Adaptive Crop Agriculture Including Innovative Farming Practices in the Coastal Zone of Bangladesh

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Climate Change Cell
Department of Environment

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Foreword

The impacts of global warming and climate change are worldwide. For Bangladesh they are most critical because of its geographical location, high population density, high levels of poverty, and the reliance of many livelihoods on climate-sensitive sectors, such as agriculture, fisheries.

To address current impacts and manage future risks of climate change and variability towards development of a climate resilient Bangladesh, the government has established the Climate Change Cell (CCC) in the Department of Environment (DoE) under the Comprehensive Disaster Management Programme (CDMP). Climate change research, covering modeling and adaptation is one of the major activities of the Cell.

CCC in association with its Technical Advisory Group (TAG) and other stakeholders identified a set of research activities related to climate change in Bangladesh through a number of consultations. The activities have been prioritized and a number of projects have been commissioned in last few years.

Cell is facilitating adaptation research in order to, fill knowledge gaps in the arena of adaptation to climate change and its impacts on the life and livelihoods; explore options to adapt with the climate change; and contribute in better understanding of adaptation options. In this regard, a number of projects have been commissioned in the field of Crop agriculture, Crop insurance, Health, Gender and disadvantaged groups.

Agricultural crops are very sensitive to the different variables of climate (temperature, rainfall, humidity) as well as different natural hazards, in particular, salinity intrusion due to sea level rise and storm surges in the coastal zone of Bangladesh. Changes in the climatic variables and increase in such natural hazards due to climate change will adversely affect the crop production. This study tried to identify and demonstrate available suitable varieties of rice and non-rice crops and adaptation measures or technologies that have the potential to help farmers of the coastal zone to adapt to climate change in future.

The research revealed that salt tolerant T. Aman varieties like BR23, BRRI dhan40, BRRI dhan41 and BRRI dhan47 would be the solution to overcome the salinity impact at later stage of crop growth in the coastal regions. Non-rice crops such as Tomato, Okra and Aroid, under improved management practices with raised bed and mulch in the medium saline soils of Satkhira have high potential.

It is expected that the research will create a strong link between agriculture researchers and other stakeholders to share research results and needs. Dissemination of the study findings, replication and expansion of such initiatives throughout the coastal zone will explore options to combat climate change impacts. Findings of such studies will facilitate policy makers and planners to formulate viable adaptation policies, strategies and action plan.

Zafar Ahmed Khan, PhD
Director General
Department of Environment

Acronyms and Abbreviations

ADB	Asian Development Bank
ARAC	Adaptation Research Advisory Committee
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BRRI	Bangladesh Rice Research Institute
BUP	Bangladesh Unnayan Parishad
CEGIS	Center for Environmental and Geographical Information Services
CCC	Climate Change Cell
CDMP	Comprehensive Disaster Management Program
DAE	Department of Agricultural Extension
DoE	Department of Environment
DFID	Department for International Development
FAO	Food and Agricultural Organization (of the United Nations)
GCM	General Circulation Models
GDP	Gross Domestic Products
GoB	Government of Bangladesh
HYV	High Yielding Variety
IPCC	Intergovernmental Panel on Climate Change
MoEF	Ministry of Environment and Forests
NAPA	National Adaptation Programme for Action
RVCC	Reducing Vulnerability to Climate Change
SLR	Sea Level Rise
SRES	Special Report on Emission Scenario
STW	Shallow Tube-Well
TAR	Third Assessment Report
UK	United Kingdom
UNDP	United Nations Development Program
WB	World Bank

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Executive Summary

CEGIS has conducted the study on “Adaptive Crop Agriculture Including Innovative Farming Practices in the Coastal Zone of Bangladesh” in Satkhira District, commissioned by the Climate Change Cell of Department of Environment (Component 4b, CDMP). The study has been conducted in partnership with BRRI, BARI, BARC and BUP. The main objective of the study was to find out suitable adaptation measures that have the potential to help farmers adapt to climate changes and to identify suitable varieties of crops that would be able to adapt to climate change.

In order to assess and analyze the problems, the study team members appraised the existing findings from literature review and community consultation. An attempt was made to understand the present and future geo-physical environment of the study area. The CROPSUIT model developed by CEGIS was used to estimate the physical suitability of land for different types of land uses or crop cultivation. Physical suitability change under climate change scenarios was analyzed to assess potential threats to current landuse practices.

Based on expert opinion, different types of rice crops and non-rice crops were selected for field-testing. For the boro season, BRRIdhan29, BRRIdhan45 and BRRIdhan47 were transplanted in the village of Roghurampur of Kaliganj Upazila. For the rabi season tomato, watermelon, okra and aroid were selected. For the T. Aman season, different varieties were selected such as BR23, BRRIdhan40, BRRIdhan41, and BRRIdhan33/39. From field experiments it was found that introduction of high yielding salt tolerant variety BRRIdhan47 could produce sustainable grain yield in the coastal regions. It was also observed that there was no salinity impact on rice production due to high rainfall during monsoon season. But in the later part, when the rainfall ceases, it was assumed that soil salinity might increase and go beyond the safe limit of rice crop (4 dS/m). So, salt tolerant T. Aman varieties like BR23, BRRIdhan40 and BRRIdhan41 may be the solution to overcome salinity impact at the later stage. Tomato, okra and aroid were grown successfully under improved management practices with raised bed and mulch in the medium saline soils of Satkhira. The existing cropping pattern of Fallow-T.Aman (Local)-Fallow or Fallow-T.Aman (Local)-Boro (Local/HYV) may be replaced with the pattern of Okra (Dharosh) - T.aman - Boro (HYV) or Okra (Dharosh) - T.aman - Tomato.

Simulation experiments were conducted for five rice cultivars namely, BR23, BRRIdhan33, BRRIdhan39, BRRIdhan40, and BRRIdhan41 using two soils, Bajoa and Barisal series for transplanted aman season. Results of simulation experiments showed that the yields of all rice cultivars varied with soils and also with different climate change scenarios. Highest yield of 5839 kg ha-1 was obtained with BRRIdhan41, followed by BRRIdhan40 (4251 kg ha-1) and lowest yield of 2836 kg ha-1 with BR23. In general yield decrease was relatively small under HADC 50 scenario and large under UKTR 70 scenario. For boro season simulation experiments were conducted for five rice cultivars namely, BRRIdhan29, BRRIdhan45, and BRRIdhan47 using Bajoa series soil. Results of simulation experiments showed that the yields of all rice cultivars responded differently with different climate change scenarios. In general yield decrease was relatively small under GFDL 50 scenario and large under UKTR 50 scenario. Simulation runs were made for aroid at two locations with Barisal and Ishwardi series soils. Results showed that irrespective of GCMs and interval aroid yields increased from 2% to 9% in case of Barisal series soil. Lower yields were recorded for Ishwardi soil

series and also yield reduction of 4% to 13%. In case of tomato all the scenarios predicted 23% to 28% yields increase.

It is difficult to confirm a crop as adaptive under climate change situations using only one season crop related data. At least three years of experimentation will be needed to confirm whether a crop is adaptive under climate change situations in the coastal region. The adapted rice and non-rice crop results along with their innovative farming practices may be expanded throughout the salt affected coastal zone of Bangladesh.

1. Introduction

1.1 Background

The Climate Change Cell (CCC) of the Department of Environment (DoE) gave CEGIS the responsibility of conducting a study on "Adaptive Crop Agriculture Including Innovative Farming Practices in the Coastal Zone of Bangladesh". CCC has been established as a part of the Comprehensive Disaster Management Program (CDMP). This study was supported by the Department for International Development (DFID) and the United Nations Development Program (UNDP)."

The impact of global climate change on agriculture has been studied extensively for various crops at different scales in many countries of the world. Available reports show that tropical and subtropical countries would be more vulnerable to the potential impacts of global warming. Bangladesh is likely to be one of the worst hit countries, being an Asian and a Third World country. The economy of Bangladesh is based on agriculture, industry and services. The agriculture sector contributes a major share in the GDP, which is about 21% and employs about 48% of the working force (Table 1.1).

Table 1.1: Occupations and GDP and sector wise contributions

Country	Occupation	GDP (At constant producer price)
Bangladesh	Agriculture: 48.1%	Agriculture: 21.10%
	Industry: 51.9%	Industry: 78.90%

Source: Statistical Pocket Book, 2007

The variability of climate change has become a challenging issue for agriculture due to global warming. Agricultural crops of Bangladesh are especially sensitive to the different variables of climate such as temperature, rainfall, humidity, day-length etc. as well as different natural disasters like floods, drought, salinity and storm surges etc. Therefore, adaptation measures have to be looked at for the sustainability of agriculture.

This study has identified suitable varieties of rice and non-rice crops and available adaptation measures or technologies for agriculture that have the potential to help farmers to adapt to climate change in the future. As per the study mandate of CCC, Satkhira District, which represents the typical coastal scenarios, was selected as study area. CEGIS had previously conducted two studies in the southwest coastal region of Bangladesh including Satkhira, Khulna and Bagerhat districts. One of these studies was the "Coastal Landuse Zoning" and the other was the "Impact of Sea Level Rise on Landuse Suitability and Adaptation Options". A large GIS database on the current landuse and land cover was developed under these studies and is available at CEGIS for further analysis.

1.2 Rationale of the Study

In the past, many studies have been conducted on climate change issues by different organizations and future impact scenarios have also been developed. Different adaptation measures, technologies and strategies have already been developed by different organizations as well as by communities to adapt with climate change. As agriculture is the main sector of this economy, it is essential to identify suitable adaptation technologies or varieties of agricultural crops through field-testing and community awareness for sustainability. Suitable and ideal adaptation measures and varieties of crops have been identified through this study. The results will give hope and confidence to farmers in adapting their crops to climate change.

1.3 Objectives

The main objective of the study was to find out suitable adaptation measures that have the potential to help farmers to adapt to climate change. The specific objectives were:

- To identify suitable varieties of crops that would be able to adapt to climate change.
- To identify the available adaptation measures or technologies for agriculture to adapt to climate change.
- To demonstrate and test the available adaptation measures or technologies or crop varieties through farmer's participation.
- To disseminate the information on available adaptation measures or technologies or crop varieties to the farmers through awareness building.

1.4 Study Area

Satkhira District under the coastal region was selected as study area (Figure 1.1). Satkhira is situated in the southwest part of Bangladesh and is located at 22°37′ N Latitude and 89°10′ E Longitude with an altitude of 3.0-3.5 m from MSL. The land type is Gangetic Tidal Floodplains and falls under AEZ 13. The main soil types are non calcareous to dark gray floodplain and non-saline to seasonally saline with a loamy clay soil texture. The average annual rainfall is about 1500 mm, but most of the rainfall occurs during the monsoon season. The maximum monthly average temperature varies from 26-36°C during the months of March-August, whereas the monthly average minimum temperature varies from 13-15 °C during the rest of the year. The monthly average relative humidity ranges from 69% to 88%.

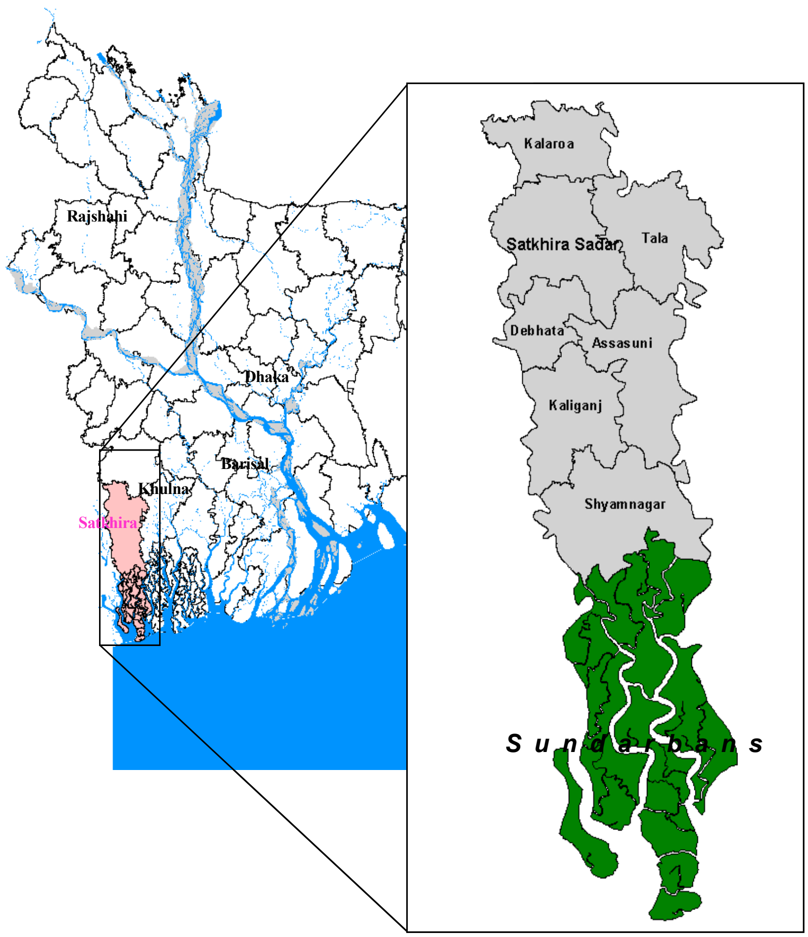


Figure 1.1: Location of the Study Area

1.5 Outputs of the Study

The outcomes expected from the study were:

- Documentation of findings on adaptive suitable and feasible crops and technologies under different climate scenarios and specific locations
- Analysis and documentation of all findings of the field tests
- Recommendations based on research findings for further dissemination of adaptation technologies and for farmers and communities.
- Hard- and soft copies of relevant CROPSUIT runs and written analysis of these runs.

2. Literature Review

2.1 Climate Change in Bangladesh Context

2.1.1 Scenarios for Temperature and Precipitation

In the early 1990s General Circulation Models (GCM) were extensively used for generating climate change scenarios for Bangladesh. The BUP-CEARS-CRU (1994) study reported a 0.5°C to 2.0°C rise in temperature by the year 2030. The same modelling effort estimated a 10 to 15% rise in average monsoon rainfall by the year 2030. Using four GCMs (CSIRO9, CCC, GFDLH, and UKMOH), ADB (1994) conducted a study and reported that, the temperature would rise by 0.3°C for 2010 with a corresponding rise of 1.5°C for 2070.

All these four models provided different results for developing monsoon rainfall scenarios. The high-estimating GFDL model (GFDLH) projected 59% higher rainfall for South Asian monsoon with a corresponding withdrawal of dry season rainfall by 16%. The CCC model, however, projected an increase of monsoon rainfall by 20% and withdrawal of dry season rainfall by 6%. Both considered a doubling of CO_2 concentration in the atmosphere (therefore, time independent). A time-dependent modelling provided a medium scenario for South Asian rainfall: the monsoon rainfall was projected to increase up to 5% by 2010 and between 5 to 30% by the year 2070, while the dry season rainfall was projected to vary between -10 to +10% by the year 2070. For the time dependent medium-scenarios, it was assumed that the concentration of CO_2 would be 400 and 640 ppmv by the years 2010 and 2070, respectively (ADB, 1994).

Model-driven climate change scenarios were generated under the 'Climate Change Country Studies Programme' using the Canadian Climate Centre Model (CCCM), the Geophysical Fluid Dynamics Laboratory equilibrium model (GFDL), and the 1% transient model of GFDL (i.e., GF01) (Ahmed et al., 1996; Asaduzzaman et al., 1997 and Huq et al., 1998). The outputs of the three GCMs for the 1990 base year were validated against a long-term 'climate normal', as provided in the published report (FAO-UNDP, 1988). Applying the same methodology, Ahmed and Alam (1998) reproduced climate change scenarios, which were largely used for a number of subsequent national assessments. Table 2.1 summarizes the results of such scenario development exercises.

Table 2.1: Outputs of GCM exercise using GFD 01 transient model

Year	Average Temperature			Temperature increase			Average Precipitation			Precipitation Increase		
	W	M	Ave	W	M	Ave	W	M	Ave	W	M	Ave
	(°C)			(°C)			mm/month			mm/month		
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

Note: W stands for winter (i.e., December, January and February: DJF) and M stands for monsoon (i.e., June, July and August: JJA)
Source: Ahmed, A.U. and Alam, M., 1998

It was reported that the average increase in temperature would be 1.3°C and 2.6°C for the two projection years, 2030 and 2075, respectively. It was reported that the winter rainfall 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% and 27% for the two projection years, respectively.

Based on an ensemble technique, Mirza (1997) developed climate change scenarios using a number of GCMs and the results were used for the World Bank Study (WB, 2000). By the year 2030, the projected rise in monsoon temperature was 0.7 ^{O}C with a corresponding rise in winter temperature of 1.3 ^{O}C. WB (2000) results showed similarities with respect to the results of Ahmed and Alam (1998). The corresponding rise in rainfall was projected at 11% for monsoon, while a decrease in rainfall by 3% was also projected for winter by the year 2030. For the year 2050, the study projected increases in temperature by 1.1 and 1.8 ^{O}C for monsoon and winter, respectively. For the same year, the projected changes for rainfall were 28% in monsoon and -37% in winter. These were adopted for the First Initial National Communication for Bangladesh (MoEF-2002).

In another study, Mirza (2005) computed changes in rainfall in response to 2^{o}C, 4^{o}C, and 6^{o}C changes in average temperature over the South Asian subcontinent, particularly over Bangladesh. Huge variations in output results were found: varying from 0.8% to 13.5% increase in mean annual rainfall for the Ganges basin and -0.03% to 6.4% change for the same for the Brahmaputra basin for a 2^{o}C temperature change scenario. It is reported that there would be increasing mean annual rainfall in both the basins with increasing global warming. The UKTR model suggested as high as a 63.3% increase in mean annual rainfall over the Ganges basin associated with a change in surface average temperature of 6^{o}C. The corresponding change in Brahmaputra basin would be much less (Mirza, 2005).

Agrawala et al. (2003) have used another ensemble of a dozen GCMs, which were driven by the MAGICC model using the SCENGEN database. Table 2.2 provides the results of the validated ensemble model runs applicable for Bangladesh (Agrawala et al., 2003).

Table 2.2: GCM projections for changes in temperature and precipitation for Bangladesh

Year	Temperature change (°C) mean (standard deviation)			Rainfall change (%) mean (standard deviation)		
	Annual	DJF	JJA	Annual	DJF	JJA
Baseline average 2030	1.0 (0.11)	1.1 (0.18)	0.8 (0.16)	3.8 (2.30)	-1.2 (12.56)	+4.7 (3.17)
2050	1.4 (0.16)	1.6 (0.26)	1.1 (0.23)	+5.6 (3.33)	-1.7 (18.15)	+6.8 (4.58)
2100	2.4 (0.28)	2.7 (0.46)	1.9 (0.40)	+9.7 (5.8)	-3.0 (31.6)	+11.8 (7.97)

Note: DJF represents the months of December, January and February, usually the winter months. JJA represents the months of June, July and August, the monsoon months.
Source: Agrawala et al., 2003.

The results were compared with previous results (in Table 2.1) as provided by Ahmed and Alam (1998). The core findings appear to be consistent with the analysis presented above. Both the studies agreed that winter warming would be greater than summer warming. The two studies also estimated little change in winter precipitation and an increase in precipitation during the monsoon. The slightly higher monsoon precipitation projected by Ahmed and Alam (1998) compared to that by Agrawala et al. (2003) may be attributed to lower climate sensitivity in more recent climate models.

According to fourth assessment report 2007, Table 2.3 shows projected changes in surface air temperature and precipitation for south East Asia under SRES A1FI (highest future emission trajectory) and B1 (lowest future emission trajectory) pathways for three time slices, namely 2020s, 2050s and 2080s.

Table 2.3: Projected changes in surface air temperature and precipitation for South East Asia

Season	2010 to 2039				2040 to 2069				2070 to 2099			
	Temperature °C		Precipitation %		Temperature °C		Precipitation %		Temperature °C		Precipitation %	
	A1FI	B1	A1FI	B1	A1FI	B1	A1FI	B1	A1FI	B1	A1FI	B1
DJF	0.86	0.72	-1	1	2.25	1.32	2	4	3.92	2.02	6	4
MAM	0.92	0.8	0	0	2.32	1.34	3	3	3.83	2.04	12	5
JJA	0.83	0.74	-1	0	2.13	1.3	0	1	3.61	1.87	7	1
SON	0.85	0.75	-2	0	1.32	1.32	-1	1	3.72	1.9	7	2

Note1: DJF: December January February, MAM: March April May, JJA: June July August and SON: September October November
Source: IPCC, 2007

Instead of developing one or more scenarios the National Adaptation Programme for Action (NAPA) for Bangladesh has developed a climate change scenario for the country. The NAPA Core Team (GOB, 2005) adopted the results obtained by Agrawala et al. (2003) for changes in temperature. Regarding changes in precipitation it modified the results of Agarwala et al. (2003) based on the judgment of the NAPA Core Team and not on the reflection of any GCM modelling exercise. The scenario provided by the NAPA document is given in Table 2.4 for comparison. The NAPA document has also provided a sea –level rise scenario for Bangladesh. Apparently, the upper values of the IPCC SLR scenarios (WGI, TAR: IPCC, 2001) were adopted for developing the scenarios for 2050 and 2100, while the curve was extrapolated for developing the 2030 SLR scenario.

Table 2.4: Scenarios provided in NAPA document

Year	Temperature change (°C) mean			Rainfall change (%) mean			Sea Level Rise (cm)
	Annual	DJF	JJA	Annual	DJF	JJA	
2030	1.0	1.1	0.8	5	- 2	6	14
2050	1.4	1.6	1.1	6	- 5	8	32
2100	2.4	2.7	1.9	10	- 10	12	88

Note: Despite the claim, the values in the shaded cells are not directly adopted from Agarwala et al. (2003). No explanation has been provided in relation to the deviations from the model-resolved ensemble data. Standard deviations were not shown.
Source: Adopted from the Bangladesh NAPA Document (GOB, 2005).

2.1.2 Scenarios for Sea Level Rise

For sea level rise, the scenarios have so far been largely speculative, not based on any modelling. For sea level rise, a range of 30 to 150 cm was assumed by Mahtab (1989) for the year 2050. However, a median value was considered by taking the mean of the two limits and adding 10cm for local subsidence, which provided for a 100 cm 'net sea level rise' by the year 2050.

In the absence of a Bangladesh-specific sea level rise scenario, the IPCC scenarios for sea level change were taken as a basis for developing net sea level change along the coastal zone of Bangladesh, as cited in Halcrow et al. (2001). MOEF (2002) considered a linear rise in sea level by 1mm/year, which resulted in a 30 and 50cm rise in sea level by the year 2030 and 2050, respectively. The NAPA document has provided a sea-level rise scenario for Bangladesh. However, no explanation has been provided in support of the data. Apparently, the upper values of the IPCC SLR Scenario (WGI, TAR: IPCC, 2001) was adopted for developing the scenarios for 2050 and 2100, while the curve was extrapolated for developing the 2030 SLR scenario.

The low-lying topography of the coastal landforms in Bangladesh suggests that a change in sea-level can have catastrophic impacts and increase vulnerability significantly. The GBM delta is morphologically highly dynamic and the coastal lands are simultaneously subject to accretion and tectonic subsidence (Huq et al., 1996; Allison et al., 2003). Compaction of sediment may also play a role in defining net change in sea level along the coastal zone due to the fact that the landform is constituted by sediment decomposition. Lacking more specific information, if one assumes that sediment loading cancels out the effects of compaction and subsidence, the net sea-level rise can be assumed to be close to the global average as projected by the IPCC.

The existing literature provides a wide range of estimates of the rate of subsidence. It is, therefore, difficult to estimate the overall extent of relative sea level rise in the coast of Bangladesh. It is not possible to project from the existing literature the future rate of subsidence of the Bengal delta. Values suggested so far range between less than a millimeter and over 20 mm per annum. Considering the estimates for the annual rate of subsidence of about 2 mm along the Ganges deltaic plain with a compensation factor of about 1mm/year due to sedimentation, the net change in elevation due to a combination of sedimentation and subsidence will be about 1 mm/year.

The latest IPCC scenario (IPCC, 2001) provides a globally averaged sea level change scenario that projects a rise of 9 to 88 cm by the year 2100. Considering a non-linear rate of change owing to the gradual accumulation of greenhouse gases in the atmosphere, the range of sea level rise will be 2 to 20 cm in 2025 and 4 to 39 cm in 2050. The 'net sea level rise' will be 4.5 to 23 cm in 2025 and 6.5 to 44 cm in 2050. Since the projected adverse impacts will be much higher for the latter case, the lower values for sea level rise may be ignored.

2.1.3 Scenario for Cyclone along the Coastal Zone of Bangladesh

Very little is found in the literature on future plausible changes in cyclone intensity along the coastal zones of Bangladesh. The BCAS-RA-Approtech (1994) study considered a net increase in 10% intensity in cyclone activities, which was based on expert judgment. Ali (1999) commented that an increase in 2°C is SST would likely cause a significant increase in the probability of formation of cyclones from a mere depression. The IPCC Third Assessment noted that currently available models could not do a good job towards resolving the influence of climate change on cyclones (IPCC, 2001). However, based on emerging insights from a few climate model experiments as well as the empirical records, the TAR of IPCC concluded that "... there is some evidence that regional frequencies of tropical cyclones may change but none that their locations will change. There is also evidence that the peak intensity may increase by 5% and 10% and precipitation rates may increase by 20% to 30%" (IPCC, 2001).

2.2 Impacts of Climate Change on Crop Agriculture

Agriculture is one of the most vulnerable systems to be affected by climate change in the south Asian region. The climate in Bangladesh is changing. It is becoming more unpredictable every year and its variability is being experienced more frequently than ever before. Hazards like floods, droughts, cyclones and others are likely to be aggravated by climate change. Salinity intrusion would be a more acute problem in the coastal region. This will have extra bearing on the agriculture and the potable water in that region. The salinity conditions in the coastal area of Bangladesh could further exacerbate due to reduced dry-season freshwater supply from upstream sources resulting from climate change (IPCC, 1998) and saline water intrusion due to sea level rise.

It is believed that climate change would increase the disparities in cereal production between developed and developing countries. The production in the developed world would benefit from climate change, while that in developing nations would decline (Walker and Steffen, 1997). Farm-level adaptation would be inadequate in reducing the disparities. It is also reported that even an extensive farm-level adaptation in the agricultural sector would not entirely prevent such negative effects. In general, the tropical and subtropical countries would be more vulnerable to the potential impacts of global warming through effects on crops, soils, insects, weeds and diseases. On the other hand, elevated carbon-di-oxide (CO_2) concentrations will have beneficial effects on crop production. Impacts of climate change would cause enhanced vulnerability to the crop production systems in Bangladesh.

A study was done to assess impacts of climatic variations on food grain Production in Bangladesh by using CERES Crop models (Z. Karim et al., 1998). Under this study eighteen experiments for rice crops and three experiments for wheat were created. Sensitivity analysis was done at $0^{O}C$, $2\ ^{O}C$ and $4\ ^{O}C$ temperature rise at three levels of CO_2 (330, 580, and 660 ppmv) to see how the crop models responded to changes in climatic variables and to assess climatic change impact on crops. Increased levels of CO_2 increased all rice yields at all study locations. The maximum yield increase was noted for CO_2 level at 660 ppmv followed by 580 ppmv. With increased temperatures yields of *aus*, *T.Aman*, and *boro* rice decreased for CO_2 levels of 330 ppmv. However, *boro* yields generally increased for a $2\ ^{O}C$ warming with CO_2 levels of 580 and 660 ppmv. Even at a $4\ ^{O}C$ temperature rise, yield increases were generally found for *T. Aman* and *boro* rice at 580 and 660 ppmv CO_2 levels. In most cases doubling of CO_2 level compensated the adverse effect of temperature rise. Wheat was severely affected by the increased temperature, even at higher levels of CO_2. Recent analysis has shown that increased CO_2 levels essentially help attain higher leaf area index, and do not contribute to increased rice yields (Abrol, 1998). These results have supplemented the finding of Walker and Steffen (1997). It may be too early to come to a conclusion regarding the direct effects of climate change on food grain production.

As there is a strong possibility that winter precipitation will decrease, it is likely that moisture content of topsoil would decrease substantially. Due to temperature rise, the high rate of evapotranspiration will result in an acute drought condition in winter months. Consequently, a late Kharif II drought in December would adversely affect Aman crop at the ripening stage, while an early *rabi* drought would more severely affect wheat and *boro* crops at both germination and vegetative growth stages (Karim et al 1998). Furthermore, increasing moisture stress in early Kharif I would significantly affect Aus production.

Together with the possible reduction in Aman rice area (as a result of greater spread of flood waters, and longer duration of flooding) and a reduction in *boro* rice area (which will be limited by available surface and ground water for irrigation), the total area suitable for rice production may in the future stagnate or possibly decrease (WB, 2000). CEGIS (2006) has shown that due to sea level rise along the southwestern region of Bangladesh Aman suitable areas would decrease significantly.

In the winter months the coastal croplands suffer due to salinity related problems. In the absence of appreciable rainfall the soil in the coastal areas starts to desiccate, and because of capillary actions salt comes up at the surface of the soil and accumulates at the root zones. Salinity problem is often intensified when high spring tides inundate low-lying coastal areas, especially when they are associated with cyclonic storm surges. Many of the crop varieties, especially those of food grain varieties, are not salinity tolerant. As a result, a large area in the coastal districts is virtually unsuitable for a number of crops, while the production of a few other crops is lesser under saline conditions. Since salinity intrusion restricts cultivation of *boro* and wheat, the potential impact cannot be ascertained. However, the varieties that are grown with the given conditions, about 0.13 Mt of food grain is lost annually due to adverse impact of soil salinity. It is reported that the effect of soil salinity on Aus production would be detrimental, and Aman season rice crop, when grown under severe climate change scenarios, could also suffer over two fold yield reductions (Habibullah et al., 1998)

Flood affects agricultural production considerably. The 1988 flood caused reduction of agricultural production by 45% (Karim *et al.*, 1996). Higher discharge and low drainage capacity, in combination with increased backwater effects, would increase the frequency of such devastating floods under climate change scenarios. Prolonged floods would tend to delay Aman plantation, resulting in significant loss of potential Aman production, as observed during the floods of 1998. Considering all the direct and induced adverse effects of climate change on agriculture, one may conclude that crop agriculture would be even more vulnerable in Bangladesh in a warmer world (WB, 2000).

2.3 Adaptation Options

Climate variability makes crop agriculture in Bangladesh highly vulnerable. It is inferred in the available literature that crop production would be extremely vulnerable under climate change scenarios, and as a result, food security of the country will be at risk (Mahtab, 1989; BCAS-RA-Approtech, 1994; ADB, 1994; Warrick and Ahmad, 1996; Huq et al., 1996; Karim et al., 1998). Although the agricultural vulnerability will be very high and adaptation needs are paramount, very little efforts have so far been made to understand the potential of agricultural adaptation in Bangladesh. Ahmed (2000) made an early attempt to analyse the adaptation potential of the country's crop agriculture in a warmer world. Faisal and Parveen (2004) examined the food security aspect and implications of climate change, however adaptation potentials were not discussed.

It is reported in the literature that there may be six generic types of adaptation in the agriculture sector with particular reference to Bangladesh (Ahmed, 2000). These are based on the IPCC typology of adaptation (UNEP, 1996), and are analyzed in relation to the current realities prevailing in Bangladesh.

Bear Crop Losses:

When potential loss of a standing crop is totally accepted by the growers, bearing crop losses is an adaptation option. It is however criticized that the option is rather theoretical, with limited applicability in Bangladesh (Ahmed, 2000).

Share Losses:

The anticipated crop losses may be shared among stakeholders. Provision of government subsidies and remission of taxes for the farmers operating in susceptible croplands could be other possible options where some of the losses might be shared among different stakeholders. Compensating farmers for trying out agricultural activities under high threats of crop loss can be a potential mechanism for sharing loss. Provision of insurance against crop loss has worked well in advanced economies.

Modify the Threats to Crop Production:

This appears to be the mostly practiced option in Bangladesh. Vulnerability analysis may provide important lessons concerning the nature and extent of the threats to crop production under a given climate regime. In such cases, adequate precautionary measures might possibly modify the threats. Development of drought and/or salinity tolerant varieties, switching to alternative cropping patterns with respect to altered agro-ecological zones etc. could modify the threat to a significant extent. Ahmed (2000) argued that good extension programs would help achieve awareness up to a desired level so that farmers may respond to the threatening environmental factors. Adequate policy framework and market instruments (technology availability at subsidized rates, credit, etc.) coupled with social engineering processes could facilitate implementation of such measures.

Prevent Adverse Effects:

Some measures might consider preventing the losses in agricultural production. Preventive measures are anticipatory and might require large-scale investments. The building of large embankments to protect prime agricultural lands from excessive flooding may be cited as an example of preventive measure.

Change Land Use:

In case it becomes extremely risky to continue agricultural activities under an altered climate scenario, an alternative land use might be considered as the next available option. If the suitability of Aus paddy in pre-Kharif months (March-June) appears to be too low, farmers should alter the land use and instead grow other suitable crops. Such alterations should ideally lead to acceptable economic returns, optimizing social goods and services. The application of an indigenous practice through capacity building and extension has allowed farmers of Jessore District to profitably change their land use and maintain livelihoods (Ahmed and Schaerer, 2004).

Change Location:

Change of location entails relocation of agricultural activities in areas that are not likely to be adversely affected. Given that land resource availability per capita is already too low and there is hardly any unproductive land in the country, relocation might not be socially accepted. For Bangladesh, this therefore appears to be a theoretical approach.

A number of interesting adaptation measures have been promoted and subsequently applied in the southwestern region of Bangladesh under a project titled Reducing Vulnerability to Climate Change (RVCC). The project was implemented in six southwestern Districts of Bangladesh from 2002 to 2005, and it applied a few agricultural adaptation measures in a bid to reduce vulnerability of communities to climate change by increasing people's coping capacity (RVCC, 2003; Schaerer and Ahmed, 2004). The agricultural adaptations are worth special mention, due primarily to their simplicity and overall social acceptance. Table 2.5 highlights the agricultural adaptation measures considered under the project.

Table 2.5: Strategic approaches considered for agricultural adaptation for the RVCC project

Strategy	Measure	Brief Description of Measure
Household level strategies in agriculture (crop, fishery, agro-forestry, & livestock)		
Increase food through agriculture	Drought tolerant crops/vegetables	Introduction of drought tolerant crops such as groundnuts, watermelon, etc.
	Floating gardens	Cultivation of vegetables on floating beds of water hyacinth (hydroponics)
	Low-cost irrigation	Demonstration of treadle pump and other simple technologies for irrigation
	Homestead gardening	Cultivation of vegetables and fruits on homestead plots for consumption and market
	Saline tolerant non-rice crops	Introduction of saline tolerant varieties of chili, mustard, maize and potato
Increase income through alternative livelihoods	Embankment cropping	Cultivation of beans, gourds, *okra* & other vegetables on embankments surrounding prawn *ghers* (ponds)
	Integrated farming systems	Using small area of land, small water body, and surrounding embankments to produce rice, fish and vegetables
	Cage aquaculture	Small-scale fish farming in cages, implemented in household ponds or common water bodies
	Prawn fish poly-culture	Prawn and fish culture in fresh-water *ghers* (ponds)
	Shrimp fish poly-culture	Shrimp and fish culture in salt-water *ghers* (ponds)
	Cattle rearing	Raising cattle for consumption and market
	Poultry rearing	Raising chickens to produce meat and eggs for consumption and market
	Crab fattening	Collection, rearing and feeding of crabs for a period of 15 days to increase their market value
	Duck rearing	Raising ducks to produce meat and eggs for consumption and market
	Goat rearing	Raising goats for consumption and market
	Pig rearing	Raising pigs for consumption and market
	Apiculture & honey processing	Beekeeping and processing of honey for market

	Nursery & homestead afforestation	Establishment of community nurseries and distribution (with handling instructions) of indigenous varieties of tree saplings (mango, coconut, *sofeda, korai*, guava, *mehaguni*, neem, *kewra*, etc.) to beneficiaries for homestead planting
	Saline tolerant tree plantation	Planting of saline tolerant fruit and timber trees for longer term income generation
	Mele (reed) cultivation	Cultivation of reeds used to produce mats that are widely used for sitting and to sleep on

Source: Modified from Schaerer and Ahmed, 2004.

Considering the above information, the NAPA, reiterated the following generic adaptation measures for the agriculture sector (GOB-UNDP, 2005):

- Mainstreaming adaptation to climate change into policies and programs in different sectors (including the agriculture sector) (priority #6);
- Promotion of research on drought, flood and saline tolerant varieties of crops to facilitate adaptation in future (priority #10);
- Promoting adaptation of coastal crop agriculture to combat increased salinity (priority #11); and
- Adaptation to the agriculture system of areas prone to enhanced flash flooding in the northeast and central region (priority #12).

In addition, the NAPA document also stressed on promotion of a crop insurance system. The recently concluded action research program considered for the drought-prone areas of Bangladesh recommended a host of options (CEGIS-FAO, 2006), which include the following:

- Promotion of less water-requiring and short rotation crops (also stressed in Karim, 1996; Huq et al., 1996; Asaduzzaman et al., 1997 etc.).
- Increase in efficiency in irrigation water use (also stressed in Karim, 1996; Huq et al., 1996; Asaduzzaman et al., 1997; Ahmed et al., 1998 etc.).
- Rainwater harvesting (various methods including traditional ones) and preferential use to offset moisture stress (also stressed in Karim, 1996; Asaduzzaman et al., 1997 etc.)

CEGIS (2006) highlighted the technical needs for maintaining a sustained flow of water along the Gorai River system in order to offset sea-level rise induced salinity in the southwestern region of Bangladesh. This echoed the concerns raised by the World Bank report (WB, 2000). It is found that, even if the OGDA Option 7 comes into reality, the crop production condition will certainly improve. However, maintenance of food self sufficiency at current levels may still not be possible due to the enhanced salinity caused by sea-level rise (CEGIS, 2006).

As a policy measure to promote agriculture even under moisture stress conditions, it is recommended that the state should engage actively in regional cooperation in the water sector. The purpose of such involvement would be to maintain a healthy flow along international rivers, which may facilitate conjunctive use of both surface and groundwater for irrigation purposes (Ahmed, 2000; Ahmed, 2004). BCAS-RA-Approtech (1994) showed how an effective water sharing arrangement with India can benefit Bangladesh by allowing adaptation under water stressed conditions (in a bid to offset drought). Habibullah et al. (1998) provided insights into on-the-ground adaptation techniques that might be followed for reducing vulnerability of crops under moderate to high saline affected conditions.

Under this study it was tried to find out rice varieties of *boro* season that can give potential yields, which will give hope and confidence to farmers in adapting their crops to salinity under climate change scenarios. It was also attempted to find out some innovation farming practices for non-rice crops that will help to escape salinity during establishment stage of crops.

3. Study Approach

3.1 Introduction

The study began with literature review involving published materials on climate change and adaptation options for crop agriculture. Existing research findings were consulted to assess and analyze the problems. Climate scenarios explain future adverse impacts on agricultural crops due to climate change. Information on the critical issues that would reduce crop agricultural potential in the coastal area was collated from the literature. In order to avoid duplication of work, the RVCC reports were reviewed. The experiences and findings of BUP, BARC, BIRRI and BARI are also utilized in the study. The flow diagram of the detailed methodology for the study is presented in Figure 3.1. The study was conducted in close consultation with relevant organizations mentioned in the study flow diagram

3.2 Understanding the Geo-Physical Environment

An attempt was made to understand the geo-physical environment of the study area. A hydrological analysis was done to understand the extent and nature of flood in the study area. The flood depth and spatial distribution of rainfall were examined during the monsoon season. Extreme temperature and soil salinity were observed for the Kharif-2 and *rabi* seasons. The effects of climate change on the geophysical environment of the study area were identified from these observations and analyses. Participation of local stakeholders was ensured during this process.

3.3 Crops Selection

Following discussions with experts and Adaptation Research Advisory Committee (ARAC) of this project, a number of rice crops and non-rice crops were selected for field-testing and demonstration. *BRRI dhan47*, *BRRI dhan45* and *BRRI dhan29* were selected for field experiments in high salinity. To find out the yield performance at different salinity gradients, different rice varieties practiced by local farmers were also selected. These rice varieties are *BRRI dhan28*, *Chaina (Shaitta)*, *Kajallata* (*Indian variety)* and *Hira (hybrid)*. The *BR23*, *BRRIdhan40*, *BRRIdhan41* were selected for the *T. Aman* season. Short duration BRRI varieties (BRRI dhan33/BRRI dhan39) were also included to accommodate vegetables, which are harvested by/before March 30 to escape the peak salinity in both soil and water. *Tomato*, *watermelon*, *okra* and *aroid* were selected for the *rabi* season.

3.4 Field -Testing Sites Selection

A five-member team of CEGIS, BRRI and BARI conducted a quick survey and visited the saline areas of Satkhira district. Based on previous data and information collected from a non-structured questionnaire survey from different stakeholders, such as scientists of different research organizations and local farmers, the team found Satkhira to be the most suitable site for conducting the experiments.

According to the suggestion of the Agricultural Research Advisory Committee (ARAC), the proposed method for field testing was modified. It had been decided to carry out the study at Benerpota farm under Satkhira Upazila both for rice and non-rice crops experiments. According to the advise of ARAC, all of the rice related experiment sites were selected at the farmers fields at Satkhira depending upon the different salinity gradients for *boro* season and *T.aman* season. For non-rice crop experiments, Benerpota farm was selected for field testing of *Tomato* and *Watermelon* but *okra* and *aroid* were tested in farmers fields based on the advice of the ARAC members.

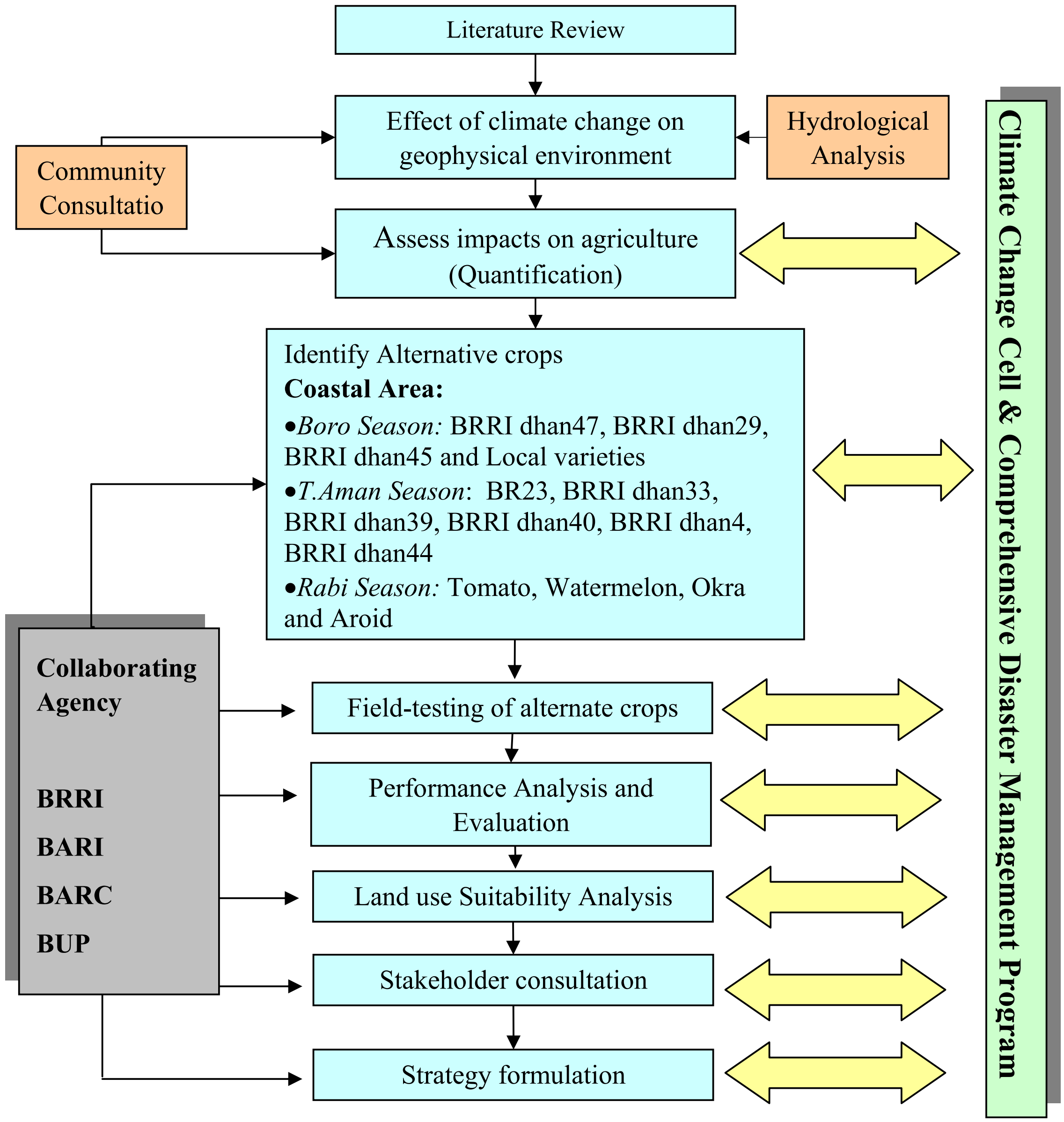


Figure 3.1: Methodology of the study

3.5 Crop Simulation Model Analysis

Since changes in climate are anticipated, the future changed scenarios should be simulated/generated for evaluating the performance of crop growth and production under the changed circumstances. The extent of change in climatic parameters or the delta values of mean temperature and precipitation was generated by using MAGICC 2.4 (Model for the Assessment of Greenhouse-gas Induced Climate Change) and SCENGEN 2.4.

The Decision Support System for Agrotechnology Transfer (DSSAT) 4.0 (2004) based crop simulation model was used to assess the yields/productions of selected crops under present and changed climate scenarios.

3.6 Suitability Analysis

An analytical tool “CROPSUIT” developed by CEGIS was used to estimate the physical suitability of land for different land use types or crops. CROPSUIT determines the physical suitability of land based on the land characteristics (LC) and land use requirement (LUR) suitability matrix. The LUR information has already been developed by CEGIS in the study of coastal land use zoning (CEGIS, 2005) under SEMP. All LC data were regenerated from the soil map (Bangla Nirdeshika Thana Map) produced by SRDI and converted into the GIS Grid format. The CROPSUIT model was used to generate the suitability maps showing highly suitable, suitable, and moderately suitable and not suitable areas for Boro season and T.Aman season rice crops. It was also used to map the suitability under different sea level rise scenarios.

3.7 Documentation

The results of the sensitivity tests and field optimization of adaptation measure(s) for alternative crops were shared amongst the farmers in the pilot study locations. The entire process of field level adaptation was documented for future reference and dissemination.

4. Geo-Physical Environment

4.1 Drainage and Flooding

CEGIS has carried out a study on Impact of Sea Level Rise on Landuse Suitability and Adaptation Options in the southwest region of Bangladesh in 2006. Information on the geo-physical environment of the study area has been collated from this study. The total area of Satkhira district is about 3,300 sq.km and about 1,800 sq.km is under protected area. Hundreds of sluices/regulators have been constructed on the embankments primarily for draining rainwater, and secondarily to prevent seawater from entering into the polder. The flooding and drainage situation for base condition was estimated based on the flood of year 2000. The flooding area of Satkhira district has been categorized in depth classes as: dry, 0-30cm, 30-90 cm, 90-180 cm, 180-300 cm and greater than 300 cm in keeping similarities with the widely practiced land classes: F0 (dry to 30 cm), F1, F2, F3 and F4. The flood status in base condition within the study area is shown in Table 4.1.

Table 4.1: Flood situation in Satkhira district in 2000

Total Area (sq.km^2)	Area flooded (sqkm)					
	Dry	**0 - 30 cm**	**30 - 90**	**90 – 180**	**180 – 300**	**>300**
3317.1	1,058.4	534.2	1,008.8	515.2	200.0	0.6
	% of area flooded by depth in cm					
	Dry	**0 - 30 cm**	**30 – 90**	**90 – 180**	**180 – 300**	**>300**
	31.9%	16.1%	30.4%	15.5%	6.0%	0.0%

4.2 Impact of SLR on Drainage and Flooding

Two scenarios, Sea Level Rise of 32 cm and 88 cm, were considered for assessing the impact of flood and drainage in the study area. The overall comparison of flooding area and land class shifting with 32 cm and 88 cm SLR against the flooding year 2000 is shown in Table 4.2. It is evident from the Table that F0 land would reduce, whereas the deeply flooded area will increase given the 32 cm and 88 cm SLRs respectively.

Table 4.2: Inundated areas under different scenarios by land class

Condition	Area of Land Class by Flood Depth (sqkm)					
	Dry	**0 - 30 cm**	**30 - 90 cm**	**90 - 180 cm**	**180 - 300 cm**	**>300 cm**
Base Year 2000	1058	534	1009	515	200	1
Sea Level Rise 32 cm	836	444	1007	710	318	2
Sea Level Rise 88 cm	537	279	878	1011	541	71

4.3 Salinity

The soil and water salinity dynamics are shown in Figure 4.1. Long-term data on Satkhira revealed that soil salinity in the crop fields ranged from 4.5-8.5 dS/m and fallow lands with that are relatively more saline ranged from 5.5-15.5 dS/m (BRRI Annual Report, 2005).

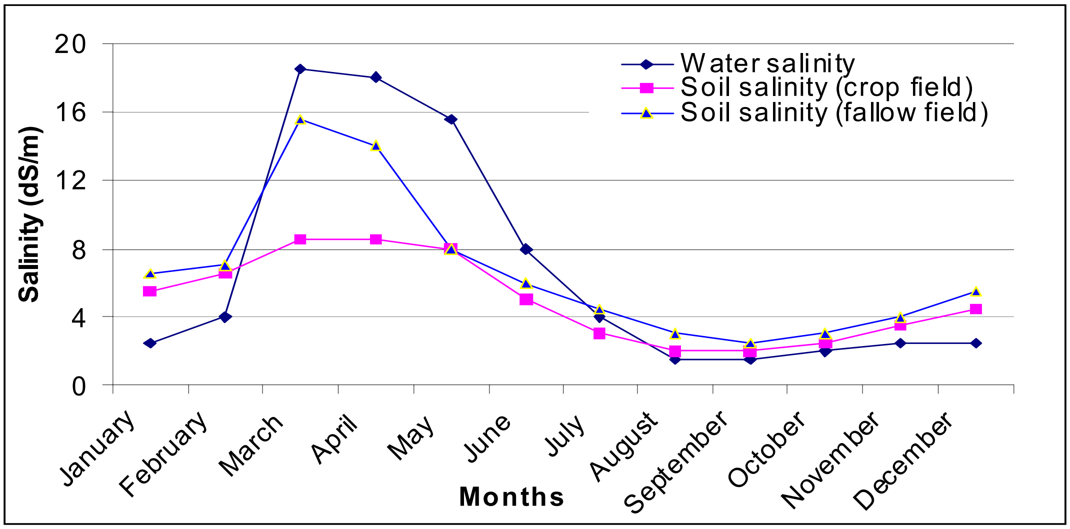
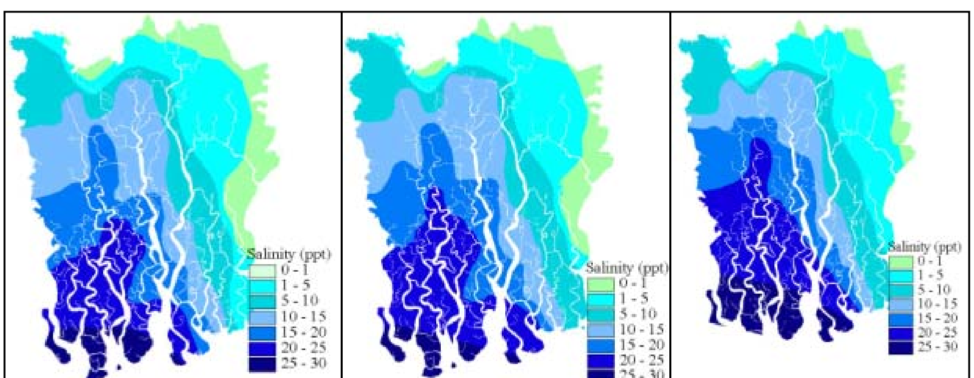


Figure 4.1: The soil and water salinity dynamics at Benarpota Farm, Satkhira, during 2001-04

4.4 Impact of SLR on Salinity

The impact of SLR on salinity was explored under the study on Impact of Sea Level Rise on Landuse Suitability and Adaptation Options in the southwest region of Bangladesh. It was observed that the salinity front will moved toward inland due to the SLR if fresh water flow from the river remains constant, it will further aggravate if the fresh water flow declines.

For the base condition, the salinity concentration was prepared and area statistics under different ranges of salinity was estimated. The salinity for different SLR scenario was then mapped for the assessment of impacts. The movement of the salinity front can be assessed from Figure 4.2.



Salinity distribution in base condition	Salinity distribution with SLR 32 cm	Salinity distribution with SLR 88 cm

Figure 4.2: Salinity distribution in different scenario

The salinity progression towards inland through different river systems was measured from the sea shoreline using salinity surface maps. The low saline area (0-1ppt) was found to have decreased with 32 cm SLR and 88 cm SLR, whereas the high saline area, e.g. 20-25 ppt had increased 32 cm SLR and 88 cm SLR.

4.5 Salt Tolerance Levels of Selected Crops

Table 4.3 shows the salt tolerant levels for *BRRIdhan47*, *BRRIdhan40* and *BRRIdhan41* at seedling stage and maturity stage. The salt tolerant levels of other rice varieties and non rice varieties experimented in this study are not reported.

Table 4.3: Salinity tolerance levels of rice crops

Sl No.	Variety	Season	Salinity (in dS m^{-1})	
			Seedling stage	Maturity stage
1	*BRRI dhan47*	*Boro*	12-14	8
2	*BRRI dhan40*	*T. Aman*	8	8
3	*BRRI dhan41*	*T. Aman*	8	8
4	Other varieties	Have no reported salt tolerance level		

4.6 Crop Suitability

4.6.1 Current Crops Practice

The major cropping pattern in Satkhira Upazila is *Fallow – T.Aman – Fallow and Fallow – T.Aman – Boro*. Table 5.2 shows the different types of crops practiced in the area. During the Kharif–1 season farmers cultivate *jute*, *aus* rice, oil seeds and different types of vegetables. During the Kharif-2 season *T. Aman* is the dominant crop. Different types of *T. Aman* rice such as *BR10*, *BR11*, *BR30* and local varieties are practiced during this season. In the *rabi* season, *boro* rice such as *IRRI 28*, *IRRI44*, *IRRI26*, and *IRRI29* are practiced. Other crops that are practiced are *mustard*, *wheat*, *pulses* and different types of vegetables. An effort was also made to know the cropping practice of 10 years ago in the study area. About 10 years ago the cropping practice was similar to the present one.

4.6.2 Physical Suitability Map

Physical suitability expresses the degree to which the sustained implementation of a land use is feasible with an acceptable level of risk to the human or natural environment. The study investigated the suitability for *T.aman*, *boro* as well as *rabi* season crop. The parameters considered were land type (flood depth), drainage, soil texture, soil moisture, soil pH, soil salinity, surface water salinity and ground water salinity. It was assumed in the study that the salinity and flood depth are the dependent variables under different SLR scenarios. The land use suitability maps produced from CROPSUIT were then compared under different SLR scenarios.

Transplanted Aman

The suitability matrix / landuse requirement table for the land utilization type – *T. Aman* is shown in Table 4.4. Six land characteristics parameters with different yield potential of land units were used in the CROPSUIT for T Aman suitability mapping. The land characteristics data on soil salinity and depth of inundation were used from the southwest regional model and the rest from SRDI soil physical properties data. Using all LC in LUR and decision criteria, the *T. Aman* suitability map was derived using CROPSUIT model and it is shown in Figure 4.3. The CROPSUIT evaluates that most of the area of the Satkhira district is "physically suitable" for T Aman cultivation under the existing situation as shown in Figure 4.3. A few areas in the northern part are "moderately suitable".

Boro Season

The Land Use Requirement (LUR)/ suitability matrix for the land utilization type – *boro* rice is shown in Table 4.5. In the CROPSUIT model, seven Land Characteristics (LC) parameters with different yield potential of land units for *boro* suitability mapping is used. The land characteristics data on surface salinity and depth of inundation are used from southwest regional MIKE 11 model. A set of equations was used in the CROPSUIT model to estimate soil and groundwater salinity from surface water salinity data and other LC data were taken from SRDI's database. CROPSUIT evaluates the physical suitability using all LC in crop suitability matrix and decision criteria. The *boro* suitability mapping was derived using CROPSUIT model is shown in Figure 4.3. CROPSUIT evaluates that about 40% area of Satkhira is "physically suitable" (i.e. S1 and S2) for *boro* rice cultivation as shown in Figure 4.3 and about 40% of the area is "moderately suitable".

Table 4.4: Suitability Matrix for Land Use type – T.aman

Land Characteristics	Unit	Factor rating			
		S1	S2	S3	S4
Topsoil texture	Class	Clay, Silty Clay	Clay loam	Loam	Silt loam, Silt
Depth of inundation	Inundation depth	1-30	30-90	90-180	>180
Drainage condition	Class	Pd	Impd	Mwd	Wd
Soil salinity in wet season	dS/m	<2	2-4	4-8	>8
Moisture holding capacity	mm/m	>300	200-300	100-200	<100
Soil reaction	pH	5.6-8.4	4.5-5.5 & 8.5-9.0	<4.5	-

Note: Pd: Poorly drained, Impd: Improved drained, Mwd: Medium well drained, Wd: Well drained

Table 4.5: Suitability Matrix for Land Use type – *boro* rice

Land Characteristics	Unit	Factor rating			
		S1	S2	S3	S4
Top soil texture	Class	C, Sic,	Sicl, Cl	Sil, L	S, Sl, Ls
Drainage condition	Class	Pd	Impd	Mwd, Vpd	Wd
Depth of inundation	Inundation depth	30-180	<30 & >180-300	-	>300
Salts in ground water	ppt	<1.0	1.0-1.5	1.5-2.5	>2.5
Salts in surface water	ppt	<1.0	1.0-1.5	1.5-2.5	>2.5
Salinity	dS/m	<2	2-4	4-8	>8
Soil reaction	pH	5.6-8-4	4.5-5.5 & 8.5-9.0	<4.5	-

Note: Pd: Poorly drained, Impd: Improved drained, Mwd: Medium well drained, Wd: Well drained

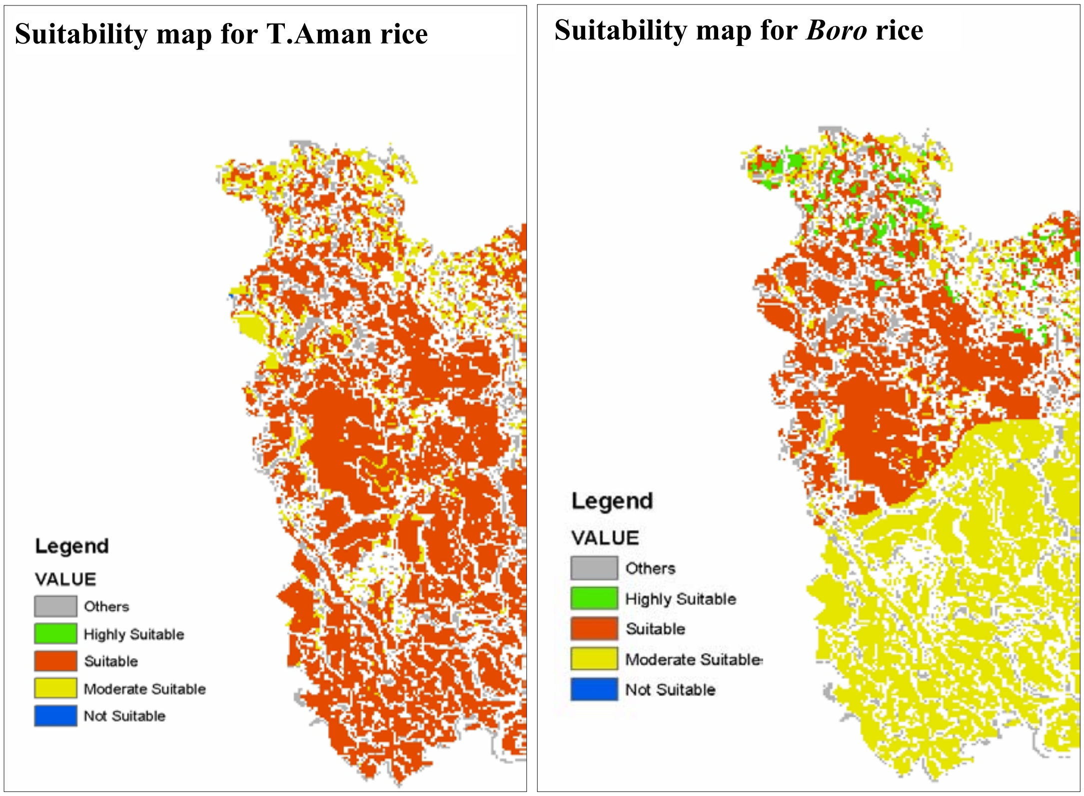


Figure 4.3: Salinity distribution in different scenario

4.6.3 Impact of SLR on Suitability

The crop suitability model, CROPSUIT, was run under different SLR scenarios and suitability maps were produced for *T.Aman* and *boro* rice crops. The change in suitability under different SLR scenarios from base are analyzed and described in the following sections. Land use suitability computation used inundation depth and salinity data under different SLR scenarios in CROPSUIT model dynamically. The surface water salinity concentration data under different SLR scenarios were estimated using the MIKE 11/HD/TD model.

T.aman

The T.aman suitability map was generated for different SLR scenarios using the CROPSUIT model as shown in Figure 4.4. The MIKE 11 model generates flood depth under different scenarios and The variable used mainly the inundation depth difference. From the analysis it was found that the area suitable for T.Aman rice cultivation reduced due to sea level rise.

Boro rice

For different SLR scenarios, the boro rice suitability map was generated using the CROSUIT model as shown in Figure 4.5. Dynamic data and flood depth and salinity, with other constant LC data (i.e. pH, Soil Moisture Holding Capacity, etc.) suitability map and statistics were generated. It was found that not suitability area increased from base condition to 88 cm SLR.

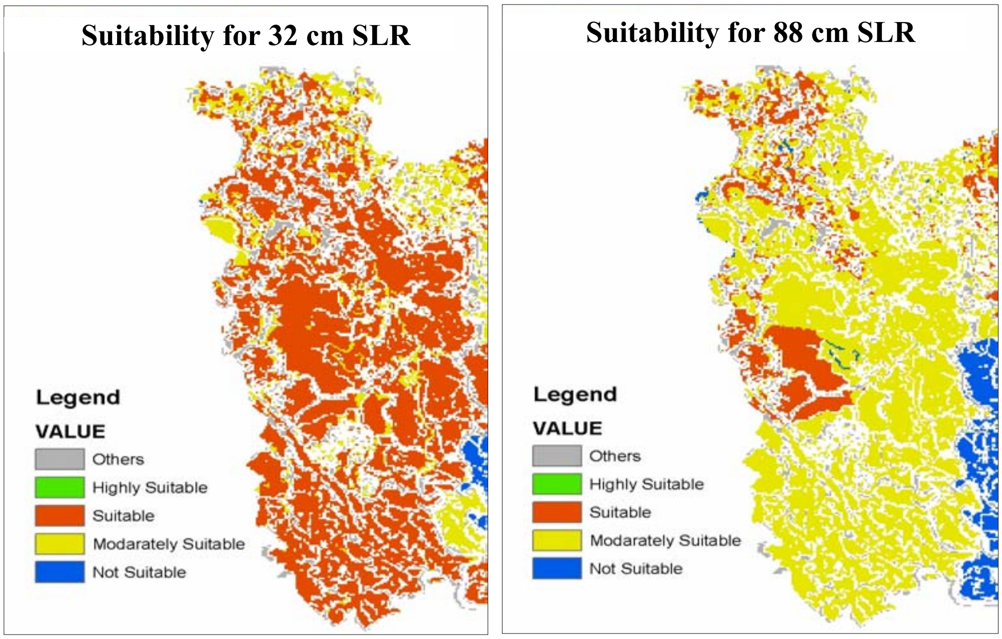


Figure 4.4: T.Aman rice suitability under diferent SLR scenarios

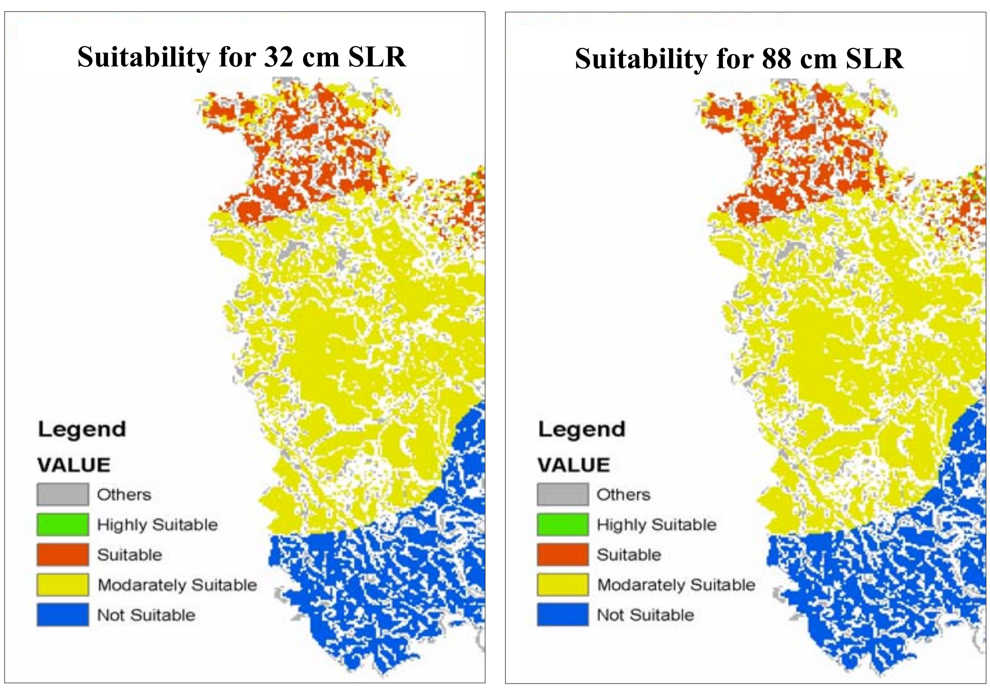


Figure 4.5: Boro rice suitability under diferent SLR scenarios

5. Boro Season Rice Experiments

5.1 Selecting *Boro* Season Rice Crops

Different rice varieties practiced by local farmers were selected to find out the yield performance at different salinity gradients. These rice varieties are *BRRIdhan28*, *Chaina (Shaitta)*, *Kajallata* (*Indian variety)* and *Hira (hybrid)*. *BRRIdhan28* is widely grown in the coastal saline areas due to short duration and high yield potential. But BRRI reported that it had no salinity tolerant capacity. It has the ability to grow well within salt free conditions. Farmers also grew *Chaina (Shaitta)*, *Kajallata (Indian variety)* and *IET* variety due to their short duration and yield potential as reported by farmers in the saline soil. One farmer of the medium saline soil also cultivated hybrid variety *Hira* for high yield goal. These varieties were monitored at different salinity gradients of the selected sites during *boro* season, 2007.

Beside these, *BRRIdhan47*, *BRRIdhan45* and *BRRIdhan29* were selected for field experiments in high salinity areas. *BRRIdhan47* is a high-level salinity tolerant variety (up to 8-10 dS/M) and is cultivated in saline areas. *BRRI dhan45* is a short duration and popularly grown variety cultivated in the coastal area and *BRRI dhan29* is a long duration high yield potential variety cultivated in the *boro* season.

5.2 Field Testing Sites

As per the suggestions of the Adaptation Research Advisory Committee (ARAC) of Climate Change Cell, the rice related experiments were conducted in farmer's field at different salinity gradients for the *boro* and *T.aman* seasons. Three locations from Kaliganj upazila, about 50 km south of Satkhira Sadar were selected based on their salinity and crop production status (Figure 5.1). The list of the selected farmers is given in Appendix A.

5.3 Soil and Land Types

The land type of the selected sites is medium high land to medium low land and used for rice cultivation in both the seasons. Due to high salinity (beyond permissible limit i.e. more than 4 dS/m) of surface water during *boro* season farmers cultivate rice crops by using groundwater from Shallow Tube Wells (STW). The soil texture of the selected area was silty clay loam to silt loam with a pH level of 7.5-8.5.

5.4 Observational Field Trial Selection

For observational trial, the land was classified according to the salinity gradient and crop production based on the perception of the farmers and local elite. These factors were low salinity (< 4 dS/m), medium salinity (4-6 dS/m) and high salinity (6-8 dS/m). The crop performance was monitored for different salinity gradients to find out crop suitability and sustainability under the climate change situation.

5.4.1 Low Salinity Area (< 4 dS/m)

Based on the farmers' perception, a low salinity area was selected at Kaliganj Upazila. The mode of extracting irrigation water was STW and the fields were maintained with continuous standing water. Three farmer's fields (in the village of Uzaimari, Probajpur and Dia of Kaliganj upazila.) were selected to grow the *boro* season rice crops of the preferred variety grown in their locality. These were *BRRIdhan28*, *Kajallata* and *Chaina (Shaitta)*. The crops were transplanted during 15-25 January 2007 with about 40-50 day-old seedlings.

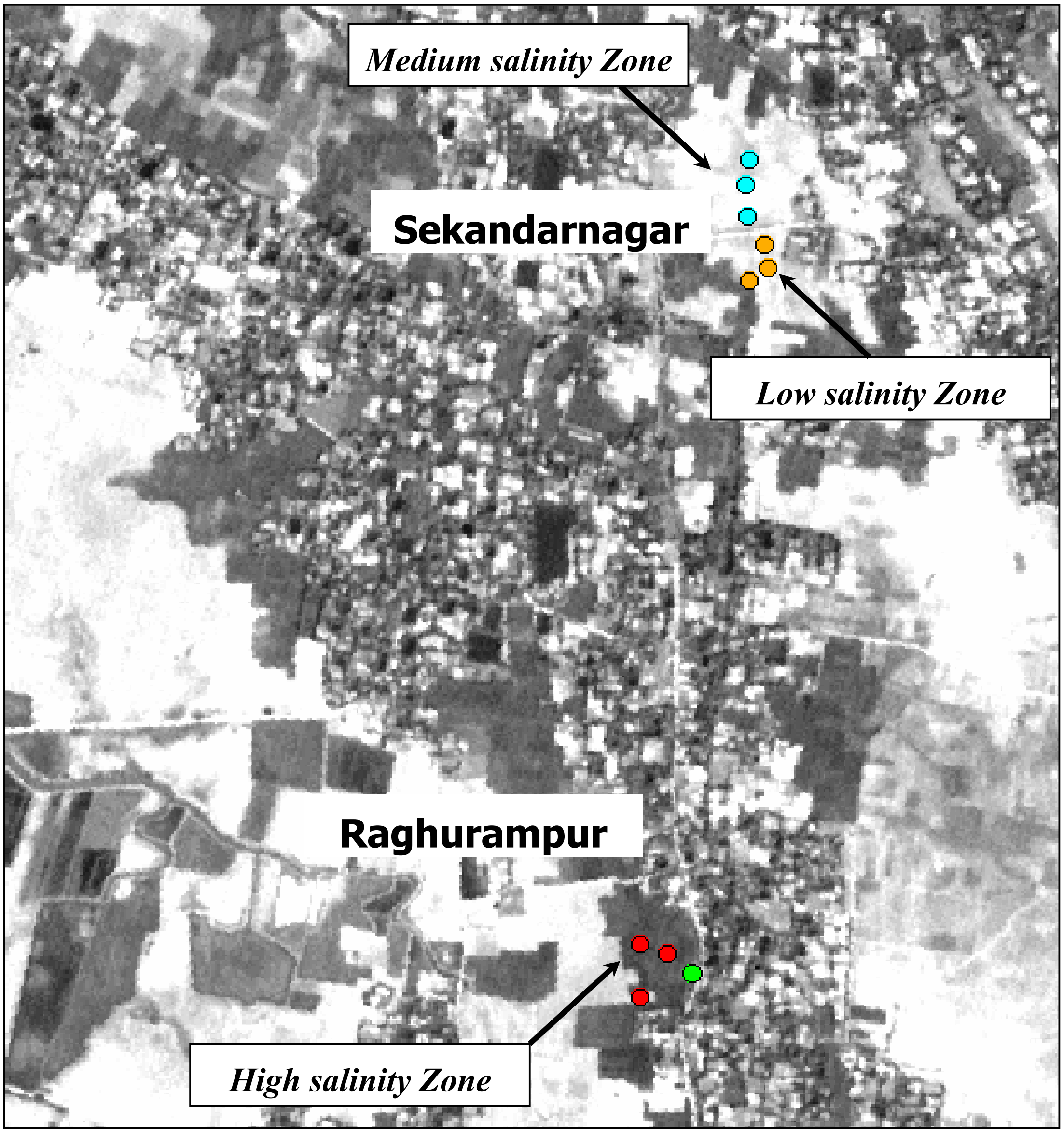


Figure 5.1: Map showing location of observation and experiment sites

(a) Kajallata *(b) Chaina (Shaitta)* *(c) BRRI dhan28*

Figure 5.2: Photographs of rice varieties planted in low salinity areas

5.4.2 Medium Salinity Area (4-6 dS/m)

Based on the farmer's perception, a medium salinity area was selected at Sekandar Nagar and Duliapur village under Mathoreshpur union of Kaliganj upazila. The mode of extracting irrigation water was STW and the fields were maintained with continuous standing water. Three farmer's fields were selected to grow the *boro* season rice crops of the preferred variety grown in their locality. These were *BRRI dhan28*, *Kajallata* and *hybrid (Hira)*. The crops were transplanted during 15-25 January 2007 with about 40-55 day-old seedlings.

(a) Hybrid (Hira) *(b) Kajallata* *(c) BRRI dhan28*

Figure 5.3: Photographs of rice varieties planted in the medium salinity area

5.4.3 High Salinity Area (6-8 dS/m)

Based on the farmer's perception, a high salinity area was selected at Raghurampur village under Kaliganj upazila. The mode of extracting irrigation water was STW and the fields were maintained with continuous standing water. Three farmer's fields were selected to grow the *boro* season rice crops of the preferred variety grown in their locality. These were *BRRI dhan28*, *Chaina (Shaitta)* and *IET*. The crops were transplanted during 15-30 January 2007 with about 40-50 day-old seedlings.

(a) Chaina (Shaitta) *(b) IET* *(c) BRRI dhan28*

Figure 5.4: Photographs of rice varieties planted in the high salinity area

5.5 Experimental Field Selection

The experimental field was selected in the high salinity zone of Raghurampur village of Kaliganj upazila. The mode of extracting irrigation water was STW and the fields were maintained with continuous standing water. A field of

Figure 5.5: Photographs of rice varieties planted in the experimental field in the high salinity area

about 17 decimal was selected for conducting the field experiment following the RCBD for accommodating three selected varieties - *BRRIdhan29*, *BRRIdhan45* and *BRRIdhan47* (PVS line). Fertilizers were applied as per BRRI recommendations (260-70-70-44-7 kg of Urea, TSP, MP, Sulphur and ZnSo4 per ha) and other management systems were followed as per farmers' suggestions. 57 day-old seedlings were transplanted on 27 January 2007 at selected farmer's fields at the spacing of 20 x 20 cm.

5.6 Data Collection

The water source, water salinity and soil salinity were monitored from the transplanting to the harvest stage. The initial soil samples were collected from the selected field up to the depth of 45 cm at an interval of 15 cm for soil water content, soil pH, soil organic mater, soil texture and soil salinity measurement. Soil samples were also collected from the neighboring fields cultivated with different varieties by the farmers. The water sample was collected from the irrigation source for water salinity measurement. At the early stage samples were collected fortnightly up to February but later it was done on a weekly basis. Weather data were collected from the Bangladesh Meteorological Departmental Office at Satkhira.

5.7 Results

5.7.1 Observational Trial

Low salinity area

The field crop performance in the low salinity area showed that all the cultivated crops grew well in that area, as there was no salinity impact on crop production. The highest grain yield was found in the variety *BRRIdhan28*, which is an excellent short duration *boro* variety. However, the variety Kajallata had the lowest grain yield due to higher sterility (Table 5.1).

Table 5.1: Yield and yield contributing characters of different *boro* varieties in observation plots of low salinity gradients during *boro* plantation, 2007

Variety	No. of panicle/hill	Panicle length (cm)	No. of filled grain	1000 grain weight (gm)	Yield (t/ha)
BRRIdhan28	14.4	21.99	92.75	21.97	7.40
Chaina (Shaitta)	14.2	20.14	83.96	22.68	6.81
Kajallata	15.4	19.28	72.39	17.06	4.81

The salinity level in the low salinity area as per farmer's perception and the pump water salinity varied from 0.7 to 1.3 dS/m. On the other hand, the soil and water salinity showed an increasing trend over time after transplanting and it had a positive response with rainfall (Figure 5.6 and Figure 5.10).

Medium salinity area

The field crop performance in the medium salinity area showed that all the cultivated crops grew well in that area, as there was no salinity impact on crop production. The salinity level of water sources, field water and soil of the crop field indicated that the farmer's perception about the salinity level of their locality did not fully match with the field condition in that area. The highest grain yield was found in a hybrid variety *Hira* (9.35 t/ha), while the variety *Chaina (Shaitta)* had the lowest grain yield (5.63 t/ha) (Table 5.2). Crop cultivation in the salinity area is a risky venture, as an increase in the salinity level makes rice crops sterile.

The pump water salinity varied from 0.8 to 1.5 dS/m, which showed a fluctuating trend. But the soil and water salinity showed an increasing trend over time after transplanting and it had a positive response with rainfall (Figure 5.7 and Figure 5.10).

Table 5.2: Yield and yield contributing characters of different *boro* varieties in the observation plot of medium salinity gradients during *boro* plantation in 2007

Variety	No. of panicle/hill	Panicle length (cm)	No. of filled grain	1000 grain weight (gm)	Yield (t/ha)
BRRIdhan28	14.8	20.15	80.88	20.08	6.08
Chaina (Shaitta)	13.6	19.72	81.36	20.37	5.63
Hybrid Hira	15.8	22.55	95.35	24.93	9.39

High saline area

The field crop performance in the high salinity area showed that all the cultivated crops did not grow well in that area, as there was a salinity impact on crop production. The highest grain yield was found in the variety BRRI dhan28 (5.27 t/ha), which is an excellent short duration *boro* variety, but does not have the optimum potential yield. The variety Chaina (Shaitta) had the lowest grain yield (4.36 t/ha) (Table 5.3).

Table 5.3: Yield and yield contributing characters of different boro varieties in the observation plot of high salinity gradients during boro plantation in 2007

Variety	No. of panicle/hill	Panicle length (cm)	No. of filled grain	1000 grain weight (gm)	Yield (t/ha)
BRRI dhan28	18.4	19.09	60.50	19.14	5.27
Chaina (Shaitta)	12.0	18.62	80.16	18.46	4.36
IET	15.6	14.70	64.85	18.29	4.59

The salinity level in the high salinity area as per farmer's perception and the pump water salinity varied from 4.25 to 7.00 dS/m. However, the soil and water salinity showed an increasing trend over time after transplanting and follows simultaneously with the pump water salinity (Figure 5.8).

5.7.2 Field Experiment

Field experiment was conducted at the high salinity gradient level to observe the performance of different BRRI varieties. The yield performance of BRRI dhan47 was found suitable due to the high salinity gradient level up to 8 dS/m in the reproductive stages (Table 5.4).

Table 5.4: Yield and yield contributing characters of the experimental plot in high salinity gradients during boro planting in 2007

Variety	No. of panicle/hill	Panicle length (cm)	No. of filled grain	1000 grain weight (gm)	Yield (t/ha)
BRRI dhan47	14.67	22.10	73.61	24.06	6.43
BRRI dhan45	24.67	19.12	40.62	21.65	5.35
BRRI dhan29	17.34	22.01	62.38	17.44	4.67

According to the BRRI Annual Report, 2005 findings, the long-term data at Satkhira indicate that the soil salinity at the crop fields ranges between 4.5-8.5 dS/m and that the fallow lands are relatively more saline, ranging between 5.5-15.5 dS/m. Though the number of panicle per hill was higher in BRRI dhan45 and BRRI dhan29, the sterility percentage was less in BRRI dhan47 salinity tolerance. Beside this, due to the long duration of BRRI dhan29 and the fact that it was affected by salinity at the later stage of growth, the yield reduced in spite of being reported as having high yield potential during the *boro* season. In the high salinity area BRRI dhan47 was able to survive up to 8 dS/m. The pump water salinity varied from 3.5 to 8.0 dS/m that showed a fluctuating trend. But the soil and water salinity was in a fluctuating and increasing trend over time after transplanting and it had a positive response with rainfall (Figure 5.9 and Figure 5.10).

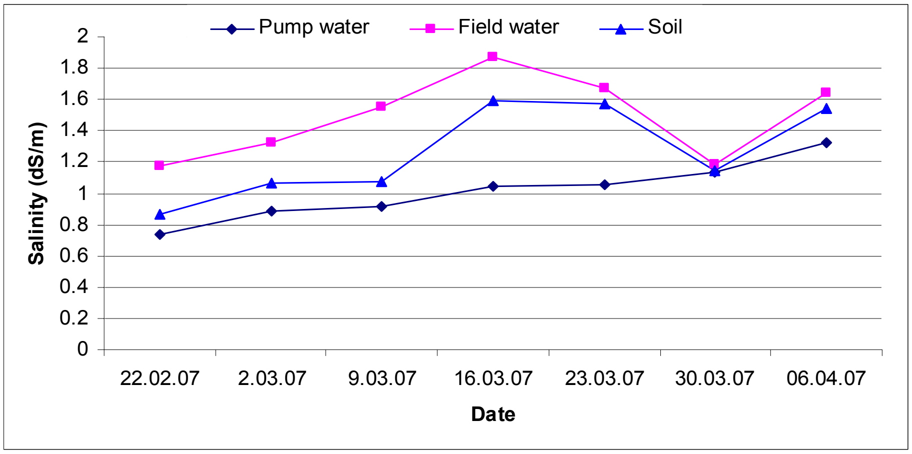


Figure 5.6: Salinity level of pumped water, field water and soil of the observational trial plot in the low salinity area during *boro* plantation in 2007

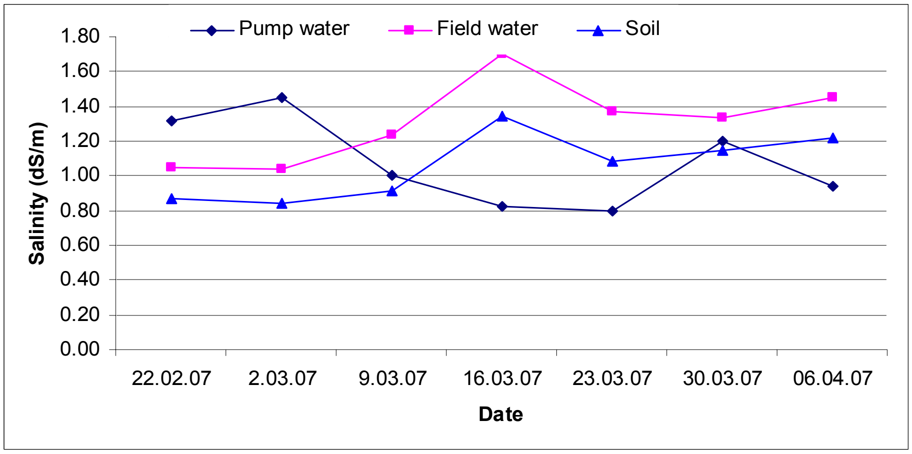


Figure 5.7: Salinity level of pumped water, field water and soil of the observational trial plot in the medium salinity area during *boro* plantation in 2007

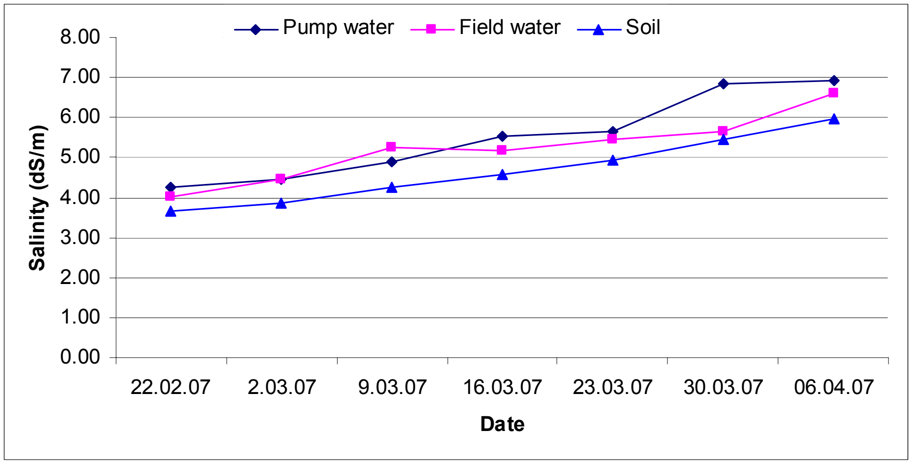


Figure 5.8: Salinity level of pumped water, field water and soil of the observational trial plot in the high salinity area during *boro* plantation in 2007

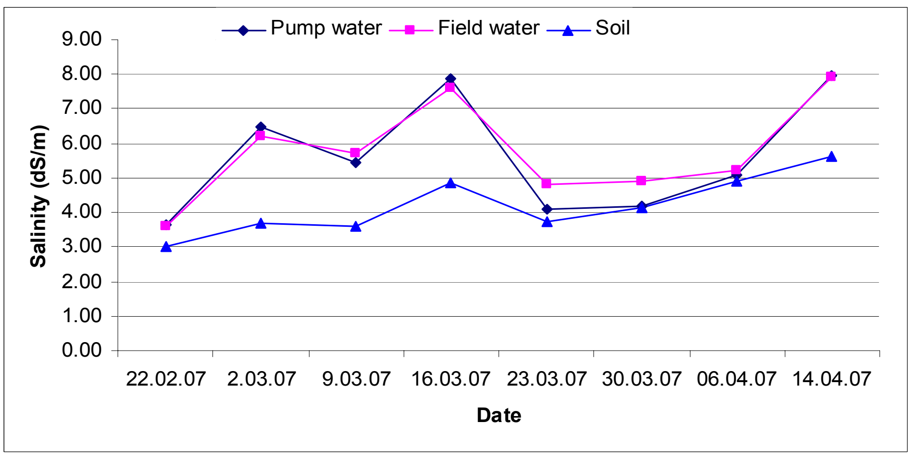


Figure 5.9: Salinity level of pumped water, field water and soil of the experimental plot in high salinity area during *boro* plantation in 2007.

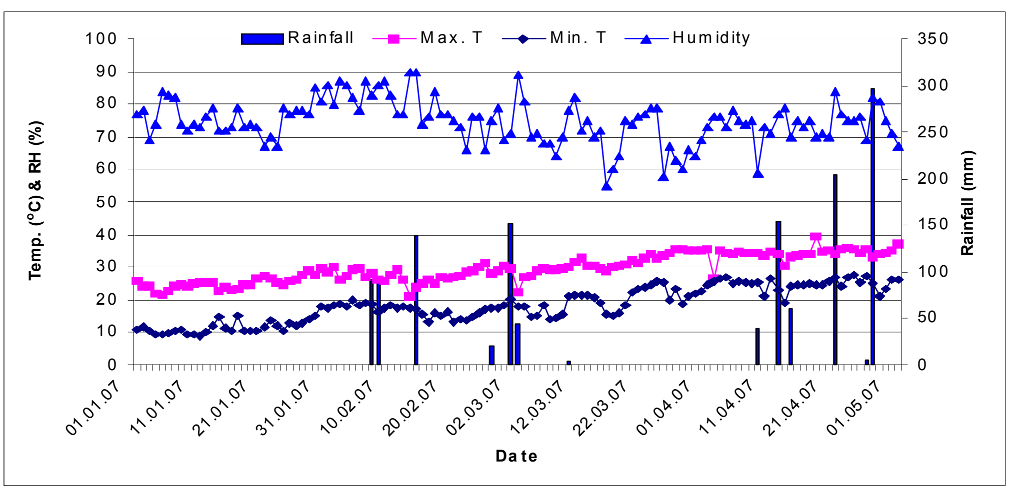


Figure 5.10: Weather data monitoring during the crop-growing period of *boro*, 2007

5.8 Discussion

Field crops of the selected observational trial showed that the grain yield decreased with the increase in salinity level irrespective of rice varieties (Tables 5.1- 5.3). Beside these, the salinity level of low and medium selected areas was within the permissible limit for the rice crop. This finding also concurs with Mondal et al., 2005, who showed that soil salinity remained suitable for modern high yielding rice cultivation in the wet season and river water quality is suitable for rice cultivation from July to mid-February. All the rice varieties performed well within the low salinity level. It also indicated that the number of field grain decreased with increased salinity level (Tables 5.1-5.3). The performance of BRRI dhan47 was found better within the salinity level up to 8 dS/m in the growing period, which is the expected level for BRRI variety. The salinity level of the pumped water, field water and soil of the crop field maintained a similar trend in every case (Figure 5.6 – 5.8). They had a direct relationship with the water source. But after the rainfall, the salinity level had the decreasing trend irrespective of area (Figure 5.6 – 5.8 and Figure 5.10). This is an indication that in the climate change situation, if the salinity level increases up to a certain level the crop and land productivity will be ensured and food security of the coastal people may thus be ensured.

5.9 Awareness Building Activities

Through this project a few awareness-raising activities were done during the crop-growing period. Field demonstrations, field days and farmers' view exchange programs were held in the project area to familiarize the local people about the project objectives and to increase the knowledge and awareness of the crops grown in the climate change situation.

Figure 5.11: Farmers' view exchange program during *boro*, 2007

Figure 5.12: Group of selected farmers in different localities visits the experimental field

6. T.Aman Season Rice Experiments

6.1 Selecting *T.Aman* Season Rice Crops

BR23, BRRIdahn40, *BRRIdhan41*, *BRRIdhan33/39* were selected for field experiment in the *T.Aman* season. In fact there is no salinity effect in the coastal region during the *T.Aman* crop growing season (salinity ranges 1.5-3 dS/m) due to high rainfall and upstream river flow. But at the later stage, there is some sort of salinity (ranges 4.6 dS/m) impact in the coastal zone.

BR23 is a weakly photosensitive variety. Areas where flood waters recede late are suitable for this variety. Besides it has the capability to tolerate some sort of salinity and water stress at the later stage. This variety is grown widely in the coastal saline areas.

BRRIdahn40 and *BRRIdahn41* are released for saline areas and they have the capability to tolerate salinity ranges up to 7-8 at the reproductive phase. These are newly released varieties with a high yield potential. These varieties may be adopted in the climate change situation.

BRRIdhan33 and *39* are the short duration variety. These have no tolerance level for salinity. The early variety will be tested in order to facilitate the early utilization of land for *rabi* crops and thereby intensify crop production in the coastal area.

6.2 Field -Testing Sites

The field experiments sites were selected in low saline area, medium saline area and high saline area, in Mathoreshpur union under Kaliganj upazila, Ratanpur union under Shyamnagar upazila and Munshiganj union under Kaliganj upazila of Satkhira respectively. Locations of experiment sites of *T.Aman* season rice crops are shown in Figure 6.1. The list of selected farmers is given in Appendix A.

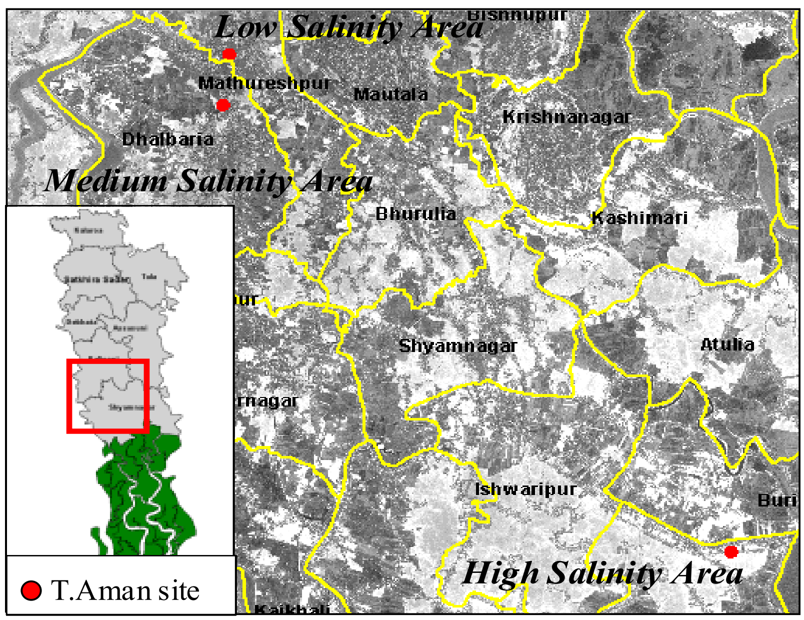


Figure 6.1: Locations of field experiments sites selected for T.aman season rice crops

6.3 Soil and Land Types

The land type of the selected sites is medium high land to medium low land and used for rice cultivation in both the seasons. The soil series of Mothurespur union under Kaliganj upazila is Barial clay loam and soil salinity is 0.82 – 1.6 dS/m. The soil series of Munshiganj under Shyamnagar upazila is also Barial clay loam and soil salinity is 0.80 – 4.0 dS/m. The soil series of Dhaibari under Kaliganj upazila is Bajoya Clay loam and soil salinity is 1.0 - 6.0 dS/m.

6.4 Observational Field Trial Selection

For observational trial, the land was classified according to the salinity gradient and crop production based on the perception of the farmers and local elite. The crop performance was monitored for different salinity gradients to find out crop suitability and sustainability under the climate change situation.

6.4.1 Low Saline Area

Based on the farmer's perception a low saline area was selected at Mothoreshpur of Kaliganj upazila. The mode of irrigation water was STW and the fields were maintained with continuous standing water for T.aman season rice crops. In these sites, five selected varieties of T.Aman season rice were cultivated. The crops were transplanted during T.aman season on 22 August 2007 with about 30 days old seedlings.

6.4.2 Medium Saline Area

Based on the farmers perception medium salinity area was selected at Munshiganj under Shyamnagar upazila. The mode of irrigation water was STW and the fields were maintained with continuous standing water. All of the five selected varieties of T.aman season were cultivated. The crops were transplanted during T.aman on 30 August 2007 with about 30-day old seedlings.

6.4.3 High Saline Area

A high saline area was selected at Ratanpur of Kaliganj upazila. The mode of irrigation water was STW and the fields were maintained with continuous standing water for T.aman season rice crops. All of the five selected varieties of T.aman season were cultivated. The crops were transplanted during *T. Aman* season on 30 August 2007 with about 30 day old seedlings.

6.5 Data Collection

The water source, water salinity and soil salinity were monitored from the transplanting to the harvest stage. The initial soil samples were collected from the selected field up to the depth of 45 cm at an interval of 15 cm for soil water content, soil pH, soil organic mater, soil texture and soil salinity measurement. Soil samples were also collected from the neighboring fields cultivated by farmers with different varieties. The water sample was collected from the irrigation source for water salinity measurement. At the early period, samples were collected fortnightly up to September and then weekly for *T. Aman* season. Weather data were collected from the Bangladesh Meteorological Departmental Office at Satkhira.

6.6 Results

6.6.1 Low Saline Area (Site 1)

Performance of the crop in the low saline area showed that all the cultivated rice crops grew well in that area, as there was no salinity impact on crop production. The highest grain yield was found in variety BRRI dhan44 (4.85 t/ha) followed by BRRI dhan40 (4.50 t/ha), which are excellent long duration *T. Aman* variety. But the varieties BRRI dhan33 and BRRI dhan39 gave the lowest grain yield due to severe rat infestation during early growth stage. Salinity level in the low saline area as per farmer's perception and the field water and soil salinity varied from 0.6 to 1.6 dS/m. But the soil salinity had an increasing trend over time at the later stage of crop growth since rainfall had ceased by that time (Figure 6.2 and 6.5).

Table 6.1: Yield and yield contributing characters of different *T. Aman* varieties in observation plots of low salinity gradients during *T. Aman*, 2007

Variety	No. of panicle/hill	Panicle length (cm)	No. of filled grain	1000 grain weight (gm)	Grain Yield (t/ha)	Straw Yield (t/ha)
BR23	9.0	16.2	59.6	20.5	2.80*	2.70
BRRIdhan33	11.0	21.6	56.4	19.0	2.98*	2.86
BRRIdhan39	12.0	26.6	69.2	20.0	4.15	4.06
BRRIdhan40	9.0	20.6	92.4	21.5	4.50	4.40
BRRIdhan41	10.0	22.4	73.2	23.0	4.27	4.35
BRRIdhan44	10.0	15.8	82.0	23.5	4.85	4.77

** Crop damaged by rat*

6.6.2 Medium Saline Area (Site 2):

The field crop performance in the medium saline area showed that all the cultivated crops grew well in that area, as there was a little salinity impact on crop production. The highest grain yield was found in BRRI dhan44 (4.93 t/ha) followed by BRRI dhan41 (4.43 t/ha), which are of the long duration varieties. Among the short duration varieties, both BRRI dhan33 and BRRI dhan39, performed well due to no salinity impact in that locality (Table 6.2). The field water and soil salinity varied slightly and moved within 1.0 dS/m. The soil salinity had an increasing trend at the later stage, but it was within the safe limit (Figure 6.3).

Table 6.2: Yield and yield contributing characters of different *T. Aman* varieties in observation plots of medium salinity gradients during *T. Aman*, 2007

Variety	No. of panicle/hill	Panicle length (cm)	No. of filled grain	1000 grain weight (gm)	Grain Yield (t/ha)	Straw Yield (t/ha)
BR23	10.0	21.0	75.8	21.5	4.07	3.85
BRRIdhan33	9.0	17.8	68.8	19.8	3.13	3.10
BRRIdhan39	8.0	18.0	82.5	21.0	3.57	3.27
BRRIdhan40	10.0	18.0	79.5	22.0	4.37	4.20
BRRIdhan41	9.0	16.9	87.5	22.5	4.43	4.48
BRRIdhan44	10.0	17.8	87.6	22.5	4.93	4.83

6.6.3 High Saline Area (Site 3)

The field crop performance in the high saline area showed that all the cultivated crops grew well in that area, as there was a salinity impact on crop production during *T. Aman*. The highest grain yield was found in variety *BRRIdhan41* (5.51 t/ha), followed by *BRRIdhan44* (5.42 t/ha) (Table 6.3). The varieties *BRRIdhan40* and *BRRIdhan41* have some salt tolerant capacity at the later stage of growth. The other varieties, including the short duration varieties *BRRIdhan33* and *BRRIdhan39* also performed well, as the high salinity ranged within the safe limit of crop growing period. Soil and water salinity level in the high salinity area varied from 1.0 to 6.0 dS/m and increased in the later stage of crop growth (Figure 6.4). So, either short duration or the salinity tolerant varieties could be grown well in that area.

Table 6.3: Yield and yield contributing characters of different T. Aman varieties in observation plots of high salinity gradients during 2007

Variety	No. of panicle/hill	Panicle length (cm)	No. of filled grain	1000 grain weight (gm)	Grain Yield (t/ha)	Straw Yield (t/ha)
BR23	10.0	17.3	84.7	22.0	3.86	3.63
BRRI dhan33	8.0	11.2	87.2	19.5	3.49	3.32
BRRI dhan39	9.0	18.7	86.0	20.0	3.98	3.85
BRRI dhan40	10.0	18.0	83.6	21.0	4.44	4.35
BRRI dhan41	12.0	25.8	83.6	22.0	5.51	5.62
BRRI dhan44	12.0	23.0	86.5	21.5	5.42	5.38

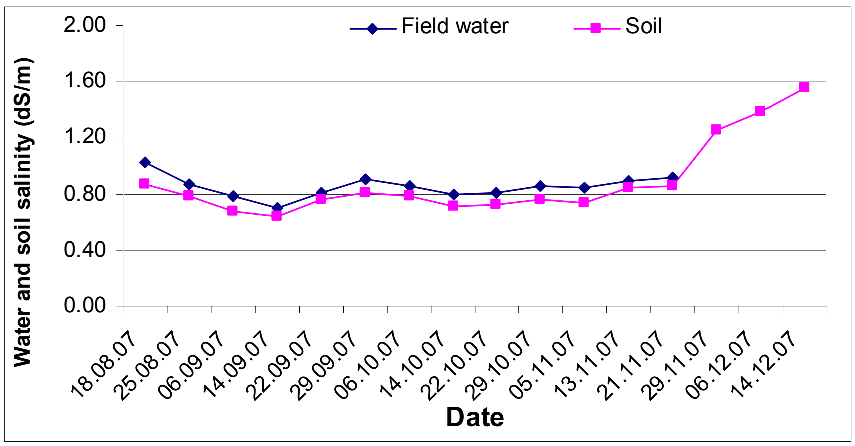


Figure 6.2: Salinity level of field water and soil of experimental plot in low saline area during *T. Aman*, 2007

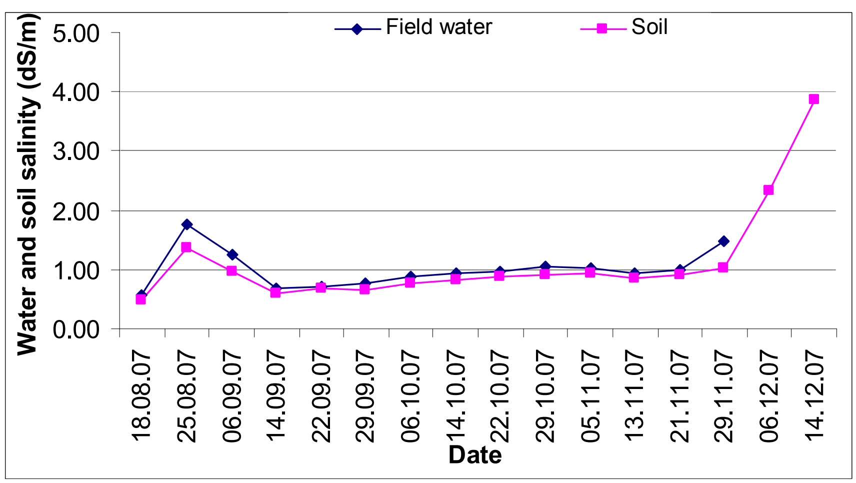


Figure 6.3: Salinity level of field water and soil of experimental plot in medium saline area during *T. Aman*, 2007

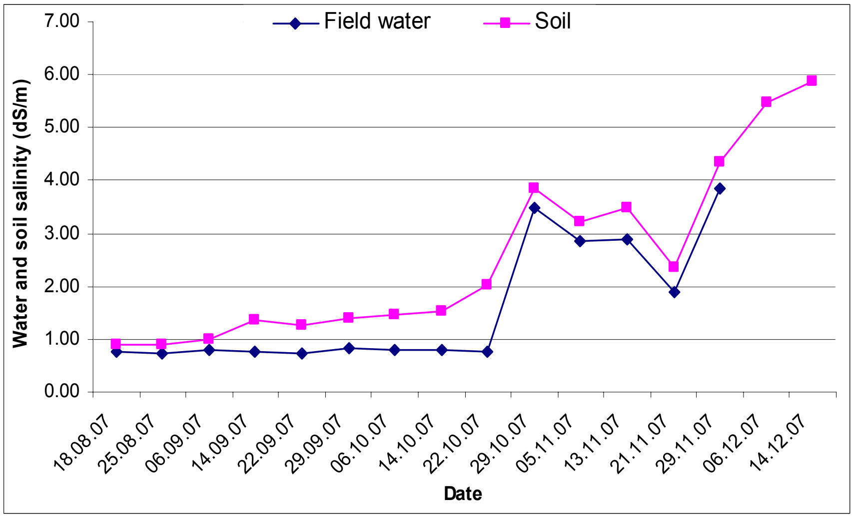


Figure 6.4: Salinity level of field water and soil of experimental plot in high saline area during T. Aman, 2007

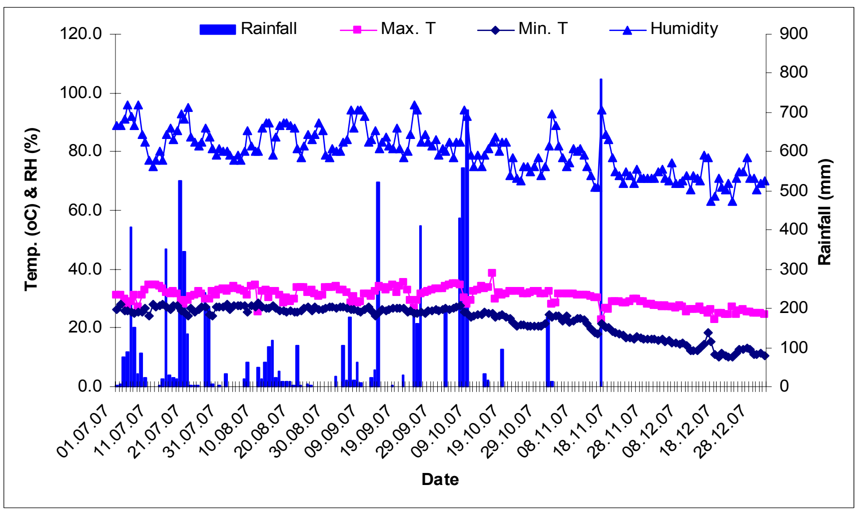


Figure 6.5: Weather data monitoring during the crop-growing period of T. Aman, 2007

6.7 Discussion

T. Aman season is a safe rice-growing season in the coastal area. No salinity impact on rice production due to high rainfall was observed to occur during this season. This is a complementary finding with Mondal et al, 2005, who reported that there was no salinity in *T. Aman* season. But in the later period of monsoon, when the rainfall is low, the soil salinity may increase and goes beyond the safe limit of rice crop (4 dS/m). So, salt tolerant *T. Aman* varieties like *BR23*, *BRRIdhan40* and *BRRIdhan41* may be the solution to overcome the salinity impact at the later stage of crop growth, as these varieties have some salt tolerant capacity and thus the food production can be ensured in that area.

6.8 Improved Cropping Patterns

The total cultivable land in the coastal saline area is about 1.00 million hectares. Most of the lands are cultivated during *aman* season by the local varieties and the yields are about 2.0-2.5

t/ha. The existing cropping pattern is *Fallow*-*T.Aman* (Local)-*Fallow* (Table 6.4). A few areas are cultivated with high yielding or local varieties during *boro* season, where the irrigation facilities are available either from surface source or groundwater sources. The cropping pattern of these regions is *Fallow*-*T.Aman* (Local)-*Boro* (Local/HYV) (Table 6.4). The *boro* areas could be expanded, introducing salt tolerant *boro* variety BRRI dhan47, where the source water salinity ranged up to 8 dS/m. It is difficult to draw a pattern-based statement in such a short study. But in conclusion, the improved cropping pattern may be *Fallow*-*T.Aman* (HYV)-*Boro* (HYV) (Table 6.5). Beside these, some *rabi* crops could be cultivated in pocket areas with some improved management, where the land and soil remain suitable. The cropping pattern may then be changed like *Okra (Dharosh)-T. Aman-Boro* (HYV) or *Okra-T.Aman-Tomato* (Table 6.5). Rice Equivalent Yield (REY) was calculated by how much rice can be bought from the return of other crops.

Table 6.4: Exiting cropping pattern

Cropping Pattern	**Fallow**	**T.Aman (Local)**	**Fallow**
Yield (tonne/hectare)		2.0 - 2.5	
Total (REY)	2.0 – 2.5		
Gross Return (Tk.)	20,000 – 25,000		
Cropping Pattern	**Fallow**	**T.Aman (Local)**	**Boro (Local/HYV)**
Yield (tonne/hectare)		2.5	4.5
Total (REY)	7.0		
Gross Return (Tk.)	70,000		

Table 6.5: Improved cropping pattern

Cropping Pattern	**Fallow**	**T.Aman (HYV)**	**Boro (HYV)**
Yield (tonne/hectare)		4.5	6.4
Total (REY)	10.9		
Gross Return (Tk.)	109,000		
Cropping Pattern	**BARI dharos-1 (Okra)**	**T.Aman (HYV)**	**Boro (Local/HYV)**
Yield (tonne/hectare)	8.18	4.5	6.4
Total (REY)	14.9		
Gross Return (Tk.)	149,000		
Cropping Pattern	**BARI dharos-1 (Okra)**	**T.Aman (HYV)**	**Tamato**
Yield (tonne/hectare)	8.18	4.5	37.86
Total (REY)	27.4		
Gross Return (Tk.)	274,000		

7. Rabi Season Experiments

7.1 Selecting Non-Rice Crops

According to the suggestions of the members of ARAC, high cash crops such as *tomato*, *watermelon*, o*kra* and *aroids* were selected for field-testing in the coastal region of Satkhira district. Though they are not salt tolerant, these high cash crops were selected to find out an innovative farming practice, which could avoid salinity at their sowing stage in the *rabi* season.

7.2 Site Description

Under this study, *tomato* and *watermelon* were tested in Benarpota farm, the Agricultural Research Sub-centre of BARI, which is about 4 km northeast from Satkhira town. *Okra* and *aroids* were tested in the farmer's fields as per suggestions of the ARAC members. The selected farmer's fields of o*kra* crops (Table A3 and A4 of Appendix A.) are located in different village of Satkhira Sadar upazila. Location of experimental site of Rabi season crops are shown in Figure 7.1.

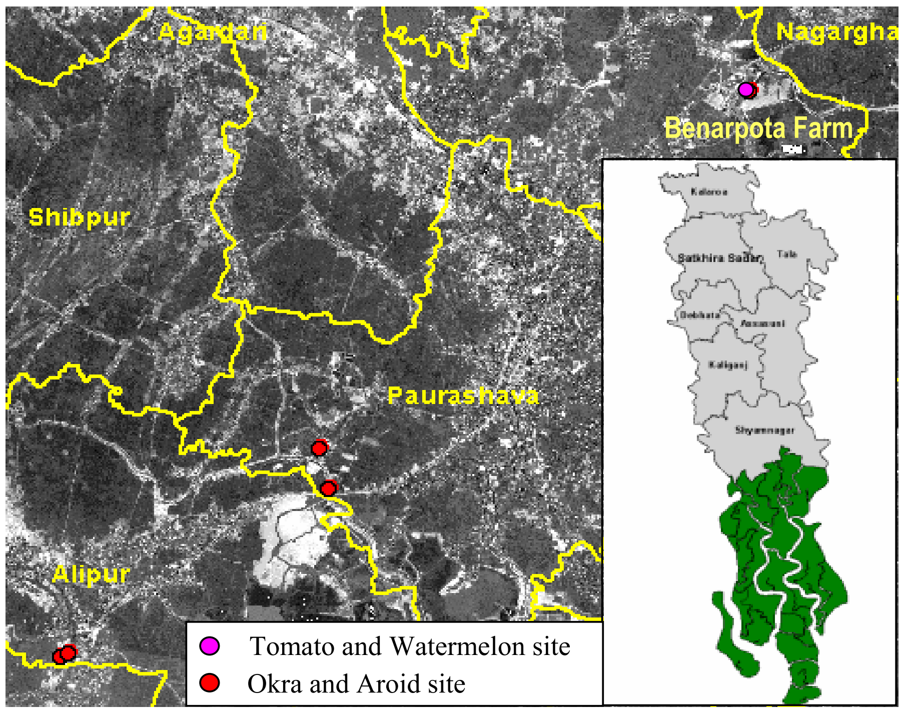


Figure 7.1: Lcation of field experiment sites for Tomato , Watermelon, Aroid and Okra

7.3 Soil and Land Type of the Experimental Sites

The soil of the selected sites for *tomato* and *watermelon* was clay in nature with a field capacity of 30% and a bulk density of 1.65 gm/cc. *Okra* and *aroids* were selected for demonstration in the farmer's fields where the soil texture was silt loam with a field capacity and bulk density of 27% and 1.4 gm/cc respectively.

7.4 Data Collection

Data on the yield contributing characters of *tomato* and *okra* were collected from the demonstration plots. The results of the analyzed data of both the crops are presented in the subsequent sections with discussions.

7.5 Field Testing of *Tomato* and *Watermelon* at Benarpota Farm

Tomato (BARI Tomato-3) was transplanted on 27 December 2006 and *watermelon* (Gloory) was planted on 22 January 2007. Figure 7.2 shows the photograph of *tomato* during the flowering and bearing stages. The w*atermelon* was damaged totally due to heavy rain and when replanted in the same plots it was damaged by rainfall and salinity for the second time. Only a few plants per plot survived but their growth was stunted and produced very low yields in the end. So, *watermelon* is not reported here.

(a) Tomato at flowering stage *(b) Tomato at bearing stage*

Figure 7.2: Photograhs of *Tomato* during (a) flowing stage and (b) bearing stage

In Benarpota farm, two different plots were selected for *tomato* demonstration. The plot size was 2.4 m X 4.0 m. Seedlings were grown in the non-saline soils of Daulatpur farm, Khulna and in the saline soils of Benarpota farm. These two categories of seedlings were planted separately in two different plots having minor variations in soil salinity. In the Benearpota farm, drip irrigation and can irrigation were used.

The following sequences of irrigation management were used:

T1 = Can irrigation in flat bed (farmers' practice)

T2 = Can irrigation in raised bed without mulch

T3 = Drip irrigation in raised bed with mulch

It is evident that drip irrigation performed better in raised bed with mulch than any other selected irrigation option (Table 7.1). The highest marketable yield (42.03 t/ha) was obtained from this treatment followed by can irrigation in raised bed without mulch (37.86 t/ha). The lowest yield (19.46 t/ha) was obtained in flat bed without mulch. It appears from the study that raised bed, mulch and drip irrigation together acted on minimizing soil salinity (Table 7.2) to a reasonably tolerable limit for *tomato.*

Table 7.1: Yield and yield contributing characters of *tomato* under different salinity management techniques

Treatment	Plant population/plot	Unit fruit weight (gm)	Fruits/plant	Marketable yield (t/ha)	Curl yield (t/ha)	Total yield (t/ha)
T_1	36.67	77.67	34.67	19.46	9.03	28.49
T_2	39.00	93.67	38.67	37.86	12.85	50.71
T_3	38.33	90.33	37.67	42.03	13.20	53.22
CV %	3.40	10.43	7.07	8.71	14.41	9.71
$LSD_{0.05}$	-	-	-	6.538	-	9.858

Table 7.2: Average soil salinity (dS/m) of *tomato* demonstration plots at Benarpota

Monitoring Dates	T1	T2	T3	Remarks
27-12-06	3.35	3.35	3.35	On 07-02-07, a heavy rainfall reduced the soil salinity of *tomato* plots
12-01-07	3.65	3.53	3.41	
23-01-07	4.50	4.16	3.82	
31-01-07	4.70	4.35	3.99	
08-02-07	2.50	2.22	1.95	
22-02-07	4.00	3.80	3.59	
13-03-07	8.00	5.53	4.05	
19-03-07	8.50	5.60	4.80	
25-03-07	9.65	6.42	5.38	

The salinity in flat bed was recorded up to 9.65 dS/m whereas at the same time, it was only 5.28 dS/m in drip irrigated plots. Raised beds disturb continuation of capillary pores, which retards the rate of the upward flux of capillary rise of water. Mulches offer a kind of shade to minimize evaporation that indirectly reduces the upward movement of soil water and drip irrigation leaches down the accumulated salts from the beds. In this way, the entire process helps reduce soil salinity. Conversely, from flat land and bare soil, the evaporation loss becomes higher, facilitating the movement of salt water upwards through the undisturbed soil pores. Hence, the evaporation loss becomes high thereby enhancing accumulation of salts at a higher rate in the root zone of the crop. In the former process, the plants obviously suffered less from salinity hazards than that in the latter. This facilitated proper plant growth in plots having raised bed with mulch and irrigation by the drip method and finally contributed to increased yields.

The yield and yield contributing parameters of *tomato* are presented in Table 7.1. The soil salinity level at different stages and the amount of irrigation water used are presented in Table 7.2 and 7.3.

Table 7.3: Amount of irrigation water applied to treatments during the crop season at Benarpota, Satkhira

Treatment	No. of irrigation	Amount of irrig. water applied (mm)	Effective rainfall (mm)	Soil water contribution (mm)	No. of rainy days	Total seasonal water (mm)
T_1	8	280	62	30	5	372
T_2	8	240	62	21	5	323
T_3	16	192	62	16	5	270

7.6 Field Testing of *Okra* at Farmer's Fields

Okra was planted in 4 different fields having different soil salinities. One of the 4 fields was damaged by cattle when the plants were 7-8 cm tall. So, this plot was discarded and is not reported here. Two of the three remaining plots were in Bolarati of Satkhira Sadar and the fourth one was in Bakal of the same upazila. At the farmer's fields only can irrigation was used and the irrigation sequences were:

T1 = Can irrigation in flat bed (farmer's practice)

T2 = Can irrigation in raised bed with mulch

T3 = Can irrigation in raised bed without mulch

Though, T1 was supposed to be in flat bed, some sort of raising was done for *okra* during the layout of the demonstration plots. Figure 7.3 shows the *Okra* in the vegetative and flowing stages in a raised bed with mulch.

(a) Okra at vegetative stage

(b) Okra at flowering stage

Figure 7.3: Photograhs of *okra* during (a) the vegetative stage and (b) flowering stage

From Tables 7.4 to 7.6, it appears that there was no significant difference in yield and yield contributing characters in the management practices. However, there exist differences in the magnitudes of the parameters and yields for the selected management options.

Table 7.4: Yield and yield contributing characters of *okra* in demonstration field-1

Treatment	Plants/plot	Plant height (cm)	Fruit length (cm)	Pods/plant	Unit fruit weight (gm)	Yield (t/ha)
T_1	39.67	111.33	16.20	8.07	23.40	9.36
T_2	40.00	115.67	16.53	8.53	24.27	9.65
T_3	39.33	108.33	16.80	8.10	22.93	9.36
CV (%)	1.46	7.24	2.30	3.58	2.89	10.33

Table 7.5: Yield and yield contributing characters of *okra* in demonstration field-2

Treatment	Plants/plot	Plant height (cm)	Fruit length (cm)	Pods/plant	Unit fruit weight (gm)	Yield (t/ha)
T_1	39.00	109.67	16.73	8.06	24.20	9.65
T_2	40.00	113.33	16.87	8.33	24.73	10.31
T_3	39.33	101.00	17.13	7.67	24.60	9.28
CV (%)	1.69	7.09	3.31	7.03	2.82	6.30

Table 7.6: Yield and yield contributing characters of *okra* in demonstration field-3

Treatment	Plants/plot	Plant height (cm)	Fruit length (cm)	Pods/plant	Unit fruit weight (gm)	Yield (t/ha)
T_1	17.67	66.83	13.40	8.33	14.93	5.52
T_2	19.33	81.20	14.67	10.20	15.79	7.77
T_3	19.00	71.47	14.13	9.53	14.69	6.66
CV (%)	3.09	7.06	2.09	7.69	7.69	20.41

Raised beds with mulch performed well by controlling the soil salinity better than any other management option giving rise to high yields in all three demonstrations. The yields of *okra* in demonstration field 1 and 2 were found lower than the potential yield. The salinity levels in demonstration fields 1 and 2 ranged between 2.0 dS/m to 4.17 dS/m in raised bed with mulch treatment whereas those in raised bed without mulch were between 2.0 dS/m to 5.12 d/Sm. In farmers' practice, the salinity was found between 2.0 dS/m to 5.26 dS/m.

In demonstration field 3, the salinity values in farmers' practice, raised bed without mulch and raised bed with mulch were found to vary between 5.53 dS/m to 6.82 dS/m; 5.53 to 6.42 dS/m and 5.53 to 5.72 dS/m, respectively. The lower yield in demonstration field 3 was due to higher soil salinity and also for using saline water for irrigation. In Tables 7.4 to 7.6, the results of the analyzed data of *okra* are presented.

7.7 Field Testing of *Aroids* at Farmer's Fields

Aroid was plated in three farmer's fields at the end of April. The detailed information of each plot is given in Table A.3 under Appendix A. The soil salinities of the fields were recorded regularly. Data on the whole season's rainfall, temperature, humidity, and evaporation were collected and analyzed for the preparation of the final report. It was harvested at the end of September 2007. At the farmer's fields only can irrigation was used and the irrigation sequences were:

T1 = Can irrigation in flat bed (farmer's practice)

T2 = Can irrigation in raised bed with mulch

T3 = Can irrigation in raised bed without mulch

Demonstration plots at different sites received adequate rainfall during the entire season. Since all the plantations were done in the 4th week of April, all the sites received some 25 mm rainfall in April. After that, some drought days were experienced in May when 2-3 irrigations amounting to 60 mm at each site were applied for tuber germination. But in June, July, August, September and October, 344, 669, 155, 193 and 143 mm rainfall was received respectively. So, no irrigation was required during these months. From the economic analysis, it is shown that the highest BCR (5.60) was obtained from the treatment T2 /can irrigation with mulch.

Due to heavy rainfall, there hardly any sharp rise was observed in soil salinity throughout the whole season. However in farmers' field with flat bed, no mulch and no irrigation sequences were used, the soil salinity was found somewhat higher than that in raised bed and raised bed with mulch. This situation led to the lowest yield in farmers' practice. Both mulch and raised bed facilitate more favorable condition for plant growth. Data collected from these demonstration plots were analyzed. The results are presented in Tables 7.7.

Table 7.7: Yield and yield parameters of *aroids* in demonstration fields

Demonstration field		Doulatpur			Bolarhati			Kulia		
Treatment		T1	T2	T3	T1	T2	T3	T1	T2	T3
Plant population		20	20	19	30	30	30	29	30	30
Leaves/plant		6.1	6.2	6.1	5.0	6.0	5.3	5.0	6.0	5.3
Plant height	**(cm)**	43.27	50.47	42.13	47.33	67.33	56.67	44.33	62.00	59.00
Leave length	**(cm)**	23.93	23.80	22.53	34.00	47.33	43.33	32.00	43.00	40.30
Leave breadth	**cm**	13.6	13.6	13.9	23.0	29.0	26.0	19.3	29.3	24.3
No. of secondary corm/plant	**(cm)**	6.80	10.67	7.20	5.0	8.3	7.0	5.0	6.3	5.4
Wt. of secondary corm/plant	**(gm)**	88.13	172.00	99.67	109.00	246.00	245.00	196.67	246.00	235.00
Cormel/plant		11.80	21.47	15.40	20.0	23.3	21.3	17.67	21.33	21.33
Wt. of cormel/plant	**(gm)**	91.33	193.00	127.33	255.00	505.00	423.00	235.00	504.00	432.00
Yield	**(t/ha)**	16.08	26.42	16.83	22.38	45.97	39.50	19.97	46.58	31.77

Table 7.7, shows that raised bed with mulch (T2) produced the highest secondary corm/plant, (10.67), wt. of secondary corm/plant (172.0 gm), cormel/plant (21.47), wt. of cormel/plant (193.0 gm) and *aroid* yield 26.42 t/ha in demonstration plot at Doulatpur. Similar trends of these parameters are also obtained from demonstration plots at Bularhati and Kulia comparing the yields at 3 demonstration plots, it is seen that the site, Kulia produced the highest *aroid* yield of 46.53 t/ha while the least yield was at Doulatpur. This was due to the higher salinity at Doulatpur than those of other two sites.

7.8 Field Demonstration

A farmers' field day was arranged by OFRD, Daulatpur, Khulna in order to show *tomato* production technologies to the farmers, DAE Officers and other invited guests of the locality (Figure 7.4). A very encouraging response was obtained from the farmers and guests.

Figure 7.4: Visit to experimental field at Benarpota farm during by Scientists, farmers and DAE personnel

7.9 Results and Discussion

Tomato (BARI*Tomato*-3) was found to give a good yield (42.03 t/ha) under drip irrigation in raised bed with straw mulch. Flat bed without mulch and can irrigation produced the lowest yield (19.46 t/ha).

In farmers' fields, *okra* produced the highest yields (9.65 t/ha, 10.31 t/ha) from can irrigation in raised bed with mulch at different locations. No significant effect of soil salinity variations on yield contributing characters of the selected crops was found due to heavy rainfall. However, in all the cases, raised bed with mulch produced the highest yields of *okra* (BARI Dharos-1).

*Aroid*s were demonstrated in 3 locations under farmers' practice (flat bed with no mulch), raised bed and raised bed with mulch. All the plots were irrigated by cans. Raised bed with mulch produced the highest yields, 26.42, 45.97 and 46.58 t/ha in Doulatpur, Bolarhati and Kulia, respectively.

8. Simulation Modeling

8.1 Introduction

The Fourth Assessment Report of the IPCC (2007) considers agriculture as one of the most vulnerable systems to be affected by climate change in the south Asian region. Most of the countries of this region generate between 20% and 40% of their GDP from the agriculture sector. The economy of Bangladesh is based on agriculture, industry and services.

The climate in Bangladesh is changing and it is becoming more unpredictable every year and its variability being experienced more frequently than ever before. Hazards like floods, droughts, cyclones and others, which are likely to be aggravated by climate change. Salinity intrusion would be a more acute problem in the coastal region. This will have extra bearing on the agriculture as well as on the potable water in that region.

As stated by Al-Farouq and Huq (1996) "Bangladesh could face a catastrophic situation, including permanent inundation of about 15%–18% of its low-lying coastal areas, loss of the Sunderbans, displacement of over 10 million people, and loss of valuable agricultural land". The salinity conditions in the coastal area of Bangladesh could further exacerbate due to reduced dry-season freshwater supply from upstream sources resulting from climate change (IPCC, 1998) and saline water intrusion due to sea level rise. The extent of vulnerability, however, depends not just on the physical exposure to sea-level rise and population affected, but also on the extent of economic activity of the areas.

The coastal areas are specifically prone to affect of sea level rise, tidal surge, salinity intrusion and cyclone. Vulnerability within the coast is again spatially and temporally different. Vulnerability is high towards the sea relative to the mainland. People at those vulnerable areas require adaptation to these consequences of climate change so that they do not move away from their habitat, this would give rise to social, economic and political crisis. Necessary adaptation tools are urgently required for the vulnerable communities.

To promote effective coping and adaptation strategies to reduce vulnerabilities associated with climate change and climate variability. In particular, this piece of work will concentrate on assessing the impact of climate change on agriculture in Bangladesh, especially on rice, *tomato* and *aroid*.

8.2 Models for Generating Climatic Scenarios

Since the changes in climate are anticipated, therefore, the future changed scenarios should be simulated and under these changed scenarios, the performance of crop growth and production need to be evaluated. In doing so, various computer models for generating climatic scenarios and estimating crop growth and yields crop models were used.

The extent of change in climatic parameters or the 'delta values' of mean temperature and precipitation were generated by using MAGICC 2.4 (Model for the Assessment of Greenhouse-gas Induced Climate Change) and SCENGEN 2.4, meaning SCENario GENerator. The following model parameters for Emission Scenario IS92a (IPCC Third Assessment Report, 2001) was used. According to the best guess of IPCC emission scenario 92a, the concentration of CO_2 for 2050 and 2070 are 515 ppmv and 575 ppmv respectively (Figure 8.1). These values were used for the simulation of crop yields.

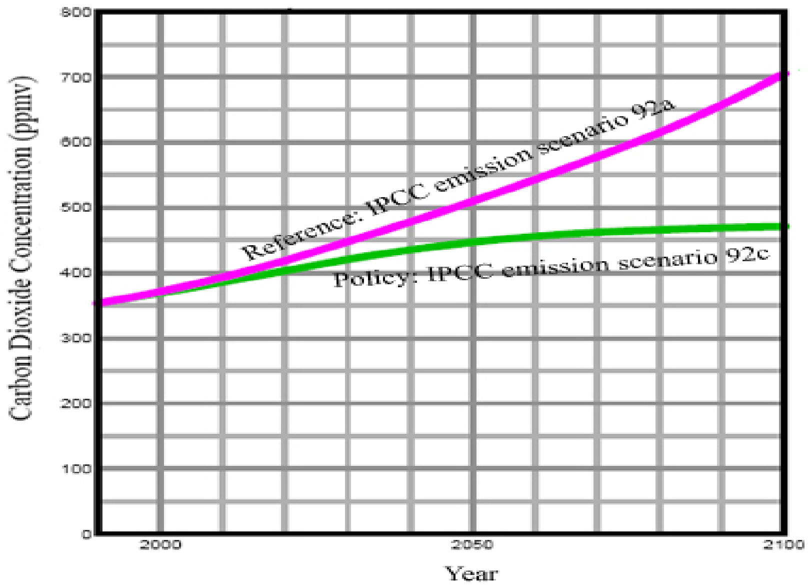


Figure 8.1: Carbon dioxide concentration (Output from MAGICC)

The variables for Carbon Cycle Model (Dn80s), Aerosol Forcing (direct and indirect) and Climate Sensitivity were as follows:

Carbon Cycle Model: Dn80s defines the 1980s-mean value of net land-use change CO_2 emissions. The default value for this variable is 1.1 Gt C (Gigatonnes of carbon) per year, which is the IPCC Second Assessment Report best-estimate.

MAGICC is a set of coupled gas-cycle, climate and ice-melt models that allows the user to determine the global-mean temperature and sea-level consequences of user-specified greenhouse gas and sulphur dioxide emissions. MAGICC is designed for two main purposes:

Aerosol Forcing: There are three components to the aerosol forcing used by MAGICC. All three components are subject to large uncertainties, but the default values in MAGICC are those used in the IPCC Second Assessment Report.

Direct: this forcing is the direct, clear-sky effect of sulphate aerosols formed from fossil fuel combustion, i.e., aerosols derived from SO_2 emissions. MAGICC uses a default current (1990) forcing estimate of -0.3Wm-2. This direct forcing effect includes the positive forcing effects of soot, estimated to be about +0.1Wm-2.

Indirect: the indirect forcing effect of aerosols is more uncertain than the direct effect. MAGICC uses a default value for the current indirect forcing of -0.8Wm-2. The range recommended by the IPCC was from 0 to -1.5Wm-2 and -0.8Wm-2 was the value used in the IPCC Second Assessment Report projections.

Climate Sensitivity: The climate sensitivity defines the equilibrium response of global-mean surface air temperature to a doubling of the CO_2 concentration. The IPCC Second Assessment Report best estimate of this parameter was 2.5°C.

The 'driver' for SCENGEN is the global-mean temperature anomaly produced by the linked software program MAGICC. MAGICC was used to produce the global-mean temperature and sea-level rise projections given in the IPCC Working Group I Second Assessment Report (IPCC, 1996). The present software therefore gives results entirely consistent with the SAR.

The Climatic Research Unit has developed SCENGEN 2.4, over the period from 1994 to 2000. It is a software tool that enables the user to exploit results from both simple and global climate model experiments, combined with observed global and regional climatologies, to construct a range of geographically- explicit future climate change scenarios for the world. The scientific rationale for the approach adopted in SCENGEN has been developed over a number of years by the Climatic Research Unit, School of Environmental Sciences, University of East Anglia, UK, working with many others around the world.

The software framework allows the user to explore the consequences for future climate of adopting different assumptions about climate system parameters and emissions scenarios. The software also allows the user to select and apply the results from a range of different General Circulation Model (GCM) experiments. The effects of sulphate aerosols on future climate are included in the software, and the user may explore these effects at both the global-mean and regional (spatial pattern) scales.

Delta values for mean temperature and precipitation were generated for the GCMs - GFDL-TR = Geophysical Fluid Dynamics Laboratory Transient, HadCM2 = Hadley Centre during 1995 and 1996 using the Second Version of the United Kingdom Meteorology Office's Unified Model UKTR = UK Met. Office/Hadley Centre Transient with respect to the base year of 1990. Default MAGGIC model parameters and high climate sensitivity was used for two time intervals 2050 and 2070.

8.3 Crop Model

To study the impact of climate change of agricultural crops as compared to the base year (1990), crop simulation studies were conducted for selected crops of Satkhira. For this Decision Support System for Agrotechnology Transfer (DSSAT) 4.0 (2004) based crop simulation model was used to assess the yields/productions of different crops under present and changed climate scenarios. The above delta values were used for generating scenarios. As mentioned earlier, three different GCMs was used for generating climate change scenarios for the study area for 2045 and 2050 with respect to the base year (1990).

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. The DSSAT includes the following modules:

- A main driver program, which controls timing for each simulation
- A Land unit module, which manages all simulation processes which affect a unit of land
- 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.

8.4 Minimum Data Sets

A minimum data set of weather, soil management, and crop response data is essential for model development and for the effective interpretation and comparison of field experiments.

The Minimum Data Set (MDS) is an attempt to reduce the number of variables which have to be collected and yet to facilitate the proper validation of a crop model. Thus a MDS contains data that are not normally or readily available, such as solar radiation, for example.

The main elements of the MDS depend on the number of limiting factors the models take into account. At the simplest level, potential productivity, soil and water related inputs are not needed. Depending on the application, the effects of diseases and pests can be overlaid on any of the three levels shown in Table 8.1.

Crops considered under this study are rice for two seasons (*boro* and *T. Aman*), *aroid* and *tomato*. For simulation runs, experiments were designed with optimum agronomic and management practices. As per requirement of the models, weather files and soil profiles were also created. For model calibration and validation the following data were collected or estimated. However, many of the parameters had to be estimated as those were not readily available.

Table 8.1: Crop model input and validation data requirements at three production levels*

(a) Potential Productivity	
Input Daily weather	• solar radiation (MJ m^{-2}) • maximum and minimum temperature (^oC)
Cultivar	• variety name
Site	• latitude
Management	• beginning and sowing date • plant population • seeding depth
Validation Development	• emergence • anthesis • maturity dates
Growth	• LAI, biomass • grain weight, leaf weight, stem weight with time • final grain yield and biomass
(b) Productivity Under Water Limiting Conditions	
Input Daily weather	• rainfall (mm)
Management	• irrigation amounts and schedules
Site	• soil albedo, runoff curve number
	• drainage rate, stage 1 evaporation
Soil (layer)	• depth of each layer
	• lower limit of plant-extractable
	• water and drained upper limit
	• saturated soil water content, bulk • density, initial soil water content
Validation Water balance	• soil water content with time

(c) Productivity Under Water- and Nitrogen-Limiting Conditions	
Input Management	• residue type, amount, and depth of incorporation
	• N fertilizer schedules, source,
	• amount, depth and method of incorporation
Soil	• initial soil NO3- and NH4+ content • initial soil pH and organic C (%)
Validation Nitrogen	• soil NO3- and NH4+ content with time
Growth	• grain and straw N uptake with time
	• final N uptake for grain and straw.

**These data requirements are additive, i.e., to run the model at level (b), inputs for both (a) and (b) are required. Similarly, to run the model at level (c), input (a), (b) and (c) are required and validation at any of the levels can be performed.*

Table 8.2 and 8.3 show the parameters and rice Cultivar Coefficients that were used for model calibration and validation.

Table 8.2: PARAM definition

CSDL	Critical Short Day Length below which reproductive development progresses with no daylength effect (for shortday plants) (hour)
PPSEN	Slope of the relative response of development to photoperiod with time (positive for shortday plants) (1/hour)
EM-FL	Time between plant emergence and flower appearance (R1) (photo thermal days)
FL-SH	Time between first flower and first pod (R3) (photo thermal days)
FL-SD	Time between first flower and first seed (R5) (photo thermal days)
SD-PM	Time between first seed (R5) and physiological maturity (R7) (photo thermal days)
FL-LF	Time between first flower (R1) and end of leaf expansion (photo thermal days)
LFMAX	Maximum leaf photosynthesis rate at 30 C, 350 vpm CO_2, and high light (mg CO_2/m2-s)
SLAVR	Specific leaf area of cultivar under standard growth conditions (cm^{-2} g)
SIZLF	Maximum size of full leaf (three leaflets) (cm^2)
XFRT	Maximum fraction of daily growth that is partitioned to seed + shell
WTPSD	Maximum weight per seed (g)
SFDUR	Seed filling duration for pod cohort at standard growth conditions (photo thermal days)
SDPDV	Average seed per pod under standard growing conditions (#/pod)
PODUR	Time required for cultivar to reach final pod load under optimal conditions (photo thermal days)

Table 8.3: Rice cultivar coefficients

ECO#	Ecotype code for this cultivar points to the Ecotype in the ECO file (currently not used).
P1	Time period (expressed as growing degree days [GDD] in °C above a base temperature of 9°C) from seedling emergence during which the rice plant is not responsive to changes in photoperiod. This period is also referred to as the basic vegetative phase of the plant.
P20	Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P20 developmental rate is slowed, hence there is delay due to longer day lengths.
P2R	Extent to which physic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P20.
P5	Time period in GDD °C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9°C.
G1	Potential spikelet number coefficient as estimated from the number of spikelet per g of main culm dry weight (less lead blades and sheaths plus spikes) at anthesis. A typical value is 55.
G2	Single grain weight (g) under ideal growing conditions, i.e. non-limiting light, water, nutrients, and absence of pests and diseases.
G3	Tillering coefficient (scalar value) relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.0.
G4	Temperature tolerance coefficient. Usually 1.0 for varieties grown in normal environments. G4 for japonica type rice growing in a warmer environment would be 1.0 or greater. Likewise, the G4 value for indica type rice in very cool environments or season would be less than 1.0.

8.5 Selected Crops for Modeling

The experiments on rice were conducted by Bangladesh Rice Research Institute (BRRI). For *boro* season the rice cultivars were *BRRIdhan47*, *BRRIdhan29* and *BRRIdhan45*. The cultivars for Transplanted *aman* were *BRRI 23*, *BRRIdhan40*, *BRRIdhan41*, *BRRIdhan33* and *BRRIdhan39*. The Bangladesh Agricultural Research Institute (BARI) conducted experiments on *aroids* (*Xanthosoma spp*.) and *Tomato* (*BARItomato-3* cultivar).

For running the models Genetic Coefficients were estimated for all the above crops. The information generated through field experiments conducted by BARI and BRRI at different locations of Satkhira were used for the model calibration.

8.6 Soil Data

The soils of the rice experiment sites belong to Barisal series and Bajoa series while the soils of the experimental sites for *aroid* and *tomato* were recognized as Barisal, Ishwardi and Daulatpur. As an input to the models Soil profile files were created. The soil file contains information that is available for the soil at a particular experimental site. Supplementary information was extracted from a soil survey database and other sources [Department of Soil Survey, GOB (1975) and Rahman M. R. (2005)]. 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 soil moisture related values were estimated based on the textural class.

8.7 Weather Data

Daily weather data were used as input to crop simulation models used in this study. The models need complete and reliable data, raw data from a weather station are often not complete. Common data problems include format errors, missing data, unreasonable values, data recorded in different units than needed, and data in an inconvenient format. Often no data was available for a specific site, or a particular variable was not in the available weather record.

Daily weather for the period 1984-2005 was collected for Satkhira station of Bangladesh Meteorological Department. This data set included maximum and minimum temperature (°C), rainfall (mm), and bright sunshine hour (hour) or cloud cover (Octas). Since the model requires solar radiation data (MJ m-2), these were calculated based on (Allen et al, 1998). All the weather data were then formatted as per model requirement into ICASA format.

8.8 Future Climate Change Scenarios

Delta values for mean temperature and precipitation with respect to 1990 (baseline) were generated for two time intervals 2050 and 2070 using three GCMs - GFDL-TR (Geophysical Fluid Dynamics Laboratory Transient), ii. HadCM2 (Hadley Centre during 1995 and 1996 using the Second Version of the United Kingdom Meteorology Office's Unified Model), and iii. UKTR (UK Meteorological Office/Hadley Centre Transient with respect to the base year of 1990). The generated delta values are presented in Table 8.4.

Table 8.4: Delta values for mean temperature and rainfall generated by various Global Circulation Models for 2050 and 2070 using MAGICC 4.1/SCENGEN 4.1

Month/ Season	Global Circulation Models											
	GFDL-TR				UKTR				HadCM2			
	Mean Temperature (°C)		Rainfall (%)		Mean Temperature (°C)		Rainfall (%)		Mean Temperature (°C)		Rainfall (%)	
	2050	2070	2050	2070	2050	2070	2050	2070	2050	2070	2050	2070
Jan	1.5	2.1	-5.4	-7.4	2.1	2.5	-9.5	-13.1	2.0	2.7	29.5	40.5
Feb	1.5	2.1	0.6	0.8	2.0	2.1	4.2	5.8	1.9	2.5	40.9	56.3
Mar	1.7	2.3	4.9	6.7	1.7	2.1	15.2	20.9	1.7	2.4	11.8	16.2
Apr	1.1	1.5	15.2	21.0	1.5	1.8	10.2	14.0	1.7	2.3	-3.1	-4.2
May	1.4	2.0	6.2	8.6	1.8	2.2	2.0	2.8	2.0	2.7	-14.0	-19.2
Jun	1.4	1.9	10.2	14.0	1.7	2.7	17.2	23.7	2.9	4.0	-17.4	-23.9
Jul	1.2	1.7	25.3	34.8	1.7	1.7	32.3	44.4	2.1	2.9	0.8	1.1
Aug	1.3	1.8	19.6	27.0	1.6	1.4	25.0	34.4	1.3	1.7	11.8	16.3
Sep	1.2	1.7	18.0	24.8	1.6	1.2	19.5	26.9	1.4	1.9	3.8	5.2
Oct	1.4	1.9	5.6	7.7	1.7	2.0	8.4	11.5	1.9	2.6	-7.5	-10.4
Nov	1.2	1.7	3.1	4.3	1.6	1.9	-21.2	-29.2	2.3	3.1	-8.7	-12.0
Dec	1.4	2.0	0.8	1.1	1.7	1.9	-10.4	-14.3	1.9	2.6	36.3	50.0
DJF	1.5	2.1	-1.4	-1.9	2.0	2.2	-5.2	-7.2	1.9	2.6	35.6	48.9
MAM	1.4	1.9	7.6	10.4	1.7	2.1	6.8	9.3	1.8	2.5	-1.8	-2.4
JJA	1.3	1.8	18.5	25.5	1.7	1.7	24.0	33.0	1.9	2.7	-0.2	-2.2
SON	1.3	1.8	7.4	10.3	1.7	1.9	-0.3	-0.4	2.1	2.9	-8.1	-5.7
Annual	1.4	1.9	11.7	16.1	1.7	2.0	13.8	19.0	1.9	2.6	7.0	9.7

The range of change in mean temperature with respect to base year was different for the three GCMs. GFDL-TR predicted delta values ranging from 1.1°C to 1.7°C for 2050, while it varied from 1.5°C to 2.3°C for 2070. Whereas, UKTR suggested mean temperature increase of 1.5°C to 2.1°C in 2050 and 1.2°C to 2.7°C in 2070. According to HadCM2 generated delta values, temperature would increase 1.3°C to 2.9°C in 2050 and 1.7°C to 4.0°C in 2070.

From Table 8.4 it could be seen that different GCMs predict different sets of values for rainfall increase (or decrease). Among the three GCMs, GFDL-TR predicted milder changes while HadCM2 suggested severe changes and the values increased with time.

In case of rainfall, GFDL-TR and UKTR both predicted a decreasing tendency in future during winter season (DJF). But, HadCM2 suggested that there would be higher precipitation (35.6% increase in 2050 and 48.9% increase in 2070) during the winter season (DJF), which will be beneficial for agriculture.

8.9 Simulation Experiments

Simulation Experiments were designed for all the rice cultivars both for *boro* and *T. Aman* seasons. It was also designed for non-rice crops - *aroid* and *tomato*. For each crop the following treatments were designed are given in the Table 8.5.

Table 8.5: Designed treatments for each crop

Crop	Cultivar	Soils	Climate Scenarios	No. of Treatments
Boro	3 (BRRI Dhan47, BRRI Dhan29 and BRRI Dhan45)	1(Bajoa)	Base+(3GCMs x 2 intervals) = 7	21
T. Aman	BRRI 23	2 (Barisal, Barisal and Bajoa)	Base+(3GCMs x 2 intervals) = 7	14
	BRRI Dhan40	2 (Barisal, Barisal and Bajoa)	Base+(3GCMs x 2 intervals) = 7	14
	BRRI Dhan41	2 (Barisal, Barisal and Bajoa)	Base+(3GCMs x 2 intervals) = 7	14
	BRRI Dhan33	2 (Barisal, Barisal and Bajoa)	Base+(3GCMs x 2 intervals) = 7	14
	BRRI Dhan39	2 (Barisal, Barisal and Bajoa)	Base+(3GCMs x 2 intervals) = 7	14
Aroid	1 (*Xanthosoma spp.*)	2 (Barisal, Ishwardi and Daulatpur)	Base+(3GCMs x 2 intervals) = 7	14
Tomato	1 (BARI *Tomato*-3)	1 (Ishwardi) x 3 Irrigation/bed type	Base+(3GCMs x 2 intervals) = 7	7

Calibrations of Models CERES-Rice for different cultivars, CROPGRO for *tomato* and AROID-Taro/Tanier (*aroid*) for *aroid* were done. After calibration of these models, outputs for the above mentioned crops were generated.

Simulation studies conducted on different crops using climatic data on rainfall, maximum and minimum temperature, and solar radiation of Satkhira weather station of Bangladesh Meteorological Department and DSSAT Crop simulation models (CERES Rice, CROPGRO for *tomato* and AROID-Taro/Tanier) for base year and three different GCMs (Geophysical Fluid Dynamics Laboratory Transient; Hadley Centre and United Kingdom Meteorology Office's Unified Model) for the years 2050 and 2070 with 515 and 575 ppmv CO_2 concentrations respectively to assess the impact of change in climatic factors on crops.

8.10 Impact on Crops

Bangladesh is endowed with a climate, which is favorable for the cultivation of a wide range of both tropical and temperate crops. Since rice is the staple food of the Bangladeshis, it is grown all year round and is followed by wheat, potato, sugarcane and many other crops like jute, oilseeds, pulses, etc. Production of these crops are being hampered to some extent because of climatic variability like- un-timely and uneven distribution of rainfall, which causes flooding/water logging and droughts; abrupt rise of temperature especially affect the *rabi* crops which are temperature sensitive – wheat, potato, etc.

It has been reported that CO_2 fertilization effect enhanced under elevated temperatures, at least up to a point. Idso *et al.* (1987) and Kimball et al. (1993) showed that the growth modification factor (or biomass growth modification ratio) due to a 300 m mol/mol enrichment was 0.08 per °C (average daily temperature) across the range of 12°C to 34°C.

A biomass growth modification ratio response to temperature of -0.031 per °C for soybean seed biomass yield and -0.026 per °C for total biomass accumulation was calculated by Allen (1991). He also reported that elevated temperatures tended to shorten the grain-filling period of this crop.

While Baker *et al*. (1989) found that soybean seed yield tended to decrease slightly with temperature over the day/night range of 26/19° to 36/29°. The number of seed per plant increased slightly with increase of both CO_2 and temperature. Mass per seed decreased sharply with increasing temperature. Although CO_2 enrichment resulted in increased seed yield and above-ground biomass, harvest index was decreased with both CO_2 and temperature.

Reilly *et al.* (1996) reported that in Asia including Bangladesh, under different GCM scenarios, and sites; the yields of cereals varied with CO_2 effect. The range of variations for rice, maize, and wheat were -22 to +28, -65 to-10, and -61 to +67; respectively.

Karim *et al*. (1996) conducted a simulation study to assess the vulnerability of food grain production (rice and wheat) in six locations of Bangladesh to potential climate change due to enhanced CO_2 and temperature. Increased levels of CO_2 increased yields of rice in all locations. The maximum yield increase of 44% was noted for a CO_2 level of 660 ppmv. The per cent average increases of HYV Aus, *aman* and *boro* rice at 660 ppmv CO_2 level were 40, 33% and 30%, respectively. The average increase of wheat was 48%. Under elevated CO_2 (330, 580 and 660 ppmv) and temperature (0, 2 and 4 ºC) levels the yield increases at 660 ppmv CO_2+2 ºC and 660 ppmv CO_2+4 ºC treatments were respectively 32% and 20% for rice and 9% and -31% for wheat. The reductions in wheat yield at higher temperatures were quite significant. Even at elevated CO_2 levels, the reduction in yield was remarkable with gradual increase in temperature.

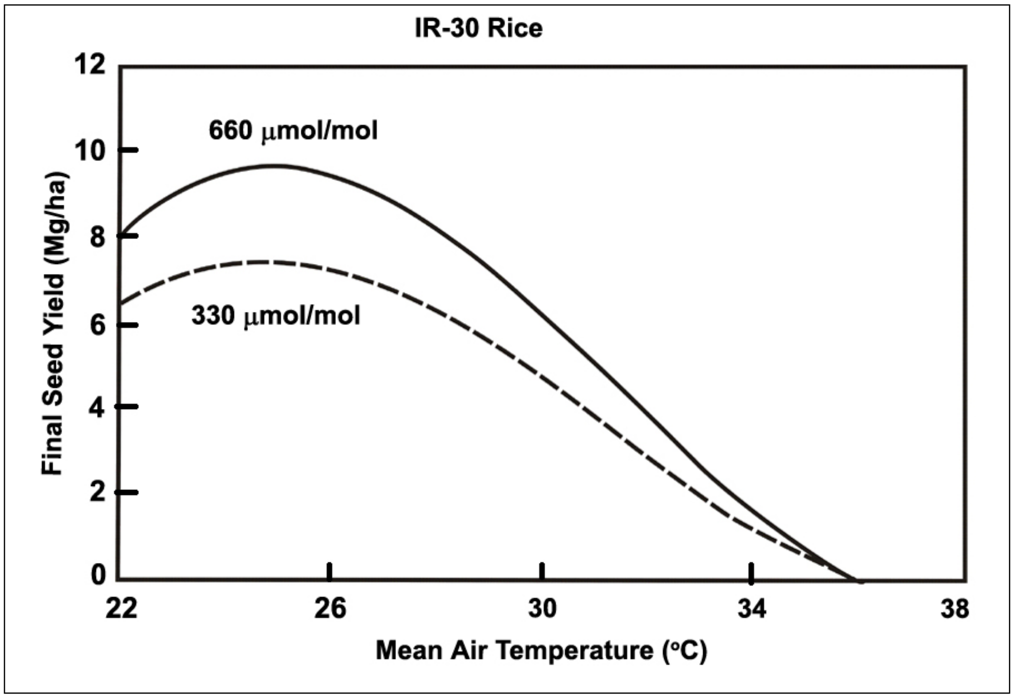


Figure 8.2: Rice seed yield vs. weighted mean day/night air temperature for plants grown to maturity in CO_2 concentrations of 330 and 660 µ mol/mol in five separate experiments. (Adapted from Allen *et al*. 1996)

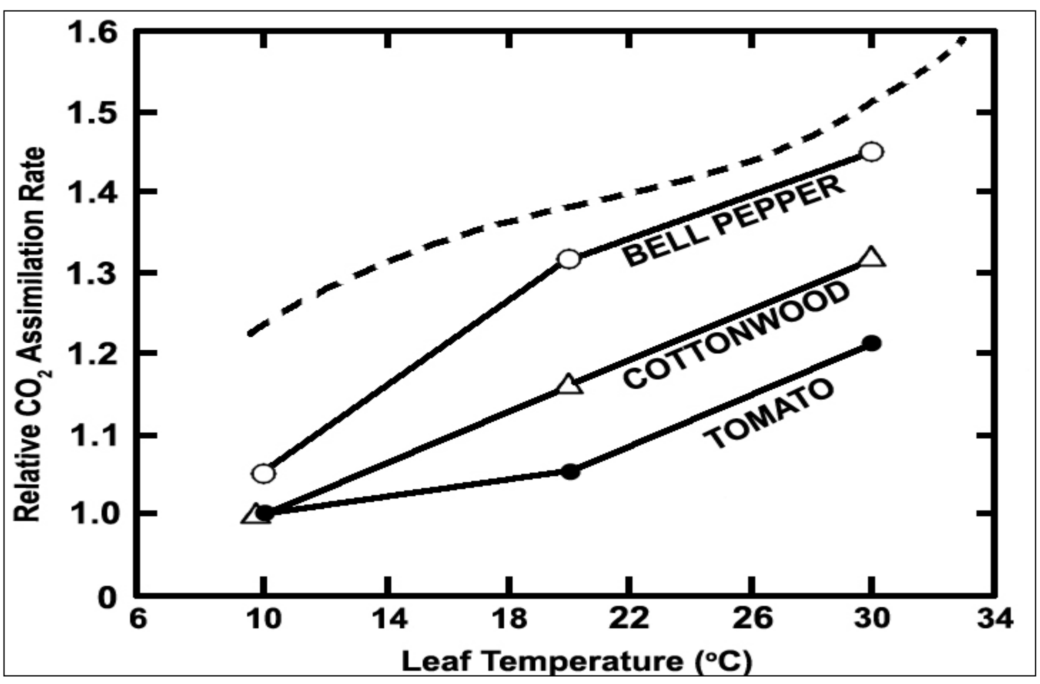


Figure 8.3: Variation of relative CO_2 assimilation rate (net photosynthesis at an intercellular CO_2 concentration of 600 µ mol/mol divided by net photosynthesis at 300 µ mol/mol) with leaf temperature for bell pepper, *tomato* and cottonwood tree. The dotted line is the relationship predicted by the analysis of Long, 1991. (Adapted from Idso, 1990)

Recent simulation studies conducted by Karim *et al.,* (1999) showed that cereal production (rice and wheat) in Bangladesh decreased due to rise in temperature. Wheat was more susceptible than rice. The GFDL General Circulation Model (GCM) predicted about 17 per cent decline in overall rice production and as high as 61 per cent decline in wheat production compared to the baseline situation. GCM CCCM predicted lower values of decline. It was found that 4 °C increase in temperature would have severe impact on food grain production, especially for wheat production. On the other hand, CO_2 fertilization would facilitate the food grain production. A rise in temperature will cause significant decrease in production, some 28 and 68 per cent for rice and wheat respectively. The apparent increase in yield of *boro* (dry-season paddy) and other crops might be constrained by moisture stress. A 60 per cent moisture stress on top of other effects might cause as high as 32 per cent decline in *boro* yield instead of having an overall 20 per cent net increase.

8.11 Results and Discussion

For comparing the impact of climate change, yields of crops under this study were generated for baseline (360 ppmv CO_2, temperature and precipitation of 1990) climate and with no stress condition (no stress means that optimum levels of fertilizer and irrigation). Results in Table 8.6 – 8.10 show that different crop responded differently under different climate change scenarios. In all cases of rice, irrespective of cultivar, soil and GCMs, simulation results showed negative impact. The magnitude of the impact varied with cultivar, soil, and GCMs. In case of *aroid*, yield increases were noted in Barisal Soil Series, while in Ishwardi Soil Series reduction of yields were observed. For *tomato* yield increases were predicted under different GCMs. In most cases for rice both *T. Aman* and *boro*, the effect of elevated CO_2 at 515 and 575 ppmv level scenarios, the negative influence of temperature rise was more prominent but more water was required to meet the evapotranspiration demand.

For simulating the crop yields of all crops under this study soil fertility, pest and diseases were assumed to be non-limiting. Impact of soil salinity was not considered. In the coastal districts salinity is a problem and which is very likely to increase due to higher rate of evaporation and sea level rise. The problem of salinity intrusion would aggravate. In case of rice, depending on the tolerance of different crops and cultivars towards salinity are likely to vary significantly.

8.11.1 T.Aman Rice

Simulation experiments were conducted for five rice cultivars namely, BR23, BRRI Dhan33, BRRI Dhan39, BRRI Dhan40, and BRRI Dhan41 using two soils, Bajoa and Barisal series for transplanted *aman* season. Results of simulation experiments showed that the yields of all rice cultivars varied with soils and also with different climate change scenarios. Highest yield of 5839 kg ha^{-1} was obtained with BRRI Dhan41, followed by BRRI Dhan40 (4251 kg ha^{-1}) and lowest yield of 2836 kg ha^{-1} with BR23 (Figure 8.4). In general yield decrease was relatively small under HADC 50 scenario and large under UKTR 70 scenario (Table 8.6).

GFDL50 and GFDL70 scenarios

With different climate change scenarios it was evident that in case of *T. Aman* rice under GFDL50 and GFDL70 scenarios13% and 21% yield reduction for BR23 rice respectively were noted. For BRRI Dhan33 rice yield reductions of 15% and 21% were predicted under

GFDL50 and GFDL70 scenarios; respectively. Under these scenarios yield varied between 2% to -9%. For BRRI Dhan40 and BRRI Dhan41 5% to 12% yield reductions were noted.

HADC50 and HADC70 scenarios

It was evident from the table that T. Aman rice cultivars under HADC50 and HADC70 scenarios yield reductions were 11% and 23% for BR23 and BRRI Dhan33. For BRRI Dhan39, BRRI Dhan40 and BRRI Dhan41the magnitude of yield reductions were between 4% to 16%.

UKTR50 and UKTR 70 scenarios

For BR23 and BRRI Dhan33 rice cultivars grown during the *T. Aman* season the yield reductions varied between 19% and 33%. Yield reductions were 6% to 20% for BRRI Dhan39, BRRI Dhan40 and BRRI Dhan41 rice cultivars.

Table 8.6:`Percent yield difference and harvest date difference with respect to baseline scenario (1990) for *T. Aman* Rice

Scenarios	Rice Cultivars									
	BR23		BRRI Dhan33		BRRI Dhan39		BRRI Dhan40		BRRI Dhan41	
	Soil Series									
	Bajoa	Barisal	Bajoa	Barisal	Bajoa	Barisal	Bajoa	Barisal	Bajoa	Barisal
Yield difference										
Baseline	-	-	-	-	-	-	-	-	-	-
GFDL 50	-13	-13	-15	-13	-7	2	-6	-5	-7	-10
GFDL 70	-21	-20	-21	-20	-9	-2	-7	-10	-9	-12
HADC 50	-14	-12	-14	-11	-5	6	-4	-5	-9	-11
HADC 70	-23	-21	-22	-21	-13	-8	-12	-12	-14	-16
UKTR 50	-22	-20	-22	-19	-13	-6	-12	-14	-13	-15
UKTR 70	-33	-30	-33	-30	-20	-14	-20	-20	-19	-21
Harvest date difference										
Baseline	30-Oct	30-Oct	6-Oct	6-Oct	5-Nov	5-Nov	21-Nov	20-Nov	21-Nov	20-Nov
GFDL 50	19-Oct	24-Oct	28-Sep	1-Oct	26-Oct	30-Oct	12-Nov	14-Nov	12-Nov	14-Nov
GFDL 70	18-Oct	22-Oct	27-Sep	1-Oct	25-Oct	28-Oct	10-Nov	13-Nov	10-Nov	13-Nov
HADC 50	19-Oct	24-Oct	28-Sep	2-Oct	26-Oct	30-Oct	11-Nov	13-Nov	11-Nov	13-Nov
HADC 70	18-Oct	22-Oct	27-Sep	1-Oct	24-Oct	28-Oct	8-Nov	11-Nov	8-Nov	11-Nov
UKTR 50	19-Oct	23-Oct	27-Sep	1-Oct	25-Oct	29-Oct	11-Nov	14-Nov	11-Nov	14-Nov
UKTR 70	17-Oct	21-Oct	26-Sep	30-Sep	23-Oct	27-Oct	8-Nov	11-Nov	8-Nov	11-Nov

Baseline = (360 ppmv CO_2, temperature and precipitation of 1990); GFDL50 and GFDL70 = Geophysical Fluid Dynamics Laboratory Transient model for year 2050 and 2070 respectively; HadC50 and HadC70 = Hadley Centre model for 2050 and 2057, respectively; and UKTR50 and UKTR70 = UK Meteorology Office/Hadley Centre Transient model for year 2050 and 2070 respectively.

All cultivars of *T. Aman* rice were sown on July 15 and transplanted on August 15 for running the simulations. The length of growing period for the *T. Aman* rice varied with cultivars and also soils. Under different climate change scenarios the growing lengths were shortened by 6 to 13 days (Table8.6).

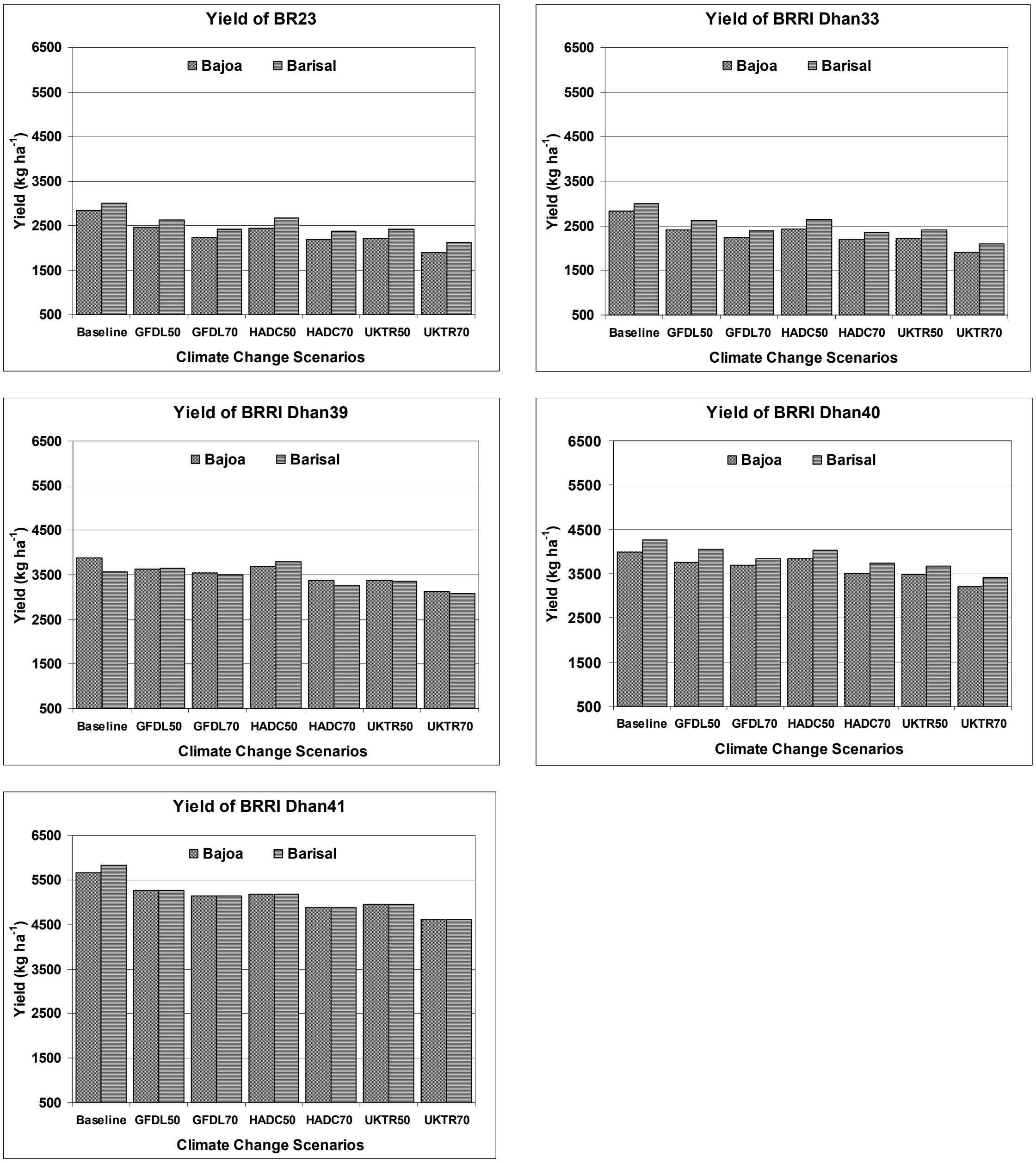


Figure 8.4: Yields of different *T. Aman* rice cultivars under different scenarios

8.11.2 Boro Rice

For *boro* season simulation experiments were conducted for five rice cultivars namely, BRRI Dhan29, BRRI Dhan45, and BRRI Dhan47 using Bajoa series soil. Results of simulation experiments showed that the yields of all rice cultivars responded differently with different climate change scenarios. In general yield decrease was relatively small under GFDL 50 scenario and large under UKTR 50 scenario (Table 8.7 and Figure 8.5).

GFDL50 and GFDL70 scenarios

From the predicted yields of different cultivars of *boro* rice it was evident that in case of GFDL50 and GFDL70 scenarios yield decrease varied between 10% to 14% and 13% to

16% respectively. BRRI Dhan45 and BRRI Dhan47 behaved similar but the latter cultivar yields were higher.

HADC50 and HADC70 scenarios

Under HadC50 and HadC 70 scenarios different cultivars of *boro* rice yield decrease of 14% to15% and 15% to 18% respectively were noted. BRRI Dhan45 and BRRI Dhan47 behaved similar but the latter cultivar yields were higher (Table 8.7).

UKTR50 and UKTR 70 scenarios

Boro rice yield decrease of 14% to 22% and 16% to 19% respectively were noted under UKTR50 and UKTR 70 scenarios for different cultivars. BRRI Dhan45 and BRRI Dhan47 behaved similar but the latter cultivar yields were higher (Table 8.7).

Table 8.7: Per cent yield difference and harvest date difference with respect to baseline scenario (1990) for *boro* Rice

Scenarios	Rice Cultivars		
	BRRI Dhan47	BRRI Dhan29	BRRI Dhan45
Yield difference (Change, %)			
Baseline	-	-	-
GFDL50	-10	-14	-10
GFDL70	-16	-13	-16
HADC50	-15	-14	-15
HADC70	-18	-15	-18
UKTR50	-22	-14	-22
UKTR70	-19	-16	-19
Harvest date difference			
Baseline	7-May	5-May	2-May
GFDL 50	16-Apr	20-Apr	9-Apr
GFDL 70	8-Apr	8-Apr	3-Apr
HADC 50	11-Apr	14-Apr	6-Apr
HADC 70	7-Apr	6-Apr	2-Apr
UKTR 50	11-Apr	10-Apr	6-Apr

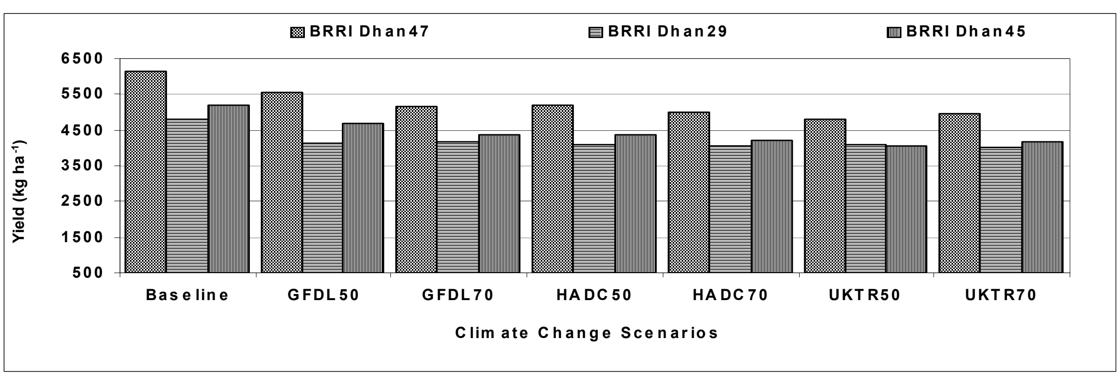


Figure 8.5: Yields of different *boro* rice cultivars under different scenarios

All cultivars of *boro* rice were sown on 02nd November and transplanted on 15th December for running the simulations. The length of growing period for the *boro* rice varied with cultivars. Under different climate change scenarios the growing lengths were shortened by 15 to 30 days (Table 8.7).

8.11.3 Aroid

Aroid was planted on 14th April 2006 and harvested on 2nd December 2006 (260 days). Under different scenarios physiological maturity date was 12 to 18 days earlier.

Simulation runs were made for *aroid* at two locations with Barisal and Ishwardi series soils. Results showed that irrespective of GCMs and interval *aroid* yields increased from 2 to 9% in case of Barisal series soil. Lower yields were recorded for Ishwardi soil series and also yield reduction of 4% to 13%.

In this region *tomato* could be the favored crops as these has the potential for producing more under most of the scenarios considered in this study. Therefore, in the event of climate change the cropping pattern of the region may change considerably.

It was noticed that in most cases due to temperature rise the evapotranspiration demand of all the crops under study have increased substantially and the crop growing lengths have shortened by 2 to 14 days in general.

Table 8.8: Per cent Yield difference and Harvest date with respect to baseline scenario (1990) for *Tomato*

Climate Change Scenarios	Yield (kg/ha)	Change (%)	Harvest Date
Base	14084	-	02-Apr
GFDL 50	17387	23	23-Mar
GFDL 70	18047	28	20-Mar
HadC 50	17427	24	20-Mar
HadC 70	17741	26	16-Mar
UKTR 50	17216	22	21-Mar
UKTR 70	17608	25	16-Mar

8.11.4 Tomato

In case of *tomato* all the scenarios predicted 22% to 28% yield increase. Since *tomato* is grown during the *rabi* season (winter) and the predicted temperature increase by all three GCMs would be in the tune of 1.5^0 to 2.6^0 (during winter); this would still be within the threshold level. Therefore, CO_2 fertilization effect will be more prominent in this case. Planting date for *tomato* was 14 November and harvest date was 02 April. The life cycle of *tomato* was shortened by 10 to 16 days but the yields were higher than the baseline. Similar results were reported by Allen *et al*. 1996.

In this region *tomato* could be the favored crops as these has the potential for producing more under most of the scenarios considered in this study. Therefore, in the event of climate change the cropping pattern of the region may change considerably.

8.12 Adaptation

Climate change would make agriculture the most vulnerable sector. Depending on the local agro-climatic environment as well as the magnitude of the changes easing strategies has to be developed. With the available technologies it would be possible to increase food production substantially, which would depend on the dissemination of these technologies to the end-users and also on the availability and affordability of extra input required for this purpose. However, under changed scenarios, new technologies need to be developed to combat climate change and sea level rise coupled with the great pressure of population increase.

The magnitude of climate change impact on different resources would vary. Simulation studies have shown that the impacts could result in significant reductions in rice yields, in most cases, and thereby production. It is obvious that effect of the changes would vary because of the differences in the variety and local differences in growing seasons, crop management etc. On top of these, soil salinity regime in the coastal zone is very likely to increase with climate change which will have extra bearing on agriculture. Scarcity of irrigation water would be a problem especially during the winter months which will again have negative implication of the yield of *boro* rice.

Most of these crop model simulations studies have considered only a few components of the production system/ecosystem. When other environmental aspects like; floods, droughts, and cyclones, salinity and social parameters such as settlement, urban migration, etc. are superimposed, the sector becomes more vulnerable. On top of this, due to climate change it is likely that the incidences of pests and diseases would increase, which might further aggravate the situation.

Climate change may increase input use like fertilizers and irrigation. As a consequence of climate change the trend shows that drier regions would be drier in the winter season. Therefore, possibility of growing rain fed crops would diminish. To tackle the water scarcity problem, effort should be made to develop crop cultivars with high water use efficiency. Rice being a C3 crop transpires about 500 molecules of water to fixing a molecule of CO_2 during photosynthesis. Changing the food habit would be another option, reducing the dependency on rice, and switching to maize, which is a C4 crop with a transpiration ratio of about 250.

As the incidences of floods and droughts are likely to increase in frequency, effort should be made to develop crop cultivars tolerant to these hazards. On the other hand, agronomic manipulations such as shifting the planting dates, using short duration crop cultivars could be other options.

During the dry months of March and April, salinity problems, resulting from seawater intrusion, are more acute and lands are commonly left fallow as crop production is restricted by the presence of salts. Cash crops such as *tomato*, *aroid*, and chili can be grown with proper management of soil and water. Use of raised beds and irrigated through drip irrigation systems permit proper leaching of salts from the root zone. This system of crop cultivation produces high economic benefit compared to traditional methods.

9. Conclusions and Recommendations

The results of the experimental and farmer's fields will be disseminated to the farmers of the targeted areas. Necessary inputs and technology will be provided to the farmers with a purpose to start farming practices in their respective fields with the recommended variety and technology. Based on the above findings and the farmer's participatory project activities the following conclusions and recommendations may be made:

9.1 Conclusions

9.1.1 Rice Crops

- Introduction of high yielding salt tolerant variety BRRI dhan47 could produce sustainable grain yield in the coastal regions
- *T. Aman* season is a safe rice-growing season in the coastal area. There was no salinity impact on rice production due to high rainfall that occurred during this season. But in the later part, when the rainfall ceased, it was assumed that the soil salinity might increase and go beyond the safe limit of rice crop (4 dS/m). So, salt tolerant *T. Aman* varieties like BR23, BRRI dhan40 and BRRI dhan41 may be the solution to overcome the salinity impact at later stage of crop growth.
- The existing cropping pattern is *Fallow-T.Aman* (Local)-*Fallow* and *Fallow-T.Aman* (Local)-*Boro (*HYV*)*. These patterns may be changed like *Okra (Dharosh)-T. Aman – Boro* (HYV) or *Okra (Dharosh)-T.Aman-Tomato*.

9.1.2 Non-Rice Crops

- *Tomato*, o*kra* and *aroids* could be grown successfully under improved management practices with raised bed and mulch in the medium saline soils of Satkhira.

9.1.3 Crop Simulation Experiments

- Results of simulation experiments carried out for *T.Aman* season crops showed that the yields of all rice cultivars in *T.Aman* season varied with soils and also with different climate change scenarios. Highest yield of 5839 kg ha^{-1} was obtained with BRRRIdhan41, followed by BRRIdhan40 (4251 kg ha^{-1}) and lowest yield of 2836 kg ha^{-1} with BR23. In general yield decrease was relatively small under HADC 50 scenario and large under UKTR 70 scenario.
- Results of simulation experiments carried out for *T.Aman* season crops showed that the yields of all rice cultivars in *boro* season responded differently with different climate change scenarios. In general yield decrease was relatively small under GFDL 50 scenario and large under UKTR 50 scenario. Under HadC50 and HadC70 scenarios different cultivars of *boro* rice yield decrease of 14 to15% and 15 to 18% respectively were noted. BRRI Dhan45 and BRRI Dhan47 behaved similar but the latter cultivar yields were higher.
- Simulation runs were made for *aroid* at two locations with Barisal and Ishwardi series soils. Results showed that irrespective of GCMs and interval *aroid* yields increased from 2 to 9% in case of Barisal series soil. Lower yields were recorded for Ishwardi soil series and also yield reduction of 4 to 13%.

- In case of *tomato* all the scenarios predicted 22% to 28% yields increase. In this region *tomato* could be the favored crops as these have the potential for producing more under most of the scenarios considered in this study. Therefore, in the event of climate change the cropping pattern of the region may change considerably.

9.2 Recommendations

- It is difficult to confirm a crop as adaptive under climate change situations using only one season crop related data. At least three years of experimentation is required to conclude if a crop is adaptive under climate change situations in the coastal regions. The finding for rice crops cultivated in *boro* season and *T.Aman* season need to be confirmed by more trails.
- The results found from *rabi* season experiments (*tomato, okra* and *aroids*) are preliminary findings. The findings for *rabi* crops need to be confirmed by more trails.
- The findings should be disseminated to the farmers of the whole coastal areas. Necessary inputs and technology should be provided to the farmers with a purpose to start farming practices in their respective fields with the recommended variety and technology. The finding should be expanded throughout the salt affected coastal zone of Bangladesh.

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Appendix A: List of farmers selected for field experiments

Table A1: List of farmers selected for field experiments of *boro* season rice crops in the observational plots at different salinity gradients

Sl.	Farmer's name	Village	P. Office	Upazila	Variety
Low salinity zone					
1	Bashudeb Ghosh	Uzaimari	Mathoreshpur	Kaliganj	Kajallata
2	Gopal Chandra Ghosh	Probajpur	Mathoreshpur	Kaliganj	Chaina (Shaitta)
3	Roghunath Ghosh	Dia	Mathoreshpur	Kaliganj	BRRI dhan28
Medium salinity zone					
4	Md. Abdur Rahman	Sekandar Nagar	Mathoreshpur	Kaliganj	Hybrid (Hira)
5	Md. Abdur Rahman	Sekandar Nagar	Mathoreshpur	Kaliganj	Kajallata
6	Lakhi Rishi	Duliapur	Mathoreshpur	Kaliganj	BRRI dhan28
High salinity zone					
7	Md. Ismail Hossain*	Rughurampur	Dhalbaria	Kaliganj	Chaina(Shaitta)
8	Sree Joydeb	Rughunathpur	Dhalbaria	Kaliganj	IET
9	Proyloy Kumar Sardar	Rughunathpur	Dhalbaria	Kaliganj	BRRI dhan28

** Experimental plot was set in the land of this farmer*

Table A2: List of farmers selected for field experiments of T.Aman season rice crops in the observational plots at different salinity gradients

Sl.	Farmer's name	Village	P. Office	Upazila
1	Md. Anser Ali	Sekandar Nagar	Mathoreshpur	Kaliganj
2	Sree Dhanonjoy	Dhan Khali	Munshiganj	Shymnagar
3	Roghunath Ghosh	Dhaibari	Ratanpur	Kaliganj

Table A3: List of farmers selected for field experiments of *okra* crops at different salinity gradients

Sl.	Name	Village	Plot Size (m)	No. Plot	Plantation Data	Harvesting
1	Abul kasem sardar	Bolarati	4x2	9	10 mar 2007	June
2	Azizul Haque Sardar	Bolarati	4x2	9	10 mar 2007	June
3	Chandi Sarkar	Daulatpur	4x2	9	10 mar 2007	June
4	Sudhangshu Sarkar	Bakal	2x2	9	10 mar 2007	June

Table A4: List of farmers selected for field experiments of *Aroids* at different salinity gradients

Sl.	Name	Village	Thana	Plot Size (m)	No. Plot	Plantation Data
1	Abul Kasem	Bolarati	Satkhira Sadar	4 X 2	9	28 April 2007
2	Kabir Hossain	Kulia	Debhata	4 X 2	9	28 April 2007
3	Prasad Sarker	Bakal	Satkhira Sadar	2 X 2	9	29 April 2007

Appendix B: Soil data used for simulation runs

```
BASR750001  SRDI        SIC      67 Barisal
@SITE        COUNTRY          LAT     LONG SCS FAMILY
 Batiaghata  Bangladesh     22.480  89.750 Typic Endoaquepts
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
     Y  0.17   6.0  0.05  61.0  1.00  1.00 IB001 IB001 IB001
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC  SADC
     5   Ap1 0.273 0.435 0.453 1.000  0.09  1.42  1.74  47.5  51.4   1.1 0.170   7.4   -99  28.7   -99
     7   Ap2 0.270 0.434 0.454 1.000  0.09  1.42  1.65  47.0  52.2   0.8 0.150   7.4   -99  26.3   -99
    12   B21 0.281 0.423 0.436 1.000  0.09  1.42  1.59  48.4  51.1   0.5 0.150   5.4   -99  28.5   -99
    21   B22 0.331 0.437 0.476 1.000  0.06  1.39  2.53  57.2  39.9   2.9 0.230   4.6   -99  31.5   -99
    30    C1 0.261 0.427 0.434 0.600  0.09  1.42   -99  45.6  53.6   0.8   -99   4.2   -99   -99   -99
    37    C2 0.238 0.404 0.427 0.512  0.09  1.42   -99  42.8  54.8   2.4   -99   4.4   -99   -99   -99
    51  HA1b 0.186 0.366 0.423 0.415  0.15  1.46   -99  33.7  66.2   0.1   -99   4.0   -99   -99   -99
    67  HIC3 0.240 0.406 0.429 0.307  0.09  1.42   -99  42.9  55.0   2.1   -99   -99   -99   -99   -99
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*BASR750002  SOILRESOURC    C    122 Dautalpur, Clay
@SITE        COUNTRY          LAT     LONG SCS FAMILY
 Satkhira    Bangladesh       -99    -99  Typic Humaquepts
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
    BN  0.13   6.0  0.05  61.0  1.00  1.00 IB001 IB001 IB001
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC  SADC
    15   -99 0.387 0.427 0.451 1.000  0.06  1.38  2.19  64.6  35.0   0.4 0.210   5.3   -99  38.9   -99
    30   -99 0.359 0.474 0.484 0.638  0.06  1.32  6.67  76.6  21.1   2.0 0.560   7.2   -99  40.2   -99
    46   -99 0.340 0.441 0.491 0.468  0.09  1.41  0.42  57.2  42.6   0.2 0.060   7.2   -99  36.2   -99
    76   -99 0.400 0.437 0.556 0.295  0.06  1.37   -99  66.4  31.2   2.4   -99   7.5   -99   -99   -99
    91   -99 0.228 0.400 0.445 0.188  0.09  1.40   -99  40.4  54.9   4.7   -99   7.6   -99   -99   -99
   122   -99 0.127 0.296 0.418 0.119  0.68  1.38   -99  24.4  67.9   7.7   -99   8.0   -99   -99   -99
```

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*BASR750003  SOILRESOURC SIC     142 Bajoa, Clay Loam
@SITE        COUNTRY          LAT     LONG SCS FAMILY
 Satkhira    Bangladesh       -99    -99  Typic/Aeric Haplaquept
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
     G  0.13   6.0  0.05  61.0  1.00  1.00 IB001 IB001 IB001
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC  SADC
    10   -99 0.229 0.400 0.429 1.000  0.09  1.44  1.99  40.6  59.0   0.4 0.190   6.8   -99  28.5   -99
    20   -99 0.218 0.393 0.427 1.000  0.15  1.45  1.18  38.9  61.0   0.1 0.140   7.1   -99   -99   -99
    36   -99 0.177 0.355 0.423 0.571  0.15  1.45  0.75  32.5  66.5   1.0 0.100   7.4   -99  22.5   -99
    64   -99 0.261 0.429 0.434 0.368  0.09  1.43  0.59  45.4  54.5   0.1 0.090   7.2   -99  30.1   -99
    81   -99 0.223 0.394 0.427 0.235  0.09  1.43   -99  40.2  58.2   1.6   -99   7.4   -99   -99   -99
   107   -99 0.205 0.357 0.419 0.153  0.09  1.35   -99  40.1  50.4   9.5   -99   7.0   -99   -99   -99
   142   -99 0.397 0.533 0.551 0.083  0.06  1.37   -99  66.8  32.0   1.2   -99   7.0   -99   -99   -99

*BASR750004  SOILRESOURC SIC     114 Ishwardi, Silty Clay
@SITE        COUNTRY          LAT     LONG SCS FAMILY
 Tajulpur    Bangladesh       -99    -99  Aquic
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
     G  0.13   6.0  0.25  61.0  1.00  1.00 IB001 IB001 IB001
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC  SADC
    15   -99 0.348 0.541 0.585 1.000  0.09  1.25  1.78  55.4  43.6   1.0 0.170   5.9   -99  29.1   -99
    30   -99 0.285 0.442 0.452 0.638  0.09  1.37  0.62  50.0  47.4   2.6 0.090   7.7   -99  27.0   -99
    53   -99 0.274 0.431 0.439 0.436  0.09  1.42  0.33  48.6  49.8   1.6 0.060   7.7   -99  26.9   -99
    89   -99 0.320 0.434 0.469 0.242  0.06  1.41  0.25  58.8  39.2   2.0   -99   7.9   -99   -99   -99
   114   -99 0.243 0.414 0.419 0.131  0.09  1.47  0.10  43.1  56.2   0.7   -99   8.0   -99   -99   -99
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