C. Temperature has a profound influence on germination stage. The effect of temperature on germination can be examined in terms of temperature, time and germination percentage. 90-97% germination was attained in 2 days for incubation at 27^0-37^0C; the germination percentage dropped sharply below or above this range (Yoshida.1981). When the incubation time was extended to 6 days, germination was 90% or higher at temperatures between $15^0$and 37^0C. At 8^0 and 45^0C, no germination occurred. Seedling emergence is the time when the tip of a seedling emerges from the soil or water surface and, thus includes both germination and post germination growth. Physiological age of seedling is very much affected by environment. Even for the same location and variety, variable weather conditions affect the rate of seedling growth. In first week of post-germination growth, the growth rate increases linearly in temperature range between 22^0 and 31^0C. For the maximum seedling growth, the best temperature range is 25^0-30^0C. Growth may be reasonably good up to 35^0C, above which it declines sharply. Above 40^0C seedling may die. The critical minimum temperature for shoot elongation ranges from 7^0 to 16^0C and that for root elongation from 12^0 to 16^0C. Hence, about 10^0C may be considered as the critical minimum temperature for both shoot and root. Seedlings for transplanted rice are normally raised in lowland nurseries compare to upland nurseries. The upland-grown seedlings perform well when temperatures are cool at transplanting and quick recovery from transplanting is desirable. Tillers are branches that develop from the leaf axils at each unelongated node of the main shoot or from other tillers during vegetative growth. The optimum temperature for tillering stage is 25-31^0C. The effect of temperature on tillering is affected by the level of sunlight. Basically, higher temperatures increase the rate of leaf emergence, and provide more tiller buds. Under low light conditions, some of the tiller buds may not develop into tillers because of a lack of carbohydrate necessary for growth. When light is adequate, however, higher temperatures increase tiller number.

The reproductive phase refers to the period from panicle initiation stage to the milking stage. It is characterized by clum elongation, decline in tiller number, and emergence of the flag leaf, booting, heading, and flowering. The low, high and optimum temperature ranges in reproductive phase are normally 20^0C, 35^0C and 30-35^0C and water requirement for heavy soil is 240 mm and for light soil 343 mm. These temperature ranges and water requirement in reproductive phase vary according to variety, duration of critical temperature, diurnal changes, and physiological status of the plant and soil condition. The reproductive phase is subdivided into panicle initiation booting, heading, flowering, and milking stage. The major elements of a panicle are the base, axis, primary and secondary branches, pedicel, rudimentary glumes and spiklet. The initiation of panicle primordium starts about 30 days before heading; it corresponds to the time when the fourth leaf from the top begins to elongate. The total duration of panicle development varies with variety and weather and ranges from 27 to 46 days. The minimum critical temperature for panicle initiation stage is 15^0C. Heading means panicle exsertion. It usually takes 10-14 days for all the plants in the field to complete heading. Heading date is generally defined as the time when 50% of the panicles have exserted. Low temperatures aggravate poor panicle exsertion. Anthesis (flowering) refers to a series of events between the opening and closing of the spikelet, lasting about 1-2.5 hours. When a portion of the panicle has exserted, anthesis will occur, starting with the spikelets at the tip of upper panicle branches. Hence the date of anthesis is the same as the date of heading. The date of anthesis of individual spikelets varies within the position of the spikelets within the same panicle. Spikelets on the upper branches have earlier anthesis than those on the lower branches. The low, high and optimum temperature ranges in anthesis stage are normally 22^0C, 35^0C and 30-33^0C.

The ripening period is characterized by grain growth increase in size and weight, changes in grain color, and senescence of leaves. At the early stages of ripening, the grains are green; they turn yellow as they mature. The texture of the grains changes from a milky, semifluid state to a hard solid. On the basis of such changes the ripening period is subdivided into soft dough, hard dough and ripening stage. Before heading, a considerable amount of starch and sugar accumulates in the culms and leaf sheaths. This accumulated carbohydrate is translocated to the grains during ripening. In cool regions, some leaves remain green even at maturity. The low, high and optimum temperature ranges in ripening phase are normally 12^0C, 35^0C and $30\text{-}35^0C$ and water requirement for heavy soil is 153 mm and for light soil 208 mm.

Qualitative Assessment of Temperature in December-May on growth phases of Boro Rice

December month is located in the vegetative phase and low, high and optimum temperature ranges in this phase are $10\text{-}12^0$, 40^0 and $20\text{-}30^0C$, respectively. The predicted temperatures by the PRECIS model show that in none of the 12 selected stations temperature will be in the optimum range in December for the years 2030, 2050 and 2070. This is because the minimum temperature of almost all stations is predicted to be below 20^0C. During this period germination starts when seed dormancy has been broken down, the seed absorbs adequate water, and is exposed to a temperature ranging from about 10^0 to 40^0C. For those stations, in which minimum temperature is below 20^0C, the germination may be slightly affected. It was observed that in Dinajpur, Jessore, Satkhira, Madaripur, Chandpur and Comilla, the minimum predicted temperature was very close to 10^0C in 2030 and this could affect the rate of germination. The minimum temperature in 2050 and 2070 was predicted to be slightly higher than 2030, which may be beneficial for good germination for boro rice.

Temperatures below 10^0C would affect the rice plant establishment after seedling has been transplanted and then they begin to rooting. In January, low temperature during transplanting affects root growth and poor leaf development leading to poor crop establishment. The low temperature at the early growth stages affects natural nutrient uptake and metabolic activities leading to poor vegetative growth reflected, as yellowing of leaves, stunt growth and reduced tiller number (Nishiyama et al., 1995). According to the model predictions, none of the stations will have optimum temperature for seedling growth ($25\text{-}30^0C$) up to 2070. It was observed that the minimum temperature of all stations except Satkhira (2070) was predicted to be below 20^0C in 2030, 2050 and 2070. These stations with the temperature below 20^0C but above 10^0C may be slightly affected in terms of seedling growth and discoloration of seedling (Kaneda and Beachell, 1974).

The predicted monthly average maximum and minimum temperature in December and January (2030, 2050 and 2070 from PRECIS-Model) are shown in Table 4.11.

Table 4.11: Monthly average maximum and minimum temperature in December and January (2030, 2050, 2070)

Locations	December Month						January Month					
	Max. Temp. ^{0}C 2030	Min. Temp. ^{0}C 2030	Max. Temp. ^{0}C 2050	Min. Temp. ^{0}C 2050	Max. Temp. ^{0}C 2070	Min. Temp. ^{0}C 2070	Max. Temp. ^{0}C 2030	Min. Temp. ^{0}C 2030	Max. Temp. ^{0}C 2050	Min. Temp. ^{0}C 2050	Max. Temp. ^{0}C 2070	Min. Temp. ^{0}C 2070
Northwestern region												
Rajshahi	25.32	11.81	28.15	14.39	27.01	14.78	24.10	11.93	26.75	13.24	27.75	17.49
Bogra	24.76	11.25	27.74	13.51	26.92	14.44	23.55	11.88	26.00	12.61	27.34	17.24
Dinajpur	25.15	10.56	27.76	12.63	27.05	13.59	23.91	11.40	26.00	11.80	28.36	16.23
Central region												
Mymensingh	23.97	11.77	26.72	14.00	26.39	15.26	22.83	12.53	24.21	12.96	25.36	17.48
Tangail	24.58	10.98	27.67	14.26	26.91	14.61	23.40	12.24	25.66	12.91	26.93	18.07
Southwestern region												
Jessore	25.33	10.42	27.78	15.54	27.84	14.80	23.99	13.06	26.34	13.90	28.82	19.54
Satkhira	25.57	10.74	27.81	16.32	28.11	15.19	24.25	13.67	26.82	14.68	29.98	20.54
Southern region												
Barisal	25.79	10.91	28.05	15.21	28.20	15.10	23.94	12.84	25.90	14.10	28	19.5
Madaripur	25.52	10.65	27.93	15.09	27.90	14.80	23.86	12.43	25.74	13.75	27.77	18.99
Southeastern region												
Chandpur	25.76	10.75	28.10	14.97	28.11	14.85	24.22	12.26	25.76	13.81	27.75	18.69
Comilla	25.51	10.42	27.65	14.16	27.55	14.40	24.18	11.92	25.43	13.40	27.38	17.80
Eastern region												
Sylhet	24.59	11.65	27.23	13.42	26.17	14.45	23.22	12.04	23.00	13.04	25.00	16.57

February represents in the Initial and Maximum tillering stage (Vegetative phase) and Panicle Initiation stage (Reproductive phase). Temperature range in this month is more critical, because two important growth phases are there in this month. The optimum temperature for tillering stage is 25-31^{0}C. Basically, higher temperatures increase the rate of leaf emergence, and provide more tiller buds. Under low light conditions, some of the tiller buds may not develop into tillers because of a lack of carbohydrate necessary for growth. When light is adequate, however, higher temperatures increase tiller number. The climate model (PRECIS) predicted maximum temperature above 35^{0}C in Rajshahi, Bogra, Dinajpur, Tangail, Jessore, Satkhira, Barisal, Madaripur and Chandpur in 2070. The lowest limit of minimum temperature (15.39 and 15.68^{0}C) was predicted for Dinajpur in February, 2030 and 2050, respectively. For Bogra, the lowest minimum temperature was predicted to be 15.99^{0}C in 2030. These low temperatures may trend to stunt vegetative growth characterized by reduced height and tillering, delayed heading, incomplete panicle exsertion (Kaneda and Beachell, 1974). In short, the model predicted temperature shows that the temperatures will remain more or less within the range of maximum and minimum temperature for most of the selected locations.

March month represents the Reproductive phase and low, high and optimum temperature ranges in this phase are 20^0, 35^0 and 30-33^{0}C, respectively. The predicted temperatures show that none of the selected locations will have minimum temperature below 20^{0}C in March in 2030, 2050 and 2070. So it will be beneficial for future boro production. In a technical sense, the temperature in this month may have a significant effect on boro rice production; because this is the time when the rice plants undergo may be Panicle Initiation, Booting, Heading and a part of Flowering and Milking, on which the best performance of rice depends. The monthly average maximum temperature above 35^{0}C was predicted almost all parts of the country for 2050 and 2070 except the eastern region where boro production is negligible. So, boro production in 2050 and 2070 may be hampered significantly due to higher maximum temperature. Fertility of spikelets was 75% for plants held at 35^{0}C for 4 hours, about 55% at 38^{0}C for 4 hours, and about 15% at 41^{0}C for 2 hours (Satake and Yoshida, 1978). In 2070, the predicted maximum temperature in northwestern, southwestern and central (Tangail) regions often exceeded 40^{0}C, which may have a significant role to reduce fertility of spikelets. According to Satake and Yoshida (1978), spikelet sterility from high temperature is induced largely on the day of flowering. Within the flowering day, high temperature during anthesis was the most detrimental to spikelet fertility, high temperature just before anthesis was the second most detrimental and high temperature after anthesis had little effect on spikelet fertility. The predicted monthly average maximum and minimum temperature in February and March (2030, 2050 and 2070 from PRECIS-Model) are shown in Table 4.12.

Table 4.12: Monthly average maximum and minimum temperature in February and March (2030, 2050, 2070)

Locations	February Month						March Month					
	Max. Temp. ^{0}C 2030	**Min. Temp. ^{0}C 2030**	**Max. Temp. ^{0}C 2050**	**Min. Temp. ^{0}C 2050**	**Max. Temp. ^{0}C 2070**	**Min. Temp. ^{0}C 2070**	**Max. Temp. ^{0}C 2030**	**Min. Temp. ^{0}C 2030**	**Max. Temp. ^{0}C 2050**	**Min. Temp. ^{0}C 2050**	**Max. Temp. ^{0}C 2070**	**Min. Temp. ^{0}C 2070**
Northwestern region												
Rajshahi	27.05	16.02	34.21	16.68	38.04	21.07	34.55	23.66	38.79	24.78	42.11	25.97
Bogra	26.98	15.99	32.91	16.09	36.66	20.24	32.83	23.58	37.90	24.23	41.16	25.53
Dinajpur	27.74	15.39	32.54	15.68	36.81	19.92	31.15	22.56	38.24	22.93	40.36	24.49
Central region												
Mymensingh	25.88	16.62	29.94	16.18	32.77	18.85	29.11	22.61	33.80	22.84	37.49	24.56
Tangail	27.14	16.76	32.96	16.64	36.28	20.40	32.78	23.83	37.37	24.63	40.69	25.92
Southwestern region												
Jessore	28.55	18.13	34.51	18.61	37.91	21.79	34.69	24.55	37.77	25.14	41.19	27.33
Satkhira	28.77	18.64	34.67	19.25	38.04	22.43	34.81	24.68	37.92	25.30	40.96	27.58
Southern region												
Barisal	28.10	18.22	31.93	19.05	35.8	21.4	31.49	24.01	35.27	24.39	37.63	26.8
Madaripur	28.05	17.94	32.63	18.72	36.58	21.31	32.18	24.02	36.13	24.46	38.93	26.88
Southeastern region												
Chandpur	28.19	17.79	31.74	18.77	35.84	21.12	31.56	23.98	35.44	24.57	37.95	26.93
Comilla	27.91	17.11	30.84	18.21	34.88	20.27	30.74	23.36	35.09	24.34	37.96	26.69
Eastern region												
Sylhet	24.75	16.02	26.63	16.01	30.54	18.74	26.59	21.10	29.83	22.04	32.60	24.13

April represents the Milking stage in the Reproductive phase and Soft and Hard drafting stage in Ripening phase. Temperature largely affects these two phases. Maximum temperature above 35^{0}C in April is predicted for northwestern and southwestern regions in 2030, 2050 and 2070 and a parts of central (Tangail) and southern (Madaripur) region in 2030; this is likely to significantly affect the Reproductive and Ripening phases. Increase in temperature shortens the Reproductive phase, decreasing the time during which the canopy exists and thus the period during which it intercepts light and produces biomass. Higher temperatures lead to lower yields and may also lead to higher rates of evaporation and therefore reduced moisture availability that can also be expected to affect yields.

Ripening phase starts at the end of April and continue up to the middle of May. Maximum temperature is predicted to be above 35^{0}C in most of the regions except eastern portion in 2030, 2050 and 2070 and minimum temperature is predicted to be above 30^{0}C in most parts of northwestern regions and southwestern regions in 2070. The length of ripening is inversely correlated with daily mean temperature. Thus, persistent cloudy weather conditions will be more detrimental to grain filling under high temperatures because of a shorter ripening period. In fact, a combination of high temperatures and low light can seriously impair ripening, since grain weight and percentage of filled spikelets are both affected by light and temperature (Yoshida, 1973). The monthly average maximum and minimum temperature in April and May (2030, 2050 and 2070 from PRECIS-Model) are shown in Table 4.13.

Table 4.13 Monthly average maximum and minimum temperature in April and May (2030, 2050, 2070)

Regions	April Month						May Month					
	Max. Temp. ^{0}C 2030	Min. Temp. ^{0}C 2030	Max. Temp. ^{0}C 2050	Min. Temp. ^{0}C 2050	Max. Temp. ^{0}C 2070	Min. Temp. ^{0}C 2070	Max. Temp. ^{0}C 2030	Min. Temp. ^{0}C 2030	Max. Temp. ^{0}C 2050	Min. Temp. ^{0}C 2050	Max. Temp. ^{0}C 2070	Min. Temp. ^{0}C 2070
Northwestern region												
Rajshahi	41.88	27.33	45.65	29.42	39.23	28.93	44.10	28.96	40.45	29.62	41.94	30.92
Bogra	39.39	26.85	44.17	28.87	37.79	28.76	41.80	27.92	38.72	29.05	40.08	30.24
Dinajpur	36.02	24.39	42.13	27.55	34.76	27.71	36.86	25.47	36.37	27.83	35.45	27.72
Central region												
Mymensingh	32.49	25.88	38.03	27.49	35.38	27.55	35.24	26.76	34.93	27.74	35.10	28.78
Tangail	38.98	27.31	43.54	29.16	38.23	28.82	41.90	28.37	39.34	29.32	40.39	30.40
Southwestern region												
Jessore	39.30	27.79	42.34	28.98	39.00	28.97	41.70	29.22	40.44	29.81	40.69	30.72
Satkhira	39.15	27.78	41.78	28.90	39.23	29.22	42.36	29.39	40.32	29.66	40.90	30.79
Southern region												
Barisal	33.48	27.25	37.88	28.29	36.9	28.31	35.92	28.43	37.20	29.46	37.23	30.1
Madaripur	35.05	27.35	39.57	28.46	37.77	28.42	37.53	28.39	38.49	29.59	38.25	30.23
Southeastern region												
Chandpur	33.70	27.33	38.20	28.39	37.54	28.44	35.99	28.29	37.74	29.59	37.55	30.23
Comilla	32.83	26.73	37.63	28.00	37.31	28.02	36.36	27.59	37.76	29.03	36.66	29.61
Eastern region												
Sylhet	27.99	24.29	31.36	25.53	32.45	26.14	30.85	25.20	30.79	26.19	31.60	27.26

4.3.1.2 Rainfall

Variability in the amount and distribution of rainfall is the most important factor limiting yields of rice. In Bangladesh, winter rice crop (boro) is an irrigated crop. Of the country's three rice seasons, it is the longest season, producing the highest grain yield. The season begins in December and ends at the end of May in low-lying depressions. The early beginning of the season in low-lying areas is because of farmers' intensions to use surface water left after the recession of floodwater to grow seedlings and the subsequent crop. In high lands, farmers sow their seeds in December and transplant the seedlings in February when temperature increases. They harvest this crop in May or June (Gomosta. 2001). Water is the most critical input for successful crop production. The net cropped area of land in Bangladesh is about 8.5 million hectares of which about 56% (4.8 Mha) is under irrigation (Bangladesh Economic Review, 2004). Rice yield is almost similar in all the water regimes mainly due to the application of more irrigation water than the ET (Evapotranspiration) demand for rice. In a dry day, the ET demand is met from the first storage of soil surface if there is water in it. When the first storage is exhausted, ET demand is met from the second storage. In a continued dry period if the second storage is unable to satisfy ET demand, the crop suffers from drought and reduce yield. The amount of drought varies from different growth phases of rice, e.g., vegetative, reproductive and ripening phase. The average drought amount and drought duration in vegetative phase is higher than the other two growth phases (BRRI, 2006). Therefore, ET and seepage and percolation (S&P) are considered water requirements for rice grown under low land environments. The total water requirements for boro rice are varies from 750 to 800 mm depending on the variable water regimes imposed in the rice field.

Qualitative Assessment of Rainfall in Winter and Pre-monsoon on Growth Phases of Boro Rice

Vegetative phase of boro rice starts at the end of the December and extend up to March. The total amount of water requirement is 548 to 550 mm for light soil and 440 to 450 mm for heavy soil during this period. The water requirement in vegetative phase differs according to variety, duration of critical temperature, diurnal changes, and physiological status of the plant and soil condition. No or negligible amount of rainfall was predicted during winter season (December-February) in all 12 selected locations; ranging from 4.64 mm (Dinajpur, 2070) to 182.9 mm (Sylhet, 2050). In coming years, boro production may face a to shortage water due to low rainfall in Winter season because rainfall pattern in Winter season follows a decreasing trend in most of the regions in 2030, 2050 and 2070. The rainfall in winter for the north-western, southern, southeastern and southwestern regions in Bangladesh was predicted to decrease significantly in the years 2030, 2050 and 2070. In these regions irrigated crop (boro rice) may face into drought condition. So, excess irrigation water will be necessary in these regions compared with the others parts of the country.

Table 4.14 Model predication data in Winter and Pre-monsoon season in various locations in Bangladesh (2030, 2050 and 2070)

Station Name	Winter Season			Pre-monsoon Season		
	Total Rainfall mm 2030	Total Rainfall mm 2050	Total Rainfall mm 2070	Total Rainfall mm 2030	Total Rainfall mm 2050	Total Rainfall mm 2070
Northwestern region						
Rajshahi	61.1	14.51	41.45	333.9	226.2	442.75
Bogra	113.3	16.46	27.15	571	354.8	590.5
Dinajpur	51	13.04	4.64	540	312.3	578.1
Central region						
Mymensingh	67.1	39.3	31.35	1283	598.5	890.9
Tangail	120.6	17.16	34.58	558	300.4	484.5
Southwestern region						
Jessore	42.5	13.64	17.9	152.8	135.1	287.6
Satkhira	45.4	13.26	16.01	302.4	107.3	207.5
Southern region						
Barisal	34.63	24.49	14.97	200.5	125.5	340.78
Madaripur	44.8	21.51	16.65	265.1	134.4	377.52
Southeastern region						
Chandpur	40.7	24.28	11.43	282.1	132.7	300.89
Comilla	62	26.76	17.32	425	162.3	304.54
Eastern region						
Sylhet	140.7	182.9	124.6	3184	1694	2128

Reproductive (the most critical) and Ripening (critical) phase of boro rice starts at the first week of the March and extend up to middle of May. The total water requirement for reproductive phase is 340 to 345 mm for light soil and 235 to 240 mm for heavy soil. For ripening phase, it is 205 to 210 mm for light soil and 150 to 155 mm for heavy soil. Variability of rainfall affects the rice crop at different times. If the variability is associated with the onset of the rain, establishment and growth duration of rice are affected. If variability is associated with an untimely cessation at the reproductive or ripening stage of the rice crop, yield reduction is severe (De Datta, 1976). The substantially low rainfall during Pre-monsoon season may directly affect the most critical phases. Yield losses resulting from water deficit are particularly severe when drought strikes at booting stage. Effects on yield, however, are small as compared to drought stress at reproductive stages, which irreversibly reduces the number of fertile spikelets (Igngram et al.,1993). Total rainfall in Winter and Pre-monsoon season are given in Table 4.14.

4.3.2 Impact of Climate Change Scenarios on Boro yields (CO_2 fixed)

Agricultural practices in Bangladesh are largely dependent on the temperature and rainfall patterns. Historically, Bangladesh often experiences severe droughts in winter season and flood during the monsoon months, with significant crop losses during both extreme conditions. A boro crop encountering critical low temperature is appeared to suffer from cool injury. The extent of cool injury depends on the nature and duration of low temperature and diurnal change of low (night) and high (day) temperature. A simulation study was conducted to assess the vulnerability of boro production in Bangladesh to potential climate change in the years of 2008, 2030, 2050 and 2070.

These predictions have been made using a fixed irrigation application (855 mm in 14 applications), fertilizer dose (130 kg/ha in 3 applications), cultivar (BR3 and BR14) and CO_2 of 379 ppm (the value reported for the year 2005 in fourth assessment report of IPCC) in all locations during those periods. Soil data were varied on location basis. 15 January was selected for planting date for all locations and years. Climate scenarios for the selected years were obtained from prediction made using the PRECIS model.

4.3.2.1 Impact of climate change scenarios on BR3-Rice

Table 4.15 shows predicted BR3 rice yield for the selected locations. It shows reduction in yield (compared to 2008 yield) across all locations (except Rajshahi) and time period. Simulated BR3 rice yield ranged from 3063 kg/ha (Rajshahi) to 6848 (Dinajpur) kg/ha in 2008, 4083 kg/ha (Rajshahi) to 5987 kg/ha (Comilla) in 2030, 3265 kg/ha (Rajshahi) to 5750 kg/ha (Sylhet) in 2050 and 1785 kg/ha (Rajshahi) to 3595 kg/ha (Sylhet) in 2070. It is evident from Table 4.15 that a significant reduction in rice yields is likely in future due to predicted changes in climatic condition. Compared to 2008, predicted average reductions of yield of BR3 variety for the 12 selected locations are about 11% for the year 2030, 21% for 2050 and 54% for 2070. Some regional variation could be observed in the predictions (Fig. 4.4), with somewhat higher reductions predicted for central, southern and southwestern regions. Some increase in yield was predicted for Rajshshi for the years 2030 and 2050. The maximum yield reduction of 29.6% was predicted at Dinajpur in 2030, 36.3 % at the same location in 2050 and 65.4% in 2070 at Barisal.

Table 4.15: Predicted yield of BR3 variety of boro rice (kg ha^{-1}) at 12 selected locations for the years 2008, 2030, 2050 and 2070

Locations	Cultivar	2008 (379 ppm)	2030 (379 ppm)	2050 (379 ppm)	2070 (379 ppm)	% change in yield for 2030	% change in yield for 2050	% change in yield for 2070
Northwestern region								
Rajshahi	BR3	3063	4083	3265	1785	33.30	6.59	-41.72
Bogra	BR3	5741	5119	4070	2036	-10.83	-29.10	-64.53
Dinajpur	BR3	6848	4824	4364	2692	-29.55	-36.27	-60.68
Central region								
Mymensingh	BR3	5995	5275	4455	2739	-12.01	-25.68	-54.31
Tangail	BR3	5487	5160	3874	1938	-5.95	-29.39	-64.68
Southwestern region								
Jessore	BR3	5571	4432	4583	1997	-20.44	-17.73	-64.15
Satkhira	BR3	4700	4364	3603	2066	-7.14	-23.34	-56.04
Southern region								
Barisal	BR3	6043	4006	3972	2091	-33.70	-34.27	-65.39
Madaripur	BR3	4582	4017	3647	2186	-12.33	-20.40	-52.29
Southeastern region								
Chandpur	BR3	5975	5455	4039	2772	-8.70	-32.40	-53.60
Comilla	BR3	6115	5987	4456	3075	-2.09	-27.13	-49.71
Eastern region								
Sylhet	BR3	5960	5117	5750	3595	-14.14	-3.52	-39.68

Rice production can be dramatically affected by temperature. Grain yield decreases above a critical temperature greater than 30^0C (US DOE, 1989). Higher temperature also leads to increase plant growth rate and decreased growth durations leading to shorter grain filling period, spikelet sterility (Yoshida and Parao, 1976), which becomes very severe near 40^0C, resulting in complete loss of crop production. The maximum temperature of almost all stations was predicted to be above 35^0C during the phases of Panicl Inition-End Leaf Growth and Grain Filling out of five phases of boro rice in 2050 and 2070. But optimum temperature range for total growing period of boro rice is 20-35^0C. It is reported for every 2^0C rise in temperature boro rice yield may be reduced by up to 9.70% and for every 4^0C, it may be 21.60% (Mahmood et al., 1998). During the critical growth phases, it was observed that predicted temperatures varied from (model output sheet) 37 to 42^{0}C in 2050 and 36 to 47^{0}C in 2070. Increasing temperature also affected the water requirement of rice and it was reflected by higher predicted water stress in 2030, 2050 compared to 2008 (irrigation application was same).

The growth and yield of crops are directly related to the rate photosynthesis and phenology, and their response to temperature and radiation. Optimum temperatures for maximum photosynthesis range from 25 to 30^{0}C for rice under climatic conditions of Bangladesh. The model results of four years (2008, 2030, 2050 and 2070) shows that the effect of climate change would drastically reduce rice yield at all selected the locations except Rajshahi (2030 and 2050). In Rajshahi, the predicted maximum temperatures in End Leaf Growth-Begin Grain Filling phase (41.6^{0}C) and Grain Filling Phase (43.5^{0}C) in 2008, were comparatively higher than those in 2030 (38.2^{0}C and 43.1^{0}C, respectively) and 2050 (36.2^{0}C and 44.1^{0}C, respectively), but lower than the corresponding values in 2070. In 2070, during most of the four development phases (out of five) exceeded optimum temperature range and water and nitrogen stress were also higher than 2008, 2030 and 2050, resulting in significant reduction in yield (Fig. 4.1). The physiological maturity day and leaf area index (LAI) in 2008 were 88 days and 1.37, respectively and in 2070, those were 83 days and 1.04. So, physiological maturity day and leaf area index both decreased in 2070 which significantly contribute to the reduction of BR3 yield. According to Vergara (1970), the growth period of short-duration plants (of less than 100-day maturity) grown under normal field conditions usually do not permit the production of sufficient leaf area to result in production of larger number of panicles with well filled spikelets.

In Barisal region (Fig 4.2), there were no phases where the maximum temperatures exceed optimum temperature range in 2008 for BR3 and water and nitrogen stress of those phases were comparatively lower than 2030, 2050 and 2070. The maximum temperature in Emergence-End Juvenile, End Juvenil-Pancil Inition, Panicl Inition-End Leaf Growth, End Leaf Growth Begin Grain Filling and Grain Filling phase were 25^{0}C, 25.7^{0}C, 30.8^{0}C, 33.8^{0}C and 35.2^{0}C, respectively, in 2008 whereas in 2070 those values were 28.0^{0}C, 37.3^{0}C, 36.3^{0}C, 38.2^{0}C and 37.6^{0}C, respectively. Significant fluctuations in minimum temperature, rainfall and solar radiation were observed during on those phases in the simulation years (model output sheet). The physiological maturity day and leaf area index (LAI) in 2008 were 99 days and 3.18 and in 2070, those were 80 days and 1.30 for BR3. The yield losses for BR3 in 2030, 2050 and 2070 were 33.70%, 34.27% and 65.39%, respectively at Barisal. The variation of maximum and minimum temperature, solar radiation, photoperiod, rainfall, evapotranspiration and nitrogen and water stresses in the different development phases (BR3) for Rajshahi, Barisal are presented in Table 4.16 and 4.17, respectively. Similar in formation for the other locations are presented in Appendix B.

It appears that higher temperature in future, exceeding the number of optimum growing period temperatures (20 to 35^{0}C) for rice production, would significantly reduce boro yield. For example, in 2008 the numbers of days with T_{max} above 35^{0}C are 0, 0, 13, 27 and 30 in January, February, March, April and May, respectively, for Rajshahi. Whereas the corresponding figures in 2070 are 0, 22, 30, 23 and 25. The numbers of days with T_{min} below 20^{0}C are 30, 26, 4, 0 and 0 for January, February, March, April and May, respectively, in 2008. Whereas the corresponding figures for 2070, those were 26, 11, 0, 0 and 0. Similarly at Barisal region, the total numbers of days with T_{max} above 35^{0}C are 0, 0, 7, 17 and 20 in 2008, whereas in 2070, the corresponding figures are 0, 19, 24, 21 and 22 in January, February, March, April and May, respectively. The numbers of days with T_{min} below 20^{0}C are 30, 21, 4, 0 and 0 in 2008; whereas in 2070, the corresponding figures are 14, 9, 0, 0 and 0. Similar results were also found for Jessore and other regions in Bangladesh (Table 4.18). Table 4.19 shows predicted total monthly rainfall during January to May at the12 selected locations for the simulation years. It shows that the predicted total rainfall in January to May are about 157 mm, 526 mm, 236 mm and 453 mm in 2008, 2030, 2050 and 2070, respectively at Rajshahi, 145 mm, 235 mm, 148 mm and 356 mm at Barisal and 135 mm, 195 mm, 144 mm and 301 mm at Jessore. Analysis of predicted rainfall data shows that rainfall in winter season (December to February) which could be useful for boro rice, is decreasing with time in almost all locations (except Rajshahi in 2030); on the other hand relatively high rainfall is predicted for May (PRECIS daily rainfall data) in 2030, 2050 and 2070, when water requirement for boro is not significant. Variability of rainfall affects the rice crop at different times. If the variability is associated with the onset of the rain, stand establishment and growth duration of rice are affected. If variability is associated with an untimely cessation at the reproductive or ripening stage of the rice crop, yield reduction is severe (De Datta, 1976).

Table 4.16: Predicted climatic parameters and stresses in different development phases of BR3 rice at Rajshahi region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	25	24.8	15.6	12.2	10.81	26.4	61.1	0.014	0.02 2	0.398	0.270
End Juvenil-Panicl Inition	9	27.5	17.7	12.3	11.11	3.6	23.5	0.000	0.00	0.290	0.173
Panicl Inition-End Leaf Growth	32	33.4	23.0	15.7	11.58	32.8	148.5	0.000	0.00	0.417	0.275
End Leaf Growth-Begin Grain Filling	8	41.6	27.0	21.7	12.05	1.2	60.3	0.000	0.00	0.000	0.000
Grain Filling Phase	13	43.5	28.3	24.2	12.31	5.7	91.0	0.199	0.23 5	0.000	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	27	24.8	13.5	9.8	10.82	188.2	56.4	0.000	0.00	0.394	0.263
End Juvenil-Panicl Inition	11	27.3	15.7	16.5	11.18	1.2	33.8	0.000	0.00	0.475	0.321
Panicl Inition-End Leaf Growth	33	33.0	22.0	16.6	11.68	69.7	142.4	0.000	0.00	0.410	0.268
End Leaf Growth-Begin Grain Filling	8	38.2	25.9	19.6	12.18	4.2	53.7	0.000	0.00	0.143	0.000
Grain Filling Phase	15	43.1	27.1	22.9	12.45	3.5	123.7	0.000	0.01 1	0.059	0.020

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	20	28.1	15.9	13.1	10.89	2.2	51.8	0.000	0.005	0.472	0.324
End Juvenil-Panicl Inition	10	32.8	13.3	19.5	11.12	0.0	23.9	0.000	0.00	0.738	0.561
Panicl Inition-End Leaf Growth	32	37.4	20.9	20.1	11.53	16.6	167.0	0.000	0.00	0.347	0.200
End Leaf Growth-Begin Grain Filling	8	36.2	26.0	15.6	11.96	10.3	49.1	0.000	0.00	0.000	0.000
Grain Filling Phase	13	44.1	29.6	23.4	12.19	3.0	88.6	0.136	0.168	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	15	25.7	17.8	7.0	10.73	5.2	23.6	0.000	0.00	0.448	0.307
End Juvenil-Panicl Inition	12	36.4	19.2	16.8	10.95	0.7	35.7	0.000	0.00	0.691	0.521
Panicl Inition-End Leaf Growth	32	39.5	24.0	19.0	11.41	4.6	146.7	0.000	0.00	0.210	0.154
End Leaf Growth-Begin Grain Filling	8	42.1	22.9	25.0	11.88	0.0	54.5	0.000	0.00	0.000	0.000
Grain Filling Phase	18	42.1	28.4	21.4	12.20	7.9	108.9	0.000	0.013	0.000	0.000

Table 4.17: Predicted climatic parameters and stresses in different development phases of BR3 rice at Barisal region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	26	25.0	14.3	13.0	10.90	30.0	62.8	0.012	0.021	0.484	0.334
End Juvenil-Panicl Inition	10	25.7	18.2	10.0	11.21	47.9	24.1	0.000	0.00	0.036	0.000
Panicl Inition-End Leaf Growth	36	30.8	21.8	15.2	11.69	12.0	135.0	0.000	0.00	0.123	0.021
End Leaf Growth-Begin Grain Filling	8	33.8	25.5	16.6	12.19	1.4	39.1	0.000	0.00	0.097	0.000
Grain Filling Phase	18	35.2	26.6	19.0	12.47	4.5	95.5	0.000	0.00	0.052	0.011

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	24	26.1	15.3	11.6	10.89	29.5	59.7	0.000	0.00	0.453	0.306
End Juvenil-Panicl Inition	10	27.6	15.0	18.5	11.17	0.9	33.1	0.000	0.00	0.361	0.214
Panicl Inition-End Leaf Growth	34	30.5	22.5	13.1	11.63	26.1	109.3	0.000	0.00	0.382	0.249
End Leaf Growth-Begin Grain Filling	9	32.4	25.9	14.4	12.11	14.8	35.1	0.000	0.00	0.000	0.000
Grain Filling Phase	16	33.0	26.9	13.4	12.38	1.8	56.4	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	21	27.6	16.4	13.4	10.86	1.8	55.6	0.000	0.002	0.464	0.318
End Juvenil-Panicl Inition	9	30.0	15.8	15.4	11.10	1.9	18.6	0.000	0.00	0.720	0.541
Panicl Inition-End Leaf Growth	32	34.5	22.1	17.5	11.52	22.9	146.1	0.000	0.00	0.257	0.154
End Leaf Growth-Begin Grain Filling	9	33.5	25.3	14.9	11.97	8.5	37.3	0.000	0.00	0.000	0.000
Grain Filling Phase	15	37.7	27.5	17.9	12.24	19.0	83.8	0.000	0.00	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	19	28.0	19.6	10.2	10.85	9.2	45.6	0.000	0.00	0.439	0.298
End Juvenil-Panicl Inition	7	37.3	18.3	18.8	11.05	0.2	20.8	0.000	0.00	0.683	0.505
Panicl Inition-End Leaf Growth	30	36.3	23.7	18.0	11.42	2.2	126.4	0.000	0.00	0.226	0.169
End Leaf Growth-Begin Grain Filling	8	38.2	26.7	20.0	11.83	45.4	53.9	0.000	0.00	0.000	0.000
Grain Filling Phase	15	37.6	27.7	17.1	12.08	6.0	76.8	0.000	0.00	0.000	0.000

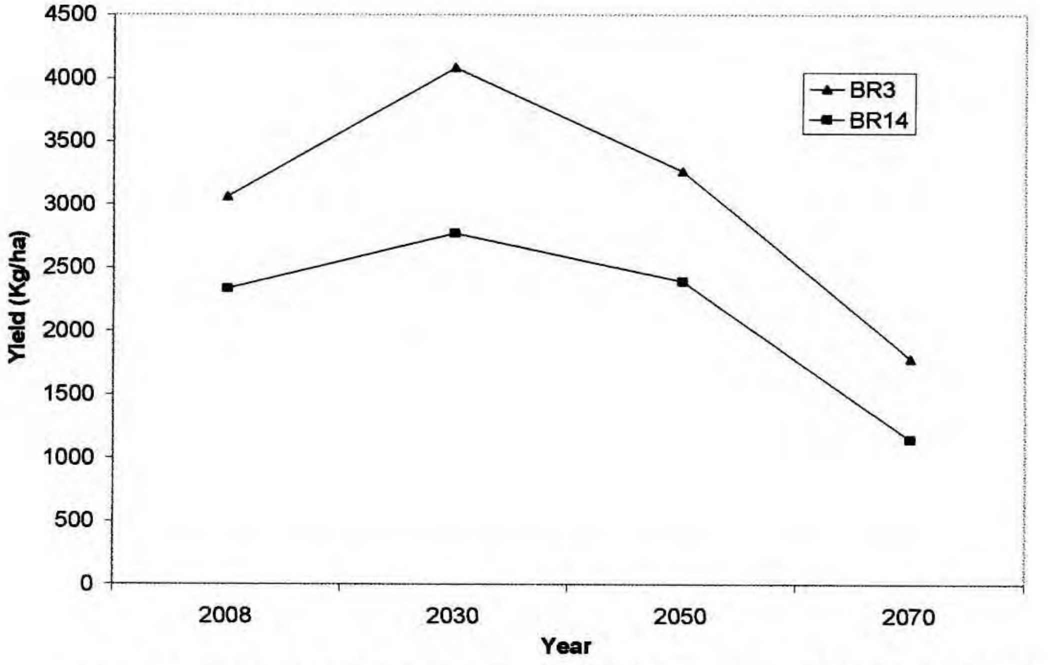

Figure 4.1: Predicted yield of BR3 and BR14 varieties of rice for Rajshahi

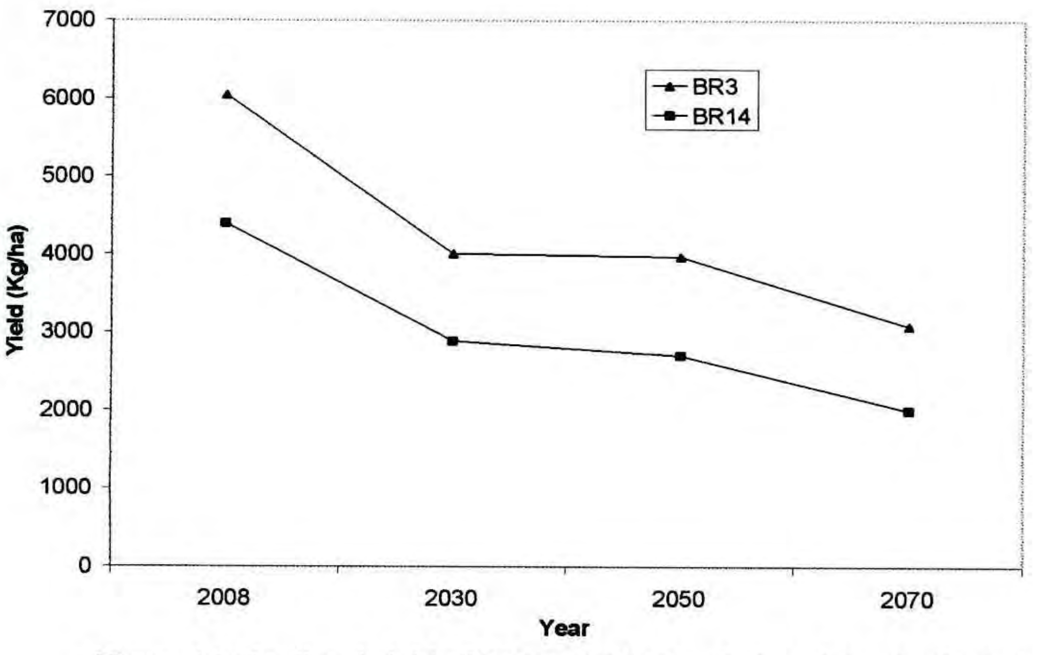

Figure 4.2: Predicted yield of BR3 and BR14 varieties of rice for Barisal

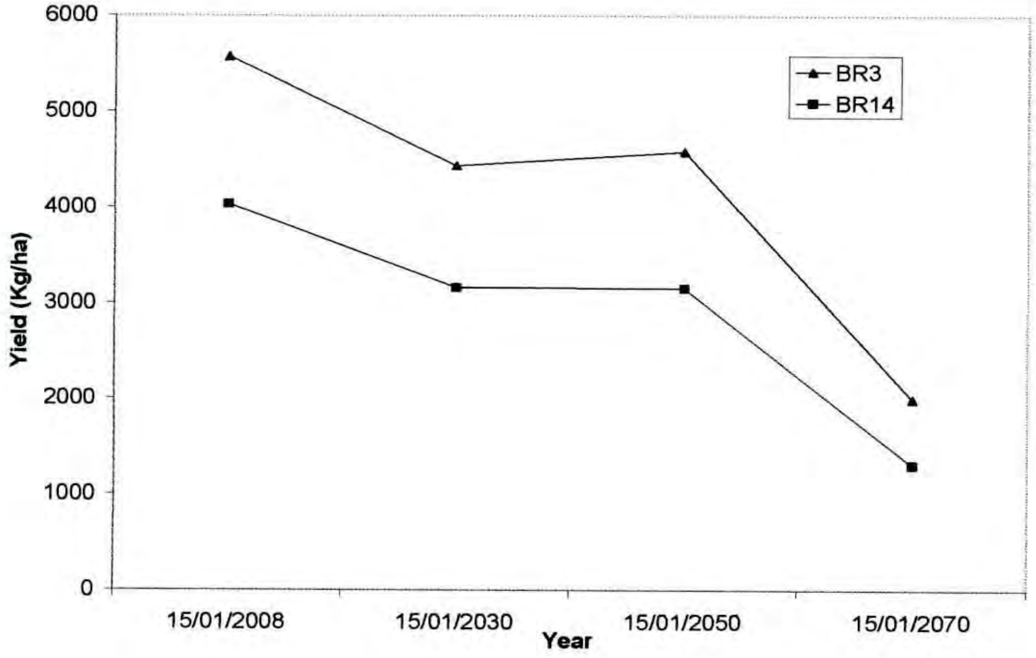

Figure 4.3: Predicted yield of BR3 and BR14 varieties of rice for Jessore

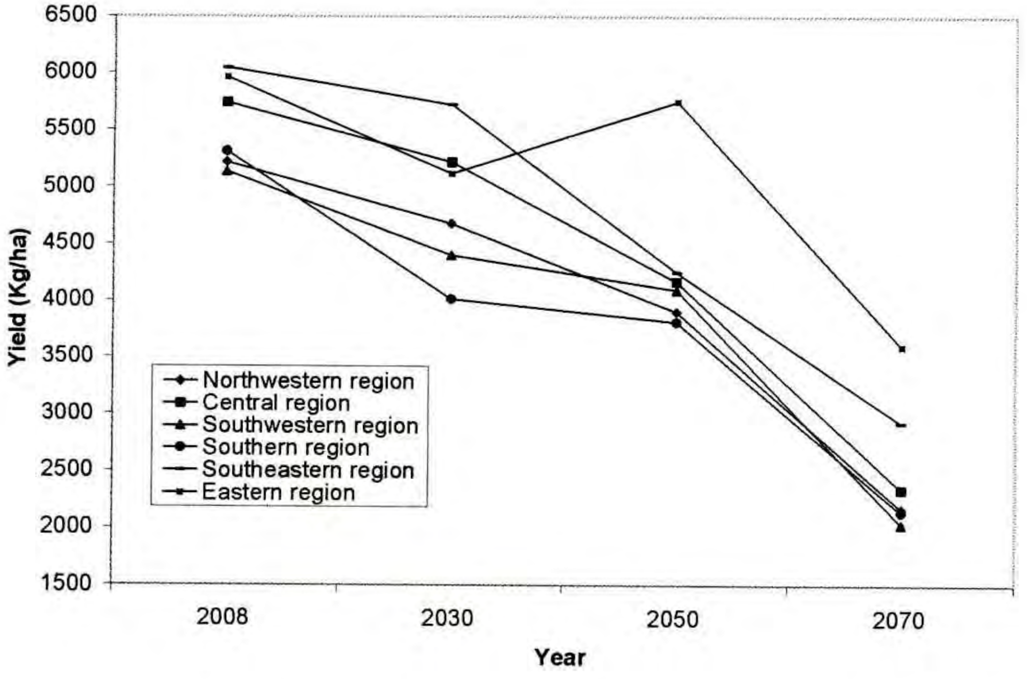

Figure 4.4: Region-wise prediction of yield of BR3 varity of rice

Table 4.18: Predicted number of days with T_{max} above 35^0C and T_{min} below 20^0C at the 12 selected locations in 2008, 2030, 2050 and 2070

Location	Year	Month									
		January		February		March		April		May	
		T. Max	T. Min	T. Max	T. Min	T. Max	T. Min	T. Max	T. Min	T. Max	T. Min
Rajshahi	2008	0	30	0	26	13	4	27	0	30	0
	2030	0	30	0	27	15	2	29	0	30	0
	2050	1	27	12	23	25	5	30	0	21	0
	2070	0	26	22	11	30	0	23	0	25	0
Bogra	2008	0	30	0	26	8	4	26	0	27	0
	2030	0	30	0	25	10	2	27	0	27	0
	2050	0	28	10	24	24	6	28	0	18	0
	2070	0	25	17	11	30	1	20	0	24	0
Dinajpur	2008	0	30	0	29	8	6	19	0	21	0
	2030	0	30	1	26	6	2	17	2	21	0
	2050	0	30	7	25	27	7	29	0	17	0
	2070	0	28	16	15	30	4	11	0	11	0
Mymensingh	2008	0	30	0	25	2	3	11	0	15	0
	2030	0	30	0	24	2	6	7	0	15	0
	2050	0	30	6	22	13	4	22	0	16	0
	2070	0	25	9	16	24	3	18	0	16	0
Tangail	2008	0	30	0	22	7	4	26	0	29	0
	2030	0	30	0	24	10	2	26	0	29	0
	2050	0	28	8	20	22	3	27	0	22	0
	2070	0	18	17	12	28	0	20	0	24	0
Jessore	2008	0	30	0	21	13	2	25	0	29	0
	2030	0	30	0	17	15	2	27	0	29	0
	2050	0	27	12	16	23	3	28	0	25	0
	2070	0	16	23	8	30	0	22	0	27	0
Satkhira	2008	0	29	0	20	11	2	26	0	30	0
	2030	0	29	1	17	0	6	1	0	30	0
	2050	0	23	10	12	23	2	27	0	26	0
	2070	0	11	22	7	30	0	23	0	28	0
Barisal	2008	0	30	0	21	7	4	17	0	20	0
	2030	0	30	0	22	3	4	11	0	20	0
	2050	0	28	6	14	19	2	25	0	24	0
	2070	0	14	19	9	24	0	21	0	22	0
Madaripur	2008	0	30	0	21	8	3	20	0	22	0
	2030	0	30	0	22	6	4	16	0	22	0
	2050	0	28	6	18	21	3	25	0	26	0
	2070	0	18	19	11	27	0	22	0	24	0
Chandpur	2008	0	30	0	21	7	5	16	0	18	0
	2030	0	30	0	22	4	4	10	0	18	0
	2050	0	28	6	16	21	2	24	0	26	0
	2070	0	21	18	11	24	0	23	0	23	0
Comilla	2008	0	30	0	23	5	5	16	0	20	0
	2030	0	30	0	24	1	6	5	0	20	0
	2050	0	28	6	17	18	2	22	0	27	0
	2070	0	24	14	11	27	0	23	0	17	0
Sylhet	2008	0	30	0	27	0	4	0	0	2	0
	2030	0	30	0	25	0	7	0	0	2	0
	2050	0	29	0	23	0	4	0	0	1	0
	2070	0	30	0	16	2	0	6	0	6	0

Table.4.19 Total rainfall during January-May at 12 selected locations in 2008, 2030, 2050 and 2070

Location	Year	Month					Total Rainfall (mm)
		January	February	March	April	May	
		Rainfall (mm)	Rainfall (mm)	Rainfall (mm)	Rainfall (mm)	Rainfall (mm)	
Rajshahi	2008	15.83	45.33	16.60	30.35	48.94	157.05
	2030	44.42	148.23	70.94	71.99	190.56	526.14
	2050	2.23	8.08	21.58	17.63	186.57	236.09
	2070	8.06	2.49	9.75	237.51	195.39	453.2
Bogra	2008	11.59	64.45	34.62	54.56	62.64	227.86
	2030	34.88	78.38	121.69	132.35	317.00	684.3
	2050	1.76	11.72	28.74	31.08	294.87	368.17
	2070	6.32	2.53	12.47	316.49	262.24	600.05
Dinajpur	2008	4.27	76.47	58.30	48.28	68.87	256.19
	2030	19.93	30.83	158.12	105.43	277.04	591.35
	2050	1.84	10.28	16.62	41.68	253.58	324
	2070	3.53	0.514	10.06	296.77	270.54	581.41
Mymensingh	2008	9.27	107.45	67.59	151.08	260.61	596
	2030	30.13	36.36	308.04	392.42	583.32	1350.27
	2050	4.30	30.82	81.88	77.60	439.09	633.69
	2070	16.46	7.65	47.90	370.05	472.86	914.92
Tangail	2008	12.77	78.27	22.08	52.05	79.92	245.09
	2030	45.78	74.79	107.75	141.07	308.83	678.22
	2050	1.56	13.16	31.86	25.48	243.32	315.38
	2070	7.52	3.36	23.47	239.60	220.96	494.91
Jessore	2008	21.28	61.63	6.26	13.82	32.41	135.4
	2030	14.91	27.56	30.72	49.28	72.84	195.31
	2050	2.14	8.20	16.56	15.53	102.53	144.96
	2070	9.86	3.24	12.56	156.31	119.37	301.34
Satkhira	2008	17.44	42.44	6.54	5.76	10.58	82.76
	2030	11.36	33.97	118.90	151.58	31.44	347.25
	2050	2.24	6.52	10.70	14.78	81.77	116.01
	2070	9.65	3.66	4.95	116.75	85.61	220.62
Barisal	2008	30.04	61.55	4.79	8.01	40.32	144.71
	2030	7.63	27.00	37.34	76.45	86.69	235.11
	2050	3.19	19.78	20.05	16.23	89.24	148.49
	2070	12.33	2.37	6.78	185.45	149.20	356.13
Madaripur	2008	31.46	68.55	5.02	11.75	48.04	164.82
	2030	13.55	31.21	43.52	96.57	124.74	309.59
	2050	2.41	17.27	27.78	18.85	87.72	154.03
	2070	13.43	1.75	9.52	185.48	142.76	352.94
Chandpur	2008	32.20	56.48	4.26	13.20	43.34	149.48
	2030	11.66	29.00	49.67	96.40	136.33	323.06
	2050	2.28	20.49	30.28	18.92	83.50	155.47
	2070	8.42	2.11	5.89	166.86	127.55	310.83
Comilla	2008	26.43	80.33	15.93	17.29	60.62	200.6
	2030	28.52	33.52	119.44	138.59	167.48	487.55
	2050	2.35	22.91	42.47	27.99	91.81	187.53
	2070	8.54	2.78	8.54	156.00	139.82	315.68
Sylhet	2008	17.99	277.63	300.35	656.41	570.80	1823.18
	2030	44.43	88.54	737.52	1155.25	1290.94	3316.68
	2050	38.33	138.07	372.93	467.80	853.35	1870.48
	2070	69.58	47.22	252.93	850.53	1023.56	2243.82

4.3.2.2 Impact of climate change scenarios on BR14-Rice

Table 4.20 shows predicted yield of BR14 rice at the selected locations. It shows reduction of yield (compared to 2008 yield) across all locations (except Rajshahi, Satkhira) and simulations periods. Predicted BR14 rice yield ranged from 2334 kg/ha (Rajshahi) to 5047 kg/ha (Dinajpur) in 2008, 2771 kg/ha (Rajshahi) to 4368 kg/ha (Comilla) in 2030, 2392 kg/ha (Rajshahi) to 4240 kg/ha (Sylhet) in 2050 and 1148 kg/ha (Rajshahi) to 2378 kg/ha (Sylhet) in 2070. Table 4.20 shows a significant reduction in rice yields in future due to predicted changes in climatic condition. Compared to 2008, predicted average yield reductions of BR14 variety for the 12 selected locations are about 14% for the year 2030, 25% for 2050 and 58% for 2070. Some regional variation could be observed in the predictions (Fig. 4.4), with somewhat higher reductions predicted for southern and southwestern regions.

Table 4.20: Predicted yield of BR14 variety of boro rice (kg ha^{-1}) at 12 selected locations for the years 2008, 2030, 2050 and 2070

Locations	Cultivar	2008 (379 ppm)	2030 (379 ppm)	2050 (379 ppm)	2070 (379 ppm)	% change in yield for 2030	% change in yield for 2050	% change in yield for 2070
Northwestern region								
Rajshahi	BR14	2334	2771	2392	1148	18.72	2.48	-50.81
Bogra	BR14	4306	3668	2637	1398	-14.81	-38.75	-67.53
Dinajpur	BR14	5047	3374	3023	1656	-33.14	-40.10	-67.18
Central region								
Mymensingh	BR14	4353	3790	3186	1873	-12.93	-26.80	-56.97
Tangail	BR14	4104	3883	2565	1297	-5.38	-37.5	-68.39
Southwestern region								
Jessore	BR14	4032	3160	3153	1305	-21.62	-21.80	-67.63
Satkhira	BR14	3153	3171	2434	1377	0.57	-22.80	-56.32
Southern region								
Barisal	BR14	4397	2889	2705	1457	-34.29	-38.48	-66.86
Madaripur	BR14	3229	2606	2578	1491	-19.29	-20.16	-53.82
Southeastern region								
Chandpur	BR14	4389	3981	2801	1842	-9.29	-36.18	-58.03
Comilla	BR14	4678	4368	3063	1978	-6.62	-34.52	-57.71
Eastern region								
Sylhet	BR14	4596	3764	4240	2378	-18.10	-7.74	-48.25

Significant decreases in yield were predicted at Barisal (34.29% in 2030), Dinajpur (40.10% in 2050) and Tangail (68.40% in 2070). Some increases in yield were predicted for Rajshahi and Satkhira (see Table 4.20).

Similar to BR3, the predictions show significant reduction in yield of BR14 for most of the locations in the years 2030, 2050 and 2070, compared to yield of 2008. Effects of temperature (T_{max} and T_{min}) on yield are similar to those described for BR3. Effects of physiological maturity, solar radiation, rainfall and LAI are also similar to those described for BR3. For example, the physiological maturity and LAI, in 2008 were 92 days and 1.28, respectively and 2070, those were 86 days and 0.83. So, physiological maturity and LAI both decreased in 2070, which contributed to the reduced yield. The variation of maximum and minimum temperature, solar radiation, photoperiod, rainfall, evapotranspiration and nitrogen and water stresses in different development phases for BR14 for all regions are shown in Appendix B. Figure 4.5 shows region wise predicted yield of BR14 rice variety.

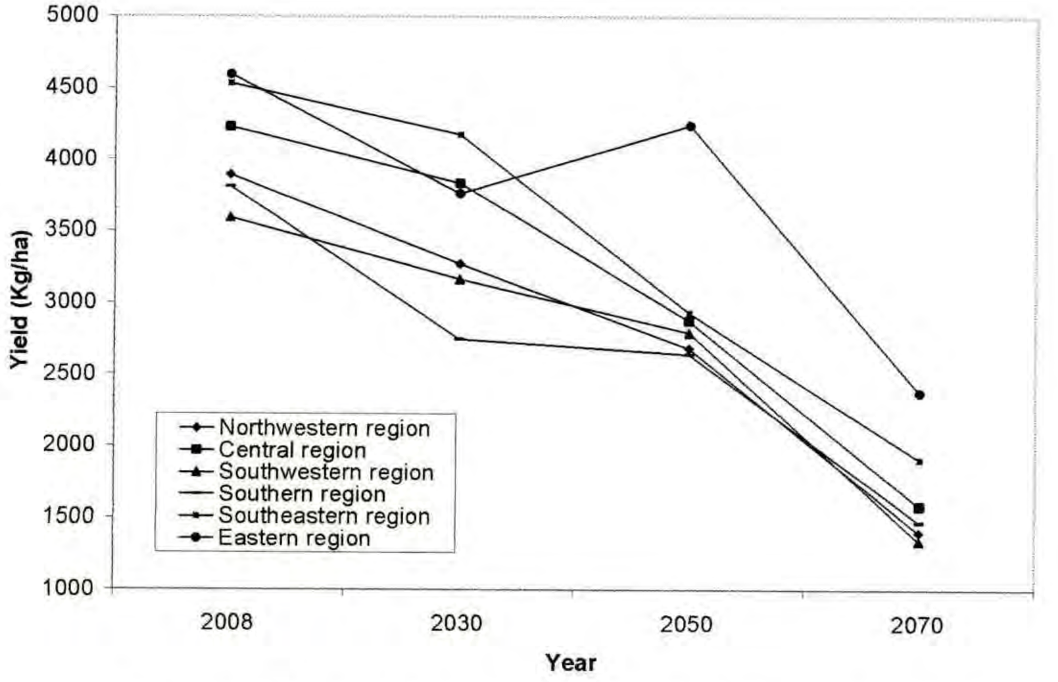

Figure 4.5: Region-wise prediction of yield of BR14 variety of rice

4.3.3 Impact of Climate Change Scenarios on Boro yields (CO_2 variable)

Climate change characterized by increasing carbon dioxide and temperature and variability in rainfall pattern, all of which can have a significant effect on crop growth, development and yield. In general, only increasing CO_2 would have a positive impact on agriculture. CO_2 is vital for photosynthesis, and increases in CO_2 concentration would increase the rate of plant growth. Photosynthesis is the net accumulation of carbohydrates formed by the uptake of CO_2, so it increases with increasing CO_2. A doubling of CO_2 may increase the photosynthetic rate by 30 to 100%, depending on other environmental conditions such as temperature and available moisture (Parry, 1990). More CO_2 enters the leaves of plants due to the increased gradient of CO_2 between the external atmosphere and air space inside the leaves. This leads to an increase in the CO_2 available to the plant for conversion into carbohydrate. The difference between photosynthesis gain and loss of carbohydrate by respiration is the resultant growth.

Indirect effects of global climate change on rice production will also occur via ecosystem response. Changes in weed competition, insect infestation, disease severity, nitrogen fixation by symbiotic organisms and other components of the ecosystem due to increased CO_2 and temperature could severely impact rice production. However, the direction of these effects is unknown. For finding yield of boro rice under the variable CO_2 concentrations in the period of 2008, 2030, 2050 and 2070 (compared to 2008 yield), 15 January was selected for planting date for all locations. The rate of change of atmospheric CO_2 concentration from 1994 (358 ppm) to 2005 (379 ppm) (i.e., about 1.9 ppm per year) was used to set the CO_2 concentrations in the years 2030 (at 427 ppm), 2050 (at 465 ppm), and 2070 (at 503 ppm). This section briefly describes the effect of CO_2 on boro rice yield, and then explains the results of model simulations on rice yield, based on the model simulation results. Table 4.21 shows predicted yield of BR3 at 12 selected locations under variable (i.e., increasing) CO_2 concentrations. The predicted average (for 12 locations) reductions in BR3 yield are 8.9%, 18% and 48.7% for the years 2030, 2050 and 2070, respectively (compared to 2008 yield). Comparing with Table 4.15, we can say that increasing CO_2 concentrations are likely to offset only slightly the adverse effects of other climatic parameters (i.e., temperature, rainfall and solar radiation) on rice yield. Figure 4.6 shows the effect of increasing CO_2 on yield of BR3 rice variety in Jessore. Karim et al. (1996) also reported the effect of increasing CO_2 on rice yield, based on simulation results.

Table 4.21: Predicted yield of BR3 variety of boro rice (kg ha^{-1}) at 12 selected locations for the years 2008, 2030, 2050 and 2070

Locations	Cultivar	2008 (379 ppm)	2030 (427 ppm)	2050 (465 ppm)	2070 (503 ppm)	% change in yield for 2030	% change in yield for 2050	% change in yield for 2070
Northwestern region								
Rajshahi	BR3	3063	4141	3366	1700	35.19	9.89	-44.493
Bogra	BR3	5741	5115	4151	2258	-10.90	-27.69	-60.66
Dinajpur	BR3	6848	4868	4593	3011	-28.91	-32.92	-56.03
Central region								
Mymensingh	BR3	5995	5459	4590	2973	-8.94	-23.43	-50.40
Tangail	BR3	5487	5301	4087	2066	-3.38	-25.51	-62.34
Southwestern region								
Jessore	BR3	5571	4546	4717	2157	-18.39	-15.32	-61.28
Satkhira	BR3	4700	4463	3815	2283	-5.04	-18.82	-51.42
Southern region								
Barisal	BR3	6043	4097	4140	3453	-32.20	-31.49	-42.85
Madaripur	BR3	4582	4099	3787	2410	-10.54	-17.35	-47.40
Southeastern region								
Chandpur	BR3	5975	5660	4225	3118	-5.27	-29.28	-47.81
Comilla	BR3	6115	6207	4468	3309	1.50	-26.93	-45.88
Eastern region								
Sylhet	BR3	5960	5301	6063	3920	-11.05	1.72	-34.22

Table 4.22 shows predicted yield of BR14 rice variety at 12 selected locations for future years under increasing CO_2 concentrations. The predicted average (for 12 locations) reductions in BR14 yield to 11.64%, 21.62% and 53.72% for the years 2030, 2050 and 2070, respectively. Comparing with Table 4.20, we can say that increasing CO_2 concentrations are likely to offset only slightly the adverse effects of other climatic parameters on rice yield. Figure 4.7 shows effect of increasing CO_2 on yield of BR14 rice variety in Jessore.

Table 4.22: Predicted yield of BR14 variety of boro rice (kg ha^{-1}) at 12 selected locations for the years 2008, 2030, 2050 and 2070

Locations	Cultivar	2008 (379 Ppm)	2030 (427 ppm)	2050 (465 ppm)	2070 (503 ppm)	% change in yield for 2030	% change in yield for 2050	% change in yield for 2070
Northwestern region								
Rajshahi	BR14	2334	2912	2478	1216	24.76	6.16	-47.90
Bogra	BR14	4306	3772	2813	1467	-12.40	-34.67	-65.93
Dinajpur	BR14	5047	3459	3255	1864	-31.46	-35.50	-63.06
Central region								
Mymensingh	BR14	4353	3940	3189	2074	-9.48	-26.74	-52.35
Tangail	BR14	4104	3847	2744	1341	-6.26	-33.13	-67.32
Southwestern region								
Jessore	BR14	4032	3179	3287	1448	-21.15	-18.47	-64.08
Satkhira	BR14	3153	3250	2633	1527	3.07	-16.49	-51.56
Southern region								
Barisal	BR14	4397	2952	2808	2257	-32.86	-36.13	-48.66
Madaripur	BR14	3229	2662	2666	1626	-17.55	-17.43	-49.64
Southeastern region								
Chandpur	BR14	4389	4151	2975	2027	-5.42	-32.21	-53.81
Comilla	BR14	4678	4256	3053	2249	-9.02	-34.73	-51.92
Eastern region								
Sylhet	BR14	4596	3915	4518	2603	-14.81	-1.69	-43.36

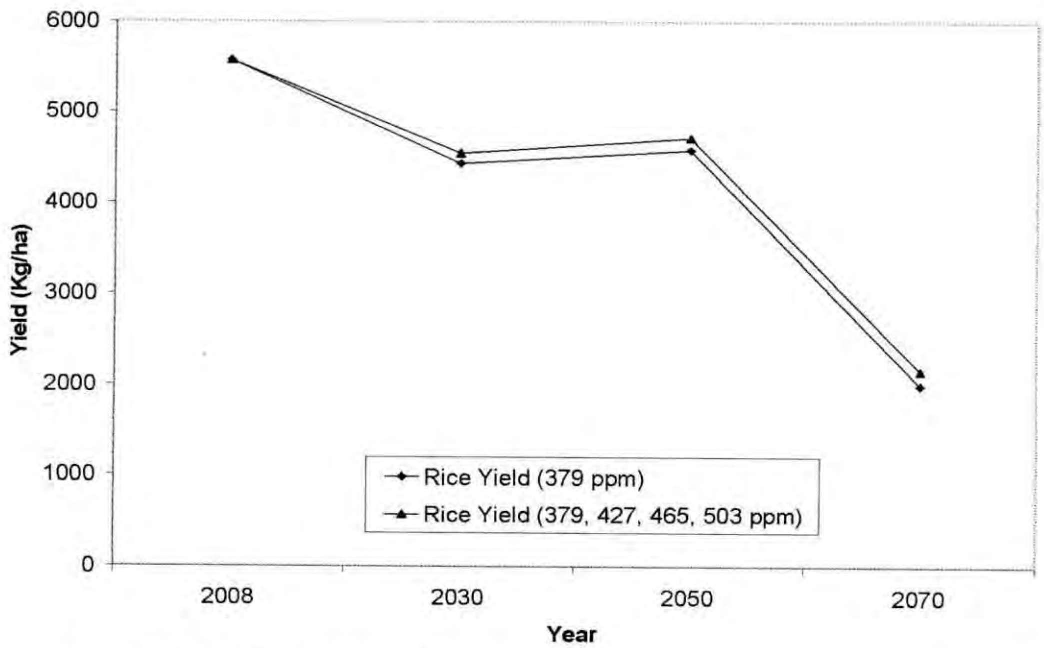

Figure 4.6: Predicted yield of BR3 rice in Jessore at different atmospheric CO_2 concentrations

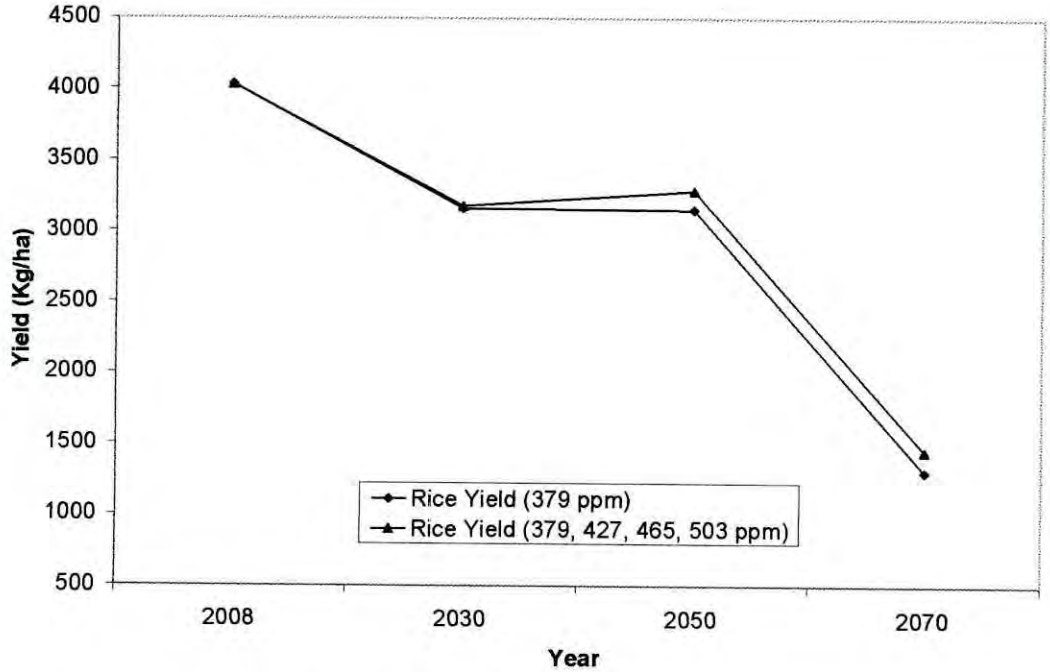

Figure 4.7: Predicted yield of BR14 rice in Jessore at different atmospheric CO_2 concentrations

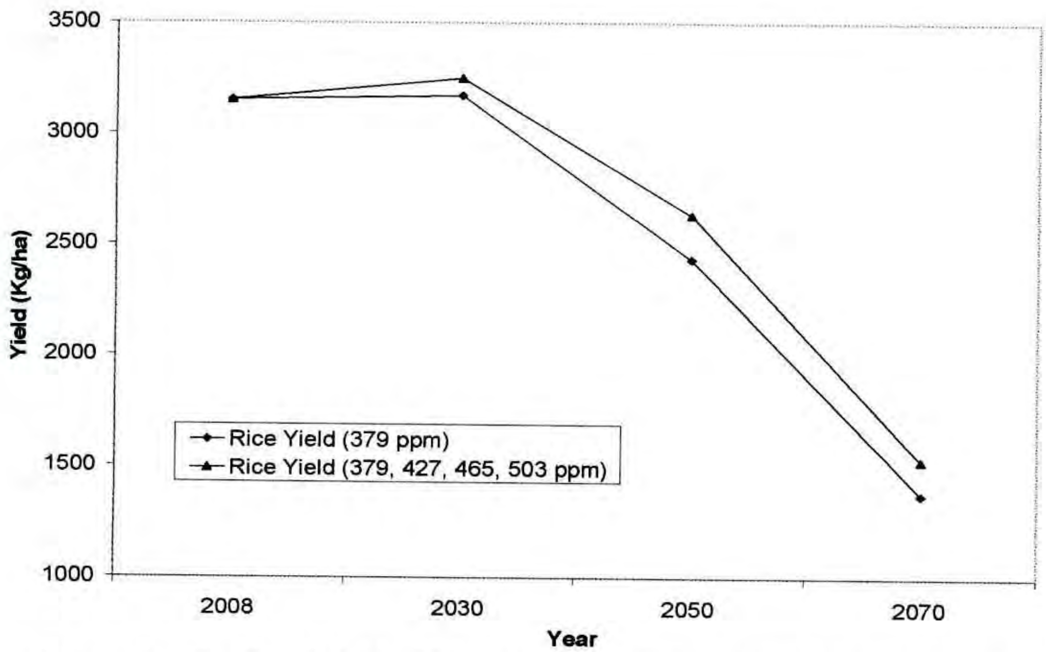

Figure 4.8: Predicted yield of BR14 rice in Satkhira at different atmospheric CO_2 concentrations

4.3.4 Sensitivity of Yield to Climatic Parameters

The effect of warming on agriculture in developing countries is uncertain, so it is essential to understand the climatic factors which will play a significant yield reduction for rice production in future. It is also necessary to develop new verities of rice which can tolerate this climatic condition easily for upcoming year. There are many climatic factors relate to rice production but some climatic factors have a significant role such as daily maximum and minimum temperature, rainfall, solar radiation and CO_2. For this reason, the climatic parameters used in the model are daily maximum temperature (T_{max}), daily minimum temperature (T_{min}), daily solar radiation (Srad) and daily precipitation (Rain).

In order to assess relative importance of different climatic parameters (i.e., T_{max}, T_{min}, S_{rad} and Rainfall) on predicted rice yield, sensitivity analysis was carried out by predicting BR3 rice yield for selected locations using predicted climatic parameters for the years 2008 and 2070 changing one parameter at a time. As reported earlier (Table 4.15) predicted yield of BR3 decreased from 6043 kg ha^{-1} in 2008 to 2091 kg ha^{-1} in 2070. Table 4.23 and Fig 4.9 show the results of the sensitivity analysis.

Table 4.23: Sensitivity of BR3 yield at Barisal on climatic parameters

	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2070 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2070 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2070 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2070	T_{max}= 2070 T_{min}= 2070 Srad= 2070 Rain= 2070
Rice yield (kg ha^{-1})	6043	4160	5039	6714	4354	2091

Table 4.23 shows sensitivity of BR3 yield to climatic parameters at Barisal. Table 4.23 shows that T_{max} has the most significant negative impact on rice yield, followed by Rainfall, and T_{min}; predicted solar radiation on the other hand has some positive effect on yield. Analysis of predicted temperatures (see Fig. 4.10) shows that average T_{max} during January-May (i.e., rice growing season) for 2008 and 2070 are 30.7 and 35.1°C, respectively; this significant increase resulted in a reduction of about 31% in the yield of

BR3 rice. Average T_{min} during this period for 2008 and 2070 were 21.5 °C and 25.2 °C, which caused a reduction of 17% in the predicted yield. Average solar radiation in 2008 and 2070 are 15.37 and 16.71 MJ/m^2/day, respectively and this increase in solar radiation actually increases the predicted yield by about 11%.

Table 4.23 shows significant negative effect of rainfall on BR3 rice yield. Since a fixed irrigation schedule (855 mm in 14 applications) was used in all model simulations, change in rainfall would affect predicted yield by changing availability of water. Analysis of predicted rainfall data (see Fig. 4.10) shows total rainfall (during January to May) of 144.6 mm and 356.1 mm for 2008 and 2070, respectively. So, total water available from rainfall was higher in 2070. However, a closer look shows that in 2008, significant rainfall (96.3 mm) is predicted during January to March, which represent the vegetative phase and a part of reproductive phase of rice plant and during which water requirement is the highest. In 2070 only 21.6 mm rainfall is predicted for this critical growth phase; on the other hand relatively high rainfall of 334.5 mm is predicted for April-May, when water requirement is not significant. This variation in rainfall pattern is responsible for the predicted reduction in rice yield in 2070. However, in theory, this reduction in yield may be avoided by applying additional irrigation during the early stages of growth. Depending on predicted changes in rainfall pattern, the effect of rainfall on yield for other locations could be different. Table 4.24 shows sensitivity of BR3 yield to climatic parameters at Dinajpur, Mymensingh, Jessore and Comilla.

Table 4.24: Sensitivity of BR3 yield under climatic parameters (T_{max}, T_{min}, S_{rad} and Rainfall)

(a) Dinajpur

	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2070 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2070 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2070 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2070	T_{max}= 2070 T_{min}= 2070 Srad= 2070 Rain= 2070
Rice yield (kg ha^{-1})	6848	4224	5921	6930	5440	2692
% Change in yield		- 38.32	-13.53	+ 1.20	- 20.56	- 60.68

(b) Mymensingh

	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2070 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2070 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2070 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2070	T_{max}= 2070 T_{min}= 2070 Srad= 2070 Rain= 2070
Rice yield (kg ha^{-1})	5995	4232	5880	6641	4357	2739
% Change in yield		- 29.40	-1.92	+ 10.78	- 27.33	- 54.31

(c) Jessore

	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2070 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2070 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2070 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2070	T_{max}= 2070 T_{min}= 2070 Srad= 2070 Rain= 2070
Rice yield (kg ha^{-1})	5571	2780	4971	6665	4297	1997
% Change in yield		- 50.10	- 10.77	+ 19.64	- 22.86	- 64.15

(d) Comilla

	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2070 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2070 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2070 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2070	T_{max}= 2070 T_{min}= 2070 Srad= 2070 Rain= 2070
Rice yield (kg ha^{-1})	6115	4133	5082	7304	4738	3075
% Change in yield		- 32.42	- 16.90	+ 19.44	- 22.52	- 49.71

Similar to BR3, sensitivity analysis was also carried out by predicting BR14 rice yield for selected locations using predicted climatic parameters for the years 2008 and 2070, changing one parameter at a time. As reported earlier (Table 4.20), predicted yield of BR14 decreased from 4397 kg ha^{-1} in 2008 to 1457 kg ha^{-1} in 2070. Table 4.25 shows the results of the sensitivity analysis for Barisal. Table 4.27 shows the predicted of monthly average maximum and minimum temperature; solar radiation and rainfall at Barisal. Predicted climatic parameters for other regions are given in Appendix B. Like BR3, similar yield reductions were also predicted for BR14 rice. T_{max} contributed to 28.7% yield reduction, 19% for T_{min}, 29.5% for rainfall and slightly rice yield increased for solar radiation about 12.5%. Similar results were also obtained for other regions (see Table 4.26.

Table 4.25: Sensitivity of BR14 yield at Barisal on climatic parameters

	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2070 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2070 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2070 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2070	T_{max}= 2070 T_{min}= 2070 Srad= 2070 Rain= 2070
Rice yield (kg ha^{-1})	4397	3134	3564	4950	3101	1457

Table 4.26: Sensitivity of BR14 yield under climatic parameters

(a) Dinajpur

	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2070 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2070 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2070 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2070	T_{max}= 2070 T_{min}= 2070 Srad= 2070 Rain= 2070
Rice yield (kg ha^{-1})	5047	2900	4088	5244	4012	1656
% Change in yield		- 42.54	- 19.00	+ 3.90	- 20.50	- 67.18

(b) Mymensingh

	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2070 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2070 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2070 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2070	T_{max}= 2070 T_{min}= 2070 Srad= 2070 Rain= 2070
Rice yield (kg ha^{-1})	4353	2984	4050	4410	3061	1873
% Change in yield		- 32.27	- 6.96	+ 1.31	- 29.68	- 56.97

(c) Jessore

	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2070 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2070 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2070 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2070	T_{max}= 2070 T_{min}= 2070 Srad= 2070 Rain= 2070
Rice yield (kg ha^{-1})	4032	2109	3588	5232	3131	1305
% Change in yield		- 47.7	- 11.01	+ 29.76	- 22.35	- 67.63

(d) Comilla

	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2070 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2070 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2070 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2070	T_{max}= 2070 T_{min}= 2070 Srad= 2070 Rain= 2070
Rice yield (kg ha^{-1})	4678	3049	3679	5468	3304	1978
% Change in yield		- 34.82	- 21.36	+ 16.90	- 29.37	- 57.71

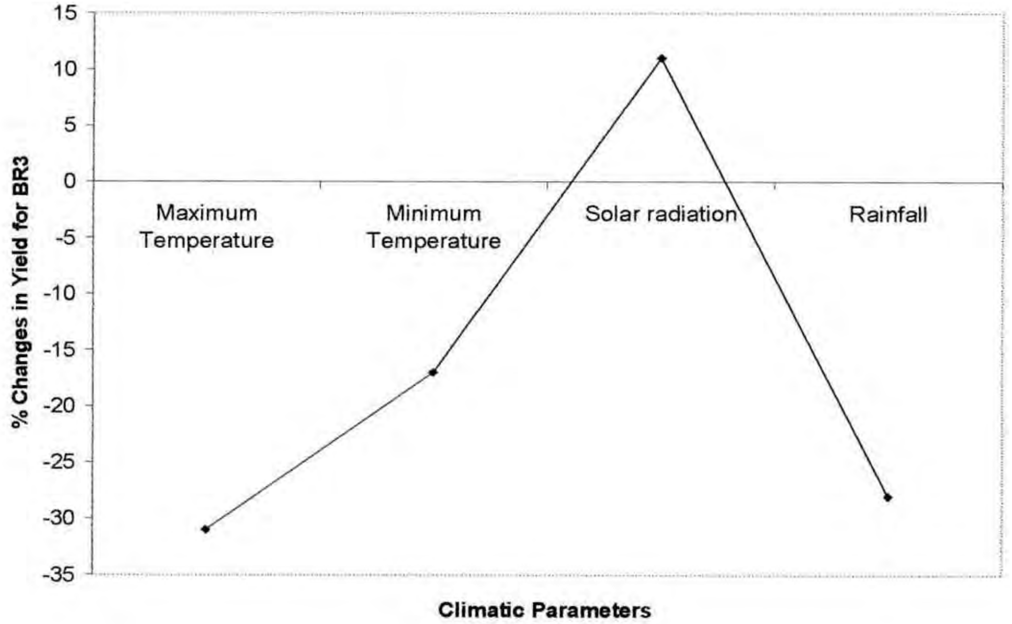

Figure 4.9: Sensitivity analysis for percentage change in BR3 yield

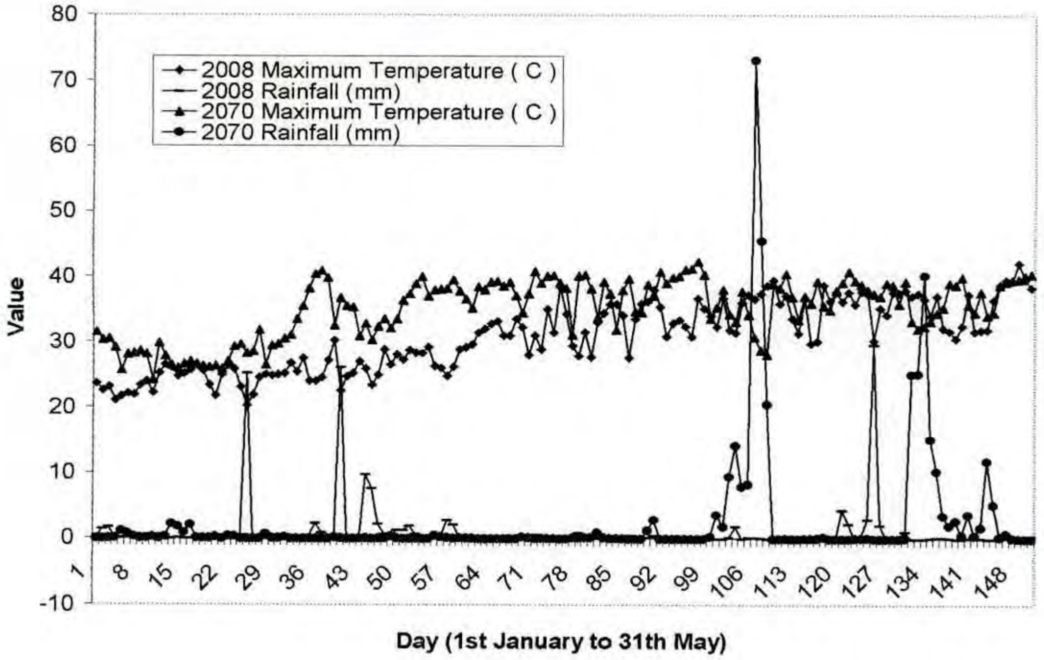

Figure 4.10: Variation of T_{max} and Rainfall during January-May in 2008 and 2070

Table 4.27: Monthly average maximum and minimum temperature, solar radiation and rainfall at Barisal in 2008, 2030, 2050 and 2070

2008, Barisal				
Month	**Tmax (^{0}C)**	**Tmin (^{0}C)**	**Srad (MJ/m^2/day)**	**Rainfall (mm)**
January	23.94	12.36	12.67	1
February	26.5	18.36	10.72	2.05
March	32.5	23.13	17.07	0.16
April	34.78	26.1	17.71	0.27
May	35.92	27.65	18.66	1.34
December	23.17	10.83	13.71	0.11
Average	**29.47**	**19.74**	**15.09**	**0.82**

2030, Barisal				
Month	**Tmax (^{0}C)**	**Tmin (^{0}C)**	**Srad (MJ/m^2/day)**	**Rainfall (mm)**
January	23.94	12.84	13.31	0.25
February	28.10	18.22	14.29	0.90
March	31.49	24.01	13.80	1.24
April	33.48	27.25	14.80	2.55
May	35.92	28.43	18.74	2.88
December	25.79	10.91	16.43	0.00
Average	**29.79**	**20.28**	**15.23**	**1.3**

2050, Barisal				
Month	**Tmax (^{0}C)**	**Tmin (^{0}C)**	**Srad (MJ/m^2/day)**	**Rainfall (mm)**
January	25.90	14.10	13.20	3.20
February	31.93	19.05	16.10	19.78
March	35.27	24.39	16.99	0.70
April	37.88	28.29	20.05	0.54
May	37.20	29.46	16.35	2.97
December	28.05	15.21	13.97	0.05
Average	**32.71**	**21.75**	**16.11**	**4.54**

2070, Barisal				
Month	**Tmax (^{0}C)**	**Tmin (^{0}C)**	**Srad (MJ/m^2/day)**	**Rainfall (mm)**
January	28	19.5	9.77	0.411
February	35.8	21.4	17.55	0.08
March	37.63	26.8	18.27	0.23
April	36.9	28.31	18.86	6.18
May	37.23	30.1	19.1	4.97
December	28.20	15.10	15.31	0.01
Average	**33.96**	**23.54**	**16.48**	**1.98**

4.3.5 Impact of Transplanting Date on Rice Yield

Planting date can have a significant effect on crop development and yield. It is important to assess how rice cultivars respond to different planting dates. The effect of planting date on rice yield was assessed by setting the planting date on 1, 5, 15 and 25 January and simulating yield for each case.

4.3.5.1 Impact of Transplanting date for BR3-Rice

Table 4.28 shows predicted yield of BR3 for different planting dates for the 12 selected locations. It is noticeable that these are regional variation in rice yield response to transplanting dates. First January is the most productive time for transplanting in the northwestern, southwestern, southeastern regions in 2008 but 5 January for the central and 15 January for the southern and eastern regions in Bangladesh. Some variations within a particular region were also observed. For example, 5 January is the most suitable transplanting time for Rajshahi district and 15 January for Dinajpur district, but over all 1 January is the most effective for the northwestern region in 2008. In 2030, the most productive time is 5 January for all regions in Bangladesh except central region (1 January). In general, the predictions indicate significant reduction in rice yield for delayed planting, especially beyond 15 January. For example, for planting date 25 January the over all yield reduction was 8.6 to 29% in 2008 and 18 to 38 % in 2030 (compared to yield for planting date of 1 January).

The effect of planting date appears to be more pronounced for the years 2050 and 2070. Also the predicted yields appear to show more pronounced effect of planting data for locations in northwestern and central regions. For example, for planting dates of 15 and 25 January, the average reduction in yield (compared to yield for planting date of 1 January) for the three locations in northwestern region (i.e., Rajshahi, Bogra and Dinajpur) are 23% and 40%, respectively for the year 2050; and 35% and 41%, respectively for the year 2070.

Table 4.28: Predicted yield of BR3 (kg ha^{-1}) for different planting dates

Location	2008				2030				2050				2070			
	1st	5th	15th	25th	1st	5th	15th	25th	1st	5th	15th	25th	1st	5th	15th	25th
Northwestern																
Rajshahi	4310	4847	3063	2020	5305	6056	4083	2907	4498	4216	3265	2417	2589	2035	1785	1662
Bogra	6439	6063	5741	4538	6205	5969	5119	4162	5435	4352	4070	2781	3492	2684	2036	1961
Dinajpur	6071	5186	6848	5357	6419	7063	4824	4586	5338	5085	4364	3913	3929	3401	2692	2290
Central																
Mymensingh	5599	5808	5995	5595	5985	5977	5275	3652	4634	5181	4455	4944	4550	4235	2739	2856
Tangail	6141	6039	5487	4733	6419	5963	5160	3998	5425	4192	3874	3269	3444	2662	1938	1763
Southwestern																
Jessore	5235	4929	5571	4851	4956	4808	4432	4187	4785	4313	4583	3342	2794	2602	1997	1857
Satkhira	5092	4660	4700	3803	4865	5630	4364	3608	4377	4001	3603	3481	2955	2621	2066	1966
Southern																
Barisal	5850	4603	6043	4618	4301	5686	4006	3798	4924	4250	3972	4246	3941	3732	3084	2546
Madaripur	4630	3389	4582	4205	4121	5174	4017	3070	4039	4193	3647	3812	3450	3499	2186	2238
Southeastern																
Chandpur	6417	6025	5975	5462	4475	5949	5455	3993	5130	4685	4039	4422	3999	4123	2772	2629
Comilla	7034	6400	6115	5623	6646	6788	5987	4110	5095	4871	4456	4401	4130	4248	3075	2798
Eastern																
Sylhet	5797	5559	5960	5299	5398	5425	5117	4309	6007	5511	5750	5032	4885	4546	3595	4756

Among the climatic factors, daily maximum and minimum temperatures changes most significantly due to changes in planting date. For example, in Dinajpur district in 2070, it is observed that the maximum temperature in Emergence-End Juvenile, End Juvenil-Pancil Inition, Panicl Inition-End Leaf Growth, End Leaf Growth Begin Grain Filling and Grain Filling phase are 28.0^{0}C, 29.6^{0}C, 36.9^{0}C, 40.5^{0}C and 40.9^{0}C, respectively for 1 January planting date, respectively. On the other hand, if planting date is shifted to 25 January these values are 33.5^{0}C, 34.4^{0}C, 39.5^{0}C, 41.5^{0}C and 37.8^{0}C, respectively. Minimum temperatures for 1 January of those phases are 15.6^{0}C, 17.7^{0}C, 20.5^{0}C, 27.0^{0}C and 23.3^{0}C, respectively whereas for 25 planting date, the corresponding values are 17.8^{0}C, 18.4^{0}C, 23.9^{0}C, 23.3^{0}C and 28.3^{0}C. Thus, there are significant variations in maximum and minimum temperature depending on planting date. Similarly at Satkhira for BR3, the maximum temperature in Emergence-End Juvenile, End Juvenil-Pancil Inition, Panicl Inition-End Leaf Growth, End Leaf Growth Begin Grain Filling and Grain

Filling phases are 30.3^{0}C, 29.2^{0}C, 36.4^{0}C, 40.5^{0}C and 41.2^{0}C, respectively, for 1s January planting in 2070. For 25 January planting these values are 34.5^{0}C, 36.1^{0}C, 39.9^{0}C, 40.6^{0}C and 40.9^{0}C. Minimum temperatures of these phases are 20.0^{0}C, 20.1^{0}C, 22.4^{0}C, 24.6^{0}C and 27.2^{0}C, respectively, for 1 January planting; whereas for 25 January planting these values are 20.4^{0}C, 21.3^{0}C, 26.0^{0}C, 27.0^{0}C and 28.8^{0}C. There are also high fluctuations of rainfall and solar radiation in these phases. Tables 4.29 and 4.30 show the climatic parameters and stresses in different development phases of BR3 at Dinajpur and Satkhira regions for 1 and 25 January planting date in the year 2070.

Table 4.29 (a): Climate parameters and stresses in different development phases of BR3 rice at Dinajpur for 1 January in 2070

Development Phase	Time Span Days	Temp Max. ^{0}C	Temp Min. ^{0}C	Solar Rad. MJ/m^{2}	Photop [day] Hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	22	28.0	15.6	12.9	10.52	1.5	53.6	0.003	0.031	0.420	0.284
End Juvenil-Panicl Inition	9	29.6	17.7	14.8	10.73	1.9	18.6	0.000	0.0	0.668	0.493
Panicl Inition-End Leaf Growth	33	36.9	20.5	18.7	11.16	1.6	166.6	0.000	0.0	0.137	0.071
End Leaf Growth-Begin Grain Filling	7	40.5	27.0	20.9	11.63	1.8	50.2	0.000	0.0	0.000	0.000
Grain Filling Phase	18	40.9	23.3	23.2	11.95	3.0	128.7	0.047	0.063	0.002	0.000

Table 4.29 (b): Climate parameters and stresses in different development phases of BR3 rice at Dinajpur for 25 January in 2070

Development Phase	Time Span Days	Temp Max. ^{0}C	Temp Min. ^{0}C	Solar Rad. MJ/m^{2}	Photop [day] Hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	16	33.5	17.8	16.9	10.83	1.9	48.2	0.020	0.058	0.370	0.184
End Juvenil-Panicl Inition	8	34.4	18.4	17.8	11.07	0.0	25.1	0.000	0.0	0.636	0.465
Panicl Inition-End Leaf Growth	30	39.5	23.9	20.7	11.52	3.8	151.9	0.000	0.0	0.280	0.215
End Leaf Growth-Begin Grain Filling	9	41.5	23.3	24.0	12.02	2.5	62.5	0.000	0.0	0.000	0.000
Grain Filling Phase	15	37.8	28.3	18.4	12.33	71.4	81.2	0.000	0.0	0.000	0.000

Table 4.30 (a): Climate parameters and stresses in different development phases of BR3 rice at Satkhira for 1 January in 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] Hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	17	30.3	20.0	11.8	10.68	7.8	41.9	0.019	0.07 2	0.293	0.154
End Juvenil-Panicl Inition	9	29.2	20.1	11.8	10.82	0.9	21.3	0.000	0.00	0.473	0.318
Panicl Inition-End Leaf Growth	31	36.4	22.4	16.0	11.15	4.5	135.4	0.000	0.00	0.176	0.119
End Leaf Growth-Begin Grain Filling	8	40.5	24.6	21.6	11.54	0.1	54.1	0.000	0.00	0.000	0.000
Grain Filling Phase	17	41.2	27.2	21.5	11.81	2.2	116.4	0.041	0.04 7	0.003	0.000

Table 4.30 (b): Climate parameters and stresses in different development phases of BR3 rice at Satkhira for 25 January in 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] Hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	15	34.5	20.4	15.3	10.97	1.0	44.4	0.000	0.00 4	0.314	0.175
End Juvenil-Panicl Inition	7	36.1	21.3	18.1	11.16	0.5	25.6	0.000	0.00	0.409	0.254
Panicl Inition-End Leaf Growth	30	39.9	26.0	19.2	11.54	3.7	153.1	0.000	0.00	0.274	0.181
End Leaf Growth-Begin Grain Filling	8	40.6	27.0	21.1	11.96	2.0	53.3	0.000	0.00	0.000	0.000
Grain Filling Phase	16	40.9	28.8	21.7	12.23	2.6	103.0	0.000	0.00	0.000	0.000

Nitrogen stress was comparatively lower for 1 January planting than 25 and it was reflected in model output sheet clearly (Tables 4.29 and 4.30). High nitrogen stresses in some development phases are the main causes of yield variations between those two planting dates. Rice plant loses a significant amount of volatile N in conjaction with the transpirational water vapour. These are marked differences in the rates of volatile N loss among rice cultivars. The increase in temperature from 30 to 35^{0}C (for 5^{0}C) greatly increases the rate of volatile N loss. Within a maturity group, a difference in rates of N loss among cultivars depends on their relative sensitivity to temperature variation (Stutte and da Silva, 1981). The physiological maturity and leaf area index (LAI) for BR3 for 1 January planting are 90 days and 1.93; for 25 January planting, these are 79 days and 1.07 at Dinajpur district in 2070. At Satkhira in 2070, these are 83 days and 1.59 for 1 January planting and 77 days and 1.09 for 25 January planting. The shorter the physiological maturity (day) with lower percentage of productive tillers was associated with a smaller number of spikelets per unit area, which was attributed of the lower yield. Relatively higher LAI for earlier planting (i.e., 1 January planting) ultimately contributed towards higher rice yield.

4.3.5.2 Impact of climate change scenarios on Transplanting date for BR14-Rice

Table 4.31 shows predicted yield of BR14 for different planting dates for the 12 selected locations. It shows regional variation of rice yield response to transplanting date. 1 January is the most productive time for transplanting in the northwestern, southwestern, southern and southeastern regions in 2008 but 15 January for the central and eastern regions in Bangladesh. Some location variations within a particular region were also observed in same regions. For example, 5 January is most suitable transplanting time for Rajshahi district and 15 January for Dinajpur district, but overall 1 January was the most effective time for the northwestern region in 2008. In 2030, the most productive time is 5 January for all regions in Bangladesh except central and eastern region (1 January). In general, the predictions indicate significant reduction in rice yield for delayed planting, especially beyond 15 January. It appears that 1 to 15 January is the most effective time for BR14 rice transplanting in 2008 and 2030 for future. Rice yield significantly reduced for transplanting on 25 January. For example, for planting date of 25 January (compared to yield for planting date of 1 January) the overall yield reduction was 6% (eastern) to 32% (northwestern) in 2008 and 7% (southern) to 37 % (northwestern) in 2030 for BR14. The effect of planting date appears to be more pronounced for the years 2050 and 2070. First January would be the most productive time for transplanting compared to 5, 15 and 25 January. Also the predicted yields appear to show more pronounced effect of planting data for locations in northwestern and central regions. For example, for planting date 25 January, the average reduction in yield (compared to yield for planting date of 1 January) for all regions are 9.8% (southern) to 41% (northwestern) for the year 2050; and 29% (southeastern) to 37% (northwestern) for the year 2070.

Table 4.31: Predicted yield of BR14 (kg ha^{-1}) for different planting dates

Location	2008				2030				2050				2070			
	1^{st}	5^{th}	15^{th}	25^{th}	1^{st}	5^{th}	15^{th}	25^{th}	1^{st}	5^{th}	15^{th}	25^{th}	1^{st}	5^{th}	15^{th}	25^{th}
Northwestern																
Rajshahi	2744	3362	2334	1125	3726	4225	2771	1673	3269	2810	2392	1750	1724	1651	1148	1076
Bogra	4794	4093	4306	3534	4523	4324	3668	3195	3968	2879	2637	2135	2050	1907	1398	1223
Dinajpur	4614	3452	5047	4045	4677	4927	3374	3461	3977	3354	3023	2715	2130	2136	1656	1417
Central																
Mymensingh	4171	4264	4353	4263	4326	4340	3790	2919	3435	3503	3186	3628	2770	2749	1873	1923
Tangail	4195	3971	4104	3388	4607	4413	3883	3043	3913	2741	2565	2171	2088	1703	1297	1182
Southwestern																
Jessore	3783	3247	4032	3690	3420	3395	3160	3060	3033	2855	3153	2413	1853	1720	1305	1297
Satkhira	3527	3055	3153	2967	3323	4277	3171	2597	2855	2763	2434	2406	1924	1606	1377	1309
Southern																
Barisal	4382	3127	4397	4031	2963	4001	2889	3029	3510	2800	2705	2798	2481	2546	2001	1674
Madaripur	3372	2323	3229	3088	2858	3614	2606	2383	2745	2869	2578	2762	2274	2357	1491	1534
Southeastern																
Chandpur	4664	3902	4389	4243	3158	4243	3981	3171	3644	2862	2801	3163	2461	2675	1842	1770
Comilla	4964	3884	4678	4507	4887	4916	4368	3293	3639	3345	3063	3187	2598	2790	1978	1827
Eastern																
Sylhet	4252	4257	4596	4000	4394	4131	3764	3281	4493	3793	4240	3813	3255	2875	2378	3470

As in the case for BR3, daily maximum and minimum temperatures have the most significant role with regard to changes in planting date and hence on predicted yield. For example, in Dinajpur in 2070, the maximum temperatures in Emergence-End Juvenile, End Juvenil-Pancil Inition, Panicl Inition-End Leaf Growth, End Leaf Growth Begin Grain Filling and Grain Filling phases are 29.4^{0}C, 26.4^{0}C, 35.7^{0}C, 38.6^{0}C and 41.3^{0}C, respectively, for 1 January planting whereas in 25 January planting these values are 31.5^{0}C, 36.1^{0}C, 39.5^{0}C, 41.5^{0}C and 36.3^{0}C. Minimum temperatures of these phases are 15.6^{0}C, 15.6^{0}C, 19.7^{0}C, 25.5^{0}C and 23.6^{0}C, respectively, for 1 January planting whereas for 25 January planting these values are 16.8^{0}C, 19.1^{0}C, 23.9^{0}C, 23.0^{0}C and 27.7^{0}C. Thus, there are significant variations of maximum and minimum temperature during different development phases due to change the planting date. Tables 4.32 and 4.33 show the climatic parameters and stresses in different development phases of BR14 at Dinajpur and Satkhira regions for 1 and 25 January planting date in the year 2070. Effect of planting date on physiological maturity, LAI and hence yield are similar to these observed for BR3.

Table 4.32 (a): Climate parameters and stresses in different development phases of BR14 rice at Dinajpur for 1 January in 2070

Development Phase	Time Span Days	Temp Max. ^{0}C	Temp Min. ^{0}C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	14	29.4	15.6	14.2	10.47	0.1	35.9	0.000	0.023	0.388	0.238
End Juvenil-Panicl Inition	12	26.4	15.6	12.1	10.62	1.4	25.1	0.000	0.00	0.603	0.432
Panicl Inition-End Leaf Growth	33	35.7	19.7	17.8	11.05	2.4	141.8	0.000	0.00	0.206	0.157
End Leaf Growth-Begin Grain Filling	8	38.6	25.5	20.5	11.52	1.1	49.8	0.000	0.00	0.020	0.000
Grain Filling Phase	20	41.3	23.6	23.3	11.88	4.7	139.1	0.033	0.052	0.000	0.000

Table 4.32 (b): Climate parameters and stresses in different development phases of BR14 rice at Dinajpur for 25 January in 2070

Development Phase	Time Span Days	Temp Max. ^{0}C	Temp Min. ^{0}C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	12	31.5	16.8	16.4	10.79	1.9	36.2	0.002	0.054	0.373	0.225
End Juvenil-Panicl Inition	12	36.1	19.1	18.0	11.03	0.0	33.9	0.000	0.00	0.610	0.444
Panicl Inition-End Leaf Growth	30	39.5	23.9	20.7	11.52	3.8	137.7	0.000	0.00	0.282	0.221
End Leaf Growth-Begin Grain Filling	8	41.5	23.0	24.2	12.01	0.0	51.4	0.000	0.00	0.000	0.000
Grain Filling Phase	20	36.3	27.7	15.8	12.36	264.6	88.5	0.000	0.00	0.000	0.000

Table 4.33 (a): Climate parameters and stresses in different development phases of BR14 rice at Satkhira for 1 January in 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	11	31.2	19.0	13.6	10.66	1.4	29.1	0.000	0.07 9	0.367	0.214
End Juvenil-Panicl Inition	12	28.9	20.7	9.7	10.77	7.1	26.7	0.000	0.0	0.377	0.216
Panicl Inition-End Leaf Growth	32	35.5	22.1	15.5	11.11	4.2	119.0	0.000	0.0	0.222	0.158
End Leaf Growth-Begin Grain Filling	8	40.7	23.9	21.7	11.50	0.5	54.0	0.000	0.0	0.000	0.000
Grain Filling Phase	19	41.1	27.2	21.3	11.79	2.3	121.7	0.000	0.0	0.000	0.000

Table 4.33 (b): Climate parameters and stresses in different development phases of BR14 rice at Satkhira for 25 January in 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	11	31.7	19.8	13.7	10.94	1.0	32.5	0.000	0.0	0.367	0.214
End Juvenil-Panicl Inition	12	38.1	21.9	18.3	11.13	0.9	36.6	0.000	0.0	0.435	0.263
Panicl Inition-End Leaf Growth	30	40.1	26.0	19.3	11.56	3.3	143.2	0.000	0.0	0.247	0.170
End Leaf Growth-Begin Grain Filling	8	40.6	27.3	21.5	11.98	2.1	51.7	0.000	0.0	0.000	0.000
Grain Filling Phase	19	39.4	28.8	19.6	12.28	25.7	107.9	0.000	0.0	0.000	0.000

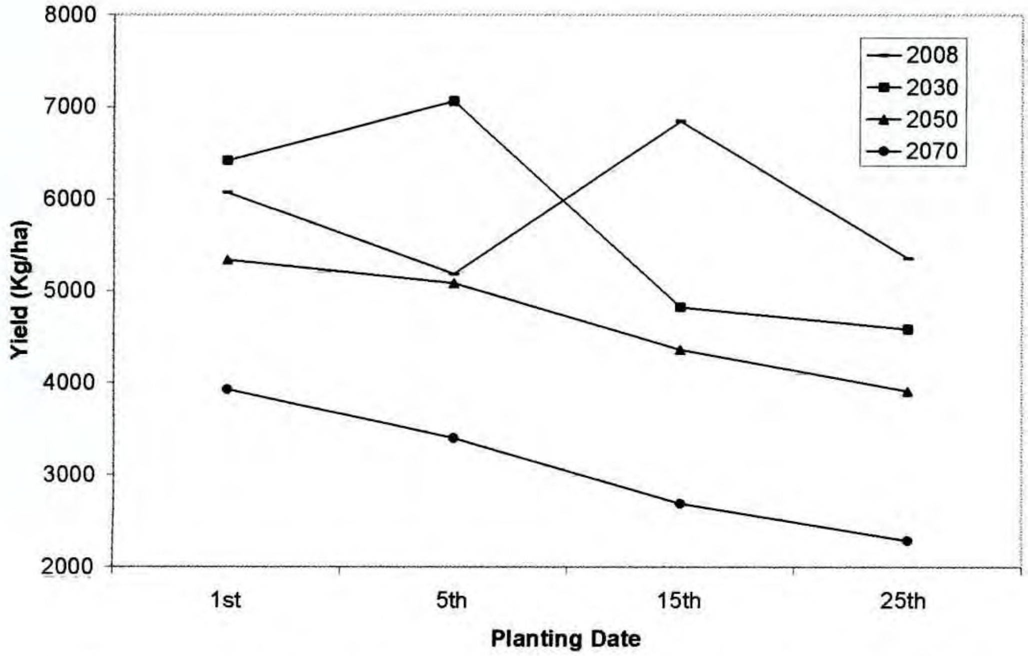

Figure 4.11: Predicted yield of BR3 in Dinajpur for different planting dates

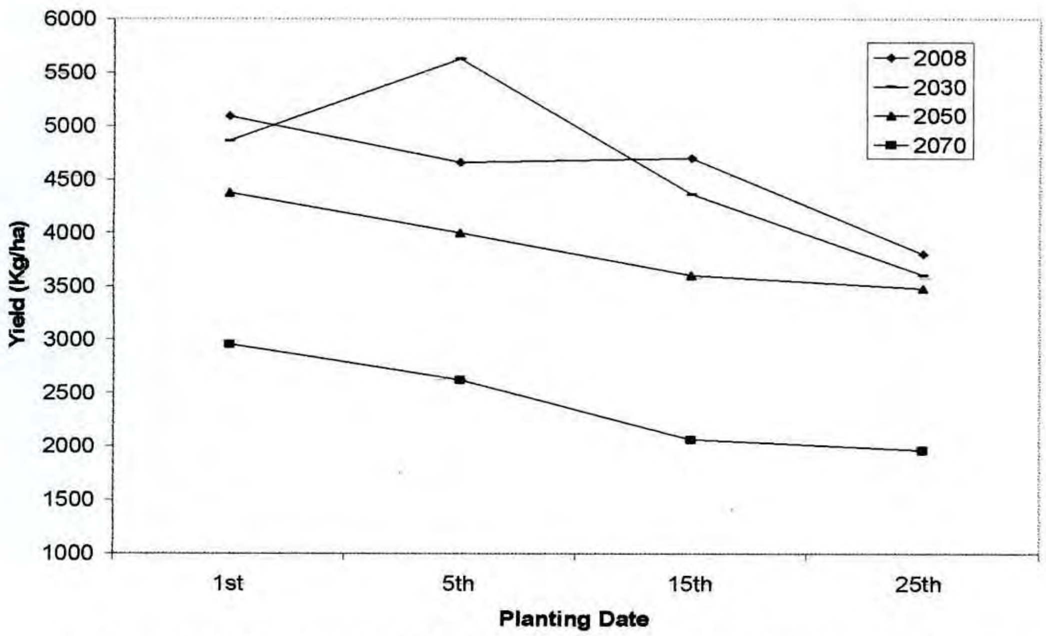

Figure 4.12: Predicted yield of BR3 in Satkhira for different planting dates

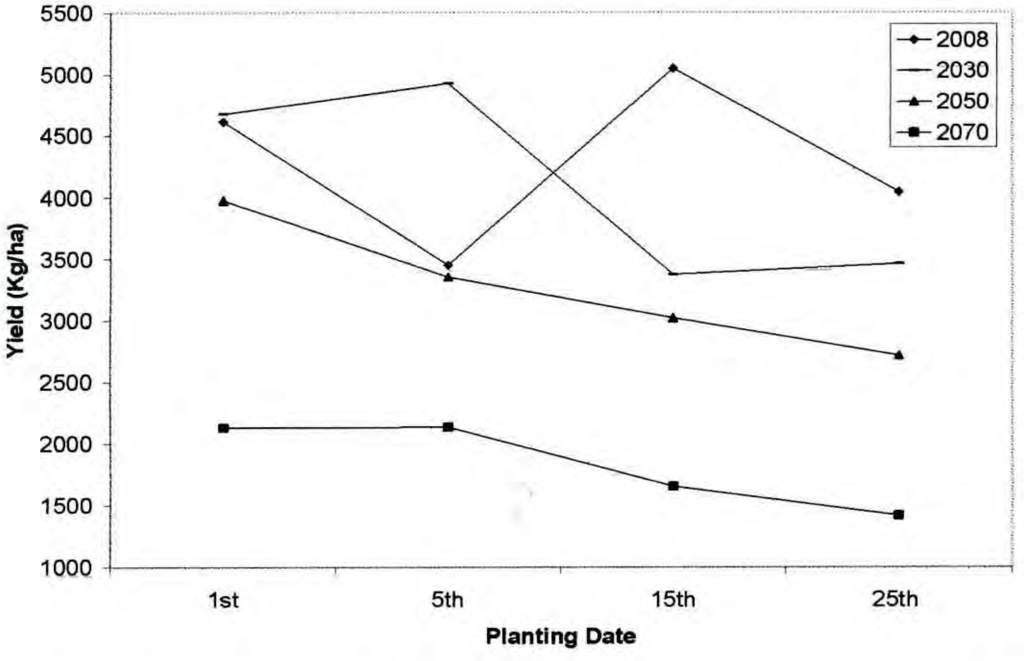

Figure 4.13: Predicted yield of BR14 in Dinajpur for different planting dates

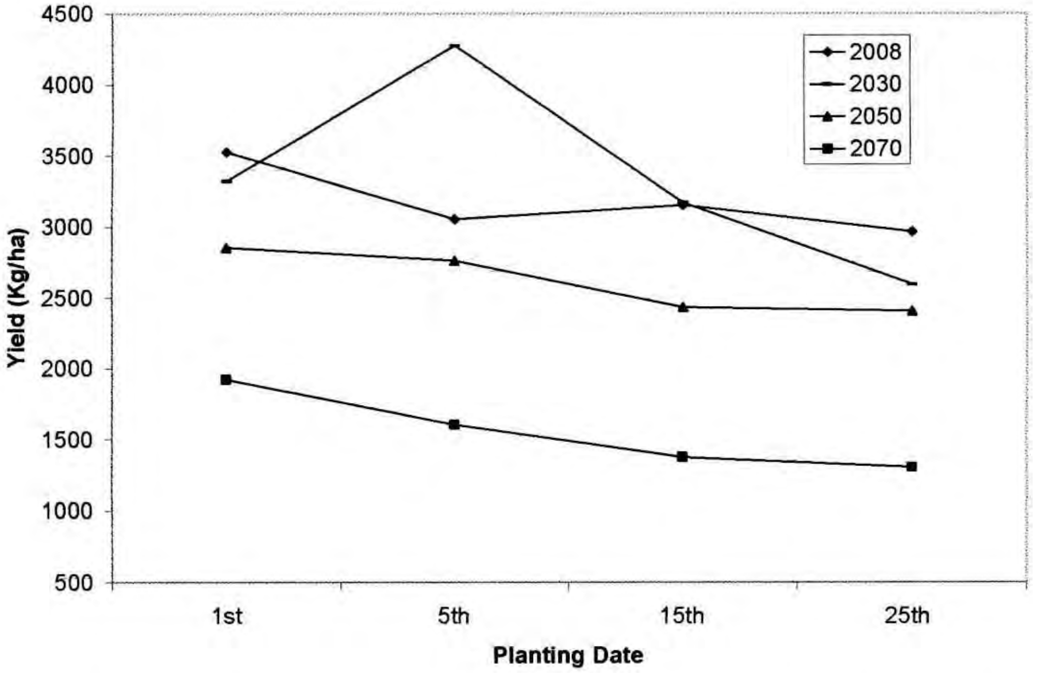

Figure 4.14: Predicted yield of BR14 in Satkhira for different planting dates

4.3.6 Effect of Climate Change on Irrigation Water Requirement

Agricultural of any kind is strongly influenced by the availability of water. Climate change will modify rainfall, evaporation, run-off and soil moisture storage. Changes in total seasonal precipitation or in its pattern of variability are both important. Water is indispensable to plant life. A plant's water content varies by species and within various plant structures and also diurnally during the entire growth period. The formative water for the plant is obtained mainly from soil through absorption by the plant roots. The plant uses less than 5% of the water absorbed. The rest is lost to the atmosphere through transpiration from the plant leaves. An adequate water supply is one of the most important factors in rice production. In many parts of tropical Asia, rice plants suffer from either too much or too little water because of irregular rainfall and landscape patterns. Water management embraces the control of water for optimum crop yield and the best use of a limited supply of water. Proper management of water and irrigation systems, especially those that rely on stored water, enables a water supply during the dry season when yields generally are high due to high solar radiation and greater fertilizer nitrogen response.

Less rainfall during winter due to climate change will lead to decrease in moisture content of the top soil, as well as less recharging of the ground water. Higher evaporation causes drought-like condition. The occurrence of moisture stress during flowering, pollination and grain-filling is harmful to rice. Increased evaporation from the soil and accelerated transpiration in the plants themselves will cause moisture stress; as a result yield may be reduced significantly (discussed early). To estimate water requirement, the following conditions were used in the model simulations: 855 mm irrigation in 14 applications, fertilizer 130 kg/ha, and CO_2 379 ppm. Table 4.34 shows the predicted water requirement for BR3 rice. Model results show at northwestern region water requirement are 815 mm, 802 mm, 823 mm and 791 mm (calculated average value of three districts); at central region 748 mm, 655 mm, 737 mm and 729 mm; at southwestern region 810 mm, 749 mm, 800 mm and 756 mm; at southern region 736 mm, 640 mm, 706 mm and 673 mm; at southeastern region 706 mm, 653 mm, 713 mm and 715 mm;

and at eastern region, it was 535.2 mm, 439.4 mm, 558.4 mm and 592.8 mm in the year 2008, 2030, 2050 and 2070, respectively. It should be noted that the DSSAT model does not count the water required for preparation of land before transplanting (which usually varies from 200 to 300 mm, depending on soil and weather condition). Thus, it is observed that water requirement decreased in future BR3 rice production in the central, southwestern and southern regions (compared to 2008). It is also found that in 2050 and 2070 water requirement was slightly higher than 2008 for the northwestern, southeastern and eastern regions and it is also slightly higher in 2050 compared to 2030 and 2070. From analysis of predicted rainfall data, it was found that the total rainfall (during January to May) in 2050 was comparatively lower than 2030 and 2070. Changes the annual precipitation patterns also affect the water requirement (see Table 4.19).

Table 4.34: Predicted water requirement (mm) of BR3 for different regions

Location	2008	2030	2050	2070
Northwestern				
Rajshahi	795.4	852.8	795.4	783.4
Bogra	862.4	800.6	841.6	792.8
Dinajpur	787.6	752	831.6	797
Central				
Mymensingh	651.8	549.2	703.2	687.8
Tangail	844	761.6	771.6	770.8
Southwestern				
Jessore	841.8	755.6	840.4	778.2
Satkhira	779	742.6	760.2	733.2
Southern				
Barisal	729.6	611.4	689.4	673
Madaripur	742.2	667.8	721.8	673.4
Southeastern				
Chandpur	712.4	650.2	702.8	703
Comilla	700.4	656.4	723.8	726.2
Eastern				
Sylhet	535.2	439.4	558.4	592.8

Some location variations are also observed in some region. For example, in 2050 and 2070 water requirement was higher than 2008 at Mymensingh but overall the water requirement was comparatively lower than that in 2008 in the central regions. A closer look shows that in 2008, 2030, 2050 and 2070, maximum water requirements are predicted in northwestern region which represent drought prone region in Bangladesh. So, additional irrigation must be made available for boro cultivation in this region to reduce water stress in future. The minimum water requirements are predicted in eastern region where more rainfall occurs in boro season. Table 4.34 shows effect of planting date on water requirement. It shows that water requirement is comparatively higher, if boro rice is planted on 1 to 5 January (compared to 15 and 25 January).

Table 4.35: Predicted water requirement (mm) of BR3 for different planting dates

	2070			
Location	1 January	5 January	15 January	25 January
Northwestern				
Rajshahi	811.4	784.8	783.4	764
Bogra	815.6	779.2	792.8	747.6
Dinajpur	856.4	839.6	797	739.6
Central				
Mymensingh	745.2	731.4	687.8	661.6
Tangail	788.4	764.4	770.8	727.8
Southwestern				
Jessore	779.2	753.8	778.2	788.4
Satkhira	763.4	751.6	733.2	774.4
Southern				
Barisal	699.2	673.2	673	700
Madaripur	729.8	725.6	673.4	723
Southeastern				
Chandpur	697	712.8	703	720.6
Comilla	708	723.2	726.2	723.6
Eastern				
Sylhet	657.2	634.8	592.8	597.2

The amount of water available for plant growth is affected by a combination of climatic and non-climatic variables such as precipitation, temperature, sunshine, wind speed as well as soil porosity, slope etc. Climatic factors and physiological maturity have a significant role on water requirement for plant. Higher temperature and higher solar radiation lead to higher evapotranspiration but shorter the physiological maturity day. For lower of physiological maturity, water requirement for rice becomes lower. So, these two effects are opposite. Significantly shorter physiological maturity in 2070 (compared to 2008, 2030 and 2050) is one of the main reasons for lower water requirement in 2070.

Table 4.36 shows predicted water requirement for BR14 rice variety for different regions and Table 4.37 shows effect of planting date on water requirement for BR14.

Table 4.36: Predicted water requirement (mm) of BR14 for different regions

Location	2008	2030	2050	2070
Northwestern				
Rajshahi	834.8	879.8	837.8	748.4
Bogra	935.8	855	845	770.2
Dinajpur	842.2	807	892.2	784.8
Central				
Mymensingh	683.4	589.6	771.2	677.2
Tangail	903	845	807.6	752.4
Southwestern				
Jessore	888.8	814.4	868.6	775.2
Satkhira	840.8	806.8	790.6	735
Southern				
Barisal	788.8	640.6	714.4	696.2
Madaripur	770.8	681.6	755.6	702.2
Southeastern				
Chandpur	772.8	694	742	702.8
Comilla	774.8	691.8	740.2	724.6
Eastern				
Sylhet	569.6	460	580.2	613.2

Table 4.37: Predicted water requirement (mm) of BR14 for different planting dates

Location	**2070**			
	1 January	5 January	15 January	25 January
Northwestern				
Rajshahi	857.6	784.8	748.4	739.2
Bogra	783	752.6	770.2	706.4
Dinajpur	800.6	798.4	784.8	713.2
Central				
Mymensingh	704.2	719.8	677.2	691
Tangail	761.6	735.6	752.4	700.8
Southwestern				
Jessore	734.8	766.6	775.2	791.4
Satkhira	723.8	754	735	755.8
Southern				
Barisal	690.2	696.2	696.2	713.4
Madaripur	732.8	742.6	702.2	719.2
Southeastern				
Chandpur	686	708	702.8	709.8
Comilla	708.4	742.4	724.6	729.4
Eastern				
Sylhet	663.6	643.2	613.2	615.6

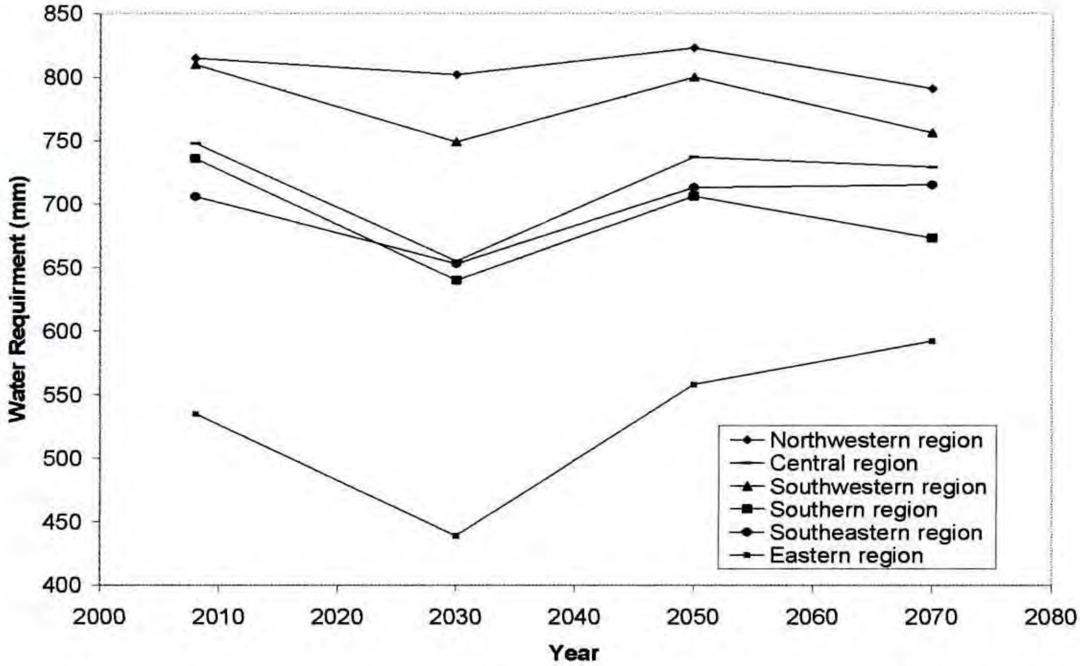

Figure 4.15: Region-wise prediction of water requirement (mm) of BR3 rice

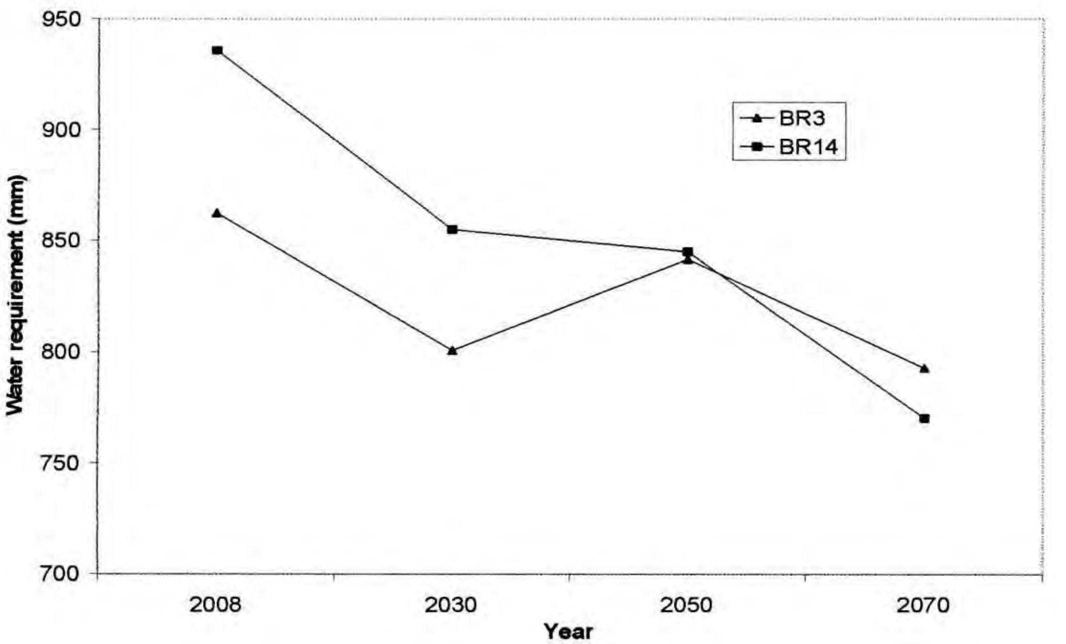

Figure 4.16: Predicted water requirement (mm) of BR3 and BR14 varieties of rice for Bogra

4.3.7 Effect of Climate Change on Physiological Maturity

A base line estimate for BR3 and BR14 rice physiological maturity time has been calculated by running the model for 12 major rice growing areas in Bangladesh. The development stage (DVS) of a plant defines its physiological age and is characterized by the formation of the various organs and their appearance. The most important phonological change is the one from the vegetative to reproductive stage. The vegetative phase of rice is extended due to low temperature (Vergara and Chang., 1985). Table 4.38 shows the predicted physiological maturity of BR3 for different regions and for different years. Model results also showed significant effect of climate change on physiological maturity of rice. The time of physiological maturity has been predicted to decrease significantly due to changes in climatic scenario. For an example, physiological maturity (in days) of BR3 rice varieties varied from 93 (in Satkhira) to 114 (in Sylhet) in 2008; while the corresponding values are 77 and 90 in 2070. Some regional variation could be observed in the predictions (Fig. 4.20). It should be noted that the DSSAT model counts physiological maturity from the time of "Emergence-End Juvenile" period. It takes about 10-12 days to come to this stage after transplantation. In addition transplanting age of 35 days was considered. However, transplanting age may be up to 45 days under actual field condition. If transplanting age increase by one day, physiological maturity usually increase 0.5 day (Biswas, 2009). These increases should be kept in mind which estimating physiological maturity under field condition.

Changes in temperatures and solar radiation are important factors affecting physiological maturity of rice. The changing pattern of temperature and solar radiation not only vary from year to year but also vary from different planting dates which also affect the physiological maturity. Table 4.39 shows effect of planting on physiological maturity. In 2008 for 1 January planting the physiological maturity is 114, whereas for 25 January planting, it is 101 for BR3 at Mymensingh. At Madaripur, it is 104 for 1 January planting and 90 for 25 January planting. Similar result also found for other regions in Bangladesh.

Table 4.38: Predicted physiological maturity (days) of BR3 for different regions

Location	2008	2030	2050	2070
Northwestern				
Rajshahi	88	95	84	83
Bogra	100	100	89	83
Dinajpur	105	99	89	82
Central				
Mymensingh	106	105	96	86
Tangail	99	98	87	84
Southwestern				
Jessore	96	91	84	80
Satkhira	93	89	82	77
Southern				
Barisal	99	94	87	80
Madaripur	96	94	86	80
Southeastern				
Chandpur	99	97	87	81
Comilla	102	100	92	82
Eastern				
Sylhet	114	114	104	90

Table 4.39: Predicted physiological maturity (days) of BR3 for different planting dates

Location	2008			
	1 January	5 January	15 January	25 January
Northwestern				
Rajshahi	98	97	88	82
Bogra	108	106	100	94
Dinajpur	113	108	105	99
Central				
Mymensingh	114	112	106	101
Tangail	107	105	99	93
Southwestern				
Jessore	102	100	96	90
Satkhira	101	98	93	87
Southern				
Barisal	107	106	99	91
Madaripur	104	102	96	90
Southeastern				
Chandpur	107	105	99	94
Comilla	111	109	102	98
Eastern				
Sylhet	121	119	114	109

Table 4.40 shows the predicted physiological maturity for BR14 rice variety. The physiological maturity (in days) of BR14 rice varieties varied from 92 (in Rajshahi) to 121 (in Sylhet) in 2008; while the corresponding values are 86 and 95 in 2070. Some regional variation could be observed in the predictions Table 4.41 shows effect of planting on physiological maturity. In a summery, increasing temperature shortens the

physiological maturity time of rice, decreasing the time during which the canopy exists and thus the period during which it intercepts light and produces biomass. An increase in temperature above the optimum value should therefore generally lead to lower yields for boro rice in Bangladesh.

Table 4.40: Predicted physiological maturity (days) of BR14 for different regions

Location	2008	2030	2050	2070
Northwestern				
Rajshahi	92	99	88	86
Bogra	105	105	90	87
Dinajpur	110	104	93	85
Central				
Mymensingh	112	111	101	90
Tangail	104	104	90	87
Southwestern				
Jessore	101	96	87	83
Satkhira	97	94	86	81
Southern				
Barisal	105	99	91	84
Madaripur	101	98	91	85
Southeastern				
Chandpur	105	102	92	84
Comilla	109	105	96	85
Eastern				
Sylhet	121	121	110	95

Table 4.41: Predicted physiological maturity (days) of BR14 for different planting dates

Location	**2008**			
	1 January	5 January	15 January	25 January
Northwestern				
Rajshahi	100	100	92	88
Bogra	111	108	105	101
Dinajpur	115	110	110	107
Central				
Mymensingh	117	116	112	108
Tangail	108	108	104	100
Southwestern				
Jessore	105	103	101	97
Satkhira	103	101	97	96
Southern				
Barisal	111	102	105	102
Madaripur	108	106	101	98
Southeastern				
Chandpur	110	108	105	101
Comilla	114	109	109	105
Eastern				
Sylhet	125	124	121	119

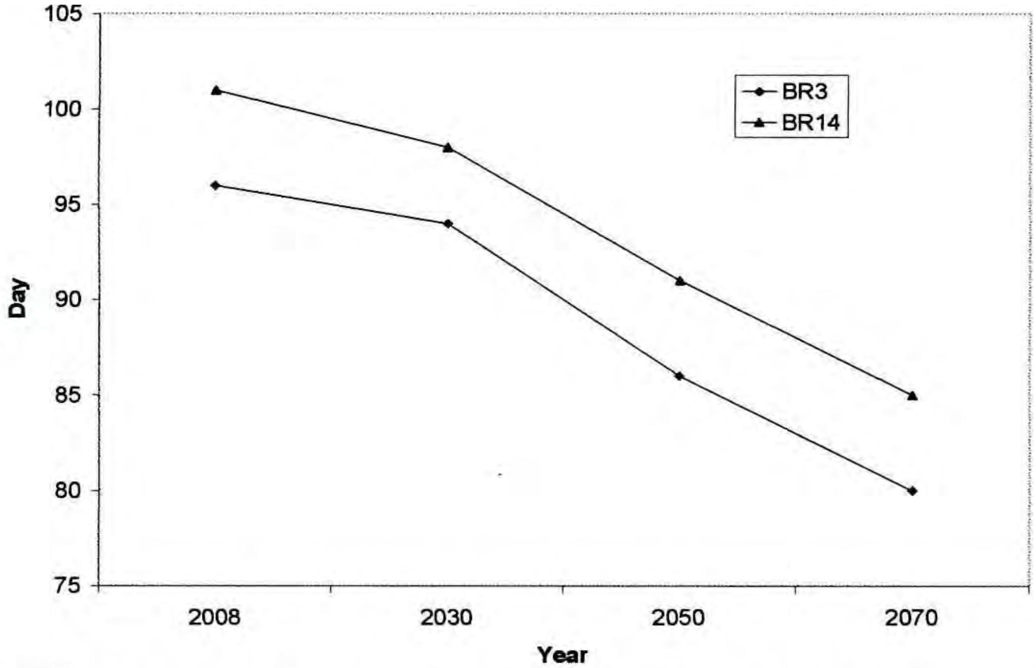

Figure 4.17: Predicted physiological maturity (days) of BR3 and BR14 varieties of rice for Madaripur

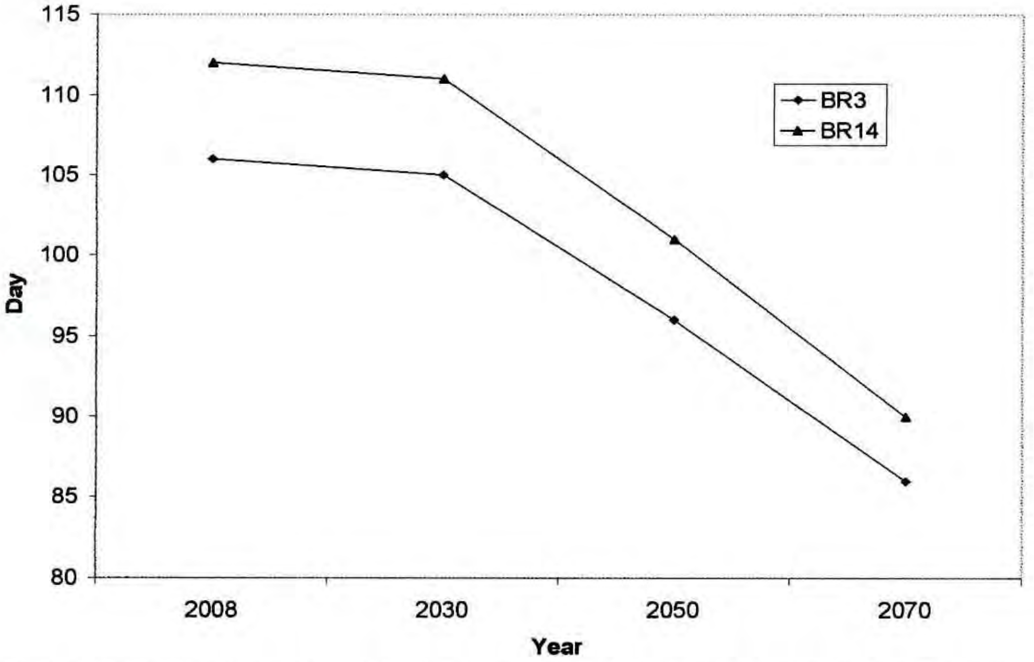

Figure 4.18: Predicted physiological maturity (days) of BR3 and BR14 varieties of rice for Mymensingh

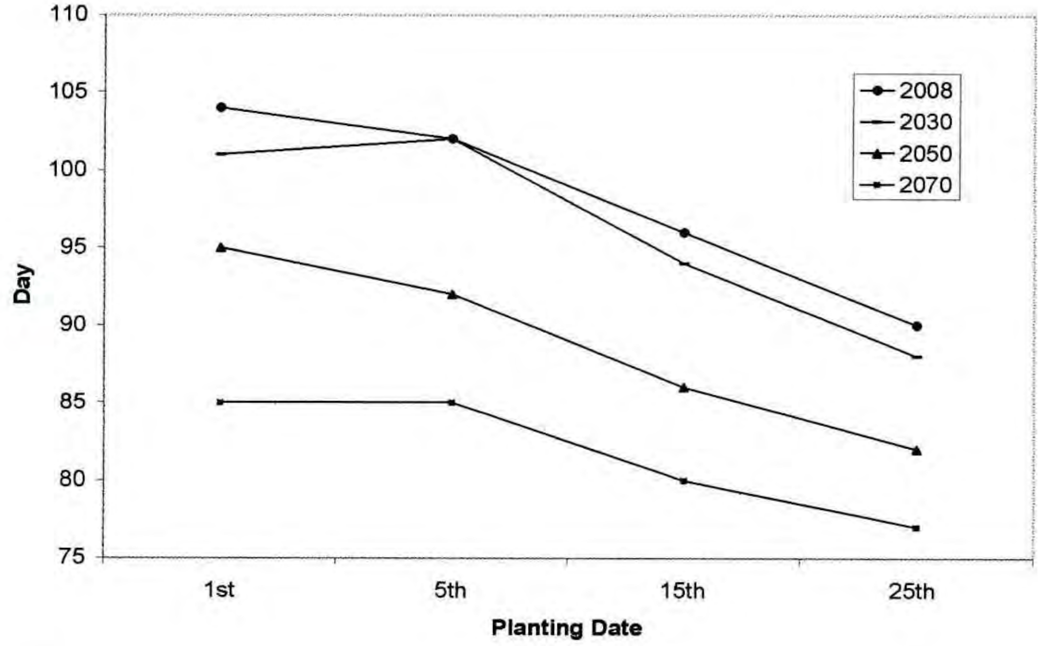

Figure 4.19: Predicted physiological maturity (days) of BR3 for different planting dates at Madaripur

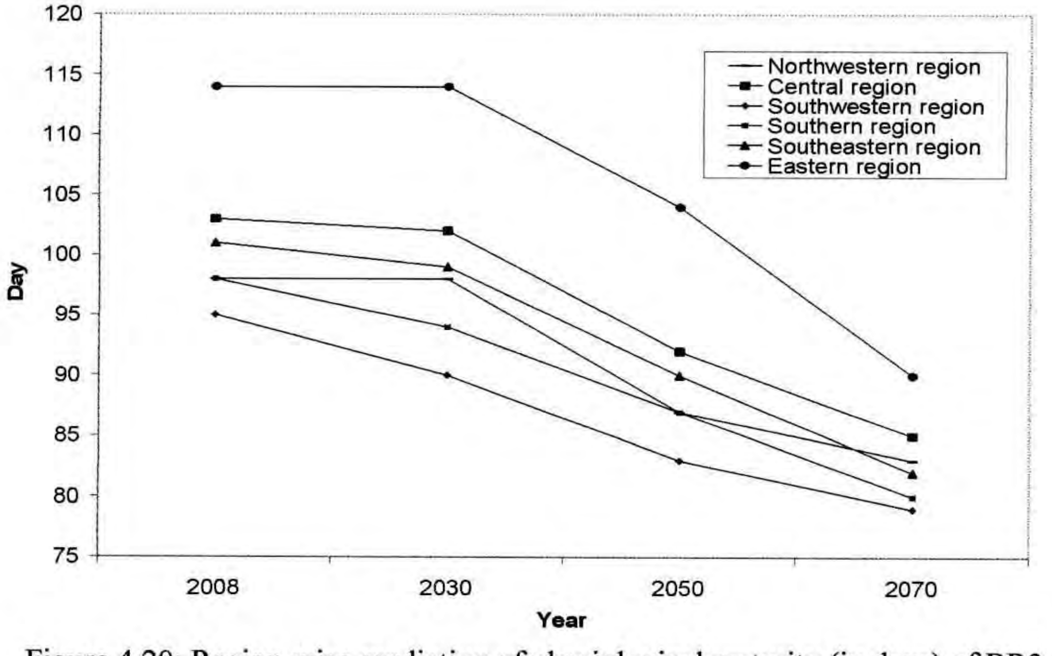

Figure 4.20: Region-wise prediction of physiological maturity (in days) of BR3 rice

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Major conclusions and findings from the present study are summarized below:

(A) Trend in Maximum Temperature and Number of Hot Days:

- Yearly average maximum temperature for the period 1976-2005 shows increasing trends at most of the weather stations all over the country.Yearly average maximum temperature shows increasing trend in 28 out of 34 stations; increasing trend at 15 stations are significant at 99% confidence level and 1 station at 95%. Yearly average temperature increased at the rate of 0.0193^0C per year during 1976-2005.
- Monthly average maximum temperature during 1976-2005 shows increasing trend, even with higher level of significance. Monthly average maximum shows increasing trend for all months of the year except January; the increasing trend was particularly significant for the months of February, April and May. On an average, monthly-average maximum temperatures of each of these months have increased by about 1 °C during the 30 year period from 1976-2005.
- Number of hot days (i.e., day with avg. temperature exceeding 29.3^0C) show sharp increasing trend in 18 (out of 32) weather stations.

(B) Trend in Minimum Temperature and Number of Cold Days:

- Yearly average minimum temperature for the period (1976-2005 and cold days show sharp increasing trend. Yearly average minimum temperature shows increasing trend in 27 out of 34 stations all over the country; increasing trend at 10 stations were significance level at 99% confidence. Yearly average temperature during the period 1976-2005 increased at rate of 0.0152^0C per year.

- Monthly average minimum temperature during the period 1976-2005 also showed increasing trend. Monthly average minimum temperature shows increasing trend for all months of the year except January; the increasing trend was particularly significant for the months of February, April and May. On an average, monthly-average minimum temperatures of each of these months increased by about 0.80 °C during the period (i.e., 1976 to 2005).
- Number of cold days (i.e., days with average temperature below $20.1^{0}C$) shows decreasing trend in 13 stations and increasing in 18 stations during the period from 1976-2005.

(C) Changes in Precipitation Pattern:

- During 1976-2005, total rainfall shows an increasing trend during the pre-monsoon (March-May) period and a decreasing trend during the winter (December-February).
- During pre-monsoon, the total rainfall showed increasing trend for 20 out of 34 weather stations; however, the changes in only 5 stations have significance above 90%.
- Total rainfall during winter shows decreasing trend in 18 out of 34 stations, with 4 stations having trends significant above 90% level of confidence.

(D) Impacts of Climate Change on Boro-Rice Yield:

- Significant reduction in boro-rice yields in future is predicted changes in climatic condition.
- Compared to 2008, predicted average reductions of BR3 variety of rice for the 12 selected locations are about 11% for the year 2030, 21% for 2050 and 54% for 2070. Some regional variation could be observed in the predictions with somewhat higher reductions predicted for central, southern and southwestern regions. The maximum yield reduction was predicted at Dinajpur (29.55% in 2030, 36.27 % in 2050) and at Barisal (65.39% in 2070).

- Compared to 2008, predicted average reductions of BR14 variety for the 12 selected locations are about 14% for the year 2030, 25% for 2050 and 58% for 2070. Some regional variation could be observed in the predictions. The maximum yield reduction was predicted at Barisal (34.29% in 2030), at Dinajpur (40.10% in 2050) and at Tangail (68.39% in 2070). BR14 appears to be slightly more sensitive to climate change than BR3.
- Increasing CO_2 concentrations are likely to offset only slightly the adverse effects of other climatic parameters on rice yield. When the CO_2 levels were increased to 427, 465 and 503 ppm in 2030, 2050 and 2070, respectively, predicted yield increased by 0.91 to 12.5% for BR3 rice and 0.09 to 13.7% for BR14 rice.
- Increases in daily maximum and minimum temperatures have been found to be primarily responsible for reduction in yield. Increases in incoming solar radiation and atmospheric carbon-di-oxide concentration increases rice yield to some extent, but their effects are not significant compared to the negative effects of temperature. Variations in rainfall pattern over the growing period have also been found to affect rice yield and water requirement.

(E) Impact of Climate Change and Transplanting Date on Yield:

- Rice yield appears to be very vulnerable to transplanting date model result predicted significant reduction in yield as transplanting date is delayed, especially beyond 15 January.
- The predictions indicate that 1 to 15 January is the most effective time for boro rice transplanting in 2008 and 2030. The effect of planting date appears to be more pronounced for the years 2050 and 2070. 1 January would be the most productive time for transplanting in 2050 and 2070.
- These are regional variation on effect of transplanting date. Predicted yields show more pronounced affect of planting data for locations in northwestern and central regions for both (BR3 and BR14) varieties.

(F) Effect of Climate Change on Water Requirement:

- Maximum water requirements were predicted for northwestern region, which represent drought prone region in Bangladesh and the minimum water requirements are predicted for eastern region where more rainfall occurs in boro season.
- Planting dates influence water requirement significantly. It was found that water requirement was comparatively higher, if boro rice is planted during 1 to 5 January (compared to 15 and 25 January).
- Climatic factors (temperature, rainfall, etc.), soil conditions and physiological maturity days have a significant role on water requirement for rice. Higher temperature and increased solar radiation lead to higher evapotranspiration but shortens the physiological maturity duration; these two phenomenons have opposite effect on water requirement. Changes the annual precipitation patterns also affect the water requirement.

(G) Effect of Climate Change on Physiological Maturity:

- The time of physiological maturity has been predicted to decrease significantly due to changes in climatic scenario. Changes in temperatures and solar radiation are the main factors affecting physiological maturity of rice. Physiological maturity (in days) of BR3 rice varieties varied from 93 (in Satkhira) to 114 (in Sylhet) in 2008; while the corresponding values are 77 and 90 in 2070.
- Planting dates influence physiological maturity significantly. Physiological maturity was predicted to be relatively higher if boro rice is planted during1 to 5 January (compared to 15 and 25 January).

(H) Issues to be Considered for Adaptation:

- Since higher temperature could significantly reduce yield of boro rice, it is necessary to develop more temperature and drought tolerant rice varieties.
- Management practices e.g. selected of transplanting date, application of irrigation and fertilizer should be optimized to adapt for changing climate scenarios.

5.2 RECOMMENDATIONS FOR FUTURE STUDIES

Based on present research work, some recommendation can be suggested for further study. These are as follows:

- The temperature and precipitation patterns are of great importance for an agro-based economy like Bangladesh. Therefore, it is necessary to regularly and systematically compile, monitor and analyze climatic parameters related to agriculture.
- The trends for intense precipitation events (which could not be assessed in this study due to absence of relevant data) should be analyzed and its impact on flood (especially flash flood) and agriculture should be assessed.
- The risk of drought is a major concern and the risk of drought should be assessed. It would be useful to develop a simple drought index which could be used to easily assess the drought situation in any particular region (e.g., the northern region).
- Many other climate change phenomenon (e.g., more intense precipitation, increase in flood and cyclone peaks, increase of heat index over lands etc.) could be analyzed to predict the future changes and projections.
- BR3 and BR14 rice varieties are not widely used at present, the model simulations carried out in this study provide useful insight into the possible effects of climate change on rice yield. Further research can be performed to evaluate the effect of climate change for new varieties like BRRIdhan28, BRRIdhan29 and other crops.
- The yield of two boro varieties BR3 and BR14 for the years 2008, 2030, 2050 and 2070 have been simulated for 12 districts of Bangladesh, which were selected from among the major rice growing areas in different regions of Bangladesh. Similar type of study can be conducted for other rice growing areas of Bangladesh.

- In the present study, soil data were collected from literature for the 12 rice growing areas. More reliable predictions could be made if the required soil parameters for different regions could be generated based on laboratory and field experiment.
- Sensitivity analysis was carried out for some selected areas only, using predicted climatic parameters for the years 2008 and 2070, changing one parameter at a time. Similar type of study can be conducted for other areas of Bangladesh to assess relative importance of these parameters on rice yield.
- Further research can be performed under various treatments and management conditions like irrigation, fertilizer, chemical applications, organic carbon, atmospheric CO_2 concentrations, etc.
- The predicted (using PRECIS) temperature and rainfall values used in the present study have not been calibrated on daily scale. Uncertainty in assessing possible impacts of climate change may be reduced using high resolution climate model outputs with ensembles and calibrated outputs.

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APPENDIX- A
(Assessment of Climate Change Trends in Bangladesh)

Table A 3.1: Regression equation and correlation coefficient of average maximum temperature for different stations in January for the period 1976-2005

Station	Trend Line Equation	Value of Correlation coefficient (r)	Significant/Insignificant
Barisal	Y=-0.0165X+58.196	-0.17059	Below 90% Significant
Bhola	Y=-0.0269X+79.044	-0.27258	Below 90% Significant
Bogra	Y=-0.0908X+205.33	-0.48795	99% Significant
Chandpur	Y=-0.0698X+163.7	-0.56524	99% Significant
Chittagong	Y=0.0327X-39.05	0.33675	90% Significant
Chuadanga	Y=-0.0635X+151.09	-0.27982	95% Significant
Comilla	Y=-0.0381X+101.08	-0.33985	90% Significant
Tangail	Y=-0.057X+137.52	-0.24331	Below 90% Significant
Cox's Bazar	Y=0.0362X-45.176	0.38262	95% Significant
Dhaka	Y=-0.0512X+127.02	-0.37162	95% Significant
Dinajpur	Y=-0.0756X+173.77	-0.38392	95% Significant
Faridpur	Y=-0.0281X+80.245	-0.22517	Below 90% Significant
Feni	Y=-0.0455X+116.5	-0.42942	95% Significant
Sylhet	Y=0.028X-30.383	0.18248	Below 90% Significant
Hatiya	Y=0.0424X-58.135	0.40336	95% Significant
Ishurdi	Y=-0.0507X+125.13	-0.40644	95% Significant
Jessore	Y=-0.0432X+111.49	-0.38794	95% Significant
Khepupara	Y=-0.005X+35.728	-0.0707	Below 90% Significant
Khulna	Y=-0.0158X+56.806	-0.1562	Below 90% Significant
Kutubdia	Y=-0.0222X-18.828	-0.181107	Below 90% Significant
M. Court	Y=-0.0438X+112.35	-0.39446	95% Significant
Madaripur	Y=-0.0345X+93.923	-0.28827	Below 90% Significant
Mongla	Y=0.0086X+8.0277	0.04795	Below 90% Significant
Mymensingh	Y=-0.0519X+127.97	-0.39	95% Significant
Patuakhali	Y=-0.0218X+68.964	-0.23388	Below 90% Significant
Rajshahi	Y=-0.0548X+133.19	-0.4322	95% Significant
Rangamati	Y=0.0326X-39.298	0.33793	90% Significant
Rangpur	Y=-0.0205X+63.825	-0.09165	Below 90% Significant
Shandwip	Y=-0.0424X+109.27	-0.34612	90% Significant
Satkhira	Y=-0.0614X+148	-0.51147	99% Significant
Sayedpur	Y=0.0146X-6.5164	0.04583	Below 90% Significant
Sitakunda	Y=0.0424X-58.135	0.40336	95% Significant
Srimangal	Y=-0.0264X+77.703	-0.19925	Below 90% Significant
Teknaf	Y=0.0225X-17.498	0.26495	Below 90% Significant

Table A 3.2: Regression equation and correlation coefficient of average maximum temperature for different stations in February for the period 1976-2005

Station	Trend Line Equation	Value of Correlation coefficient (r)	Significant/Insignificant
Barisal	Y=0.0414X-54.059	0.36687	95% Significant
Bhola	Y=0.021X-13.396	0.17464	Below 90% Significant
Bogra	Y=-0.0561X+143.28	-0.39038	95% Significant
Chandpur	Y=0.0194X-10.866	0.16309	Below 90% Significant
Chittagong	Y=0.0863X-143.4	0.57175	99.9% Significant
Chuadanga	Y=0.0596X-90.61	0.22361	Below 90% Significant
Comilla	Y=0.0232X-18.508	0.19975	90% Significant
Tangail	Y=0.0594X-91.355	0.25	Below 90% Significant
Cox's Bazar	Y=0.0723X-115.17	0.56365	99.9% Significant
Dhaka	Y=0.0222X-16.006	0.14832	Below 90% Significant
Dinajpur	Y=0.0387X-50.654	0.22	Below 90% Significant
Faridpur	Y=0.0373X-46.538	0.28478	90% Significant
Feni	Y=0.0087X+11.51	0.07874	Below 90% Significant
Sylhet	Y=0.0528X-77.612	0.3245	90% Significant
Hatiya	Y=0.0501X-72.131	0.45266	90% Significant
Ishurdi	Y=0.0336X-39.529	0.24269	Below 90% Significant
Jessore	Y=0.0355X-41.981	0.25159	Below 90% Significant
Khepupara	Y=0.0352X-41.608	0.27549	Below 90% Significant
Khulna	Y=0.0463X-63.575	0.37589	95% Significant
Kutubdia	Y=0.0596X-91.561	0.46615	95% Significant
M. Court	Y=0.0373X-46.493	0.2773	Below 90% Significant
Madaripur	Y=0.0159X-3.3623	0.12329	Below 90% Significant
Mongla	Y=0.0978X-166.59	0.43577	90% Significant
Mymensingh	Y=-0.0148X+56.495	-0.11314	Below 90% Significant
Patuakhali	Y=0.038X-47.115	0.30083	Below 90% Significant
Rajshahi	Y=0.0222X+16.403	0.15524	Below 90% Significant
Rangamati	Y=0.0693X-109.21	0.43127	95% Significant
Rangpur	Y=0.0518X-77.103	0.25338	Below 90% Significant
Shandwip	Y=0.0103X+6.8543	0.07348	Below 90% Significant
Satkhira	Y=0.0093X+10.378	0.07141	Below 90% Significant
Sayedpur	Y=0.1014X-176.21	0.30984	Below 90% Significant
Sitakunda	Y=0.0885X-147.58	0.55426	99% Significant
Srimangal	Y=0.0522X-76.13	0.32	90% Significant
Teknaf	Y=0.033X-36.713	0.2429	Below 90% Significant

Table A 3.3: Regression equation and correlation coefficient of average monthly maximum temperature for different stations in March for the period 1976-2005

Station	Trend Line Equation	Value of Correlation coefficient (R)	Significant/Insignificant
Barisal	Y=0.0046X+22.962	0.03606	Below 90% Significant
Bhola	Y=-0.0128X+57.235	-0.09899	Below 90% Significant
Bogra	Y=-0.0561X+143.28	-0.39038	95% Significant
Chandpur	Y=-0.0211X+73.624	-0.16217	Below 90% Significant
Chittagong	Y=0.0422X-53.221	0.35114	90% Significant
Chuadanga	Y=0.0301X-26.962	0.10392	Below 90% Significant
Comilla	Y=-0.008X+46.676	-0.0648	Below 90% Significant
Tangail	Y=0.0423X-52.997	0.18248	Below 90% Significant
Cox's Bazar	Y=0.0646X-97.361	0.53413	99% Significant
Dhaka	Y=-0.0121X+56.517	-0.07211	Below 90% Significant
Dinajpur	Y=0.0141X+2.7767	0.06403	Below 90% Significant
Faridpur	Y=-0.0168X+65.816	-0.1044	Below 90% Significant
Feni	Y=-0.0281X+87.253	-0.20518	Below 90% Significant
Sylhet	Y=0.0202X-9.7733	0.12961	Below 90% Significant
Hatiya	Y=-0.004X+38.585	-0.04358	Below 90% Significant
Ishurdi	Y=-0.0186X+69.862	-0.10392	Below 90% Significant
Jessore	Y=-0.0074X+48.11	-0.04472	Below 90% Significant
Khepupara	Y=0.0235X-15.225	0.18735	Below 90% Significant
Khulna	Y=-0.0064X+45.708	-0.04359	Below 90% Significant
Kutubdia	Y=0.0478X-65.369	0.3228	Below 90% Significant
M. Court	Y=0.0145X+2.3354	0.11314	Below 90% Significant
Madaripur	Y=-0.0164X+65.206	-0.11789	Below 90% Significant
Mongla	Y=0.0757X-118.68	0.3002	Below 90% Significant
Mymensingh	Y=-0.0712X+172.66	-0.44283	99% Significant
Patuakhali	Y=0.0297X-27.145	0.23108	Below 90% Significant
Rajshahi	Y=-0.0241X+80.99	-0.14071	Below 90% Significant
Rangamati	Y=0.0374X-42.512	0.24597	Below 90% Significant
Rangpur	Y=0.0146X+1.0388	0.06708	Below 90% Significant
Shandwip	Y=0.0098X+10.345	0.08544	Below 90% Significant
Satkhira	Y=-0.0254X+83.522	-0.15427	Below 90% Significant
Sayedpur	Y=-0.0268X+84.191	-0.09381	Below 90% Significant
Sitakunda	Y=0.0648X-98.161	0.41797	95% Significant
Srimangal	Y=-0.033X+97.248	-0.21189	Below 90% Significant
Teknaf	Y=0.0385X-45.905	0.44283	90% Significant

Table A 3.4: Regression equation and correlation coefficient of average monthly maximum temperature for different stations in April for the period 1976-2005

Station	Trend Line Equation	Value of Correlation coefficient (r)	Significant/Insignificant
Barisal	Y=0.0107X+12.103	0.08944	Below 90% Significant
Bhola	Y=0.0148X+3.4178	0.11916	Below 90% Significant
Bogra	Y=-0.0792X+191.42	-0.38781	95% Significant
Chandpur	Y=0.0065X+19.907	0.05196	Below 90% Significant
Chittagong	Y=0.0463X-60.341	0.39535	95% Significant
Chuadanga	Y=-0.1373X+310.08	-0.38367	90% Significant
Comilla	Y=0.0446X-56.635	0.2874	Below 90% Significant
Tangail	Y=-0.064X+161.54	-0.22517	Below 90% Significant
Cox's Bazar	Y=0.0809X-128.59	0.63741	99% Significant
Dhaka	Y=0.0078X+18.133	0.04359	Below 90% Significant
Dinajpur	Y=-0.046X+124.6	-0.16823	Below 90% Significant
Faridpur	Y=0.0204X-6.3486	0.11789	Below 90% Significant
Feni	Y=-0.0049X+41.968	-0.03606	Below 90% Significant
Sylhet	Y=0.036X-40.837	0.20904	Below 90% Significant
Hatiya	Y=0.0118X+55.406	-0.12688	Below 90% Significant
Ishurdi	Y=-0.0268X+88.861	-0.11874	Below 90% Significant
Jessore	Y=-0.0019X+39.476	-0.01	Below 90% Significant
Khepupara	Y=0.0299X-27.058	0.23685	Below 90% Significant
Khulna	Y=-0.0021X+38.742	-0.01414	Below 90% Significant
Kutubdia	Y=0.0577X-83.422	0.48539	95% Significant
M. Court	Y=0.0568X-80.554	0.40731	95% Significant
Madaripur	Y=-0.0007X+35.461	-0.00447	Below 90% Significant
Mongla	Y=0.0255X-16.433	0.11	Below 90% Significant
Mymensingh	Y=-0.0656X+162.64	-0.36905	95% Significant
Patuakhali	Y=0.0525X-71.489	0.37907	95% Significant
Rajshahi	Y=-0.0213X+78.337	-0.09487	Below 90% Significant
Rangamati	Y=0.0637X-93.717	0.36441	95% Significant
Rangpur	Y=-0.0437X+118.63	-0.21071	Below 90% Significant
Shandwip	Y=-0.0107X+52.765	-0.06324	Below 90% Significant
Satkhira	Y=-0.0213X+78.337	-0.09487	Below 90% Significant
Sayedpur	Y=-0.2179X+467.54	-0.5447	99% Significant
Sitakunda	Y=0.0615X-90.586	0.44855	95% Significant
Srimangal	Y=-0.0158X+64.262	-0.08426	Below 90% Significant
Teknaf	Y=0.0338X-35.39	0.3708	95% Significant

Table A 3.5: Regression equation and correlation coefficient of average monthly maximum temperature for different stations in May for the period 1976-2005

Station	Trend Line Equation	Value of Correlation coefficient (r)	Significant/Insignificant
Barisal	Y=0.0317X-30.02	0.32818	90% Significant
Bhola	Y=0.0259X-18.952	0.29292	Below 90% Significant
Bogra	Y=0.0246X-16.024	0.12329	Below 90% Significant
Chandpur	Y=0.0175X-1.8927	0.17578	Below 90% Significant
Chittagong	Y=0.0287X-24.744	0.35874	95% Significant
Chuadanga	Y=0.0051X+25.486	0.02236	Below 90% Significant
Comilla	Y=0.0424X-52.139	0.34	90% Significant
Tangail	Y=0.0272X-21.225	0.13601	Below 90% Significant
Cox's Bazar	Y=0.0577X-82.214	0.6403	99.9% Significant
Dhaka	Y=0.0359X-38.424	0.24393	Below 90% Significant
Dinajpur	Y=0.0273X-21.952	0.12207	Below 90% Significant
Faridpur	Y=0.0368X-39.748	0.27928	Below 90% Significant
Feni	Y=0.0057X+20.884	0.05292	Below 90% Significant
Sylhet	Y=0.0448X-58.392	0.26907	Below 90% Significant
Hatiya	Y=0.0022X+27.619	0.02449	Below 90% Significant
Ishurdi	Y=0.0216X-8.5133	0.11314	Below 90% Significant
Jessore	Y=0.0592X-82.596	0.39192	95% Significant
Khepupara	Y=0.03X-27.113	0.31289	90% Significant
Khulna	Y=0.0415X-48.218	0.41243	95% Significant
Kutubdia	Y=0.0187X-5.0758	0.1456	Below 90% Significant
M. Court	Y=0.0403X-47.663	0.29816	Below 90% Significant
Madaripur	Y=0.0404X-46.858	0.36523	90% Significant
Mongla	Y=0.0752X-115.85	0.46819	90% Significant
Mymensingh	Y=0.0148X+2.0056	0.0938	Below 90% Significant
Patuakhali	Y=0.0507X-68	0.50418	99.9% Significant
Rajshahi	Y=0.0315X-27.933	0.15811	Below 90% Significant
Rangamati	Y=0.0416X-50.04	0.30643	90% Significant
Rangpur	Y=0.0084X+14.972	0.04472	Below 90% Significant
Shandwip	Y=-0.0153X+62.098	-0.11576	Below 90% Significant
Satkhira	Y=0.0053X+24.715	0.04359	Below 90% Significant
Sayedpur	Y=0.015X+2.3433	0.04242	Below 90% Significant
Sitakunda	Y=0.0414X-50.381	0.38756	95% Significant
Srimangal	Y=-0.0121X+56.039	-0.07071	Below 90% Significant
Teknaf	Y=0.0222X-12.065	0.31969	90% Significant

Table A 3.6: Regression equation and correlation coefficient of average minimum temperature for different stations in January for the period 1976-2005

Station	Trend line equation	Value of correlation co-efficient, (r)	Significant/Insignificant
Barisal	Y=0.0051X+1.5741	0.05916	Below 90% significant
Bhola	Y=0.0077X-2.9749	0.07745	Below 90% significant
Bogra	Y=-0.0111X+33.744	-0.1048	Below 90% significant
Chandpur	Y=0.0387X-63.835	0.38884	95% significant
Chittagong	Y=0.0254X-36.757	0.2711	Below 90% significant
Chuadanga	Y=0.052X-93.13	0.26457	Below 90% significant
Comilla	Y=-0.0045X+20.972	-0.04795	Below 90% significant
Cox's Bazar	Y=0.0524X-89.223	0.52268	99.9% significant
Dhaka	Y=0.037X-60.77	0.30413	90% significant
Dinajpur	Y=0.0009X+8.4083	0.00707	Below 90% significant
Faridpur	Y=-0.0132X+38.45	-0.1473	Below 90% significant
Feni	Y=-0.0146X+41.703	-0.17117	Below 90% significant
Hatiya	Y=-0.0726X+158.93	-0.60398	99.90% significant
Ishurdi	Y=-0.0002X+10.689	-0.002	Below 90% significant
Jessore	Y=-0.0379X+86.813	-0.26286	Below 90% significant
Khepupara	Y=-0.0411X+95.583	-0.45934	99% significant
Khulna	Y=-0.0469X+105.69	-0.32924	90% significant
Kutubdia	Y=0.0104X-5.8939	0.08366	90% significant
M. Court	Y=0.0527X-91.498	0.46572	99% significant
Madaripur	Y=0.0469X-81.359	0.33778	90% significant
Mongla	Y=0.0059X+2.1176	0.04123	Below 90% significant
Mymensingh	Y=-0.0129X+55.426	-0.28496	Below 90% significant
Patuakhali	Y=-0.0155X+44.379	-0.14866	Below 90% significant
Rajshahi	Y=-0.0529X+116.12	-0.41533	99% significant
Rangamati	Y=-0.1144X+241.2	-0.71295	99.9% significant
Rangpur	Y=0.003X+4.7843	0.031	Below 90% significant
Sandwip	Y=-0.0214X+56.969	-0.17606	Below 90% significant
Satkhira	Y=-0.0414X+94.385	-0.34971	95% significant
Sayedpur	Y=0.0154X-20.12	0.06782	Below 90% significant
Sitakunda	Y=-0.051X+113.67	-0.39736	95% significant
Srimongal	Y=0.0199X-29.92	0.141	Below 90% significant
Sylhet	Y=0.0407X-68.412	0.4305	99% significant
Tangail	Y=-0.0377X+86.46	-0.22383	Below 90% significant
Teknaf	Y=-0.0078X+30.591	-0.08831	Below 90% significant

Table A 3.7: Regression equation and correlation coefficient of average minimum temperature for different stations in February for the period 1976-2005

Station	Trend line equation	Value of correlation co-efficient, (r)	Significant/Insignificant
Barisal	Y=0.0384X-61.514	0.3451	95% significant
Bhola	Y=0.0273X-38.587	0.26925	Below 90% significant
Bogra	Y=0.0496X-84.447	0.43069	99% significant
Chandpur	Y=0.0544X-92.411	0.41665	95% significant
Chittagong	Y=0.0503X-83.805	0.44215	99% significant
Chuadanga	Y=0.0669X-119.33	0.37696	Below 90% significant
Comilla	Y=0.0203X-25.167	0.2133	Below 90% significant
Cox's Bazar	Y=0.0603X-102.78	0.62809	99.9% significant
Dhaka	Y=0.0641X-111.73	0.52763	99.9% significant
Dinajpur	Y=0.0668X-120.47	0.43485	95% significant
Faridpur	Y=0.0373X-59.298	0.3477	95% significant
Feni	Y=0.0057X+4.4389	0.05385	Below 90% significant
Hatiya	Y=-0.0353X+87.073	-0.29017	Below 90% significant
Ishurdi	Y=0.0702X-126.72	0.60224	99.9% significant
Jessore	Y=0.0186X-22.342	0.2076	Below 90% significant
Khepupara	Y=0.0135X-10.098	0.14	Below 90% significant
Khulna	Y=0.0089X-2.2121	0.0728	Below 90% significant
Kutubdia	Y=0.0025X+12.325	0.02	Below 90% significant
M. Court	Y=0.0876X-158.53	0.54571	99% significant
Madaripur	Y=0.088X-160.24	0.65825	99.99% significant
Mongla	Y=-0.0311X+79.567	-0.22383	Below 90% significant
Mymensingh	Y=0.0706X-126.16	0.55136	99% significant
Patuakhali	Y=0.0147X-12.818	0.13527	Below 90% significant
Rajshahi	Y=0.0029X+7.3347	0.02645	Below 90% significant
Rangamati	Y=-0.1112X+237.08	-0.64544	99.9% significant
Rangpur	Y=0.0554X-97.414	0.41158	95% significant
Sandwip	Y=0.0278X-38.229	0.2846	Below 90% significant
Satkhira	Y=0.0138X-11.89	0.12806	Below 90% significant
Sayedpur	Y=0.1229X-232.2	0.50586	95% significant
Sitakunda	Y=-0.0284X+71.531	-0.22068	Below 90% significant
Srimongal	Y=-0.0243X+60.908	-0.17378	Below 90% significant
Sylhet	Y=0.0585X-101.95	0.47602	99% significant
Tangail	Y=0.0089X-3.4414	0.05744	Below 90% significant
Teknaf	Y=0.0036X+9.8092	0.04582	Below 90% significant

Table A 3.8: Regression equation and correlation coefficient of average minimum temperature for different stations in March for the period 1976-2005

Station	Trend line equation	Value of correlation Co-efficient, (r)	Significant/Insignificant
Barisal	Y=0.0111X-1.8946	0.07483	Below 90% significant
Bhola	Y=0.0175X-14.075	0.12767	Below 90% significant
Bogra	Y=0.0513X-83.412	0.42391	99% significant
Chandpur	Y=0.042X-63.156	0.27856	Below 90% significant
Chittagong	Y=0.0313X-41.921	0.24186	Below 90% significant
Chuadanga	Y=0.0703X-121.49	0.2853	Below 90% significant
Comilla	Y=-0.0095X+38.627	-0.06633	Below 90% significant
Cox's Bazar	Y=0.0523X-83.206	0.46368	99% significant
Dhaka	Y=0.0186X-16.474	0.13564	Below 90% significant
Dinajpur	Y=0.0798X-141.99	0.52735	99% significant
Faridpur	Y=0.007X+5.7829	0.05196	Below 90% significant
Feni	Y=-0.0231X+66.393	-0.14899	Below 90% significant
Hatiya	Y=-0.0446X+109.9	-0.39547	95% significant
Ishurdi	Y=0.0474X-76.334	0.33391	95% significant
Jessore	Y=-0.0122X+43.774	-0.09591	Below 90% significant
Khepupara	Y=0.0023X+17.122	0.02	Below 90% significant
Khulna	Y=-0.002X+24.364	-0.01414	Below 90% significant
Kutubdia	Y=-0.013X+46.942	-0.08717	Below 90% significant
M. Court	Y=0.0787X-136.71	0.40509	95% significant
Madaripur	Y=0.0445X-68.714	0.27748	Below 90% significant
Mongla	Y=0.0184X-14.857	0.0938	Below 90% significant
Mymensingh	Y=0.0778X-136.49	0.47201	99% significant
Patuakhali	Y=0.0145X-7.8981	0.10908	Below 90% significant
Rajshahi	Y=0.0113X-4.6412	0.0781	Below 90% significant
Rangamati	Y=-0.0867X+192.36	-0.48197	99% significant
Rangpur	Y=0.0645X-111.51	0.47696	99% significant
Sandwip	Y=0.0171X-12.367	0.09949	Below 90% significant
Satkhira	Y=-0.0106X+41.753	-0.0728	Below 90% significant
Sayedpur	Y=0.1068X-196.07	0.37282	Below 90% significant
Sitakunda	Y=-0.0097X+39.007	-0.05196	Below 90% significant
Srimongal	Y=-0.0131X+43.532	-0.06082	Below 90% significant
Sylhet	Y=0.0389X-59.153	0.28583	Below 90% significant
Tangail	Y=0.0184X-14.857	0.0938	Below 90% significant
Teknaf	Y=0.0172X-13.654	0.17	Below 90% significant

Table A 3.9: Regression equation and correlation coefficient of average minimum temperature for different stations in April for the period 1976-2005

Station	Trend line equation	Value of correlation co-efficient, (r)	Significant/Insignificant
Barisal	Y=0.0054X+12.843	0.0469	Below 90% significant
Bhola	Y=0.0326X-41.096	0.27964	Below 90% significant
Bogra	Y=0.0133X-3.9966	0.12083	Below 90% significant
Chandpur	Y=0.0518X-79.87	0.41472	95% significant
Chittagong	Y=0.0498X-75.665	0.41569	95% significant
Chuadanga	Y=0.0453X-67.121	0.23685	Below 90% significant
Comilla	Y=-0.012X+46.548	-0.09539	Below 90% significant
Cox's Bazar	Y=0.0334X-42.593	0.30886	90% significant
Dhaka	Y=0.0243X-24.885	0.18248	Below 90% significant
Dinajpur	Y=0.0765X-131.56	0.38832	95% significant
Faridpur	Y=0.0357X-47.983	0.29495	Below 90% significant
Feni	Y=-0.0038X+30.842	-0.03162	Below 90% significant
Hatiya	Y=-0.0065X+36.952	-0.07681	Below 90% significant
Ishurdi	Y=0.0457X-68.323	0.33045	90% significant
Jessore	Y=0.0037X+16.105	0.03605	Below 90% significant
Khepupara	Y=0.0075X+9.7601	0.06633	Below 90% significant
Khulna	Y=0.0216X-18.974	0.19544	Below 90% significant
Kutubdia	Y=0.0051X+13.929	0.03	Below 90% significant
M. Court	Y=0.0308X-37.964	0.25317	Below 90% significant
Madaripur	Y=0.0544X-85.087	0.39698	95% significant
Mongla	Y=0.0189X-12.947	0.10246	Below 90% significant
Mymensingh	Y=0.0052X+11.72	0.04123	Below 90% significant
Patuakhali	Y=0.012X+0.0178	0.1118	Below 90% significant
Rajshahi	Y=0.0174X-11.961	0.13928	Below 90% significant
Rangamati	Y=-0.0331X+88.619	-0.22494	Below 90% significant
Rangpur	Y=0.015X-8.8751	0.13856	Below 90% significant
Sandwip	Y=0.0075X+9.4306	0.0469	Below 90% significant
Satkhira	Y=-0.0052X+34.554	-0.0469	Below 90% significant
Sayedpur	Y=0.0014X+18.212	0.00894	Below 90% significant
Sitakunda	Y=-0.024X+71.316	-0.17549	Below 90% significant
Srimongal	Y=0.0008X+19.55	0.00707	Below 90% significant
Sylhet	Y=0.0275X-33.84	0.27676	Below 90% significant
Tangail	Y=0.0179X-13.165	0.09949	Below 90% significant
Teknaf	Y=0.0342X-44.265	0.29376	Below 90% significant

Table A 3.10: Regression equation and correlation coefficient of average minimum temperature for different stations in May for the period 1976-2005

Station	Trend line equation	Value of correlation Co-efficient, (r)	Significant/Insignificant
Barisal	Y=0.0163X-7.7967	0.17578	Below 90% significant
Bhola	Y=0.0377X-50.164	0.40484	95% significant
Bogra	Y=0.0319X-39.729	0.35355	95% significant
Chandpur	Y=0.0463X-67.652	0.44418	99% significant
Chittagong	Y=0.0361X-47.093	0.34626	95% significant
Chuadanga	Y=-0.0113X+47.639	-0.06855	Below 90% significant
Comilla	Y=0.0019X+20.185	0.02236	Below 90% significant
Cox's Bazar	Y=0.0157X-6.0149	0.17117	Below 90% significant
Dhaka	Y=0.0333X-41.76	0.3087	90% significant
Dinajpur	Y=0.1052X-186.71	0.43646	95% significant
Faridpur	Y=0.0466X-68.582	0.42118	99% significant
Feni	Y=0.0072X+9.9525	0.07549	Below 90% significant
Hatiya	Y=-0.006X+36.973	-0.07	Below 90% significant
Ishurdi	Y=0.0485X-72.348	0.38832	95% significant
Jessore	Y=0.0369X-48.564	0.3914	95% significant
Khepupara	Y=0.0227X-19.637	0.2184	Below 90% significant
Khulna	Y=0.0234X-21.493	0.25514	Below 90% significant
Kutubdia	Y=0.009X+7.4084	0.05916	Below 90% significant
M. Court	Y=0.0358X-46.477	0.36414	95% significant
Madaripur	Y=0.0627X-100.56	0.6044	99.99% significant
Mongla	Y=0.0005X+24.886	0.00316	Below 90% significant
Mymensingh	Y=0.061X-98.134	0.31859	90% significant
Patuakhali	Y=0.0145X-3.594	0.18138	Below 90% significant
Rajshahi	Y=0.0376X-50.677	0.33749	95% significant
Rangamati	Y=-0.0041X+32.055	-0.03316	Below 90% significant
Rangpur	Y=0.0167X-9.9952	0.17606	Below 90% significant
Sandwip	Y=-0.0045X+34.131	-0.03605	Below 90% significant
Satkhira	Y=0.0229X-20.117	0.21679	Below 90% significant
Sayedpur	Y=-0.0171X+57.605	-0.08888	Below 90% significant
Sitakunda	Y=0.0064X+11.951	0.0648	Below 90% significant
Srimongal	Y=0.006X+10.739	0.05567	Below 90% significant
Sylhet	Y=0.0378X-52.61	0.36193	95% significant
Tangail	Y=0.0198X-15.717	0.14282	Below 90% significant
Teknaf	Y=0.0263X-27.042	0.26925	Below 90% significant

Table A 3.11: Regression equation and correlation coefficient for variation of total rainfall in Winter for different stations for the period 1976-2005

Station	Trend Line Equation	Value of correlation coefficient (r)	Significant/Insignificant
Barisal	Y=0.1929X-342.9	0.0374	Below 90% Significant
Bhola	Y=-0.7595X+1557.5	-0.15795	Below 90% Significant
Bogra	Y=0.319X-603.49	0.09899	Below 90% Significant
Chandpur	Y=0.3566X-675.37	0.0894	Below 90% Significant
Chittagong	Y=1.2352X-2416.4	0.24617	Below 90% Significant
Chuadanga	Y=-3.1214X+6279.2	-0.31890	Below 90% Significant
Comilla	Y=0.682X-1313.6	0.14106	Below 90% Significant
Tangail	Y=-4.5686X+9167.7	-0.6135	99.9% Significant
Cox's Bazar	Y=0.6801X-1316.3	0.17	Below 90% Significant
Dhaka	Y=-0.3837X+806.24	-0.1019	Below 90% Significant
Dinajpur	Y=-0.3587X+746.27	-0.1077	Below 90% Significant
Faridpur	Y=-0.2897X+622.43	-0.06403	Below 90% Significant
Feni	Y=-0.2897X+622.43	-0.0608	Below 90% Significant
Sylhet	Y=0.5466X-1034.8	0.11	Below 90% Significant
Hatiya	Y=0.433X-845.51	0.09746	Below 90% Significant
Ishurdi	Y=-0.2452X+523.22	-0.06633	Below 90% Significant
Jessore	Y=-1.8484X+3731.4	-0.3248	90% Significant
Khepupara	Y=0.8076X-1569.2	0.17748	Below 90% Significant
Khulna	Y=-0.315X+683.32	-0.04242	Below 90% Significant
Kutubdia	Y=-0.7291X+1490.7	-0.10583	Below 90% Significant
M. Court	Y=-0.4795X+995.97	-0.09643	Below 90% Significant
Madaripur	Y=-0.056X+149.65	-0.01414	Below 90% Significant
Mongla	Y=-4.9615+9955.8	-0.5062	99% Significant
Mymensingh	Y=-0.408X+847.73	-0.10295	Below 90% Significant
Patuakhali	Y=0.0915X-146.62	0.02	Below 90% Significant
Rajshahi	Y=-1.022X+2070.7	-0.26057	Below 90% Significant
Rangamati	Y=0.9471X-1843.5	0.1737	Below 90% Significant
Rangpur	Y=0.1094X-190.04	0.04899	Below 90% Significant
Shandwip	Y=0.3654X-681.77	0.07	Below 90% Significant
Satkhira	Y=-0.9402X+1925.7	-0.16462	Below 90% Significant
Sayedpur	Y=-2.6209X+5263.9	-0.5342	99% Significant
Sitakunda	Y=1.5201X-2995.7	0.31096	90% Significant
Srimangal	Y=1.0422X-2028.2	0.2066	Below 90% Significant
Teknaf	Y=0.0891X-152.32	0.0244	Below 90% Significant

APPENDIX- B
(Effects of Climate Change on Boro Cultivation in Bangladesh)

Table B 4.1: Soil parameters

Parameters	Input data
Percentage of slope	1%
Run-off	Moderately Low
Fertility Factor	1
Run-off Curve Number	73
Albedo	0.11
Drainage rate	0.4
Root growth factor	0.0 to 1.0
<u>Calculate missing value</u> • Lower limit • Drained upper limit • Saturation, Bulk density (gm/cm^3) • Sat. hydraulic conduct (cm/h)	

Table B 4.2: Soil profile data for High Ganges River Floodplain (AEZ-11) (For Rajshahi region soil data)

Depth Bottom cm	Clay %	Silt %	Stones %	Organic Carbon %	pH in Water	Cation Exchange Capacity meq/100gm	Total Nitrogen %
5	6	19	0	.79	6.8	5.25	.11
15	6	19	0	.79	6.8	5.25	.11
30	6	19	0	.75	6.8	5.25	.10
45	6	19	0	.63	6.8	5.25	.09

Soil Texture: Sandy Loam

Table B 4.3: Soil profile data for Eastern Surma-Kushyara Floodplain (AEZ-20) (For Sylhet region soil data)

Depth Bottom cm	Clay %	Silt %	Stones %	Organic Carbon %	pH in Water	Cation Exchange Capacity meq/100gm	Total Nitrogen %
5	13	38	0	1.51	5.8	11.3	.14
15	13	38	0	1.51	5.8	11.3	.14
30	13	38	0	1.43	5.8	11.3	.13
45	13	38	0	1.22	5.8	11.3	.11

Soil Texture: Silt Loam

Table B 4.4: Soil profile data for Young Meghna Estuarine Floodplain (AEZ-18) (For Barisal region soil data)

Depth Bottom cm	Clay %	Silt %	Stones %	Organic Carbon %	pH in Water	Cation Exchange Capacity meq/100gm	Total Nitrogen %
5	13	38	0	.79	6.5	5.25	.23
15	13	38	0	.79	6.5	5.25	.23
30	13	38	0	.75	6.5	5.25	.22
45	13	38	0	.63	6.5	5.25	.19

Soil Texture: Silt Loam

Table B 4.5: Soil profile data for Gopalganj-Khulna Bils (AEZ-14) (For Jessore region soil data)

Depth Bottom cm	Clay %	Silt %	Stones %	Organic Carbon %	pH in Water	Cation Exchange Capacity meq/100gm	Total Nitrogen %
5	66	13	0	1.51	6.4	11.3	.41
15	66	13	0	1.51	6.4	11.3	.41
30	66	13	0	1.43	6.4	11.3	.40
45	66	13	0	1.22	6.4	11.3	.34

Soil Texture: Clayey

Table B 4.6: Soil profile data for Ganges Tidal Flood Plain (AEZ-13) (For Satkhira region soil data)

Depth Bottom cm	Clay %	Silt %	Stones %	Organic Carbon %	pH in Water	Cation Exchange Capacity meq/100gm	Total Nitrogen %
5	19	17.5	0	1.51	6.8	11.3	.23
15	19	17.5	0	1.51	6.8	11.3	.23
30	19	17.5	0	1.43	6.8	11.3	.22
45	19	17.5	0	1.22	6.8	11.3	.19

Soil Texture: Loamy

Table B 4.7: Soil profile data for Low Ganges River Flood Plain (AEZ-12) (For Madaripur region soil data)

Depth Bottom cm	Clay %	Silt %	Stones %	Organic Carbon %	pH in Water	Cation Exchange Capacity meq/100gm	Total Nitrogen %
5	13	38	0	1.51	7.0	11.3	.23
15	13	38	0	1.51	7.0	11.3	.23
30	13	38	0	1.43	7.0	11.3	.22
45	13	38	0	1.22	7.0	11.3	.19

Soil Texture: Silt Loam

Table B 4.8: Soil profile data for Old Brahmaputra Flood Plain (AEZ-9) (For Mymensingh region soil data)

Depth Bottom cm	Clay %	Silt %	Stones %	Organic Carbon %	pH in Water	Cation Exchange Capacity meq/100gm	Total Nitrogen %
5	13	38	0	.79	5.4	5.25	.14
15	13	38	0	.79	5.4	5.25	.14
30	13	38	0	.75	5.4	5.25	.13
45	13	38	0	.63	5.4	5.25	.11

Soil Texture: Silt Loam

Table B 4.9: Soil profile data for Madhupur Tract (AEZ-15) (For Tangail region soil data)

Depth Bottom cm	Clay %	Silt %	Stones %	Organic Carbon %	pH in Water	Cation Exchange Capacity meq/100gm	Total Nitrogen %
5	19	17.5	0	.79	5.2	5.25	.14
15	19	17.5	0	.79	5.2	5.25	.14
30	19	17.5	0	.75	5.2	5.25	.13
45	19	17.5	0	.63	5.2	5.25	.11

Soil Texture: Loamy

Table B 4.10: Predicted climatic parameters and stresses in different development phases of BR3 rice at Sylhet region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	29	23.6	13.4	12.3	10.81	59.3	75.2	0.000	0.00	0.369	0.254
End Juvenil-Panicl Inition	12	23.3	17.4	7.7	11.21	146.4	22.0	0.000	0.00	0.133	0.043
Panicl Inition-End Leaf Growth	40	27.6	20.7	11.9	11.83	404.5	110.4	0.000	0.00	0.137	0.005
End Leaf Growth-Begin Grain Filling	9	28.7	23.6	8.2	12.44	173.8	15.4	0.000	0.00	0.234	0.096
Grain Filling Phase	23	28.3	23.8	7.4	12.81	756.8	41.3	0.000	0.00	0.035	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	30	23.6	12.9	10.9	10.82	78.3	66.9	0.000	0.00	0.348	0.236
End Juvenil-Panicl Inition	10	25.0	17.9	11.3	11.21	36.8	24.6	0.000	0.00	0.336	0.184
Panicl Inition-End Leaf Growth	40	27.0	20.8	9.2	11.81	797.3	84.6	0.000	0.00	0.024	0.000
End Leaf Growth-Begin Grain Filling	10	28.7	24.6	6.3	12.43	260.4	14.3	0.000	0.00	0.000	0.000
Grain Filling Phase	23	27.5	24.1	4.7	12.81	1246	26	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	27	23.9	14.1	11.5	10.79	52.2	65.0	0.000	0.00	0.404	0.274
End Juvenil-Panicl Inition	9	26.6	18.3	11.8	11.13	40.4	25.6	0.000	0.00	0.146	0.025
Panicl Inition-End Leaf Growth	38	29.3	20.5	13.0	11.69	394.1	114.0	0.000	0.00	0.092	0.038
End Leaf Growth-Begin Grain Filling	9	31.3	25.4	10.3	12.27	162.1	24.5	0.000	0.00	0.000	0.000
Grain Filling Phase	20	31.0	25.6	9.6	12.62	297.0	46.1	0.000	0.00	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	22	25.8	16.1	12.1	10.75	34.6	56.9	0.000	0.00	0.515	0.358
End Juvenil-Panicl Inition	10	30.3	16.8	16.5	11.04	9.1	22.7	0.000	0.00	0.757	0.577
Panicl Inition-End Leaf Growth	33	31.9	23.0	13.2	11.53	176.9	113.9	0.000	0.00	0.210	0.131
End Leaf Growth-Begin Grain Filling	8	33.9	24.4	14.7	12.03	45.8	28.3	0.000	0.00	0.000	0.000
Grain Filling Phase	16	34.7	26.0	16.1	12.33	100.2	73.7	0.000	0.00	0.007	0.000

Table B 4.11: Predicted climatic parameters and stresses in different development phases of BR3 rice at Bogra region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	26	24.8	14.9	11.9	10.79	24.5	59.0	0.010	0.01 9	0.525	0.367
End Juvenil-Panicl Inition	11	25.3	16.0	12.0	11.14	9.0	33.4	0.000	0.00	0.099	0.000
Panicl Inition-End Leaf Growth	37	30.6	20.3	14.3	11.70	74.9	133.4	0.000	0.00	0.115	0.046
End Leaf Growth-Begin Grain Filling	8	38.6	26.0	20.7	12.25	4.3	56.2	0.000	0.00	0.000	0.000
Grain Filling Phase	17	41.4	27.4	23.1	12.56	15.2	141.0	0.000	0.00	0.001	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	28	24.7	13.1	10.1	10.81	109.4	58.0	0.000	0.00	0.386	0.252
End Juvenil-Panicl Inition	10	27.1	15.7	14.6	11.17	1.9	27.0	0.000	0.00	0.514	0.340
Panicl Inition-End Leaf Growth	35	31.6	22.4	14.1	11.70	160.7	126.0	0.000	0.00	0.158	0.086
End Leaf Growth-Begin Grain Filling	8	35.5	24.7	16.9	12.23	22.2	47.6	0.000	0.00	0.082	0.000
Grain Filling Phase	18	39.1	27.2	19.5	12.54	126.5	123.1	0.000	0.00	0.091	0.045

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	21	27.4	15.0	12.1	10.75	1.3	50.7	0.000	0.00	0.501	0.348
End Juvenil-Panicl Inition	11	31.2	13.6	18.5	11.03	0.3	21.3	0.000	0.00	0.780	0.606
Panicl Inition-End Leaf Growth	33	36.0	20.9	18.4	11.53	30.7	163.9	0.000	0.00	0.139	0.000
End Leaf Growth-Begin Grain Filling	7	39.1	27.1	20.5	12.02	11.7	56.9	0.000	0.00	0.000	0.000
Grain Filling Phase	16	41.7	28.1	21.7	12.30	27.0	106.0	0.129	0.151	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	20	27.2	17.3	10.9	10.74	3.7	46.3	0.000	0.00	0.490	0.338
End Juvenil-Panicl Inition	8	38.7	19.1	19.0	10.98	0.0	21.8	0.000	0.00	0.727	0.548
Panicl Inition-End Leaf Growth	31	38.1	23.6	18.1	11.41	4.6	152.6	0.000	0.00	0.170	0.130
End Leaf Growth-Begin Grain Filling	9	41.6	22.8	24.3	11.89	0.1	67.8	0.000	0.00	0.000	0.000
Grain Filling Phase	14	40.2	27.7	19.5	12.18	11.0	89.0	0.000	0.024	0.000	0.000

Table B 4.12: Predicted climatic parameters and stresses in different development phases of BR3 rice at Dinajpur region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	26	25.0	14.4	11.4	10.74	54.5	56.0	0.000	0.00	0.493	0.338
End Juvenil-Panicl Inition	12	26.0	14.7	15.3	11.12	3.9	43.2	0.000	0.00	0.224	0.116
Panicl Inition-End Leaf Growth	37	30.8	19.9	15.8	11.71	33.0	140.8	0.000	0.00	0.114	0.050
End Leaf Growth-Begin Grain Filling	9	32.0	21.9	17.3	12.30	1.0	38.4	0.000	0.00	0.114	0.000
Grain Filling Phase	20	34.8	25.2	18.8	12.66	27.4	107.0	0.000	0.00	0.138	0.084

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	28	25.2	12.3	11.8	10.76	44.7	64.0	0.000	0.00	0.394	0.255
End Juvenil-Panicl Inition	10	27.4	15.7	15.6	11.14	2.5	29.5	0.000	0.00	0.516	0.360
Panicl Inition-End Leaf Growth	35	31.2	21.6	14.9	11.69	158.9	129.6	0.000	0.00	0.289	0.140
End Leaf Growth-Begin Grain Filling	9	36.2	22.3	19.1	12.25	3.1	56.6	0.000	0.00	0.267	0.154
Grain Filling Phase	16	35.5	24.7	18.1	12.56	86.8	87.0	0.000	0.00	0.078	0.036

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	22	27.4	14.1	13.3	10.71	1.7	54.2	0.000	0.00	0.530	0.371
End Juvenil-Panicl Inition	11	30.3	13.8	19.0	11.02	0.1	19.6	0.000	0.00	0.800	0.627
Panicl Inition-End Leaf Growth	34	36.3	20.0	20.1	11.55	25.4	179.9	0.000	0.00	0.200	0.108
End Leaf Growth-Begin Grain Filling	7	40.7	26.4	22.1	12.07	1.3	54.8	0.000	0.00	0.000	0.000
Grain Filling Phase	14	41.6	25.7	21.7	12.34	33.7	91.9	0.131	0.159	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	20	28.4	16.3	13.6	10.69	3.3	54.5	0.000	0.00	0.484	0.334
End Juvenil-Panicl Inition	8	37.6	18.5	18.7	10.94	0.0	21.2	0.000	0.00	0.729	0.550
Panicl Inition-End Leaf Growth	31	38.0	23.2	19.4	11.39	3.8	155.4	0.000	0.00	0.170	0.131
End Leaf Growth-Begin Grain Filling	8	41.5	21.9	25.1	11.88	0.0	64.2	0.000	0.00	0.000	0.000
Grain Filling Phase	14	39.5	25.9	20.2	12.16	11.5	84.3	0.021	0.039	0.000	0.000

Table B 4.13: Predicted climatic parameters and stresses in different development phases of BR3 rice at Chandpur region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	26	25.2	13.8	13.8	10.88	31.7	64.9	0.018	0.033	0.525	0.367
End Juvenil-Panicl Inition	10	25.7	18.2	10.6	11.19	42.7	26.7	0.000	0.00	0.046	0.000
Panicl Inition-End Leaf Growth	36	30.7	21.7	14.6	11.69	14.1	128.7	0.000	0.00	0.038	0.013
End Leaf Growth-Begin Grain Filling	8	34.4	26.0	17.0	12.19	1.1	40.5	0.000	0.00	0.000	0.000
Grain Filling Phase	18	35.3	26.9	17.8	12.48	5.9	87.8	0.000	0.00	0.001	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	24	26.2	14.4	11.9	10.86	36.4	60.4	0.000	0.00	0.449	0.306
End Juvenil-Panicl Inition	11	28.1	15.3	18.5	11.16	1.8	33.6	0.000	0.00	0.356	0.211
Panicl Inition-End Leaf Growth	34	30.9	22.9	13.4	11.64	31.1	114.1	0.000	0.00	0.070	0.041
End Leaf Growth-Begin Grain Filling	9	32.3	25.9	15.7	12.13	21.0	38.1	0.000	0.00	0.000	0.000
Grain Filling Phase	18	34.2	27.2	14.7	12.44	36.0	72.0	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	21	27.4	16.1	13.4	10.84	1.4	55.0	0.000	0.007	0.473	0.325
End Juvenil-Panicl Inition	10	29.5	16.1	14.9	11.09	2.3	20.3	0.000	0.00	0.726	0.547
Panicl Inition-End Leaf Growth	32	34.9	22.2	18.0	11.53	23.8	145.6	0.000	0.00	0.209	0.119
End Leaf Growth-Begin Grain Filling	8	33.3	25.6	13.3	11.98	8.7	34.7	0.000	0.00	0.000	0.000
Grain Filling Phase	15	37.7	27.5	19.0	12.25	29.8	91.3	0.000	0.00	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	19	27.9	18.9	10.9	10.82	4.6	47.8	0.000	0.00	0.462	0.316
End Juvenil-Panicl Inition	8	36.6	18.2	18.2	11.04	0.3	21.7	0.000	0.00	0.702	0.523
Panicl Inition-End Leaf Growth	30	36.6	23.8	18.2	11.42	2.7	136.0	0.000	0.00	0.188	0.138
End Leaf Growth-Begin Grain Filling	8	38.8	26.6	20.3	11.84	0.9	50.5	0.000	0.00	0.013	0.000
Grain Filling Phase	15	38.1	27.9	17.6	12.11	4.6	78.8	0.000	0.00	0.000	0.000

Table B 4.14: Predicted climatic parameters and stresses in different development phases of BR3 rice at Jessore region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	24	25.0	15.3	11.7	10.86	19.2	58.6	0.000	0.00	0.504	0.350
End Juvenil-Panicl Inition	11	26.2	17.5	10.7	11.16	52.1	24.3	0.000	0.00	0.139	0.075
Panicl Inition-End Leaf Growth	34	31.7	21.9	14.5	11.64	12.2	134.5	0.000	0.00	0.049	0.008
End Leaf Growth-Begin Grain Filling	8	36.2	25.5	18.4	12.12	0.6	44.8	0.000	0.00	0.000	0.000
Grain Filling Phase	18	39.4	27.0	21.7	12.42	1.4	139.4	0.000	0.00	0.000	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	23	26.1	16.1	8.9	10.86	35.1	46.6	0.000	0.00	0.395	0.267
End Juvenil-Panicl Inition	11	27.3	14.1	17.5	11.14	2.9	36.9	0.000	0.00	0.375	0.228
Panicl Inition-End Leaf Growth	33	32.6	22.7	15.8	11.61	28.8	134.1	0.000	0.00	0.359	0.223
End Leaf Growth-Begin Grain Filling	8	35.5	26.3	18.3	12.07	5.5	47.9	0.000	0.00	0.000	0.000
Grain Filling Phase	15	40.4	27.5	20.7	12.34	2.9	100.0	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	20	28.5	16.5	14.1	10.83	0.8	55.4	0.000	0.016	0.443	0.301
End Juvenil-Panicl Inition	9	32.4	15.5	19.2	11.07	26.7	35.7	0.000	0.00	0.203	0.095
Panicl Inition-End Leaf Growth	32	36.9	21.9	18.5	11.49	13.5	178.1	0.000	0.00	0.343	0.192
End Leaf Growth-Begin Grain Filling	8	35.7	26.1	14.4	11.94	4.7	36.0	0.000	0.00	0.000	0.000
Grain Filling Phase	14	42.1	28.5	21.7	12.19	8.4	107.6	0.049	0.060	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	19	28.3	19.5	10.1	10.83	5.2	47.0	0.000	0.00	0.407	0.265
End Juvenil-Panicl Inition	7	39.8	19.6	19.5	11.03	0.0	24.4	0.000	0.00	0.637	0.462
Panicl Inition-End Leaf Growth	30	38.8	24.2	18.3	11.40	3.2	147.7	0.000	0.00	0.202	0.149
End Leaf Growth-Begin Grain Filling	8	42.0	27.1	21.5	11.82	0.4	55.9	0.000	0.00	0.000	0.000
Grain Filling Phase	15	41.0	27.9	21.6	12.09	11.9	101.8	0.000	0.00	0.000	0.000

Table B 4.15: Predicted climatic parameters and stresses in different development phases of BR3 rice at Comilla region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	27	25.0	13.3	13.5	10.88	47.5	69.9	0.014	0.033	0.510	0.352
End Juvenil-Panicl Inition	9	25.7	18.0	11.7	11.19	35.7	23.0	0.000	0.00	0.043	0.000
Panicl Inition-End Leaf Growth	37	29.7	21.1	13.9	11.70	30.1	125.5	0.000	0.00	0.028	0.006
End Leaf Growth-Begin Grain Filling	9	31.4	23.5	12.9	12.23	2.9	31.8	0.000	0.00	0.001	0.000
Grain Filling Phase	19	34.8	25.1	18.5	12.54	14.3	93.9	0.000	0.00	0.009	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	26	25.5	13.5	12.1	10.87	58.2	68.0	0.000	0.00	0.398	0.270
End Juvenil-Panicl Inition	10	28.1	14.8	18.3	11.18	1.3	32.3	0.000	0.00	0.371	0.226
Panicl Inition-End Leaf Growth	35	30.2	22.3	13.7	11.67	81.1	120.0	0.000	0.00	0.090	0.043
End Leaf Growth-Begin Grain Filling	9	31.5	25.5	13.5	12.18	50.2	30.5	0.000	0.00	0.000	0.000
Grain Filling Phase	19	33.2	26.5	14.9	12.50	82.1	71.9	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	22	26.8	15.7	13.3	10.83	1.5	56.4	0.000	0.005	0.486	0.335
End Juvenil-Panicl Inition	10	28.6	15.6	15.1	11.10	1.9	19.1	0.000	0.00	0.738	0.558
Panicl Inition-End Leaf Growth	33	34.3	22.2	17.3	11.56	29.2	147.9	0.000	0.00	0.193	0.115
End Leaf Growth-Begin Grain Filling	8	34.4	25.9	15.6	12.03	24.9	35.1	0.000	0.00	0.000	0.000
Grain Filling Phase	18	36.5	27.3	17.2	12.33	35.6	93.6	0.000	0.00	0.004	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	20	27.7	17.6	11.5	10.82	4.2	50.3	0.000	0.00	0.474	0.326
End Juvenil-Panicl Inition	8	35.7	17.6	18.3	11.05	0.4	19.6	0.000	0.00	0.719	0.539
Panicl Inition-End Leaf Growth	31	36.2	23.5	18.2	11.45	3.7	145.8	0.000	0.00	0.176	0.112
End Leaf Growth-Begin Grain Filling	7	38.7	26.3	20.7	11.88	1.1	44.5	0.000	0.00	0.062	0.000
Grain Filling Phase	15	38.6	27.7	17.7	12.13	7.2	82.9	0.000	0.00	0.000	0.000

Table B 4.16: Predicted climatic parameters and stresses in different development phases of BR3 rice at Madaripur region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	25	24.7	14.3	12.4	10.87	31.5	62.7	0.014	0.02 3	0.509	0.354
End Juvenil-Panicl Inition	11	25.8	17.3	11.4	11.18	54.6	25.4	0.000	0.00	0.380	0.206
Panicl Inition-End Leaf Growth	35	31.1	21.9	14.6	11.68	13.6	132.5	0.000	0.00	0.240	0.142
End Leaf Growth-Begin Grain Filling	8	35.2	25.8	17.8	12.17	1.8	38.9	0.000	0.00	0.085	0.000
Grain Filling Phase	16	36.5	26.5	19.7	12.44	2.3	98.2	0.000	0.00	0.042	0.015

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	25	25.9	14.8	11.2	10.87	39.1	63.2	0.000	0.00	0.413	0.280
End Juvenil-Panicl Inition	10	28.2	15.5	17.6	11.17	2.6	29.8	0.000	0.00	0.420	0.276
Panicl Inition-End Leaf Growth	34	31.2	22.7	13.5	11.64	28.5	117.6	0.000	0.00	0.375	0.251
End Leaf Growth-Begin Grain Filling	8	33.6	26.0	15.6	12.12	17.4	35.8	0.000	0.00	0.000	0.000
Grain Filling Phase	16	35.3	27.1	16.4	12.39	1.6	72.7	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	20	27.8	16.2	13.9	10.83	0.6	53.2	0.000	0.02	0.443	0.302
End Juvenil-Panicl Inition	10	30.3	15.9	16.4	11.08	1.9	22.4	0.000	0.00	0.685	0.506
Panicl Inition-End Leaf Growth	32	35.5	21.9	17.8	11.51	21.0	150.8	0.000	0.00	0.341	0.218
End Leaf Growth-Begin Grain Filling	8	34.1	25.5	14.4	11.96	8.8	32.9	0.000	0.00	0.000	0.000
Grain Filling Phase	15	39.2	27.6	19.5	12.22	23.1	88.9	0.000	0.00	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	19	27.5	19.1	9.3	10.83	42.3	42.3	0.000	0.00	0.452	0.308
End Juvenil-Panicl Inition	8	37.7	18.8	18.8	11.04	0.2	23.3	0.000	0.00	0.672	0.494
Panicl Inition-End Leaf Growth	30	37.5	23.9	18.4	11.42	1.7	134.8	0.000	0.00	0.286	0.195
End Leaf Growth-Begin Grain Filling	8	39.8	26.6	20.9	11.84	0.7	49.2	0.000	0.00	0.000	0.000
Grain Filling Phase	14	38.6	27.8	17.9	12.10	9.0	74.4	0.000	0.00	0.000	0.000

Table B 4.17: Predicted climatic parameters and stresses in different development phases of BR3 rice at Mymensingh region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	28	23.4	14.0	11.6	10.81	22.7	66.2	0.000	0.00 4	0.503	0.345
End Juvenil-Panicl Inition	12	24.8	17.1	11.4	11.20	26.7	32.3	0.000	0.00	0.124	0.037
Panicl Inition-End Leaf Growth	37	28.9	20.9	12.8	11.77	193.4	116.9	0.000	0.00	0.094	0.000
End Leaf Growth-Begin Grain Filling	9	34.0	24.8	15.7	12.34	6.7	35.6	0.000	0.00	0.174	0.000
Grain Filling Phase	19	34.0	25.6	13.1	12.67	80.9	69.6	0.000	0.00	0.042	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	28	24.0	13.4	11.0	10.81	58.7	64.5	0.000	0.00	0.392	0.263
End Juvenil-Panicl Inition	11	25.9	16.9	12.1	11.19	7.4	23.3	0.000	0.00	0.467	0.307
Panicl Inition-End Leaf Growth	37	28.9	22.0	10.9	11.75	310.0	100.7	0.000	0.00	0.028	0.000
End Leaf Growth-Begin Grain Filling	8	34.0	25.6	13.8	12.30	4.5	30.5	0.000	0.00	0.000	0.000
Grain Filling Phase	20	31.7	25.8	9.3	12.63	360.6	46.9	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	24	25.9	14.7	11.9	10.78	2.5	55.5	0.000	0.002	0.517	0.360
End Juvenil-Panicl Inition	10	26.7	14.5	13.3	11.09	4.6	22.0	0.000	0.00	0.746	0.569
Panicl Inition-End Leaf Growth	35	33.5	20.4	16.9	11.60	72.8	142.6	0.000	0.00	0.222	0.132
End Leaf Growth-Begin Grain Filling	8	34.5	26.4	14.5	12.13	34.1	31.8	0.000	0.00	0.000	0.000
Grain Filling Phase	18	36.9	26.8	16.8	12.45	57.7	93.7	0.000	0.00	0.079	0.044

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	22	26.3	16.6	11.1	10.76	6.4	50.5	0.000	0.00	0.503	0.349
End Juvenil-Panicl Inition	8	34.2	16.5	18.2	11.03	1.3	16.4	0.000	0.00	0.747	0.568
Panicl Inition-End Leaf Growth	31	34.9	23.2	16.1	11.46	12.4	140.2	0.000	0.00	0.238	0.144
End Leaf Growth-Begin Grain Filling	9	39.6	22.6	20.1	11.94	1.4	51.4	0.000	0.00	0.000	0.000
Grain Filling Phase	15	36.6	27.3	16.4	12.24	45.6	76.1	0.000	0.00	0.000	0.000

Table B 4.18: Predicted climatic parameters and stresses in different development phases of BR3 rice at Tangail region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	26	24.6	14.9	12.0	10.82	18.7	61.0	0.001	0.013	0.527	0.368
End Juvenil-Panicl Inition	10	24.9	16.7	10.3	11.15	36.7	24.2	0.000	0.00	0.048	0.000
Panicl Inition-End Leaf Growth	37	30.2	20.8	13.5	11.68	54.4	126.7	0.000	0.00	0.051	0.017
End Leaf Growth-Begin Grain Filling	8	38.0	26.0	20.1	12.22	0.5	51.4	0.000	0.00	0.000	0.000
Grain Filling Phase	17	41.9	27.5	22.8	12.52	12.9	147.1	0.000	0.00	0.000	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	27	24.8	13.7	10.0	10.83	109.4	57.4	0.000	0.00	0.400	0.268
End Juvenil-Panicl Inition	10	27.4	15.3	16.4	11.17	0.8	27.7	0.000	0.00	0.524	0.356
Panicl Inition-End Leaf Growth	34	31.6	22.6	14.0	11.67	92.1	123.2	0.000	0.00	0.124	0.065
End Leaf Growth-Begin Grain Filling	8	36.3	26.0	17.8	12.18	19.1	46.0	0.000	0.00	0.000	0.000
Grain Filling Phase	18	39.8	27.3	19.3	12.48	43.5	116.0	0.000	0.00	0.050	0.011

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	21	27.2	15.3	12.4	10.78	0.8	52.2	0.000	0.00	0.500	0.346
End Juvenil-Panicl Inition	11	30.9	13.9	17.3	11.06	0.8	20.7	0.000	0.00	0.775	0.600
Panicl Inition-End Leaf Growth	33	36.0	21.3	17.8	11.54	90.6	158.3	0.000	0.00	0.177	0.092
End Leaf Growth-Begin Grain Filling	7	37.3	26.6	18.6	12.02	13.7	45.5	0.000	0.00	0.000	0.000
Grain Filling Phase	14	41.4	29.0	20.5	12.27	19.9	99.1	0.069	0.093	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	20	26.9	17.9	10.2	10.77	3.5	43.7	0.000	0.00	0.483	0.333
End Juvenil-Panicl Inition	8	38.4	19.3	19.1	11.01	0.0	21.8	0.000	0.00	0.721	0.542
Panicl Inition-End Leaf Growth	32	38.1	23.8	17.7	11.44	7.3	156.2	0.000	0.00	0.169	0.128
End Leaf Growth-Begin Grain Filling	9	41.6	23.2	23.4	11.92	0.6	62.8	0.000	0.00	0.000	0.000
Grain Filling Phase	14	39.6	28.2	19.1	12.20	20.3	91.6	0.000	0.00	0.000	0.000

Table B 4.19: Predicted climatic parameters and stresses in different development phases of BR3 rice at Satkhira region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	23	25.3	15.9	11.4	10.88	15.2	54.2	0.000	0.00	0.491	0.339
End Juvenil-Panicl Inition	11	26.4	17.9	11.8	11.16	36.1	29.1	0.000	0.00	0.278	0.130
Panicl Inition-End Leaf Growth	34	31.6	22.2	14.6	11.63	10.5	133.4	0.000	0.00	0.254	0.131
End Leaf Growth-Begin Grain Filling	8	35.3	25.2	17.8	12.10	0.3	43.2	0.000	0.00	0.000	0.000
Grain Filling Phase	16	38.5	26.6	20.9	12.36	1.9	109.3	0.000	0.00	0.000	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	22	26.5	17.1	8.9	10.87	26.4	42.9	0.000	0.00	0.433	0.290
End Juvenil-Panicl Inition	11	26.8	14.7	15.8	11.14	14.1	37.0	0.000	0.00	0.315	0.181
Panicl Inition-End Leaf Growth	32	32.7	22.7	16.6	11.59	21.3	137.7	0.000	0.00	0.388	0.247
End Leaf Growth-Begin Grain Filling	8	35.6	26.2	18.4	12.03	4.4	39.3	0.000	0.00	0.000	0.000
Grain Filling Phase	15	39.2	27.4	19.6	12.29	3.2	99.1	0.000	0.00 6	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	19	28.3	16.8	14.0	10.85	0.9	52.2	0.000	0.01 5	0.438	0.298
End Juvenil-Panicl Inition	9	32.3	15.8	19.2	11.07	0.6	23.8	0.000	0.00	0.680	0.502
Panicl Inition-End Leaf Growth	31	36.8	22.1	19.0	11.47	9.3	156.4	0.000	0.00	0.257	0.117
End Leaf Growth-Begin Grain Filling	8	36.1	25.9	14.2	11.89	5.8	35.3	0.000	0.00	0.075	0.025
Grain Filling Phase	14	40.9	28.2	20.9	12.14	2.3	91.4	0.041	0.05 8	0.004	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	17	29.3	21.1	10.4	10.84	5.9	43.2	0.000	0.00	0.382	0.227
End Juvenil-Panicl Inition	7	37.5	17.9	19.2	11.02	0.1	27.2	0.000	0.00	0.597	0.429
Panicl Inition-End Leaf Growth	30	38.6	24.4	18.3	11.37	3.7	137.4	0.000	0.00	0.261	0.193
End Leaf Growth-Begin Grain Filling	7	41.8	27.6	22.0	11.77	0.5	47.3	0.000	0.00	0.000	0.000
Grain Filling Phase	15	41.1	28.0	21.4	12.02	3.0	99.9	0.000	0.00	0.000	0.000

Table B 4.20: Predicted climatic parameters and stresses in different development phases of BR14 rice at Rajshahi region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	17	24.6	15.4	12.7	10.74	5.6	42.0	0.010	0.026	0.451	0.309
End Juvenil-Panicl Inition	17	26.4	16.9	11.8	11.03	24.4	41.6	0.000	0.00	0.304	0.186
Panicl Inition-End Leaf Growth	33	33.7	23.2	16.0	11.59	33.0	156.8	0.000	0.00	0.405	0.272
End Leaf Growth-Begin Grain Filling	8	41.9	27.2	21.8	12.08	1.0	59.7	0.000	0.00	0.000	0.000
Grain Filling Phase	16	43.2	28.3	24.3	12.37	9.6	104.6	0.154	0.186	0.000	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	19	25.5	13.3	9.6	10.76	47.1	37.5	0.000	0.00	0.495	0.344
End Juvenil-Panicl Inition	20	26.0	15.1	14.2	11.11	142.3	53.2	0.000	0.00	0.428	0.282
Panicl Inition-End Leaf Growth	33	33.0	22.2	16.6	11.71	71.4	140.6	0.000	0.00	0.359	0.232
End Leaf Growth-Begin Grain Filling	8	39.2	25.7	20.2	12.20	2.7	52.9	0.000	0.00	0.202	0.000
Grain Filling Phase	18	42.5	27.7	22.2	12.51	44.7	141.0	0.000	0.013	0.003	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	14	27.1	17.2	11.1	10.85	2.0	32.1	0.000	0.002	0.447	0.307
End Juvenil-Panicl Inition	16	32.0	13.1	18.8	11.07	0.2	40.5	0.000	0.00	0.751	0.581
Panicl Inition-End Leaf Growth	32	37.4	20.9	20.1	11.53	16.6	162.3	0.000	0.00	0.315	0.187
End Leaf Growth-Begin Grain Filling	8	36.2	26.0	15.6	11.96	10.3	49.1	0.000	0.00	0.000	0.000
Grain Filling Phase	17	43.2	28.9	22.6	12.23	12.3	119.0	0.108	0.131	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	20	26.9	17.7	8.7	10.77	5.9	40.1	0.000	0.00	0.462	0.316
End Juvenil-Panicl Inition	8	39.8	19.9	19.3	11.00	0.0	23.1	0.000	0.00	0.701	0.523
Panicl Inition-End Leaf Growth	32	39.7	24.2	19.1	11.44	4.6	163.6	0.000	0.00	0.180	0.125
End Leaf Growth-Begin Grain Filling	8	42.3	22.6	25.3	11.91	0.0	59.7	0.000	0.00	0.000	0.000
Grain Filling Phase	14	41.6	28.6	20.2	12.18	7.9	87.8	0.029	0.073	0.000	0.000

Table B 4.21: Predicted climatic parameters and stresses in different development phases of BR14 rice at Sylhet region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	21	23.5	12.4	13.0	10.74	23.2	55.1	0.000	0.00	0.494	0.336
End Juvenil-Panicl Inition	22	23.7	16.4	9.9	11.15	184.0	48.4	0.000	0.00	0.090	0.036
Panicl Inition-End Leaf Growth	39	27.7	21.1	11.6	11.87	405.3	106.2	0.000	0.00	0.181	0.032
End Leaf Growth-Begin Grain Filling	10	28.5	23.9	7.3	12.47	214.5	16.0	0.000	0.00	0.298	0.108
Grain Filling Phase	28	28.7	23.9	7.7	12.90	879.0	54.1	0.000	0.00	0.001	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	21	23.7	12.7	9.9	10.74	47.8	42.1	0.000	0.00	0.470	0.316
End Juvenil-Panicl Inition	21	24.5	16.1	12.0	11.14	77.3	55.3	0.000	0.00	0.287	0.175
Panicl Inition-End Leaf Growth	40	27.1	21.0	9.0	11.86	822.5	81.7	0.000	0.00	0.032	0.000
End Leaf Growth-Begin Grain Filling	10	28.3	24.6	5.8	12.47	304.4	12.7	0.000	0.00	0.001	0.000
Grain Filling Phase	28	28.1	24.5	5.3	12.90	1429	36	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	19	23.4	15.0	10.1	10.73	36.9	41.3	0.000	0.00	0.493	0.342
End Juvenil-Panicl Inition	18	26.2	15.7	13.7	11.06	55.7	53.1	0.000	0.00	0.294	0.154
Panicl Inition-End Leaf Growth	38	29.2	20.7	12.8	11.71	415.0	109.4	0.000	0.00	0.070	0.029
End Leaf Growth-Begin Grain Filling	9	31.9	25.5	10.9	12.29	148.2	23.7	0.000	0.00	0.000	0.000
Grain Filling Phase	25	31.2	25.6	9.2	12.70	399.2	58.9	0.000	0.00	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	16	24.9	16.8	10.8	10.70	27.4	38.2	0.000	0.00	0.475	0.328
End Juvenil-Panicl Inition	15	29.5	15.5	16.5	10.97	12.8	37.7	0.000	0.00	0.769	0.597
Panicl Inition-End Leaf Growth	33	31.7	22.8	13.1	11.51	179.5	111.5	0.000	0.00	0.231	0.144
End Leaf Growth-Begin Grain Filling	8	34.1	24.1	15.6	12.01	25.3	30.8	0.000	0.00	0.000	0.000
Grain Filling Phase	22	33.1	25.8	13.1	12.38	527.0	80.0	0.000	0.00	0.000	0.000

Table B 4.22: Predicted climatic parameters and stresses in different development phases of BR14 rice at Barisal region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	19	24.6	13.2	13.9	10.85	26.3	0.0	0.000	0.00	0.000	0.000
End Juvenil-Panicl Inition	18	25.9	18.1	9.9	11.15	52.8	0.0	0.000	0.00	0.000	0.000
Panicl Inition-End Leaf Growth	35	30.9	21.7	15.5	11.71	11.8	0.0	0.000	0.00	0.000	0.000
End Leaf Growth-Begin Grain Filling	9	33.8	25.2	16.5	12.20	1.4	0.0	0.000	0.00	0.000	0.000
Grain Filling Phase	23	34.9	26.4	17.7	12.55	5.0	0.0	0.000	0.00	0.000	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	17	26.2	14.5	11.7	10.84	7.4	41.4	0.000	0.00	0.450	0.308
End Juvenil-Panicl Inition	18	27.1	15.9	15.8	11.12	23.4	53.0	0.000	0.00	0.457	0.294
Panicl Inition-End Leaf Growth	34	30.8	22.7	13.1	11.65	25.7	109.7	0.000	0.00	0.364	0.230
End Leaf Growth-Begin Grain Filling	9	32.3	26.0	14.8	12.13	14.8	34.3	0.000	0.00	0.001	0.000
Grain Filling Phase	20	33.6	27.1	14.6	12.45	31.8	76.8	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	14	26.5	16.5	12.3	10.81	0.4	33.3	0.000	0.00	0.438	0.300
End Juvenil-Panicl Inition	16	29.9	16.0	15.5	11.04	3.3	38.4	0.000	0.00	0.725	0.555
Panicl Inition-End Leaf Growth	32	34.5	22.1	17.5	11.52	22.9	142.1	0.000	0.00	0.257	0.151
End Leaf Growth-Begin Grain Filling	9	33.5	25.3	14.9	11.97	8.5	37.4	0.000	0.00	0.000	0.000
Grain Filling Phase	19	36.7	27.6	16.5	12.29	22.1	92.2	0.000	0.00	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	13	27.2	19.7	9.1	10.81	8.1	28.3	0.000	0.00	0.420	0.287
End Juvenil-Panicl Inition	13	33.8	18.9	16.0	11.00	1.3	36.3	0.000	0.00	0.662	0.494
Panicl Inition-End Leaf Growth	30	36.3	23.7	18.0	11.42	2.2	118.8	0.000	0.00	0.238	0.184
End Leaf Growth-Begin Grain Filling	8	38.2	26.7	20.0	11.83	45.4	51.8	0.000	0.00	0.000	0.000
Grain Filling Phase	19	38.2	27.6	19.0	12.13	6.0	104.4	0.000	0.00	0.000	0.000

Table B 4.23: Predicted climatic parameters and stresses in different development phases of BR14 rice at Bogra region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	18	24.1	13.6	11.6	10.72	10.0	43.1	0.005	0.02 2	0.488	0.338
End Juvenil-Panicl Inition	19	25.8	16.8	12.2	11.05	23.5	48.4	0.000	0.00	0.360	0.221
Panicl Inition-End Leaf Growth	37	30.6	20.3	14.3	11.70	74.9	133.4	0.000	0.00	0.119	0.047
End Leaf Growth-Begin Grain Filling	8	38.6	26.0	20.7	12.25	4.3	56.2	0.000	0.00	0.051	0.000
Grain Filling Phase	22	40.3	27.3	21.7	12.61	24.1	170.4	0.000	0.00	0.000	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	19	25.2	13.1	9.5	10.73	41.5	36.4	0.000	0.00	0.497	0.345
End Juvenil-Panicl Inition	20	25.6	14.8	12.9	11.09	70.0	50.2	0.000	0.00	0.443	0.299
Panicl Inition-End Leaf Growth	35	31.7	22.5	14.1	11.72	166.3	125.9	0.000	0.00	0.149	0.072
End Leaf Growth-Begin Grain Filling	8	36.8	24.7	18.6	12.25	16.6	49.4	0.000	0.00	0.237	0.000
Grain Filling Phase	22	39.4	27.2	20.3	12.61	129.6	157.1	0.000	0.00	0.083	0.033

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	15	26.6	16.4	10.1	10.70	1.1	31.3	0.000	0.00	0.467	0.322
End Juvenil-Panicl Inition	16	30.7	12.5	18.3	10.96	0.3	37.5	0.000	0.00	0.782	0.614
Panicl Inition-End Leaf Growth	33	35.8	20.7	18.1	11.51	30.3	158.3	0.000	0.00	0.150	0.075
End Leaf Growth-Begin Grain Filling	8	38.6	26.9	20.8	12.01	12.3	59.3	0.000	0.00	0.000	0.000
Grain Filling Phase	17	41.7	28.1	21.5	12.32	27.1	116.0	0.121	0.14 0	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	15	26.0	17.4	9.4	10.70	3.2	28.9	0.000	0.00	0.467	0.322
End Juvenil-Panicl Inition	12	35.8	18.6	17.4	10.92	0.5	35.2	0.000	0.00	0.729	0.557
Panicl Inition-End Leaf Growth	32	38.0	23.3	18.2	11.40	4.6	145.0	0.000	0.00	0.199	0.158
End Leaf Growth-Begin Grain Filling	8	41.7	23.1	24.1	11.88	0.1	56.8	0.000	0.00	0.000	0.000
Grain Filling Phase	19	40.4	27.7	20.0	12.22	23.0	112.1	0.000	0.00	0.000	0.000

Table B 4.24: Predicted climatic parameters and stresses in different development phases of BR14 rice at Dinajpur region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	19	24.5	13.2	11.7	10.68	3.0	42.8	0.000	0.01 2	0.503	0.350
End Juvenil-Panicl Inition	19	26.1	15.8	13.5	11.04	55.4	55.1	0.000	0.00	0.342	0.224
Panicl Inition-End Leaf Growth	37	30.8	19.9	15.8	11.71	33.0	140.7	0.000	0.00	0.110	0.051
End Leaf Growth-Begin Grain Filling	9	32.0	21.9	17.3	12.30	1.0	38.4	0.000	0.00	0.206	0.000
Grain Filling Phase	25	34.4	25.0	18.8	12.72	27.8	135.2	0.000	0.00	0.080	0.027

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	19	25.6	12.3	11.0	10.68	20.2	40.3	0.000	0.00	0.473	0.326
End Juvenil-Panicl Inition	20	25.9	14.4	14.1	11.05	27.4	53.6	0.000	0.00	0.476	0.325
Panicl Inition-End Leaf Growth	35	31.2	21.7	14.9	11.71	160.6	128.0	0.000	0.00	0.282	0.143
End Leaf Growth-Begin Grain Filling	9	37.6	22.2	21.1	12.28	1.1	61.3	0.000	0.00	0.405	0.249
Grain Filling Phase	20	35.2	25.0	18.6	12.64	99.4	110.0	0.000	0.00	0.014	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	16	26.8	14.6	11.8	10.66	1.7	34.7	0.000	0.00	0.495	0.344
End Juvenil-Panicl Inition	16	29.8	13.0	18.5	10.94	0.0	35.4	0.000	0.00	0.805	0.640
Panicl Inition-End Leaf Growth	34	36.1	19.8	20.1	11.53	24.7	171.1	0.000	0.00	0.218	0.136
End Leaf Growth-Begin Grain Filling	8	40.1	26.1	21.4	12.06	2.1	60.1	0.000	0.00	0.000	0.000
Grain Filling Phase	18	41.5	25.7	21.8	12.39	36.1	126.0	0.105	0.12 6	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	15	27.2	16.2	12.4	10.65	1.5	35.3	0.000	0.00	0.454	0.312
End Juvenil-Panicl Inition	11	35.2	17.9	17.8	10.87	1.8	33.8	0.000	0.00	0.726	0.552
Panicl Inition-End Leaf Growth	31	38.0	22.9	19.3	11.34	3.4	140.3	0.000	0.00	0.229	0.177
End Leaf Growth-Begin Grain Filling	8	40.6	22.2	23.9	11.83	0.4	57.0	0.000	0.00	0.000	0.000
Grain Filling Phase	19	40.0	26.2	21.4	12.17	14.3	120.9	0.000	0.010	0.000	0.000

Table B 4.25: Predicted climatic parameters and stresses in different development phases of BR14 rice at Chandpur region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	19	24.7	12.7	14.6	10.82	29.0	53.4	0.017	0.032	0.484	0.335
End Juvenil-Panicl Inition	18	26.2	17.9	10.9	11.13	45.7	39.8	0.000	0.00	0.322	0.209
Panicl Inition-End Leaf Growth	35	30.8	21.7	14.7	11.70	13.8	126.3	0.000	0.00	0.033	0.019
End Leaf Growth-Begin Grain Filling	9	34.4	25.7	16.8	12.20	1.1	45.5	0.000	0.00	0.000	0.000
Grain Filling Phase	23	34.9	26.6	16.7	12.56	7.6	109.2	0.000	0.00	0.000	0.000

(b) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	17	26.5	13.6	12.0	10.81	11.5	41.4	0.000	0.00	0.446	0.305
End Juvenil-Panicl Inition	18	27.1	15.7	15.8	11.09	26.7	51.2	0.000	0.00	0.418	0.273
Panicl Inition-End Leaf Growth	34	30.9	22.9	13.4	11.64	31.1	114.2	0.000	0.00	0.076	0.045
End Leaf Growth-Begin Grain Filling	9	32.3	25.9	15.7	12.13	21.0	38.1	0.000	0.00	0.000	0.000
Grain Filling Phase	23	33.5	27.2	13.8	12.49	78.4	88.2	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	15	26.4	16.6	11.8	10.79	1.0	35.2	0.000	0.00 1	0.449	0.308
End Juvenil-Panicl Inition	16	29.6	15.7	15.8	11.04	2.7	37.9	0.000	0.00	0.743	0.572
Panicl Inition-End Leaf Growth	32	34.9	22.2	18.0	11.53	23.8	141.4	0.000	0.00	0.202	0.114
End Leaf Growth-Begin Grain Filling	8	33.3	25.6	13.3	11.98	8.7	34.9	0.000	0.00	0.000	0.000
Grain Filling Phase	20	37.0	27.6	17.5	12.30	34.4	106.4	0.000	0.00	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	14	27.3	18.9	10.5	10.78	3.8	31.7	0.000	0.00	0.440	0.301
End Juvenil-Panicl Inition	12	33.7	18.3	15.7	10.98	1.0	33.5	0.000	0.00	0.696	0.524
Panicl Inition-End Leaf Growth	31	36.6	23.7	18.2	11.41	2.8	129.0	0.000	0.00	0.215	0.164
End Leaf Growth-Begin Grain Filling	7	38.6	26.4	20.2	11.83	0.8	41.2	0.000	0.00	0.000	0.000
Grain Filling Phase	19	38.8	27.8	19.1	12.13	4.7	106.9	0.000	0.00	0.000	0.000

Table B 4.26: Predicted climatic parameters and stresses in different development phases of BR14 rice at Jessore region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	18	24.5	14.3	11.9	10.82	16.6	46.2	0.000	0.00	0.460	0.316
End Juvenil-Panicl Inition	18	26.3	17.9	10.5	11.12	55.6	38.1	0.000	0.00	0.342	0.237
Panicl Inition-End Leaf Growth	34	32.0	22.0	15.2	11.67	11.3	139.8	0.000	0.00	0.058	0.014
End Leaf Growth-Begin Grain Filling	8	36.5	25.8	17.8	12.14	0.7	42.8	0.000	0.00	0.000	0.000
Grain Filling Phase	22	40.2	27.2	22.5	12.48	1.4	172.7	0.029	0.03 5	0.000	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	16	26.4	15.4	9.2	10.80	14.6	33.1	0.000	0.00	0.420	0.285
End Juvenil-Panicl Inition	19	26.7	15.6	14.1	11.09	23.4	54.7	0.000	0.00	0.373	0.233
Panicl Inition-End Leaf Growth	33	32.7	23.0	15.7	11.63	30.9	137.5	0.000	0.00	0.364	0.232
End Leaf Growth-Begin Grain Filling	8	36.7	26.6	19.4	12.10	3.5	46.6	0.000	0.00	0.000	0.000
Grain Filling Phase	19	40.0	27.7	20.9	12.40	3.8	128.5	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	14	27.5	17.7	12.1	10.79	0.8	34.1	0.000	0.015	0.423	0.276
End Juvenil-Panicl Inition	14	31.7	14.7	19.0	11.01	26.4	50.4	0.000	0.00	0.397	0.256
Panicl Inition-End Leaf Growth	32	36.7	21.6	18.6	11.47	13.5	170.8	0.000	0.00	0.361	0.210
End Leaf Growth-Begin Grain Filling	8	35.7	26.0	13.8	11.91	5.0	36.0	0.000	0.00	0.040	0.026
Grain Filling Phase	18	41.4	28.2	20.8	12.21	19.0	132.9	0.019	0.031	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	13	27.6	19.3	9.9	10.78	4.4	30.1	0.000	0.00	0.420	0.272
End Juvenil-Panicl Inition	12	34.8	19.5	15.0	10.97	0.8	35.6	0.000	0.00	0.599	0.420
Panicl Inition-End Leaf Growth	30	38.7	24.1	18.2	11.38	3.2	132.3	0.000	0.00	0.234	0.177
End Leaf Growth-Begin Grain Filling	8	42.1	27.3	21.4	11.80	0.1	50.7	0.000	0.00	0.000	0.000
Grain Filling Phase	19	41.2	28.0	22.1	12.11	12.3	123.5	0.000	0.00	0.000	0.000

Table B 4.27: Predicted climatic parameters and stresses in different development phases of BR14 rice at Comilla region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	19	24.6	12.1	14.1	10.81	25.3	52.3	0.013	0.03 5	0.480	0.331
End Juvenil-Panicl Inition	19	26.0	17.7	11.6	11.13	60.6	44.2	0.000	0.00	0.339	0.219
Panicl Inition-End Leaf Growth	36	30.0	21.1	14.2	11.73	27.4	125.4	0.000	0.00	0.019	0.008
End Leaf Growth-Begin Grain Filling	10	32.0	23.4	14.6	12.26	6.6	36.8	0.000	0.00	0.037	0.000
Grain Filling Phase	24	34.1	25.3	16.6	12.64	20.8	108.9	0.000	0.00	0.001	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	18	25.8	12.9	12.1	10.80	28.1	46.2	0.000	0.00	0.461	0.317
End Juvenil-Panicl Inition	19	26.7	15.2	15.3	11.12	31.7	55.8	0.000	0.00	0.378	0.234
Panicl Inition-End Leaf Growth	35	30.4	22.5	14.0	11.70	81.0	119.6	0.000	0.00	0.079	0.043
End Leaf Growth-Begin Grain Filling	9	31.5	25.7	13.3	12.20	50.0	31.0	0.000	0.00	0.009	0.000
Grain Filling Phase	23	32.6	26.6	13.8	12.56	127.0	83.1	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain Mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	15	25.9	16.0	11.7	10.78	1.2	34.4	0.000	0.00	0.458	0.316
End Juvenil-Panicl Inition	17	28.7	15.4	15.9	11.04	2.2	38.4	0.000	0.00	0.748	0.577
Panicl Inition-End Leaf Growth	33	34.3	22.2	17.3	11.56	29.2	143.7	0.000	0.00	0.194	0.111
End Leaf Growth-Begin Grain Filling	8	34.4	25.9	15.6	12.03	24.9	35.2	0.000	0.00	0.000	0.000
Grain Filling Phase	22	36.5	27.3	16.5	12.37	36.3	107.0	0.000	0.00	0.001	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain Mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	14	26.8	17.9	10.3	10.77	3.0	31.2	0.000	0.00	0.446	0.306
End Juvenil-Panicl Inition	13	33.0	17.6	16.4	10.98	1.5	34.4	0.000	0.00	0.719	0.547
Panicl Inition-End Leaf Growth	31	36.2	23.2	18.2	11.43	3.7	132.7	0.000	0.00	0.190	0.143
End Leaf Growth-Begin Grain Filling	8	38.4	26.4	20.4	11.87	1.2	49.8	0.000	0.00	0.052	0.000
Grain Filling Phase	18	39.3	27.6	19.0	12.17	7.2	108.6	0.000	0.00	0.000	0.000

Table B 4.28: Predicted climatic parameters and stresses in different development phases of BR14 rice at Madaripur region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	19	24.4	13.4	13.1	10.83	28.2	52.8	0.011	0.025	0.464	0.319
End Juvenil-Panicl Inition	18	25.8	17.5	10.7	11.14	59.2	35.9	0.000	0.00	0.512	0.342
Panicl Inition-End Leaf Growth	35	31.3	21.9	15.1	11.70	12.8	130.9	0.000	0.00	0.240	0.130
End Leaf Growth-Begin Grain Filling	8	34.9	25.7	16.6	12.19	1.3	41.8	0.000	0.00	0.208	0.000
Grain Filling Phase	20	37.0	26.8	19.6	12.50	3.3	120.6	0.000	0.00	0.014	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	17	26.1	14.0	11.2	10.81	13.6	42.2	0.000	0.00	0.440	0.300
End Juvenil-Panicl Inition	18	27.0	15.9	14.9	11.10	28.1	48.6	0.000	0.00	0.475	0.305
Panicl Inition-End Leaf Growth	34	31.2	22.7	13.5	11.64	28.5	115.5	0.000	0.00	0.382	0.258
End Leaf Growth-Begin Grain Filling	8	33.6	26.0	15.6	12.12	17.4	35.4	0.000	0.00	0.000	0.000
Grain Filling Phase	20	35.7	27.2	17.0	12.44	41.7	88.9	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	14	26.7	17.0	12.0	10.79	0.3	32.7	0.000	0.00	0.429	0.280
End Juvenil-Panicl Inition	16	30.3	15.3	17.0	11.02	2.2	40.2	0.000	0.00	0.707	0.534
Panicl Inition-End Leaf Growth	32	35.5	21.9	17.8	11.51	21.0	146.0	0.000	0.00	0.330	0.196
End Leaf Growth-Begin Grain Filling	8	34.1	25.5	14.4	11.96	8.8	33.0	0.000	0.00	0.000	0.000
Grain Filling Phase	20	37.8	27.6	17.6	12.28	31.4	110.8	0.000	0.00	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	14	26.7	19.4	8.1	10.79	9.2	27.0	0.000	0.00	0.432	0.295
End Juvenil-Panicl Inition	13	34.6	18.6	16.5	11.00	1.3	36.5	0.000	0.00	0.673	0.500
Panicl Inition-End Leaf Growth	30	37.5	23.9	18.4	11.42	1.7	126.3	0.000	0.00	0.288	0.204
End Leaf Growth-Begin Grain Filling	8	39.8	26.6	20.9	11.84	0.7	47.0	0.000	0.00	0.000	0.000
Grain Filling Phase	19	39.6	27.7	20.0	12.15	9.0	108.5	0.000	0.00	0.000	0.000

Table B 4.29: Predicted climatic parameters and stresses in different development phases of BR14 rice at Mymensingh region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	20	23.2	13.0	12.3	10.74	7.9	47.9	0.000	0.00	0.525	0.367
End Juvenil-Panicl Inition	21	24.6	16.6	11.3	11.12	41.5	54.1	0.000	0.00	0.310	0.168
Panicl Inition-End Leaf Growth	37	29.2	21.3	12.9	11.80	193.4	114.3	0.000	0.00	0.106	0.000
End Leaf Growth-Begin Grain Filling	8	33.5	24.7	14.6	12.35	6.7	33.9	0.000	0.00	0.289	0.052
Grain Filling Phase	25	33.6	25.4	13.3	12.73	264.0	87.1	0.000	0.00	0.043	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	20	24.0	13.2	10.0	10.74	38.8	42.3	0.000	0.00	0.502	0.349
End Juvenil-Panicl Inition	20	25.1	15.9	12.4	11.11	28.4	45.4	0.000	0.00	0.403	0.257
Panicl Inition-End Leaf Growth	37	29.1	22.0	11.2	11.77	309.4	104.1	0.000	0.00	0.023	0.000
End Leaf Growth-Begin Grain Filling	8	34.2	25.7	14.3	12.33	4.9	28.1	0.000	0.00	0.061	0.000
Grain Filling Phase	25	32.6	25.9	9.3	12.71	495.2	63.1	0.000	0.00	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	17	24.9	14.9	10.8	10.72	1.8	38.7	0.000	0.00	0.478	0.330
End Juvenil-Panicl Inition	17	27.3	14.5	13.8	11.02	5.3	37.3	0.000	0.00	0.774	0.603
Panicl Inition-End Leaf Growth	35	33.5	20.4	16.9	11.60	72.8	140.2	0.000	0.00	0.216	0.121
End Leaf Growth-Begin Grain Filling	8	34.5	26.4	14.5	12.13	34.1	31.9	0.000	0.00	0.027	0.000
Grain Filling Phase	23	36.9	27.0	16.0	12.50	61.5	121.7	0.000	0.00	0.036	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	16	25.2	17.3	9.4	10.71	5.9	30.5	0.000	0.00	0.472	0.325
End Juvenil-Panicl Inition	13	32.1	15.9	16.9	10.96	1.5	33.5	0.000	0.00	0.753	0.581
Panicl Inition-End Leaf Growth	32	34.9	22.9	16.2	11.45	12.7	135.8	0.000	0.00	0.222	0.129
End Leaf Growth-Begin Grain Filling	8	39.8	22.6	20.5	11.93	1.2	47.9	0.000	0.00	0.000	0.000
Grain Filling Phase	20	36.0	26.9	15.9	12.28	74.0	89.7	0.000	0.00	0.000	0.000

Table B 4.30: Predicted climatic parameters and stresses in different development phases of BR14 rice at Tangail region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	19	24.1	13.8	12.4	10.76	10.3	48.4	0.000	0.011	0.493	0.342
End Juvenil-Panicl Inition	18	25.4	17.4	10.3	11.09	45.7	37.8	0.000	0.00	0.318	0.192
Panicl Inition-End Leaf Growth	36	30.3	20.8	13.7	11.70	53.8	124.8	0.000	0.00	0.055	0.024
End Leaf Growth-Begin Grain Filling	8	38.0	26.0	20.1	12.22	0.5	51.4	0.000	0.00	0.000	0.000
Grain Filling Phase	22	40.7	27.4	20.7	12.57	14.6	171.4	0.000	0.00	0.000	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	19	25.2	13.5	9.6	10.76	39.7	37.6	0.000	0.00	0.507	0.353
End Juvenil-Panicl Inition	19	26.0	15.2	13.8	11.10	70.9	47.9	0.000	0.00	0.442	0.298
Panicl Inition-End Leaf Growth	35	31.7	22.8	14.1	11.71	105.5	126.3	0.000	0.00	0.099	0.040
End Leaf Growth-Begin Grain Filling	7	37.5	26.4	18.4	12.21	5.6	45.4	0.000	0.00	0.063	0.000
Grain Filling Phase	23	38.7	27.4	18.6	12.56	137.5	146.9	0.000	0.00	0.019	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photosynth	Growth	Photosynth	Growth
Emergence-End Juvenile	15	26.3	16.5	10.5	10.73	0.6	32.2	0.000	0.00	0.465	0.321
End Juvenil-Panicl Inition	16	30.6	12.9	17.8	10.99	0.8	37.3	0.000	0.00	0.785	0.617
Panicl Inition-End Leaf Growth	33	36.0	21.1	17.9	11.52	89.5	150.6	0.000	0.00	0.194	0.111
End Leaf Growth-Begin Grain Filling	8	36.4	26.4	17.0	12.01	15.0	50.1	0.000	0.00	0.000	0.000
Grain Filling Phase	17	40.9	28.7	20.3	12.31	21.3	113.1	0.053	0.074	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	15	25.9	18.2	8.7	10.73	3.2	26.9	0.000	0.00	0.462	0.318
End Juvenil-Panicl Inition	12	35.2	18.6	17.1	10.95	0.3	34.5	0.000	0.00	0.721	0.548
Panicl Inition-End Leaf Growth	32	37.9	23.5	17.6	11.42	7.3	143.1	0.000	0.00	0.203	0.160
End Leaf Growth-Begin Grain Filling	9	41.6	23.6	23.1	11.90	0.6	58.8	0.000	0.00	0.000	0.000
Grain Filling Phase	18	39.8	28.2	19.4	12.22	21.4	105.7	0.000	0.00	0.000	0.000

Table B 4.31: Predicted climatic parameters and stresses in different development phases of BR14 rice at Satkhira region in 2008, 2030, 2050 and 2070

(a) 2008

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	17	24.8	15.0	10.8	10.84	13.3	39.4	0.000	0.00	0.443	0.303
End Juvenil-Panicl Inition	17	26.6	18.1	12.3	11.11	38.0	43.3	0.000	0.00	0.471	0.280
Panicl Inition-End Leaf Growth	34	31.6	22.2	14.6	11.63	10.5	133.3	0.000	0.00	0.290	0.153
End Leaf Growth-Begin Grain Filling	8	35.3	25.2	17.8	12.10	0.3	43.4	0.000	0.00	0.000	0.000
Grain Filling Phase	30	39.5	27.0	22.1	12.41	2.0	147.3	0.000	0.00	0.000	0.000

(b) 2030

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	16	26.4	16.3	8.7	10.83	10.5	32.4	0.000	0.00	0.434	0.296
End Juvenil-Panicl Inition	18	26.9	16.3	13.9	11.10	30.0	51.9	0.000	0.00	0.370	0.236
Panicl Inition-End Leaf Growth	32	32.8	23.0	16.6	11.61	21.5	137.4	0.000	0.00	0.398	0.250
End Leaf Growth-Begin Grain Filling	8	35.7	26.4	17.3	12.05	4.3	42.1	0.000	0.00	0.000	0.000
Grain Filling Phase	19	39.7	27.4	20.5	12.35	4.7	124.5	0.000	0.003	0.000	0.000

(c) 2050

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	13	27.2	17.2	12.5	10.81	0.5	31.6	0.000	0.01 3	0.433	0.297
End Juvenil-Panicl Inition	15	31.7	15.9	18.4	11.02	1.0	41.4	0.000	0.00	0.689	0.506
Panicl Inition-End Leaf Growth	31	36.8	22.1	19.0	11.47	9.3	150.1	0.000	0.00	0.231	0.125
End Leaf Growth-Begin Grain Filling	9	36.5	25.9	15.3	11.90	6.2	40.9	0.000	0.00	0.059	0.000
Grain Filling Phase	17	41.5	28.4	21.0	12.20	10.6	114.7	0.025	0.04 2	0.000	0.000

(d) 2070

Development Phase	Time Span Days	Temp Max. ^0C	Temp Min. ^0C	Solar Rad. MJ/m^2	Photop [day] hr	Rain mm	Evapo Trans mm	Water Stress		Nitrogen Stress	
								Photos ynth	Gro wth	Photos ynth	Growth
Emergence-End Juvenile	12	28.7	20.3	10.8	10.80	5.1	31.0	0.000	0.00	0.400	0.230
End Juvenil-Panicl Inition	12	34.6	20.0	15.1	10.98	0.9	37.0	0.000	0.00	0.575	0.400
Panicl Inition-End Leaf Growth	30	38.6	24.4	18.3	11.37	3.7	128.4	0.000	0.00	0.266	0.194
End Leaf Growth-Begin Grain Filling	7	41.8	27.6	22.0	11.77	0.5	44.5	0.000	0.00	0.000	0.000
Grain Filling Phase	19	41.0	28.2	21.4	12.06	4.6	114.9	0.000	0.00	0.000	0.000

Table B 4.32: Monthly average maximum and minimum temperature, solar radiation and rainfall at Rajshahi in 2008, 2030, 2050 and 2070

Month	2008				2030			
	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)
January	24.10	12.62	11.98	0.52	24.10	11.93	12.05	1.48
February	27.02	16.94	12.69	1.51	27.05	16.02	13.85	4.94
March	34.61	23.11	16.62	0.55	34.55	23.66	17.45	2.36
April	41.99	27.79	22.75	1.01	41.88	27.33	22.39	2.39
May	44.10	29.13	25.63	1.63	44.10	28.96	22.45	6.35
Average	**32.17**	**19.8**	**17.19**	**0.87**	**32.83**	**19.95**	**17.12**	**2.92**

Month	2050				2070			
	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)
January	26.75	13.24	13.86	0.07	27.75	17.49	9.79	0.26
February	34.21	16.68	18.88	0.26	38.04	21.07	18.41	0.08
March	38.79	24.78	19.74	0.71	42.11	25.97	22.39	0.32
April	45.65	29.42	24.28	0.58	39.23	28.93	17.66	7.91
May	40.45	29.62	18.94	6.21	41.94	30.92	21.65	6.51
Average	**35.66**	**21.35**	**18.14**	**1.32**	**36.01**	**23.19**	**17.22**	**2.68**

Table B 4.33: Monthly average maximum and minimum temperature, solar radiation and rainfall at Bogra in 2008, 2030, 2050 and 2070

Month	2008				2030			
	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)
January	23.55	12.33	11.34	0.38	23.55	11.88	11.29	1.16
February	26.52	16.38	13.24	2.14	26.98	15.99	13.79	2.61
March	32.55	22.33	15.10	1.15	32.83	23.58	14.79	4.05
April	39.76	26.95	21.42	1.81	39.39	26.85	20.28	4.41
May	41.80	28.39	23.99	2.08	41.80	27.92	19.57	10.56
Average	**30.88**	**19.24**	**16.24**	**1.276**	**31.55**	**19.57**	**15.63**	**3.79**

Month	2050				2070			
	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)
January	26.00	12.61	12.92	0.05	27.34	17.24	10.92	0.21
February	32.91	16.09	18.05	0.39	36.66	20.24	17.31	0.08
March	37.90	24.23	19.34	0.95	41.16	25.53	21.32	0.41
April	44.17	28.87	23.45	1.03	37.79	28.76	16.65	10.54
May	38.72	29.05	16.87	9.82	40.08	30.24	18.62	8.74
Average	**34.57**	**20.72**	**17.37**	**2.05**	**34.99**	**22.74**	**16.39**	**3.43**

Table B 4.34: Monthly average maximum and minimum temperature, solar radiation and rainfall at Dinajpur in 2008, 2030, 2050 and 2070

Month	2008				2030			
	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)
January	23.91	12.04	11.84	0.14	23.91	11.40	11.87	0.66
February	26.61	15.62	14.31	2.54	27.74	15.39	15.35	1.02
March	32.26	21.47	15.82	1.94	31.15	22.56	14.39	5.27
April	35.34	25.38	18.59	1.60	36.02	24.39	19.34	3.51
May	36.86	26.69	20.71	2.29	36.86	25.47	16.50	9.23
Average	**29.35**	**18.22**	**15.56**	**1.43**	**30.14**	**18.3**	**15.22**	**3.28**

Month	2050				2070			
	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)
January	26.00	11.80	13.57	0.06	28.36	16.23	13.40	0.11
February	32.54	15.68	19.31	0.34	36.81	19.92	18.62	0.01
March	38.24	22.93	20.71	0.55	40.36	24.49	22.02	0.33
April	42.13	27.55	23.00	1.38	34.76	27.71	14.70	9.89
May	36.37	27.83	17.04	8.45	35.45	27.72	16.88	9.01
Average	**33.84**	**19.74**	**17.99**	**1.8**	**33.8**	**21.61**	**16.57**	**3.23**

Table B 4.35: Monthly average maximum and minimum temperature, solar radiation and rainfall at Mymensingh in 2008, 2030, 2050 and 2070

Month	2008				2030			
	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)
January	22.83	12.24	12.49	0.30	22.83	12.53	11.55	1.10
February	24.95	16.48	11.65	3.58	25.88	16.62	12.95	1.21
March	29.57	22.00	12.76	2.25	29.11	22.61	10.20	10.26
April	34.06	25.26	14.11	5.03	32.49	25.88	10.77	13.08
May	35.24	26.45	13.75	8.68	35.24	26.76	12.11	19.44
Average	**28.18**	**18.86**	**13.02**	**3.33**	**28.25**	**19.36**	**11.93**	**7.52**

Month	2050				2070			
	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)
January	24.21	12.96	12.27	0.14	25.36	17.48	9.39	0.54
February	29.94	16.18	15.45	1.02	32.77	18.85	15.79	0.25
March	33.80	22.84	15.98	2.72	37.49	24.56	17.63	1.59
April	38.03	27.49	16.58	2.58	35.38	27.55	13.41	12.33
May	34.93	27.74	12.65	14.63	35.10	28.78	12.04	15.76
Average	**31.27**	**20.2**	**14.5**	**3.54**	**32.08**	**22.08**	**13.63**	**5.12**

Table B 4.36: Monthly average maximum and minimum temperature, solar radiation and rainfall at Tangail in 2008, 2030, 2050 and 2070

Month	2008				2030			
	Tmax (^0C)	Tmin (^0C)	Srad Mj/m^2/day	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad Mj/m^2/day	Rainfall (mm)
January	23.40	12.47	11.72	0.42	23.40	12.24	11.10	1.52
February	26.16	16.85	11.76	2.60	27.14	16.76	13.75	2.49
March	32.41	22.92	14.95	0.73	32.78	23.83	14.55	3.59
April	40.17	27.10	20.81	1.73	38.98	27.31	19.33	4.70
May	41.90	28.37	23.55	2.66	41.90	28.37	19.94	10.29
Average	**30.99**	**19.54**	**15.96**	**1.37**	**31.46**	**19.92**	**15.49**	**3.77**

Month	2050				2070			
	Tmax (^0C)	Tmin (^0C)	Srad Mj/m^2/day	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad Mj/m^2/day	Rainfall (mm)
January	25.66	12.91	12.97	0.05	26.93	18.07	9.98	0.25
February	32.96	16.64	17.36	0.43	36.28	20.40	16.96	0.11
March	37.37	24.63	18.32	1.06	40.69	25.92	20.59	0.78
April	43.54	29.16	22.62	0.84	38.23	28.82	17.16	7.98
May	39.34	29.32	16.97	8.11	40.39	30.40	18.99	7.36
Average	**34.42**	**21.15**	**17.01**	**1.76**	**34.91**	**23.04**	**16.17**	**2.88**

Table B 4.37: Monthly average maximum and minimum temperature, solar radiation and rainfall at Jessore in 2008, 2030, 2050 and 2070

Month	2008				2030			
	Tmax (^0C)	Tmin (^0C)	Srad Mj/m^2/day	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad Mj/m^2/day	Rainfall (mm)
January	23.99	13.01	11.32	0.70	23.99	13.06	12.03	0.49
February	26.97	18.15	11.14	2.05	28.55	18.13	14.14	0.91
March	34.38	23.91	17.06	0.20	34.69	24.55	17.27	1.02
April	39.71	26.95	21.89	0.46	39.30	27.79	20.96	1.64
May	41.70	28.30	25.02	1.08	41.70	29.22	22.62	2.42
Average	**31.46**	**20.08**	**16.63**	**0.79**	**32.26**	**20.53**	**17.15**	**1.08**

Month	2050				2070			
	Tmax (^0C)	Tmin (^0C)	Srad Mj/m^2/day	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad Mj/m^2/day	Rainfall (mm)
January	26.34	13.90	13.53	0.07	28.82	19.54	10.23	0.32
February	34.51	18.61	18.39	0.27	37.91	21.79	17.85	0.10
March	37.77	25.14	18.06	0.56	41.19	27.33	21.09	0.41
April	42.34	28.98	23.13	0.52	39.00	28.97	19.45	5.21
May	40.44	29.81	19.98	3.41	40.69	30.72	22.29	3.97
Average	**34.86**	**22**	**17.59**	**0.82**	**35.91**	**23.86**	**17.58**	**1.7**

Table B 4.38: Monthly average maximum and minimum temperature, solar radiation and rainfall at Satkhira in 2008, 2030, 2050 and 2070

Month	2008				2030			
	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)
January	24.25	13.90	10.67	0.58	24.25	13.67	11.36	0.37
February	27.52	18.92	12.41	1.41	28.77	18.64	14.27	1.13
March	34.20	24.12	16.62	0.21	34.81	24.68	18.38	0.72
April	39.38	26.94	22.25	0.19	39.15	27.83	20.86	1.06
May	42.36	28.24	25.22	0.35	42.36	29.39	23.57	1.04
Average	**31.62**	**20.41**	**16.66**	**0.5**	**32.49**	**20.83**	**17.44**	**0.72**

Month	2050				2070			
	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)
January	26.82	14.68	13.90	0.07	29.98	20.54	11.26	0.32
February	34.67	19.25	18.79	0.21	38.04	22.43	17.94	0.12
March	37.92	25.30	18.40	0.35	40.96	27.58	21.36	0.16
April	41.78	28.90	22.33	0.49	39.23	29.22	19.66	3.89
May	40.32	29.66	21.06	2.72	40.90	30.79	23.23	2.85
Average	**34.89**	**22.35**	**17.77**	**0.67**	**36.2**	**24.29**	**18.05**	**1.24**

Table B 4.39: Monthly average maximum and minimum temperature, solar radiation and rainfall at Barisal in 2008, 2030, 2050 and 2070

Month	2008				2030			
	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)
January	23.94	12.36	12.67	1	23.94	12.84	13.31	0.25
February	26.5	18.36	10.72	2.05	28.10	18.22	14.29	0.90
March	32.5	23.13	17.07	0.16	31.49	24.01	13.80	1.24
April	34.78	26.1	17.71	0.27	33.48	27.25	14.80	2.55
May	35.92	27.65	18.66	1.34	35.92	28.43	18.74	2.88
Average	**29.47**	**19.74**	**15.09**	**0.82**	**29.79**	**20.28**	**15.23**	**1.3**

Month	2050				2070			
	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)
January	25.90	14.10	13.20	3.20	28	19.5	9.77	0.411
February	31.93	19.05	16.10	19.78	35.8	21.4	17.55	0.08
March	35.27	24.39	16.99	0.70	37.63	26.8	18.27	0.23
April	37.88	28.29	20.05	0.54	36.9	28.31	18.86	6.18
May	37.20	29.46	16.35	2.97	37.23	30.1	19.1	4.97
Average	**32.71**	**21.75**	**16.11**	**4.54**	**33.96**	**23.54**	**16.48**	**1.98**

Table B 4.40: Monthly average maximum and minimum temperature, solar radiation and rainfall at Madaripur in 2008, 2030, 2050 and 2070

Month	2008				2030			
	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)
January	23.86	12.27	12.81	1.04	23.86	12.43	13.37	0.45
February	26.47	18.03	10.96	2.28	28.05	17.94	14.12	1.04
March	33.27	23.27	17.35	0.16	32.18	24.02	14.31	1.45
April	36.55	26.36	18.99	0.39	35.05	27.35	16.53	3.21
May	37.53	27.69	19.85	1.60	37.53	28.39	18.85	4.15
Average	**30.08**	**19.69**	**15.63**	**0.94**	**30.37**	**20.13**	**15.58**	**1.72**

Month	2050				2070			
	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)
January	25.74	13.75	13.12	0.08	27.77	18.99	9.47	0.44
February	32.63	18.72	16.82	0.57	36.58	21.31	18.03	0.05
March	36.13	24.46	17.38	0.91	38.93	26.88	18.89	0.31
April	39.57	28.46	21.11	0.62	37.77	28.42	19.26	6.18
May	38.49	29.59	17.01	2.92	38.25	30.23	19.46	4.75
Average	**33.42**	**21.68**	**16.52**	**0.86**	**34.53**	**23.44**	**16.67**	**1.96**

Table B 4.41: Monthly average maximum and minimum temperature, solar radiation and rainfall at Chandpur in 2008, 2030, 2050 and 2070

Month	2008				2030			
	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)
January	24.22	11.96	13.77	1.07	24.22	12.26	13.82	0.38
February	26.65	17.96	11.88	1.88	28.19	17.79	14.97	0.96
March	32.48	23.26	16.01	0.14	31.56	23.98	13.75	1.65
April	35.00	26.33	16.97	0.43	33.70	27.33	14.69	3.21
May	35.99	27.76	17.86	1.44	35.99	28.29	17.78	4.54
Average	**29.63**	**19.66**	**15.1**	**0.85**	**29.9**	**20.07**	**15.23**	**1.79**

Month	2050				2070			
	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)	Tmax (^0C)	Tmin (^0C)	Srad $Mj/m^2/day$	Rainfall (mm)
January	25.76	13.81	13.30	2.28	27.75	18.69	10.23	0.28
February	31.74	18.77	16.03	20.49	35.84	21.12	17.66	0.07
March	35.44	24.57	17.38	1.00	37.95	26.93	18.24	0.19
April	38.20	28.39	19.65	0.63	37.54	28.44	19.11	5.56
May	37.74	29.59	17.09	2.78	37.55	30.23	19.23	4.25
Average	**32.83**	**21.68**	**16.26**	**4.54**	**34.12**	**23.38**	**16.6**	**1.73**

Table B 4.42: Monthly average maximum and minimum temperature, solar radiation and rainfall at Comilla in 2008, 2030, 2050 and 2070

Month	2008				2030			
	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)
January	24.18	11.48	13.70	0.88	24.18	11.92	13.15	0.95
February	26.39	17.36	12.63	2.67	27.91	17.11	15.24	1.11
March	31.44	22.71	15.11	0.53	30.74	23.36	13.61	3.98
April	34.91	25.92	17.45	0.57	32.83	26.73	14.43	4.61
May	36.36	27.29	18.57	2.02	36.36	27.59	16.79	5.58
Average	**29.45**	**19.16**	**15.19**	**1.13**	**29.59**	**19.52**	**14.83**	**2.71**

Month	2050				2070			
	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)
January	25.43	13.40	13.43	0.07	27.38	17.80	10.73	0.28
February	30.84	18.21	15.71	0.76	34.88	20.27	17.32	0.09
March	35.09	24.34	17.42	1.41	37.96	26.69	18.41	0.28
April	37.63	28.00	18.48	0.93	37.31	28.02	17.54	5.20
May	37.76	29.03	16.76	3.06	36.66	29.61	16.64	4.66
Average	**32.4**	**21.19**	**15.98**	**1.05**	**33.62**	**22.8**	**15.84**	**1.79**

Table B 4.43: Monthly average maximum and minimum temperature, solar radiation and rainfall at Sylhet in 2008, 2030, 2050 and 2070

Month	2008				2030			
	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)
January	23.22	11.36	13.31	0.59	23.22	12.04	11.19	1.48
February	23.77	16.32	9.92	9.25	24.75	16.02	12.12	2.95
March	27.93	21.40	11.77	10.01	26.59	21.10	8.14	24.58
April	28.78	23.54	8.78	21.88	27.99	24.29	5.68	38.50
May	30.85	24.89	9.79	19.02	30.85	25.20	7.42	43.03
Average	**26.33**	**17.96**	**11.21**	**10.1**	**26.33**	**18.38**	**9.687**	**18.5**

Month	2050				2070			
	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)	Tmax (^{0}C)	Tmin (^{0}C)	Srad Mj/m^2/day	Rainfall (mm)
January	23.00	13.04	11.56	1.27	25.00	16.57	10.70	2.31
February	26.63	16.01	13.75	4.60	30.54	18.74	15.01	1.57
March	29.83	22.04	12.21	12.43	32.60	24.13	13.07	8.43
April	31.36	25.53	9.83	15.59	32.45	26.14	11.22	28.35
May	30.79	26.19	8.46	28.44	31.60	27.26	7.99	34.11
Average	**28.14**	**19.37**	**11.67**	**10.4**	**29.73**	**21.22**	**11.91**	**12.5**