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A study on the possible impacts of climate change on food security in the central coastal area of Bangladesh

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A Study on the Possible Impacts of Climate Change on Food Security in the Central Coastal Area of Bangladesh

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By

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CANDIDATE'S DECLARATION

I, hereby, certify that the work presented in this entitled ***"A Study on the Possible Impacts of Climate Change on Food Security in the Central Coastal Area of Bangladesh"*** for the award of the degree of Masters' of Environmental Science (Research), is an authentic record of my work carried out during the period March 2009 to February2013 under the supervision of Professor John Morrison, School of Earth and Environmental Sciences, University of Wollongong, Australia.

The material presented in this thesis has not been submitted by me for any other award or degree.

By
Zubyda Siddika

Candidate Signature

Date: 25th of March,2013

ABSTRACT

Global and local climate changes can affect crop yields in the future. Recent increase of weather related stresses and damages are resulting from an increase in the frequency of climate hazards. However, agriculture in both developing and developed countries depends highly on climate factors (temperature, solar radiation and precipitation) that act as a main driver of rice production. Nevertheless, the relationship of climate variability and rice production could vary in different regions across the world. Bangladesh is perhaps one of the most climatic vulnerable countries because of geographical location and large Gnga-Meghna-Brahmuptra river systems. The costal belt of Bangladesh covers 30% of the total agricultural land in Bangladesh, and plays an important role in the country's GDP. The close dynamic relationship between climate variability and rice yield could be useful to identify yield losses or gains at different spatial scales. This relationship can have differences in their patterns as well as in magnitude at different spatial and temporal scales. This study consisted of a review of climate change issues for Bangladesh, an analysis of crop yield variations over the years 1990-2008 and some preliminary modeling of rice yields with changing climate parameters. Generally, three seasonal rice crops(Aman, Aus and Boro) have been cultivated in the study area. Based on correlation analysis, for the country's central coastal belt, no or negative relationships have been indentified between climate parameters and yield. Although there are significant uncertainties in the predicted climate parameters, DSSAT 4.5 crop simulation model is an effective tool to show the potential impacts of predicted climate change on yields. For deriving DSSAT4.5 simulation model, climate parameters and management inputs is important to predict yield under the basis of planting period investigation. Model results indicate that as climate parameters like temperature increase, farmers could get lower yields in their cropping systems. Lower yields were estimated for the heavy rainfall period when plants could be washed away plant after planting. A 2˚C rise in minimum temperature will lead to a lowering of yields of around 800 to 1000 Kg/hectare in every seasonal rice crops in the study area. As a result, changing climate parameters in the central coastal belt area of Bangladesh could lead to lower yields in every rice season. Any lowering of yields due to climate change is important for the densely populated coastal belt area in Bangladesh as this could result in food insecurity for the region.

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Acronyms

APEIS	Asia Pacific Environment Innovation Strategy
BARRI	Bangladesh Agriculture and Rice Research Institute
BARC	Bangladesh Agriculture Research Council
BBS	Bangladesh Bureau of Statistics
BCAS	Bangladesh Centre for Advance Studies
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
BRAC	Bangladesh Rural Agriculture Council
BRDB	Bangladesh Rice Development Board
BRRI	Bangladesh Rice Research Institute
CEGIS	Centre For Environmental Geophysical Information Services
CSIRO	Commonwealth Scientific and Industrial Organization
DAE	Department of Agricultural Extension
DOE	Department of Environment
ECHAM4	A Mane-Planck Institute for Meteorology Model
EPIC	Eastern Pacific Investigation of Climate
FAO	Food and Agriculture Organization
FGD	Focus Group Discussion
GB	Government of Bangladesh
GCMs	General Climate Models
GISS	Goddard Institute for Space Studies
GFDL	Geophysical Fluid Dynamics Laboratory
GDP	Growth Domestic Product
GMT	Global Mean Temperature
GMTA	Global Mean Temperature Anomaly

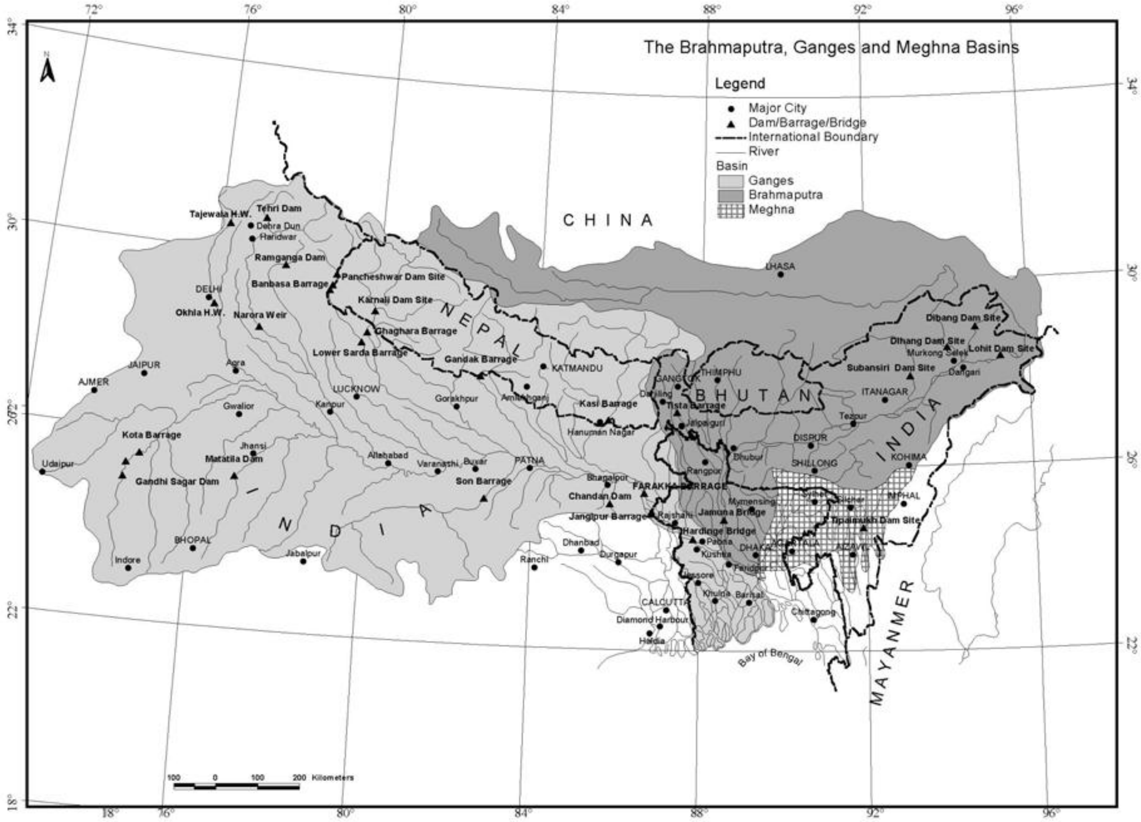
HadRM2	Hadley Centre Coupled Model
HH	House Hold
HYV	High Yielding Variety
IPCC	International Panel on Climate Change
IDE	Integrated Development Institute
MAGICC	Model for the Assessment of Greenhouse –Gas Induced Climate Change
MoEF	Ministry Of Environment and Forest
NGO	Non Government Organization
OECD	Organization For Economic Cooperation And Development
ORCHID	Opportunities and Risk of Climate Change and Disaster
PRDI	Participatory Research and Development Initiatives
RFSC	Reference Framework for European Cities
SCENGEN	A Regional Climate Scenario Generation
SLR	Sea Level Rise
SRES	Special Emissions Scenario
SRDI	Soil Resources Development Institute
SST	Sea Surface Temperature
UKMO-HadcM2	A Hadley for Climate Prediction and Research Model
UNFCCC	United Nations Framework Convention on Climate Change

Chapter 1: Introduction

1.1: Introduction

Bangladesh is perhaps the most vulnerable country in South Asia because of its climate and geographical location. The country is dominated by large Ganga-Meghna_ Brahmuputra(GBM) river system as well as tide and wave dominated coastal impacts from the Bay of Bengal surface (Woodroofe, 2005, p220). As a result, the country is influenced by the above mentioned three rivers, which are all part of the Himalaya's drainage system (Sing.*et.al.*, 2005). On the other hand, with a complex network of 230 rivers, including 57 cross boundary rivers, about 92.5% of the 175 million hectares (hac) of combined basin area of the GBM Rivers (Fig-1) is beyond the boundary of Bangladesh.

Figure -1: Map showing the GBM catchment with Bangladesh at the lowest point



Source: Dewan *et.al.*, 2003, pp54

Therefore, Bangladesh acts as a drainage outlet for cross-border runoff. On an average, annually floods engulf roughly 20.5% of the area of the country, or about 3.03 million ha (Mirza, 2003). In extreme cases, floods may inundate about 70% of Bangladesh, as occurred during the floods of 1988 and 1998 (Ahmed and Mirza, 2000).

In comparison to the whole country, the coastal area is different from the rest of the country for its unique geo-physical characteristics. The characteristics involve coastal plain islands, tidal flats, estuaries, heretic and offshore waters that extend to the edge of wide (about 20/km) continental shelf. A vast river network, a dynamic estuarine system and a drainage basin intersect the coastal zone. As a result, the coastal area is water logged. However, frequent natural disasters are currently a common factor in coastal area.

Several studies (Shamsuddhoha and Chowdhury ,2007; Sing 2002; Karim,2005) discussed the severity of natural disasters due to climate change in the coastal area of Bangladesh (Table-1). Therefore, natural disasters events related to changing climate parameters are a major concern for Bangladesh. However, the coastal belt has good agricultural land and 30 % of the country's GDP depends on the coastal belt's agricultural production.

Table 1: Severity of major natural disasters events in coastal area of Bangladesh

Types of Disaster	Area affected	Impact
Flood	Floodplains of the Brahmaputra-Jamuna, the Ganges-Padma and the Meghna river system	Loss of agricultural production, disruption of communication and livelihood system, injury, damage and destruction of immobile infrastructure, disruption to essential services, national economic loss , evacuation, and loss of human lives and biodiversity, displacement and suffering of human population and biodiversity.

Cyclone and Storm Surge	Coastal areas and offshore islands	Loss of agricultural production, disruption of communication and livelihood system, damage and destruction of immobile infrastructure, injury, national economic loss, loss of biodiversity and human lives, need for evacuation and temporary shelter.
Tornado	Scattered areas of the country	Loss of human life and biodiversity, injury , damage and destruction of property, damage of cash crops, disruption in lifestyle, damage of essential services services , national economic loss and loss of livelihood
Drought	Almost all areas, especially the Northwest region of the country	Loss of agricultural produce, stress on national economy and disruption of properties
Flash Flood	Hoar Basins of the North-east region and South-eastern hilly areas	Damage of standing crops, disruption in life style, evacuation and destruction of properties
Hail Storm and Lighting	Any part of the country	Damage and destruction of Property, damage and destruction of subsistence and cash crop and loss of livelihood
Erosion	Banks of the Brahmuputra-Jamuna, the Ganges-Padma and the river systems	Loss of land, displacement of human population and livestock, disruption of production, evacuation and loss of property
Landslide	Chittagong and Chittagong Hill Tracts	Loss of land, displacement of human population and livestock, evacuation, damage of property and loss of life
Earthquake	Northern and central parts of the country	Damage and destruction of property, loss of life and change in geomorphology

Source: Bangladesh State of Environment, 2001, p93

Since 1980, climate change has affected crop production in Bangladesh. This has been studied by the government and non-government organizations. Available IPCC, OECD, DFID, ADB, DOE findings show the evidence of potential global warming effects on Bangladesh as well as tropical and subtropical Asian regions. The IPCC 4th assessment report said that "Some extreme weather events have changed in frequency or intensity over the last 50 years (IPCC, 2007, p30)", Werle.*et.al.*,(2000) shows the rate (30%) of high frequency of natural disaster in past two decades under IPCC moderate climate change scenarios. In addition, Bangladesh's economy also depends on agriculture, industry and services (Table-2) and there is a need to consider the agriculture sector from climate change perspective as that could assist in reducing the future risk of food insecurity.

Table 2: Salient features of occupational categories in Bangladesh

Country	Occupation	GDP (At constant Producer Price)
Bangladesh	Agriculture:48.1%	Agriculture:21.1%
	Non-industry:51.9%	Industry: 78.90%

Source: CCC, 2009, p1

This research focuses on the impacts of climate variability on rice production in coastal areas of Bangladesh. Variability of climate change is measured in terms of temperature changes that can cause sea level rise, plus rainfall changes. Altered weather patterns can increase crop vulnerability due to the lack of soil nutrition. Shift of climate in different regions of the world may have different and even contradictory effects. However, considering potential impacts of climate change on food production not only varies with the mean values of expected climate parameters but also on the probability, frequency and severity of possible extreme events (Lglesias .*et.al.*, 2001, p 90-91). For example, sea level rises have major impact on salinity

because of unplanned irrigation during the dry season. IPCC(2007) has identified cyclones, river flooding, erosion, tidal surges and increased salinity in the Bangladesh coastal area and also change is still unpredictable in terms of effects on the severity and frequency of natural disasters (Asrong and Donelly, 2008, p2; Karim and Mimura, 2008). Finally, impacts of climate variability and change can be linked to the various elements of people's livelihood options like food production (Badjeck *.et.al.*, 2010, p377).

1.2. Background to the study

The coastal areas of Bangladesh contain more than 30% of country's cultivable land. Tidal and estuarine floodplains cover 98% of this 30% of total area of the coastal belt (Haque, 2006). The average crop yields are very low now in these coastal belt regions resulting from salinity problems, land erosion, flooding, low soil fertility and drought in the dry season. Delta regions are predicted to get low yields of Aman, Boro and transplanted Aman rice (Ali and Wakatsuki, 2002, p4). Therefore, agriculture production in low-lying delta regions is getting worse relative to national cropping intensity. For example, coastal belt cropping intensity range varies from 62 to 114% in comparison with the national cropping intensity [1] is 179% (Razzaque and Rafiquzzaman, 2007, p65). Thus, there is increasing evidence that crop yields are declining, as the frequency of disasters is increasing and sea level rise is causing floods as well as salinity intrusion. Therefore, delineation of climate parameters is important to identify yield vulnerability in coastal belt area of Bangladesh.

Ahmed and Alam (1998) estimate the temperature will annually increase at the rate of 0.05˚C to 0.03˚C. In addition, their estimate was that the mean temperature would be rise by 1.3˚C by the year 2030 and by 2.6˚C by the year 2075. Winter temperature will increase 1.3˚C; summer temperature will increase 0.7˚C by 2030. In addition, winter temperature will increase by 2.1˚C and summer temperature will increase 1.7˚C by 2075. GCM models were extensively used for assessing climate risk in Bangladesh in the early 1990s'. The BUP-CEARS-CRU (1994) used

[1] Cropping Intensity: The number of years of cropping multiplied by 100, and divided by the number of years of the rotation. It is expressed as "R", e.g. 3 years crop, 7 years fallow =10 years rotation. Thus, R= (3X100)/10=30

GCM modeling and found that the temperature would rise by 0.5˚C to 0.2˚C relative to 1991 by the year 2030. Using four GCMs' (CSIR09, CCC, GFDLH, and UKMOH), ADB (1994) reported that; "the temperature would rise by 0.3˚C for 2010 with a corresponding rise of 1.5˚C for 2070". Agarwala (2003) used 17 GCM models which best stimulate current climate change prediction for Bangladesh referring to the study of Karim and Mimura (2008, p493). Based on the results of the National Adaptation Program of Action (NAPA) recommended 1.0, 1.4 and 2.4˚C temperature rise by the years 2030, 2050 and 2100, respectively (MoEF, 2005).

The Meteorological Research Council of South Asia declared that Bengal based sea level would rise by 4, 6 and 7.8 mm/year over the next 22 years (SMRC, 2003). The Bangladesh country study (Agarwala *.et.al.*,2003) put the range at sea level rise is about 30 – 100 cm by 2010, while IPCC projected 26-59cm global SLR under scenario A1F1 (Meehl *.et.al.*,2007). In an earlier study, the potential SLR in Bangladesh was predicted as 30 -150 cm by 2050 (DOE, 1993). Based on IPCC reports and available SLR studies, the NAPA for Bangladesh recommended SLRs of 14, 32 and 88 cm for the years 2030, 2050 and 2100, respectively (MoEF, 2005) be used for planning.

Another important issue in coastal areas of Bangladesh is salinity intrusion. The salinity impact is increasing because of sea level rise and storm surge. Due to high salinity levels, it is difficult to cultivate any HYV (High Yielding Variety) Aman and Aus rice. Most of the coastal areas are located in medium highlands, where flooding depth range from 0.3 to 0.9 meter. Soil type of these areas is suitable for two crops per year. Thus, substantial land is tidally affected with saline water. In addition, these saline soils are infertile having very low organic matter (low nitrogen, phosphorus and micronutrients).

Food production is always vulnerable to extreme weather conditions. Despite the technological advancement (crop varieties and irrigation systems), weather and climate are still key factors in agriculture productivity. For example, rice production may fall by 10% and wheat by 30% by

2050 from climate change effects (IPCC, 2007). Furthermore, the CERES rice model predicted that Boro crop yields would be reduced by over 20% and 50 % for the years 2050 and 2070. CERES model also suggested that climate change may reduce crop production through the negative impacts on plants during transplanting period (Basak *.et.al.,* 2009, p1). Although the increase of CO^2 concentration in the air and soil can increase food production for a certain time, exceeding 35˚C temperature by 2070 will cause negative effects on rice production. In addition, the excessive rainfall changes due to increase of temperature and this will lead to a reduction in crop production (Basak *.et.al.,*2009, p2). CERES modeling suggests that planting period could have negative impacts due to the variation of the seasonal rainfall pattern. In addition, CERES model suggests that modeling tools like DSSAT system could be a useful method to assess the impact of future climate change on rice production. However, Haque (2006) study showed the variability of rainfall pattern and uncertainty of flooding damages the Aus and Aman crops. In He also suggest that heavy rainfall caused delay of Aman transplanting and flash flooding that washed away the standing crops (Haque, 2006, p1363). On the other hand, the GCM climate model's result is used by FAO for the prediction of future climate change standard scenarios (FAO-UNDP, 1998). Ahmed and Alam (1998) used the same results and these standard results were widely accepted in national climate change assessments in Bangladesh (CCC, 2009, p5). Therefore, according to Ahmed and Alam’s (1998) report, temperature would rise by 1.3˚C to 2.6˚C for the two projection years of 2030 and 2075; this is used as a national standard for Bangladesh (CCC, 2009).

1.2.1 Bangladesh coast: The worst victim to natural disaster

According to IPCC (2007), global average temperature has increased 0.6˚C to 2˚C over the twentieth century while Ali & Wakatsuki (2002) show the negative impacts of temperature rise on Boro rice production in 12 regions of Bangladesh including the coastal area (Table-3).

Table 3: Land use changes in Bangladesh (in 1000 ha) from 1967 to 1997.

Land use types	1967-1968	1996-1997	changes	%change
Net cropped area (hac)	8806	7855	-951	-10.8
Area (hac)	12729	13801	+1072	+8.42
Total cropped area (hac)	2526	3919	+1393	+55.1
Not available for cultivation (hac)	2243	2157	-86	_3.82
Cropping intensity	145	176	+31	+21.4

Sources: Computed from BBS data cited in Ali and Wakatsuki, 2002, p1184

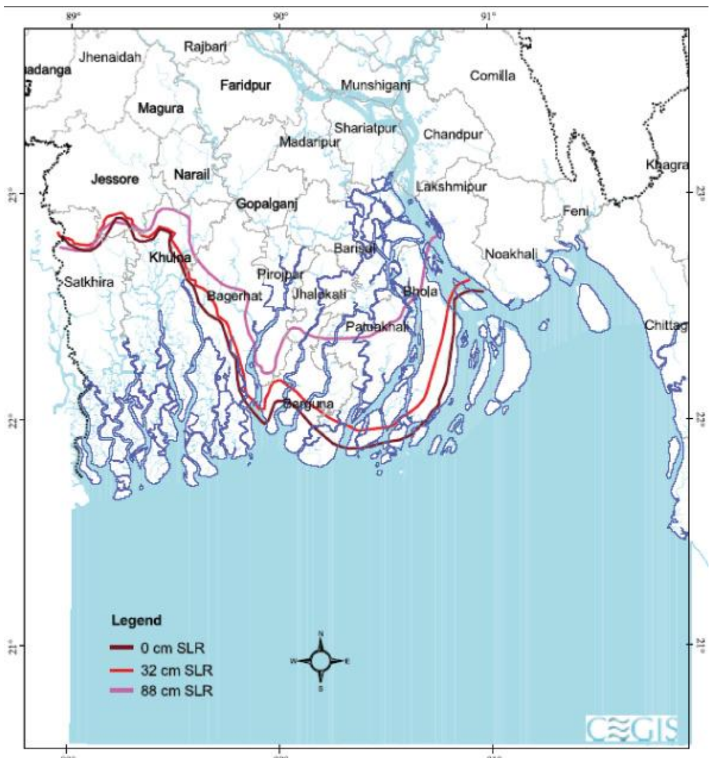
However, widespread glacier melting in the northern hemisphere due to increase of temperature has predicted at least a 0.1-meter sea level rise during 20th century. This large frequency of natural disasters from climate change is increasing the coastal belt vulnerability in Bangladesh, as the Bangladesh coast is highly exposed to natural disasters.

1.2.1.1. Salinity & water logging

Salinity problem is a common phenomenon in the coastal area of Bangladesh, as the sea level rises cause unusual height of tidal water. As an example, in the dry season when the water level drops up to 240 km in western part of Bangladesh is caused severe saline problem in 31 Upazila in Bangladesh. The anticipated sea level rise would produce salinity impacts in three fronts: surface water, ground water and soil. Soil salinity can reduce rice production. Samshuddhoa and Chowdhury (2007, p14) show that 10% more land will be saline affected and intensity will be increased by 10% in the next decade. The most dominant rice crops in the central coastal zone

are Aman and Aus that cover 25 to 28% of the local area. In future, the transplanted Aman crops area will cover only 18 to 20% due to high salinity (Haque, 2006, p1363). A recent study shows that 5ppt saline water will penetrate about 40 km inland for a SLR of 88 cm that will affect the fresh water pocket of Tetulia River in the Meghna estuary as shown in Fig-2. Thus, a big fresh water zone is disappearing and is becoming converted into saline zone from water logging in the Meghna estuary.

Fig-2: Impact on salinity, intrusion of 5 ppt salinity line for different sea level rise scenarios



Source: MOEF, 2009, NAPA, 2009, P22

1.2.1.2. Ingress of soil salinity

Salinity ingress also causes the increase of soil salinity, especially, when farmers used irrigation and take off underground water for dry season crop planting. SRDI (1998) stated that before 1980, the western region was not a saline zone, but it began to be a saline zone after 1980 for

high irrigation and shrimp farming as well as Faraqqa Dam in the Ganges River. The main cause of irrigation is lack of water in crop fields during the planting period after Faraqqa barrage that create an obstacle for the normal flow of water. Salinity is also evident during the winter season (Huq .*et.al.*,1999) from over irrigation.

1.2.1.3. Flood & water logging

The flows of Meghna, Padma and Brahmautra rivers originating from the Himalayas drain out into the Bay of Bengal flowing through the Bangladesh. In the summer, from May to August, the melting of glaciers from the Himalayas provides flow for these rivers. The rainy season provides huge precipitation, wind from south-west, and the combined effects of upstream flows of river water, precipitation, and terrestrial runoff result in flooding, causing water logging and prolonged flooding in southwestern coastal belt of Bangladesh. However, rising sea level (1-2 m) from the rising temperature in central coastal belt causes excessive flooding (Table 4) of 18% of the land in the coastal belt (elevation 3-5m) in Bangladesh. Unplanned embankments are causing water logging and flash floods in the central coastal belt of Bangladesh. The Sundarban, the world's largest mangrove forest is also vulnerable to 45cm sea level rises that would cover 65% of area with saline conditions.

Table -4 Impacts of major floods in Bangladesh

Flood event years	Impact
1954	Affected 55% of country
1974	Moderately severe, over 2,000 deaths, affected 58% of country, followed by famine with over 30,000 deaths
1984	Inundated over 50,000sq.km, estimated damage US$378 million

1987	Inundated over 50,000sq.km, estimated damage US$1 billion,2055 deaths
1988	Inundated 61% of the country, estimated damage US$ 1.2 billion, more than 45 million homeless, between 2,000- 6,500 deaths
1998	Inundated nearly 100,000 sq. km, rendered 30 million people homeless, damaged 500,000 homes, heavy loss of infrastructure, estimated damage US$ 2.8 billion, 1,100 deaths
2004	Inundation 38%, damage US$6.6 billion, affected nearly 3.8 million people. Estimated damage over $2 billion, 700 deaths
2007	Inundated 32,000sq.km, over 85,000 houses destroyed and almost 1 million damaged, approximately 1.2 million acres of crops destroyed or partially damaged, estimated damage over $1 billion, 649 deaths
2008	Inundated 3,394 sq. km, fully damaged houses is 11,448, approximately 0.35 million acres of crops destroyed or partially damaged

Source: NAPA 2005, MoEF 2009, and NAPA 2009,P16

1.2.1.4. Intrusion of saline water

Salinity intrusion in coastal areas of Bangladesh is very seasonal. In the rainy season (June-October) intrusion of saline water is low for the over flow of fresh water, but in dry and winter season is high for the following reasons:

- Increased sea level rise will cause water ingress in the rivers in the dry season;
- Decreasing trend of fresh water in dry season from the upstream will cause intrusion of saline water;
- Upward pressure of saline and fresh water interface in the level of underground aquifer for over irrigation in farming system;
- Downward seepage of saline water from surface and salinization of underground water;
- The evaporation in winter will increase soil salinity;

- Frequency and intensity of tidal surges will increase ingression of soil saline water.

1.2.1.5. Cyclones and the Bangladesh coast

Bangladesh coastal zone is prone to violent storms and tropical cyclones during the pre-monsoon and post monsoon seasons. Therefore, Bangladesh coastal belt is a geographical death trap because of its extreme vulnerability to cyclones and storm surges. Nearly one million people have been killed by cyclones since 1820 and 10% of the world's cyclones are developed in the Indian Ocean and 85% of the cyclones hit in the Bangladesh coastal belt (Table-5) (Gray, 1968). Generally, cyclone hits the Bangladesh coasts because of the following conditions:

- At least 27˚C temperature in an extended sea surface creating huge volumes of water vapour;
- Absence of vertical air or strong presence of depression area;
- Presence of Coriolis force

Table-5: Major cyclones in the Bangladesh Coast

Years	Maximum Wind Speed(km/hr)	Storm Surge Height(Metre)
1960	211	4.6- 6.1
1961	160	6.1- 8.8
1963	203	4.2- 5.2
1965	160	6.1- 7.6
1966	211	4.6-6.1
1966	146	4.6-9.1
1970	163	3.0-4.9

1970	224	6.1-9.1
1985	154	3.0-4.9
1988	160	3.0-4.0
1991	225	6.0- 7.5
1994	210	2.0- 3.0
1995	140	2.0-3.0
1997	220	3.1-4.2

Source: BBS, 1998

Cyclones are accompanied by torrential rain and devastating tidal surges that cause havoc to lives and property in the cyclone path, and the environment in the affected area. In the islands and coastal mainland of Bangladesh the major aftermaths of a cyclone are loss of human lives, livestock, fisheries, agricultural properties and production, inundation of land and ponds by saline water, loss of houses, break-down of salivation system, non-availability of safe and drinking water as well as lack of food.

Approximately 45 major cyclones have occurred in the Bangladesh coastal belt from 1973 to 1997 and the return frequency during this period is 4.5 years. The return period of cyclones is decreasing due to temperature rise. From 1991 to 2009, 7 major cyclones have happened and the amount of destruction is much higher than in previous cyclones (NAPA, 2009). For example, big cyclones (SIDR2007, AILA 2008, etc), had a severe experience in the coastal area of Bangladesh. The impact was more severe for 147 coastal Upazilas in Bangladesh and government. constructed 5107km of coastal embankments that helped to bring land under rice cultivation (Karim, 2005, p1). Although embankment help to reduce impact of saline water in local areas, unplanned and unstable embankments in the coastal area of Bangladesh cannot completely resist saline water intrusion. However, water logging in the western coastal belt area

has been experienced with the loss of yield and flash flooding devastates the polder that is more vulnerable for agriculture land and crops as well as people's livelihood options (Werle *.et.al.*, 2000).

1.2.1.6 Coastal erosion

Coastal erosion is one of the major natural hazards in Bangladesh, as the Bangladesh coastal belt is eroded because of the geographical conditions as well as soil sediment structure. IFRCS in 2001 declared large concern for coastal erosion in the Bangladesh coastal belt, while DFID (2000) identified river erosion as the country's top most disaster relates to lose of land and assets. In addition, IFRCS declared that 1 million people were displaced and 9 thousand hectares of land were impacted by river erosion annually (Razzaque and Rafiquzzaman, 2007, p21). However, every year erosion is a common phenomenon in some coastal districts like Bhola, Sandwip, Hatia, Kutubdia and this has become substantially increased in recent years.

The major causes of erosion observed by researchers are as follows:

- GBM river system carries large volumes of water and silt and during the monsoon season GBM carries 7.1 billion tonne of silt per year causing severe turbulence in the rivers. This results in a gradual undercutting of river banks leading to erosion (Shamsuddoha and Chowdhury, 2007).
- During high tide, 30868 m^3 sea water flows upward through the channels of Kutubdia, Sandwip and Hatia and in these channels upstream these huge volumes of fresh water moving through the channels during each tidal cycle results in erosion of coastal habitats (COAST, 2005).

The coastal belt is vulnerable to natural disasters and now the frequency of natural disasters is increasing from the change of climate pattern; e.g,; increase of temperature, increase the frequency or tendency of cyclonic storm, sea level rise causing the salinity intrusion and river erosion as well as water logging. Some studies (Karim, 2005; APEIS, 2006; Ali and Wakatsuki,

2002; Sing, 2002; Roy .*et.al.*,2009) describe the vulnerability to climate change in coastal area of Bangladesh, while, CCC(2009) describes the adaptation options for reducing climate change impacts on rice production. The limitations of saline resistant rice varieties and limits of CO^2 enhancement for rice production have also been noted. Therefore, climate impacts are causing devastating effects on rice production as well as people's livelihood options that need long-term study and assessment of suitable adaptation options for reducing climate risks.

1.3. Objective of the study

The objective of this study was to identify the impact of climate variability on rice production in coastal area of Bangladesh including aspects of the following:

- Review the factors influencing rice production in coastal Bangladesh
- To assess the impact of extreme events on rice production (qualitative presentation)
- To investigate the impacts of predicted climate change on rice production
- To model some impacts of climate change on rice yields.

Chapter 2: Literature review

2.1. Introduction

Today global climate change is a fact that is visible, tangible, and measurable. In other words, climate variability is an important factor that reveals climate change. In broad terms, climate is the typical range of weather, including its variability, experienced at a particular place. Generally, it is statistically revealed in terms of average temperature and rainfall over a season or a number of years and sometimes in terms of other variables such as, wind and humidity. Thus, the changes of weather pattern over the long-term scale are usually referred to as climate changes (Pittock, 2009, P2).

Climate change is visible in terms of frequency of disaster and global analysis. The IPCC (2001) claims that the human emissions of CO^2 can cause enhanced global warming, where correlation mathematical models used GMTA data to measure catastrophic condition due to climate changes. However, correlation mathematical model shows no correlation between IPCC estimated result on global warming and future catastrophic happenings (Orssengo, 2010). Moreover, catastrophic conditions due to climate change may vary in future more than in the past. For example, Berghold and Lajula, (2012) shows globally the number of catastrophic disaster conditions has increased relative to the past. However, De *et.al.,* (2005) has also shown in his statistical analysis from 1980 to 2010 on 60 flood, cyclone and 247 thunderstorm events where, the number of massive thunderstorms increased from 50 to 150 in the last 100 years in India. Researchers (Pal, 2010,;IPCC, 2001, 2007, 2003; Agarwal, 2003) conclude the following situations that can reveal climate change more visibly:

- Sea level has risen by 20 cm since the beginning of the 20th century.
- Since the late 1800s, average temperature has increased globally by about 0.7 ˚C. Some regions, such as the South Western U.S.A, had temperature increases of more than 1.4˚C.

- The first climate refugees in the U.S.A, the Yup'ik Eskimos, have begun to plan their move to higher ground, while the small south Pacific island nation of Tuvalu has already begun evacuating its citizens to New Zealand.
- Similarly, fish, wildlife, and plants are responding to climate change throughout the world.
- Up to a third of the world's biodiversity is expected to go extinct due to climate change by the end of the 21st century.
- Many of the ecosystem services that people rely on for clean water, clean air, recreation, and subsistence are at risk.
- The impact of climate change is likely to be experienced more intensely by the world's poorest nations and most vulnerable citizens (Source: FAO, 2008).

Climate change is tangible and it can be estimated by assessment of natural disaster occurrences. These happenings include cost of lives, damage of crops and destruction of homes and infrastructure that is showing the clear proof of climate change. Elliot Diringer, Vice President for International Strategies at the Pew Centre on Global Climate Change, called the Cancun talks "the most tangible progress in the UN climate talks in years (CSIS, 2011).

Climate change is measurable through the review of historical data as well as current data. Ecologists have predicted for at least three decades that when climate warming occurred, it would first be measurable at the poles, namely the Arctic and Antarctica (Frasier,1999). However, O'Brien and Wolf (2010), claim that climate change is not only measurable but also intangible too.

Long-term analysis of weather patterns is important for showing climate change. Conventionally, 30-year intervals have been used for calculating averages and estimating weather variability. However, natural climate varies on time scales from year to year, through decade-to-decade to

longer fluctuations over centuries. As extreme weather events are a part of climate, weather related history is important to calculate the sequences of climate change. Other professionals, like engineers, planners and statisticians are using the historical records also for 10 to 100 years to climate history. Reliable averages of the frequency and magnitudes of extreme events from climate history require weather observations over a longer period and sometimes it needs more years than conventionally used.

The impact of climate change is now commonly observed. The worst climatic disaster (like; Flash Flooding) situations are deadly (loss of lives and property) observed in over populated areas, coastal belt and agriculture sectors. In addition, increase of weather related stress and damage might have been due to the increases in the frequency of climate hazards resulting from climate changes. For example, the IPCC (2007) report shows the actual increase of climate hazard due to the climate changes is around 2% per year (in some areas 22% per decade), but the greater part of the total increases results in climate change vulnerability.

The agriculture sector in both developed and developing countries needs to understand the potential change of climate and trends of climate. Furthermore, the agriculture sector depends highly on climate because of temperature, solar radiation and precipitation that are the main drivers of crop growth (Rosenzweig. *et,al.* 2001, p 90). For example, increased temperature helps to increase glacier melting and results in rainfall increases in South and North West of China, in contrast with the northeastern drought area. In addition, warmer conditions and decreased rainfall in some parts cause droughts that have negative impacts on agriculture (Piao, *et. al,* 2010, p43). Therefore, extreme rainfall events are likely to decrease crop yields, particularly through increased flooding (Piao *.et.al.,*2010, p49). However, consideration of the potential impacts of climate change on agriculture should be based not only on mean values of expected climate parameters but also on the probability, frequency and severity of possible extreme events as well as spatial and temporal variation, soil condition, availability of water and agricultural yields should be considered (Rosenzweig *.et.al.,*2001, p 91).

2.2. Objective of the review

The objectives of the present review are:

- To show the present status of the knowledge of climate change impact on coastal belt agricultural production from global to Bangladesh.
- To discuss the uncertainties and limitations of the studies in Bangladesh conditions and identify future research needs.

2.3. Climate variability and rice production

Global and regional weather conditions are predicted to become more hazardous than those at present, taking into consideration the increased frequency and severity of extreme events. Despite the technological advancement, agriculture is fully dependent on weather systems. So, the impacts of climate change on agricultural food production have become a concern in all countries, especially delta regions, fragile coastal belts and poor countries.

However, temperature and rainfall patterns are important factors to determine climate change occurrences. These factors are controlling plant growth. For example, increased global temperatures may lead to forced poor maturity and poor harvest index due to the limited supply of water. In addition, high temperatures may raise sea level water and fragile coastal belt erosion is increased. Thus, crop yields become lower and crop production is reduced with an increasing frequency of flooding.

2.4. The relationship between climate variability and rice production

The relationship between climate variability and rice production could vary in different regions across the world. IPCC (2001) declared that global mean surface temperature may increase by 0.3C to 0.6C over the 20th century with the five global average the warmest years being in the 1980s and 1990's (Mathauda*.et.al., 2000* cited by Martin, 1993). In same report, IPCC (2001) predicts the average global temperature may increase by between 1.4˚C and 5.8˚C by 2100. In

addition, the global projected sea level ranging from 75 to 190 cm from the period of 1990-2100 (IPCC, 2007). The result of IPCC estimation for global temperature rise and sea level rises are shown in Table-6. These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth System Models of Intermediate Complexity and a large number of Atmosphere-Ocean General Circulation Models (AOGCMs). Year 2000 constant composition is derived from AOGCMs only.

Table 6: Projected global average surface warming and sea level rise at the end of the 21st century

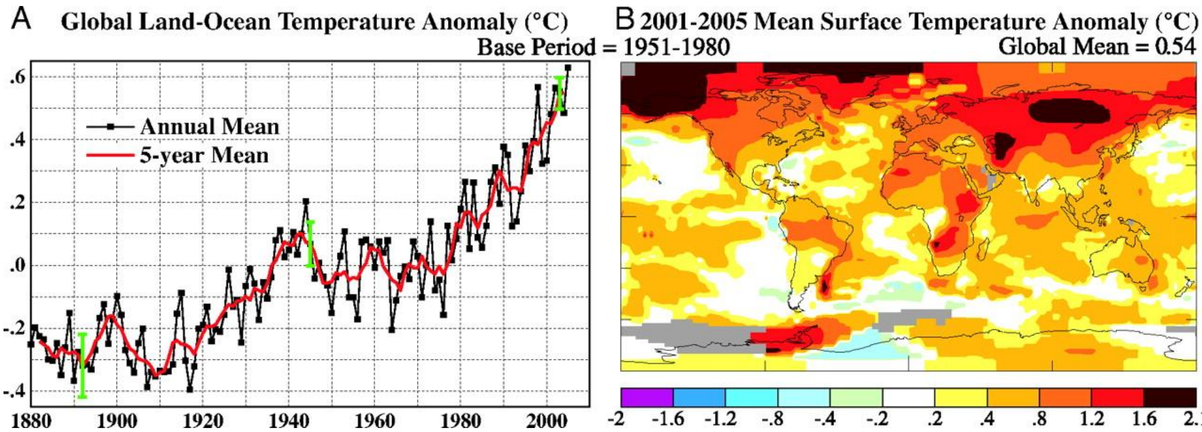
Scenarios (See in Appendix 1)	Temperature Change (°C at 2090-2099 relative to 1980-1999)[a]		Sea Level Rise) (m at 2090-2099 relative to 1980-1999)
	Best estimate	Likely range	Model based ranged excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations	0.6	0.3-0.9	-
B1 Scenario	1.8	1.1-2.9	0.18-0.38
A1TScenario	2.4	1.4-3.8	0.20-0.45
B2Scenario	2.4	1.4-3.8	0.20-0.43
A1BScenario	2.8	1.7-4.4	0.21-0.48
A2Scenario	3.4	2.0-5.4	0.23-0.59
A1FIScenario	4.0	2.4-6.4	0.26-0.59

Sources: IPCC Fourth Assessment Report: Climate Change 2007

2.4.1. Global changes in climatic parameters

Climate change is a major concern for all. The global climate change scenario is predicted on the basis of climate parameters (Fig- 3). The climate parameters comprise temperature, rainfall and sea level rise. IPCC (2001) observed the climate change from the changes of different climate parameters, such as global average air warming, ocean temperatures, widespread melting of snow and ice, rising global sea level (Pittock., 2009, P2). In addition, Piao .*et.al.*,2010 discussed "the impacts of climate change on water resources and agriculture in China" covering the change of rainfall pattern all over China.

Figure -3: Globally observed temperature



Source: Hansen.*et. al.*, 2006

Over recent decades, scientists have observed different climate variables across the world. IPCC (1990) report and all following IPCC reports reported on the current regional trends in variation of temperature and precipitation. In the tropical Asian region, no long term trend has been recorded in mean rainfall variation in some parts, while other countries have shown a decreasing trend of rainfall in recent decades (IPCC, 1996). However, Kriplani and Kumar (2004) showed average low rainfall in India over the whole year. However, the Indian statistics show monsoon rainfall in summer seasons increased in 14 (1980-1990) summer seasons out of every 34(1980-1990) summer seasons during the period from 1981 to 1990 years. The increase of summer seasons may results from warm events in the Pacific Oceans due to El Nino events. In addition, Piao,.*et.al.*,2010 show that North eastern China is affected by drought weather conditions for the lack of seasonal rain whereas, in southeastern area of China high rainfall and extreme events of flooding are observed (Piao, *et .al.*, 2010, p49).

Temperature has increased by about 0.4˚C to 0.8˚C over 20^{th} century all over the world (National Research Council, 2002). From 1901 to 2009, surface temperature rose at an average rate of 0.12 degrees per decade, while over the last 30 years ocean temperature rose more quickly at the rate of 0.21 degrees per decade (NOAA, 2010). Therefore, some studies (Iizumi .*et.al.*, 2007; Priya &

Shibasaki, 2009) suggest that land surface temperature and seasonal variation due to the changes of Earth temperature could also have different magnitudes at different spatial locations and different spatio-temporal scales. IPCC (2001) also predicted more high temperature than recent temperature that can result from higher CO^2 concentrations in the air in future. The findings of the IPCC (2001) report also showed an increase of mean temperature in the range of 0.3°C to 0.8°C across the tropical Asian region over the past 100 years. However, studies (Iizumi *.et.al.*, 2007; Priya & Shibasaki, 2009) considered the location analysis and their method used a vertical and horizontal shape of the land surface for mapping that may be more authentic to reduce the GCM models bias. For example, soil quality varied across whole world based on geographical conditions and seasonal patterns. So, fine resolution data in the GIS technique can be used for analyzing soil ingredients characteristics and crop management quality. However, temperature has varied across the area and it may need proper delineation for further research.

Generally, the impact of the temperature parameter can be calculated by observing the seasonal pattern for the area (Priya & Shibasaki, 2009). This calculation may be made more specific by the observation of daily maximum and minimum temperature and this helps to show the more specific climate change scenario in a particular area by the use of a fine resolution grid system across the area than using mean variation data. For example, the downscaling method shows the daily maximum and minimum temperature in Japan increased by 0.0 to 4.5K throughout the area and the hot summer temperature is slightly more increased than in the cool summer. However, average maximum temperature is causing the warm conditions during the flowering seasons. Therefore, crop yield is seriously affected by the increase of land surface temperature in the dry season (Iizumi *.et.al.*, 2007, p21).

2.4.2. Global changes in crop production parameters and their relationships to climatic condition

The dynamic variability of climate parameters can also have significant impact on rice production. The impacts of climate change are already happening and the magnitude of climate risks is increasing (Nguyen, 2009). The magnitude is measured from different climate parameters

like: sea level rising, increasing hazards frequency and this change can cause serious declines of agricultural production (Nguyen, 2009). The IPCC 4th assessment report (2007) already predicts a greater variation of climate change in the next century all over the world indicating a massive food security challenge in many of the regions due to the severe decline of crop yields, FAO mentioned the capacity of food production may vary all over the region because of different physical, economical and environmental conditions (IPCC, 2007, P300; FAO, 2002, 2005). The simulated impacts of crop production due to climate change have shown in GCM (Table-7) models.

Table 7: Simulated static impact using three GCMs (GISS, GFDL, UKMO)

	Cereals production % change			**Crop production % change**			**GDP agriculture % change**		
	GISS	**GFDL**	**UKMO**	**GISS**	**GFDL**	**UKMO**	**GISS**	**GFDL**	**UKMO**
WORLD TOTAL									
without phys. Effect of CO^2	-22.1	-21.8	-22.4	-25.4	-24.4	-25.0	-33.6	-33.0	-33.5
with phys. Effect of CO^2	-5.1	+2.8	-0.1	-9.0	+0.3	-2.8	-18.2	-8.9	-12.2
Adaptation Level 1	-1.7	+2.8	+0.9	-5.5	+0.3	-1.7	-12.9	-8.3	-10.1
Adaptation Level 2	+1.4	+4.6	+3.2	-1.1	+2.3	+1.0	-6.1	-3.3	-4.4
DEVELOPED									
without phys. Effect of CO^2	-13.9	-6.1	-10.3	-21.3	-15.3	-18.6	-30.4	-27.1	-28.9
with phys. Effect of CO^2	+2.6	+18.6	+10.6	-5.1	+9.6	+2.1	-15.8	-3.2	-9.8
Adaptation Level 1	+7.8	+18.6	+13.1	+0.1	+9.9	+5.0	-6.7	-0.1	-3.6
Adaptation Level	+7.8	+18.7	+13.1	+3.3	+9.9	+6.4	-2.8	+1.4	-0.8

2									
DEVELOPING									
Without phys. effect of CO^2	-28.5	-25.3	-26.5	-28.6	-26.4	-27.1	-36.2	-34.3	-35.1
With phys. effect of CO^2	-11.2	-0.7	-3,7	-12.0	-1.8	-4.5	-20.1	-10.2	-13.0
Adaptation Level 1	-9.2	-0.7	-3.2	-10.0	-1.8	-3.9	-17.8	-10.1	-12.3
Adaptation Level 2	-3.6	+1.4	-0.1	-4.5	+0.6	-0.8	-8.7	-4.3	-5.6

Source, FAO, 1996

The changes to rice production could be considered as an indicator of climate variability and could be used to show the climate change at different spatial scales. Hence it is necessary to identify the different relationships that could exist among different climate variables and the dynamics of rice production. These relationships can have differences in their patterns as well as in magnitude at different spatial and temporal scales.

The impacts of climate change on rice production have been studied by numerous researchers. From historical data, since the 1960s, surface water temperatures have warmed by 0.2 to 2°C in lakes and rivers in Europe, North America and Asia (IPCC, 2007, p91). However, extreme temperatures (whether low or high) can cause injury to the rice plant. In tropical regions, high temperatures are a constraint to rice production (Nguyen, 2009, P26). Although there have been increasing trends of rising crop production over forty years through technological developments, climate change effects have been linked to the decrease of production trends (Feng, *et.al.*,2009; Hafner, 2003, in IPCC, 2007, p104). IPCC stated that the globally catastrophic flood hazard has increased in a recent 10 years period (between 1996 and 2005) and the per decade catastrophic flood return period has increased by two times in the last century (IPCC, 2007, p178).

The close relationship that exists between the dynamics of rice production and climate variables is reflected by the yield loss of 15% for each 1°C increase of growing-season minimum temperature in the dry season (Feng *.et.al.*,2004). In addition, IPCC 4th Assessment Report shows the potential for global food production is projected to increase with the increases in local average temperature over a range of 1 to 3°C, but above 1 to 3°C the food production would decrease under the medium confidence level (Table -8) (IPCC, 2007, p48).

Table: 8-IPCC indicators about confidence levels (IPCC, 2007)

Likelihood indicators (WG1)	Confidence indicators (WG1 & WG2)	Qualitative, 2-dimensional scale for treatment of uncertainty (WG3)
-Extremely likely: >95% (probability of occurrence) – Very likely: >90% – Likely: >66% – More likely than not: >50% – Very unlikely: <10% – Extremely unlikely: <5%	-Very high confidence: At least 9/10 chance (of being correct) – High confidence: About 8/10 chance – Medium confidence: About 5/10 chance – Low confidence: About 2/10 chance – Very low confidence: Less than 1/10 chance	-Level of agreement (high, medium, low): level of concurrence in the literature – Amount of evidence (much, medium, limited): number and quality of independent sources

Source, IPCC, 2007

However, flood frequency and tendency will be dramatically affected by climate change. IPCC (2007) stated that surface runoff in recent decades has been enhanced due to glacier melting in the tropical Andes and in the Alps. The expected high rainfall intensity and the frequency of floods and storms caused by the changes in rainfall and its distribution pattern (Depledge, 2002, cited in Nguyen, 2009, p27) would have negative effects on the transport and distribution of rice to consumers. Nguyen (2007) used the amount of production in a particular season and does not indicate any parameter for the loss of rice production, while Xiong *.et.al.*,(2009) indicated the

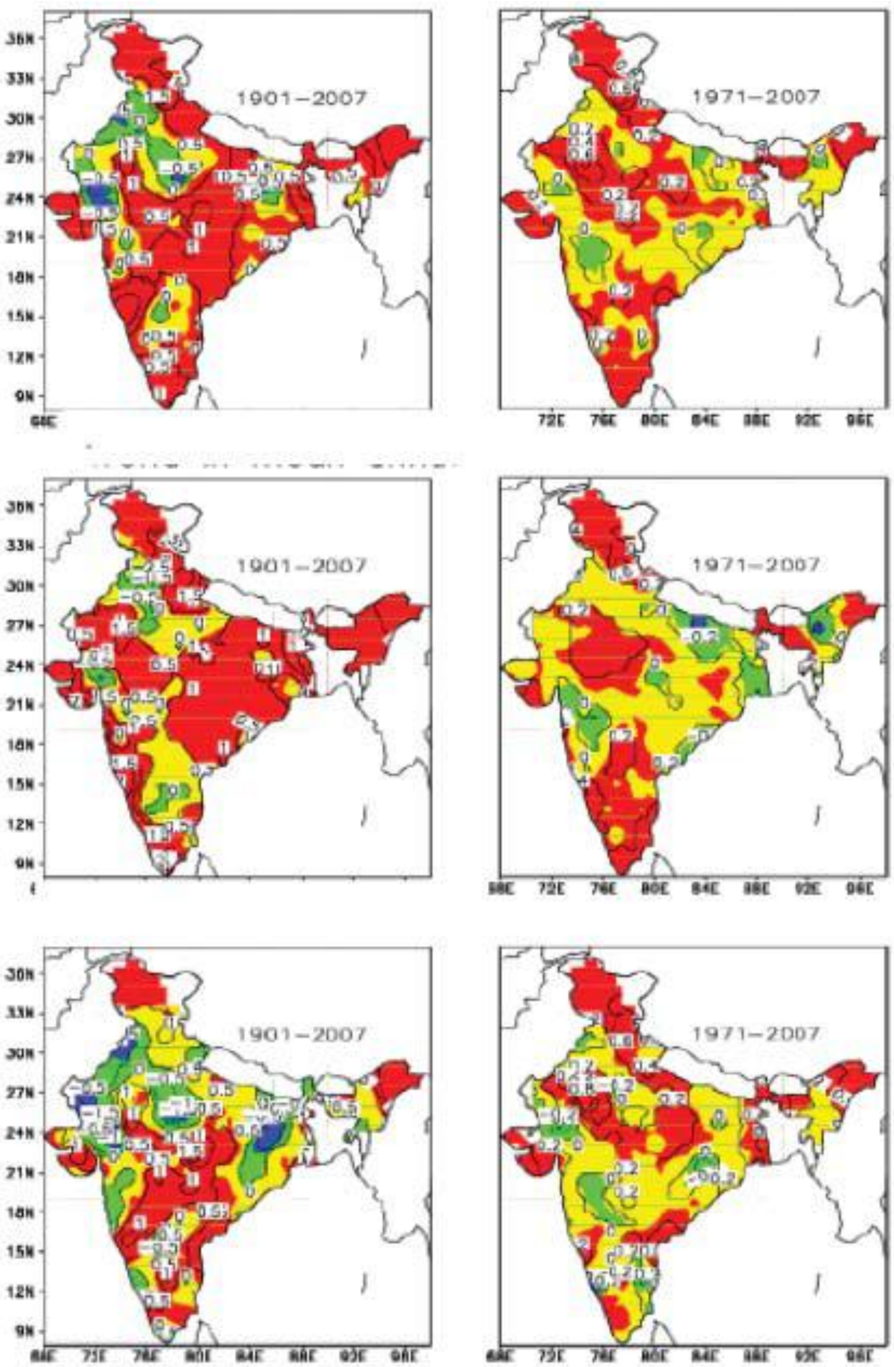
possible reason for the simulated decrease of rice yield and production for the more frequent of crop failure in future and yield losses was due to the higher heat stress (Xiong, *.et.al.*,2009, p33). Xiong used the CERES crop model which is an embedded decision support system for agro technology (DSSAT 4) transfer software package (Jones.*et.al*.,2003, cited by Xiong *.et.al.*,2009). CERES model has several advantages, as it can use widely available data for plant genetics, management practices, weather and soil conditions for studies on the growth of plant, development and yield of rice plants (Sing & Padilla 1995; Mall & Agarwal, 2002; and Mahmood *.et.al.*,2003). In addition, Xiong *.et. al.,* (2009) observed a specific site, with simulated values of rice plants being within ±10% of observed duration and ±15% of observed yield. So, yield variation was well captured in the CERES model.

Erosion is another hazard that leads to the loss of land and it causes damage to agriculture production. The IPCC 3rd Assessment Report (2001) observed erosion is associated with shoreline development, clearing of mangroves (Thampanya *.et.al.*,2006) and mining of beach sand and coral. Sediment starvation due to the construction of large dams upstream also contributes to coastal erosion (Frihy *.et.al.,*1996; Chen *.et.al.*,2005; Georgiou *.et.al.*,2005; Penland and Kulp, 2005; Syvitski *.et.al.*,2005; Ericson *.et.al.*,2006, cited in IPCC, 2007, p92). However, anthropogenic activities have intensified beach erosion in many parts of the world, including Fiji, Trinidad, and parts of tropical Asia (Mimura and Nunn, 1998; Restrepo *.et.al.*,2002; Singh and Fouladi, 2003; Wong.*et.al.*, 2004, cited in IPCC, 2007 p92). Therefore, coastal erosion is now a threat for the future land availability and contributes to losses of property. Coastal erosion and losses of wetlands are widespread problems today as well as the current rate of sea-level rise and coastal erosion is caused by anthropogenic modification of the shoreline. The erosion would also create difficulty in the distribution of and access to rice.

2.5. Projected climate change scenarios over the Indian Subcontinents

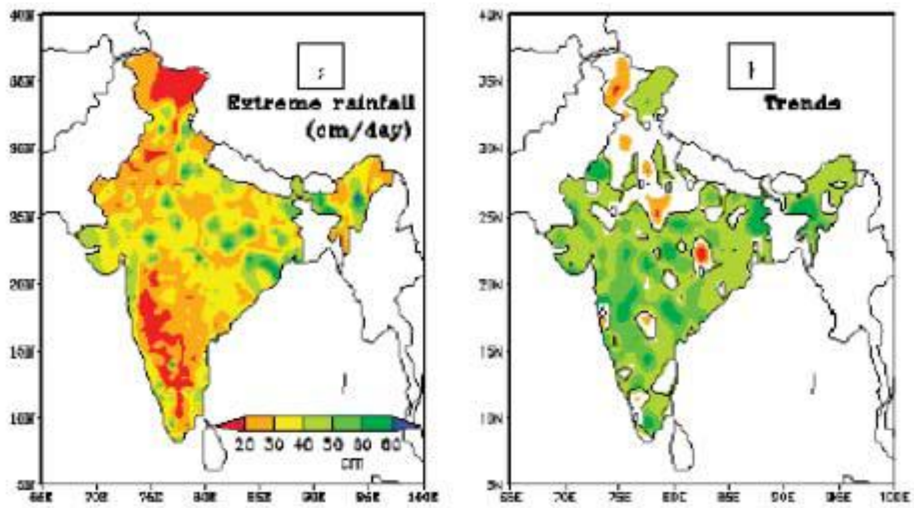
India is the neighbor of Bangladesh and it is also situated in the Ganges belt. Thus the physical conditions in some parts of India are quite similar to Bangladesh. However, global average temperature and rainfall have changed with all over the world at increasing rates in the 20th century (Easterling, *et.al.*, 1999; IPCC, 2001; Jung .*et.al.*,2002; Balling Jr and Cerveny, 2003; Fauchereau .*et.al.*,2003 cited in Mall, *et.al.*, 2006). In India, during the last century there has been observed an increasing trend in surface temperature (Hingane .*et.al.*,1985; Srivastava *et. al.*, 1992; Rupa Kumar .*et.al.*,1994; De and Mukhopadhyay, 1998; Pant .*et.al.*,1999; Singh and Sontakke, 2002; Singh .*et.al.*,2001), with no significant trend in rainfall on an all India basis (Mooley and Parthasarathy, 1984; Thapliyal and Kulshrestha, 1991; Pant and Rupakumar, 1997; Pant .*et.al.*,1999; Stephenson .*et.al.*,2001), and decreasing/increasing trends in rainfall on a regional basis (Chowdhury and Abhyankar, 1979; Rupa Kumar .*et.al.*,1992; Kripalani .*et.al.*,1996, 2003; Singh and Sontakke, 2002). The trends of temperature and rainfall in INDIA are shown in figure-4(a and b).

Fig-4 a: trends of annual mean, maximum and minimum temperature in India



Upper panel: Mean annual temperatures; Middle panel: Trends in maximum temperatures; Lower panel: Trends in minimum temperatures

Figure-4 b: Highest recorded rainfall (cm) during 1951-2004 and trends of rainfall in India

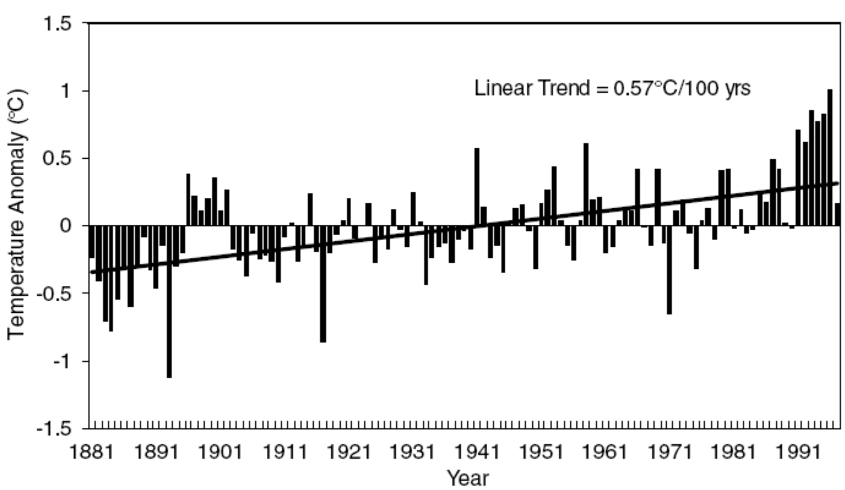


(a) Trends in annual extreme rainfall and (b) Dark green color indicates significant increasing trend.

Source: INCCA, 2010

Pant & Kumar, (1997) have shown a significant warming trend of seasonal and annual temperatures in India of about 0.57˚C per hundred years (Fig-5), while other research (Ahmed and Warrick, 1996; Chaudhari, 1994; Rupakumar and Patil, 1996; IPCC, 2001) suggests a similar trend in Pakistan, Nepal, Sri Lanka and Bangladesh.

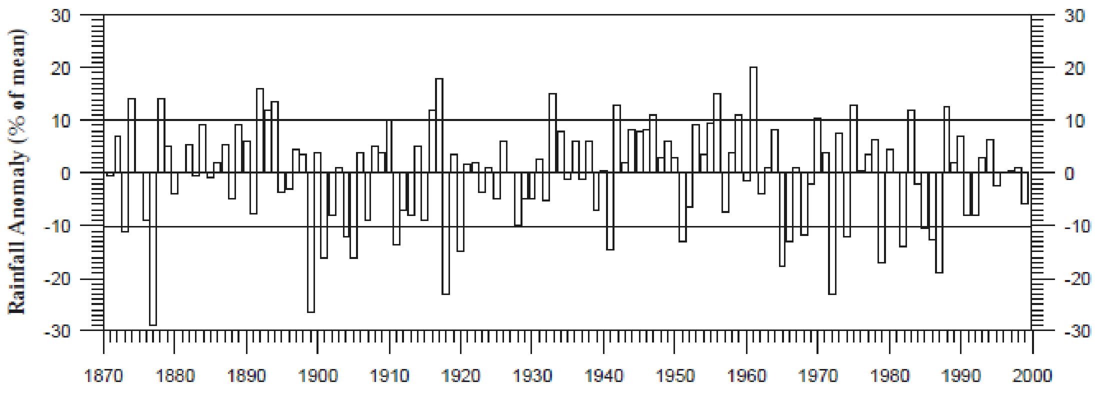
Fig: 5 All-India Mean Annual Surface Air Temperature Anomalies (1881–1997).



Source: Pant and Kumar, 1997

In addition, the fluctuations of rainfall pattern in India have been largely random over the last century (Fig-6). However, areas of increasing trend in the seasonal rainfall have been found along the West Coast, North Andhra Pradesh and Northwest India, and those of decreasing trend over East Madhya Pradesh, Orissa and Northeast India during recent years in Table-9 (Rupakumar .*et.al.*,1992).

Fig 6: All India summer monsoon rainfall anomalies (1971-1999)



Source: Lal, 2001

Table 9: Comparison of magnitudes of Extreme Precipitation Rainfall Event (EPRE) in cms, before and after 1980 in selected regions

Station	Region	Maximum EPRE up to 1980	Max EPRE recorded between 1980 and 2010
Himalayas			
Ambala	Punjab	23(Aug 10, 1896)	34 (Aug 03, 2004)
Leh	Jammu and Kashmir	-	250 mm/hr (Aug 6, 2010)

Coastal region			
Amini devi	Lakswadeep	25 (Nov 21, 1977)	170 (May 06, 2004)
Santacruz	Mumbai	38(July 05, 1974)	94 (July 27, 2005)
Male gaon	Mumbai	16(July 26, 1896)	29 (Oct 11, 2001)
Bhira	Konkan and Goa	43 (June 29, 1967)	71 (July 24, 1984)
Sand heads	Anadaman	37 (July 14, 1972)	51 (June 12, 1981)
Sagar	West Bengal	38(July 30, 1973)	48 (April07, 2005)
North East			
Cherrapunji	Assam	19 (Sept 13, 1974)	156 (June 16, 1995)
Silchar	Assam	29 (May 30, 1983)	47 (July 07, 1991)
Jalpaiguri	North Bengal	39(July 8, 1892)	47 (July 10, 1989)
Malda	North Bengal	2424 (oct 1, 1971)	57 (Sept28, 1995)
North West			
Jaipur	Rajasthan	19 (Aug 16, 1959)	22 (July 19, 1981)

Source: INCCA, 2010, P34

Extreme events like, different hazards have direct negative impacts on crop production, while some authors (Agarwal, 2003; Piao *.et.al.*,2010) suggest that the changes of climate parameters may reduce the crop production due to the negative relationship between climate parameters and the dynamics of cropping patterns. In addition, Nagyan (2009) and Piao *et.al.,(*2010) also suggest that the cultivated areas are subject to a broader range of influences, including changes in commodity prices, costs of inputs and availability of irrigation water. Thus, the direct and indirect influence of climate on harvested areas may cause a decrease of crop production. For example, shortfalls in rainfall can reduce irrigation water supplies and increase of temperature and will lead to forced maturity and poor harvest index due to limited water supply (Kumar *.et.al.*,2004 & Mathauda *.et.al.*,2000). In addition, Mall & Sing (2000) stated that India faced adverse climatic conditions and food grains production declined from their estimation (212.02Mt to 174.19Mt). While, Mall and Sing (2000) show the fluctuation of crop yield, Pathak *.et.al.,*(2003) reveal the negative trends of solar radiation and an increase of minimum temperature as well as the declining trends of potential yields of rice and wheat in the Indo-Gangetic plains of India.

Although Selvaraju (2003) found inter annual variations in summer monsoon rainfall, the magnitude of change in food grain production is smaller than rainfall (Mall *.et.al.,* 2006, p451-452). Selvaraju's correlation formula represented great variation among the years for the changes of rainfall pattern and it was significant at the 1% level. Kumar *.et.al.*,(2004) used the same method but made a division among seasons instead of the average per year. Kumar's method was useful for calculating annual variation in pre monsoon, monsoon and post monsoon seasonal impacts of climate change on crop production.

In addition, the CERES Rice model was applied for a particular place in India (Ludhiana) for a period of 20 years weather data. The weather data from normal rice crop seasons was considered and showed the crop responses to variations in temperature under five climatic scenarios. The result shows a decline of crop yield because of the increases of temperature. An increase of temperature can result in smaller levels problems with root sink , hard soil conditions for tillers

and shorter period of solar radiation resulting in considerable decline in biomass and grain. Dhiman *.et.al.*,(1985) and Saini & Nanda (1987) report that increases of temperature hasten the rate of leaf senescence resulting in reduction in leaf area. Similarly, decreases of crop life pattern and grain yield with the increases of temperature have been observed by others (Mavi& Chaurasia 1974, Bagga& Rawson, 1977, Sing *.et.al.*,1991, Wardlaw 1970; Wardlaw *.et.al.*,1989; Mathauda. *et.al.*, 2000, p95).

2.5.1. Projected future climate change scenarios over the Indian Sub-continent

Variability of climate change is high all over the Indian Sub-continent, especially in coastal belt areas. The main conclusion of the IPCC third assessment report is that the average global surface temperature will rise by between 1.4˚C to 3˚C above 1990 levels by 2100 for low emission scenarios and between 2.5˚C and 5.8˚C_for higher emission scenarios of greenhouse gases and aerosols in the atmosphere. However, different models suggest the variability of climate change and its impact on rice production will vary at different scales. For example, the result of UKMO GCM model (Bhaskaran *.et.al.*,1995) predicts a total rainfall increase of approximately 20% and a total temperature in winter (Rabi cropping season) increase of 1˚C-4˚C as well as the increase of CO^2 concentration in the air. The model also predicts a greater number of heavy rainfall days during the summer monsoon or *kharif* period, and an increased inter-annual variability. In addition, the HadCM2 model indicates that crop yields could increase up to 20% in East and South-East Asia while it could decrease by up to 30% in Central and South Asia even if the direct positive physiological effects of CO^2 are taken into account. As a consequence of the combined influence of the CO^2 fertilization effect and the accompanying thermal stress and water scarcity (in some regions) under the projected climate change scenarios, rice production in Asia could decline by 3.8% by the end of the 21st century (IPCC, 2007, p 480).

Although various studies (Lonergan, 1998; Lal, *et.al.*,1995) suggest a rise of temperature due to the increase of CO^2 concentration, the projection may be lower in magnitude in contrast to ocean thermal changes, land surface analysis and seasonal monsoon pattern analysis. For example, ECHAM4 and HadCM2 models considered the seasonal monsoon uncertainty. Rupakumar and

Ashrit (2001) have projected a 13% increase in monsoon or kharif season rainfall in India using the ECHAM4 model, while the HadCM2 suggests reduction in kharif rainfall by 6%. Both GCMs suggest an increase in annual mean temperature by more than 1◦C (1.3◦C in ECHAM4 and 1.7◦C in HadCM2). However, as regional models (HadRM2/HadCM2) primarily describe the global warming and did not show rainfall changes, observation from the model may not show the clear picture of climate change in terms of Regional India. Specific location wise analysis may reduce the vulnerability of the gap of the model results. Kumar *.et.al.*,(2003) selected a particular area and smaller scale and this helps to show the significant difference of temperature rises and rainfall changes among different parts of India on both an annual and a seasonal basis.

2.5.2. Variability of crop production

The magnitude of yield gains or losses of crops at selected sites under elevated atmospheric CO^2 and associated climate change parameters are highlighted in several studies(Abrol *.et.al.*,1991; Sinha and Swaminathan, 1991; Aggarwal and Sinha, 1993; Aggarwal and Kalra, 1994; Gangadhar Rao and Sinha, 1994; Mathauda and Mavi, 1994; Gangadhar Rao *.et.al.*,1995; Mohandass *.et.al.*,1995; Lal *.et.al.*,1998,1999; Francis, 1999; Rathore *.et.al.*,2001; Mall and Aggarwal, 2002; Aggarwal and Mall, 2002; Aggarwal, 2003; Attri and Rathore, 2003, Mall *.et.al.*,2004).

The magnitude of climate change is high in some places and less in other areas. For example, in a subtropical (above 23˚N) environment, farmers have experienced in a small decrease of potential yields (1.5 to 5.8%) , where as in tropical locations the rate of potential yield decrease is much higher (17%-18%) due to the severe natural calamities, extreme events, changes of climate parameters (Luo & lin, 1999). Parry *.et.al.*,(1992) described the yield impacts due to climate change that varied across of Thailand, Indonesia, Malyasia, as this study took into consideration farmer’s livelihood options. In addition, Parry *.et.al.*,(1992) stated that coastal inundation may threaten rice production in terms of sea level rise, extreme flooding, sudden and flash floods.

The annual climate variation is quite clear in different models that have severe impacts on crop production. Mohandass *.et.al.*,(1995) used the ORYZA1 model (Kropff *.et.al.*,1994) to simulate rice production in India under current and future climates. ORYZA1 model reduces the bias of GCM that shows the increase of crop production under the GCM's model results. The main reason was to increase the cropping yields and using technology and increase the use of fertilizer. However, although ORYZAI model showed a large decrease in the second season's crops due to high temperature, the relatively low proportion of total rice produced in terms of that season shows the low effects on overall production. Mohandass *.et.al.*,(1995) used the ORYZAI model on overall annual crops but this was not able to show the particular seasonal change and crop reduction. Uprety *.et.al.*,(1996) observed a limitation of ORYZAI model that reveals the variation of same crop growing in dry and cold regions and suggested study on a particular crops model.

The CERES model was examined in various studies (Lal *.et.al.*,1998, Singh *.et.al.*,1993 Godwin *.et.al.*,1989, Chatterjee 1998, Sahoo 1999, Rathore *.et.al.*,2001, Mall and Aggarwal, 2002) and shows the impacts of climate variability on a daily basis, monthly basis, seasonal basis, per crops basis etc. The CROP GRO model was developed by Mandal (1998) Lal *.et.al.*,(1999) Mall *.et.al.*,(2004) for the upgrade of the CERES model this shows that agriculture will become vulnerable due to the increased incidence of weather extremes, such as, change in rainy days, rainfall intensity, duration and frequency of drought and floods, diurnal asymmetry of temperature, change in humidity, and pest incidence and virulence in terms of different crop season in a particular site. This crop growth model may be used as a standard rationalization technique as suggested by IPCC (2007), as this model may cover all climatic variability in terms of a single crop growing season as well as being able to show the difference of crop production in each season due to the climate change (Carter *et.al.*,; 1999, Mearn *.et.al.*,2001). However, the International Rice Research Institute observed a decrease of crop production of 10% for each 1˚C rise of temperature in the food growing seasons (Peng *.et.al.*,2004). In addition, a 2°C increase in mean air temperature decreased rain-fed rice yields by 5 to 12% in China (Lin *.et.al.*,2004).

Food insecurity and loss of livelihood would be further exacerbated by the loss of cultivated land and nursery areas for fisheries through inundation and coastal erosion in low-lying areas (FAO, 2003, in IPCC, 2007, p297-298). With regard to India, the East Coast is more vulnerable than the West Coast with respect to the frequency of occurrence of extreme events like cyclones and depressions (Patwardhan *.et.al.,*2003) where IPCC (2007) shows the worst effect of climate change in the coastal regions of Gujarat and Maharashtra on agricultural land is inundation and salinity intrusion (IPCC, 2008, P1). In addition, the net cereal production in South Asian countries are projected to decline at least between 4 to 10% by the end of this century under the most conservative climate change scenario (Lal, 2007; IPCC, 2007, p481). In the Indian subcontinent scenario, it is also likely that there will be an increase in the frequency of heavy rainfall events in South and Southeast Asia. The average temperature change is predicted to be in the range of 2.33° C to 4.78° C with a doubling in CO^2 concentrations (Watson *.et.al.*, 1996).

Thus, South Asian countries will face greater temperature rise and sea level rises in 21st century, Lal *.et.al.,*(1995) stated that the surface air temperature over the Indian subcontinent (area-averaged for land regions only) is likely to rise by 1°C (during the monsoon) to 2°C (during the winter) by the middle of the 21st century. This may result in the changes of scheduled cropping seasons and duration of crop growing periods. As a result, agriculture in the topical Asia region will not only be affected by the temperature rise but also may be affected by the changes in the monsoon pattern and nature. For example, the CERES model shows that the combined effect of enhanced CO^2 and imposed thermal stress on the wheat (rice) crop is 21% (4%) increase in yield for the irrigation schedule presently practiced in the region. While the adverse impacts of likely water shortage on wheat crops would be minimized to a certain extent under elevated CO^2 levels, they would largely be maintained for the rice crops resulting in about 20% net decline in rice yields (Papademetriou, 2000)

Other studies estimate that the increase of temperature rise will increase the sea level rise that may be responsible for the destruction of food and agricultural crops in tropical regions. IPCC (2001) stated that destruction of agriculture crops will lead to an increase of food prices.

However, climate change researchers are now trying to find solutions for mitigating the risk of climate change variability on food production in tropical region developing countries.

McGuigan *et al,* 2002 suggest that

"It is also important to note that the analytical framework for assessing agricultural impacts is undergoing an evolution, with large scale, global modeling losing importance, as more local level studies are underway. There is a general consensus among developing countries that individual analysis is necessary and 45 developing countries, in their national communications to the UNFCCC (2001) have focused particularly on the agricultural sector, examining the vulnerability of more than 10 specific crops and cultivars under a variety of climate change scenarios"

Cho and Oki (2012) considered rice production in a widely accepted way, as his methods used fine resolution data from coarse resolution data. His model was able to show the site specific crop yield variation due to recent climate change. In addition, his model results show the changing of climate variability on rice production as well as a function of seasonal climatic variations, soil water holding characteristics and the applied crop management strategies. Moreover, the study was successful in evaluating the future climate change impact on cereal crops. This method may be applicable for Bangladesh studies, as Bangladesh conditions are quite similar those in India. This method is capable of simulating a number of crop management systems, based on the selection of the study area and data provision. The main limitation of the EPIC model to assess the impact of climate change on crop production at the district level, as each district contains different soil, water, river channel and landscape patterns. But Cho and Oki suggests using a multi scale approach helps to simulate data in national scale where data is always limited.

2.6. Severity of Impacts of Climate change in Bangladesh

A climate change has been observed through temperature rises, sea level rise and rainfall changes in South Asian countries. IPCC (2001) has predicted global temperatures will rise between 1.8˚C to 4˚C by the late 21st century, where BCCAAP (2010) shows the impacts of this (IPCC predicted results) temperature rise on Bangladesh may result in the overflow of river water and sea level rises between 0.18 to 0.79 meters as well as the increased coastal flooding and salinity intrusion for the whole coastal belt area in Bangladesh. In addition, BCCAAP (2010) also predicted increases of rainfall in South Eastern and Western parts as well as the dry Northern part of Bangladesh. Therefore, on the basis of BCCAAP and IPCC(all reports) and the country's current statistical report on climate pattern, MoEF(2008) declared the Bangladesh is a most vulnerable country, as the country is situated in the most tropical cyclone prone area and sixth most vulnerable country to floods in the South Asian region (MoEF, 2008). However, the IPCC declared the changing rainfall pattern will increase with the change of global temperature and this can increase sea level rise as well as the salinity intrusion in the South and North Eastern regions in Bangladesh, Heikens (2006) show the increase of the frequency of floods in Meghna Besin with the rising sea level and increases of rainfall. On the basis of the vulnerability to climate change occurring (temperature rise, sea level rise and rainfall changes) Hussain (2008) uses the CERES model for the prediction of the impacts of the climate change on rice production. Hussain (2008) shows a decline of Aus rice by 1.5-25.8% and Aman rice by 0.43-5.3% as a result of higher temperature, although Boro rice may increase by 1.2-9.5%, Boro rice could not cope with temperatures of up to 35˚C. However, Hussain (2008) focuses on the whole of Bangladesh, but is unable to give clear picture for each region of dry and wet areas in Bangladesh.

CCC (2009) used the CROPSUIT model as well as GCM findings for a particular area of Bangladesh. The CROPSUIT model is based on a modification of the CERES model that is effective for data correlation between yield characteristics and land use requirements, which finally develop a grid map for showing the change of crop yields for the changing of different climate parameters. Although CCC (2009) show the relationship between climate change and land use characteristics for future adaptation, other reports (e.g, OECD, 2003) emphasize the

strategy of the current action plan of adaptation options and the need for global and structural policies and a network of environmental and developmental co-operation. In addition, CEGIS (2006) showed that the climate change vulnerability may vary with location and action strategies which are important not only for adaptation options but also for the mitigation and development of risk reduction strategies for every global and local project in Bangladesh. However, Hussain (2008) highlight the need to ensure food security and need for the analysis of food grain markets. On the other hand, Bangladesh needs to focus on domestic rice production due to the impacts of climate change, as the country is losing 0.5 million tonnes of rice per year from floods, which accounts for nearly 30% of the country's annual food grain production (Ayers and Haque, 2008, p5). Therefore, the country has been losing on average, 28% of rice production in recent decades due to the change of temperature, rainfall and salinity intrusion.

2.6.1. Climate vulnerability in the coastal belt area of Bangladesh

Climate vulnerability is a major concern in the coastal area of Bangladesh. Generally, the Bangladesh coastal belt has been delineated based on three criteria, namely the limits of tidal fluctuation, salinity intrusion and cyclonic risk (Karim and Mimura,2008, p491). Karim and Mimura's (2008) study can be justified by the IPCC 1st assessment report (1990) which stated that the world oceans and coastal resources are under threat by coastal inundation and the need for particular interest in analyzing climate change risk to coastal areas (Shea and Dyoulgerov, 1997, p113). In addition, the IPCC 1st assessment report suggests a comprehensive national coastal management plan on the basis of climate change impact, minimizing the risk to people's lives and maintaining the important coastal ecosystem (Shea and Dyoulgerov, 1997, p113), but the scope of that type of study is limited in developing countries like Bangladesh for the different pattern of hazards (Karim and Mimura , 2008, p491). For example, the Bangladesh coastal belt is a low lying area and it is vulnerable to both storm surge and monsoon flooding. Abnormal floods will inundate 30% of the low lying areas in Bangladesh and in a major flooding period (1988, 1998, 2004) more than 60% of land has been inundated; the Bangladesh coastal belt faces a major cyclone on an average once per year and tidal surge may be up to 6- 10m (Karim and Mimura, 2008, p492). The same findings are reported in Karim (2005) where he observed the three types of coastal zone in Bangladesh and although he stated that the Barisal- Noakhali coast

is relatively less vulnerable for tidal surge , recent cyclones (SIDR and Aila) prove that this site is also vulnerable to tidal surges. In addition, sea level rise is an important zonal factor for assessing climate change vulnerability in the central coasts in Bangladesh (Singh, 2002, p251), where 65% of the coastal area is affected by tidal surge and seasonal flooding (Haque, 2006, p1360).

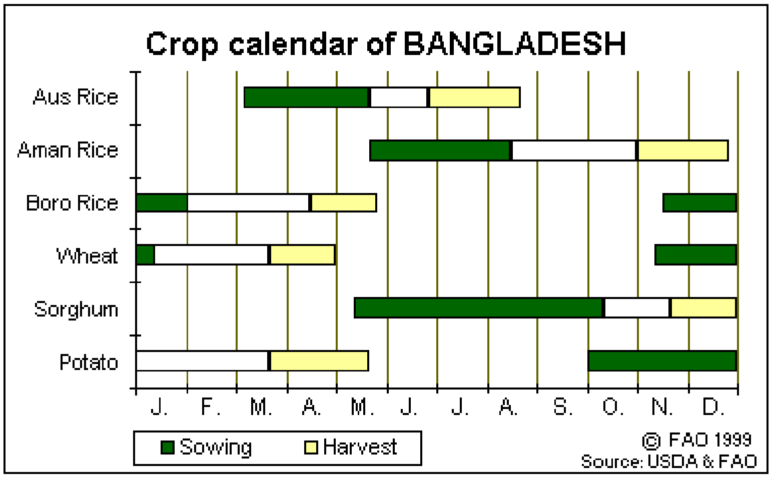
On the other hand, the effect of tides is manifested by the regular alteration of the sea water level and the estuarine/tidal channels/creeks. The impacts of tidal surge in coastal areas vary on the basis of the relative elevation of the sea surface and land area (high>9m, low<3m or medium<3-6m>). In addition, most of the central coastal belt in Bangladesh is located in medium high land where flooding depth ranges from 0.3-0.9 meter (Haque, 2006,p1363). Sea level rise and tidal surge are important factors for climate change vulnerability in the central coastal area of Bangladesh. Sea levels generally rise globally due to glacier melting and other factors related to an increase of temperature. However, variability of rainfall due to the seasonal climate change, uncertain dates of onset and recession of seasonal floods are important features for analyzing climate change vulnerability in coastal areas of Bangladesh. For example, uncertain rainfall delays transplanting of rice and flood/tidal surges damage various crops (Haque, 2006, p1363). Similar findings are mentioned in Roy *.et.al.*,(2009) who reported the Aus rice production would be reduced by 15% under a moderate climate change scenario while Aman rice production would see more than a fourfold reduction under a severe climate change scenario.

2.6.2. Cropping pattern in coastal area of Bangladesh

Three seasonal rice crop groups are recognized in Bangladesh and dominate the cropping pattern throughout the country. Almost 90 percent of the population are rice eaters. The three rice crop groups cultivated throughout the year as Aus, Aman and Boro. The varieties of Aman are transplant, broadcast and high yielding variety (HYV), varieties of Aus are local and HYV and varieties of Boro are local, HYV and hybrid. Among these crops Aman is the most important and occupies about 48.5% of the rice cultivated land (42.7% and 9% of the land is occupied by Boro and Aus respectively). Rice covers about 70 percent of the total annual cropped area.

Transplanted Aman is grown throughout Bangladesh and broadcast Aman is grown mostly in the south and south-eastern part of the country. Aus is cultivated in scattered areas in most districts. In Fig-7, shows rice grown seasons throughout the year that provides employment for 75 percent of the total labour force in the rural areas of Bangladesh.

Fig 7: Crop calendar in Bangladesh



Source: Bangladesh Bureau of Statistics (BBS, 2002)

Aus paddy is sown in the pre-monsoon season and harvested in the monsoon season, grown both as a dry land crop (broadcast Aus) and as transplant Aus. Aman paddy is growing in the monsoon season and harvested after the monsoon season; and Boro is grown in the dry season. Aman is divided into deepwater Aman, mainly sown as a dry land crop pre-monsoon, growing in up to 4 meters of water in the monsoon season, and harvested post-monsoon; and transplanted Aman, sown in seedbeds in mid-monsoon, transplanted to fields in <30 cm water in August-September, and harvested post-monsoon. Boro paddy is always transplanted and is mainly irrigated (GOB, 2009).

However, crop combination is a pattern of cultivating two or more crops in a cropping season. This practice provides farmers with opportunities for harvesting diverse crops from the same land, increasing total land productivity, and maintaining or improving soil fertility using legumes. The major cereal cropping system of Bangladesh is rice and wheat grown on the same field but in different seasons during the year. Although the rice-wheat cropping pattern is the

major cereal production pattern, farmers sow continuous cereals year after year. Although the area of rice-wheat may not change over time at a national level, farmers themselves are changing their cropping pattern within their plots. Farmers sow pulses, oilseeds, potatos, vegetables and sugarcanes on the plots previously in rice-wheat. Commonly used 2-crop combinations are Aman-Boro rice, Aman-aus rice and Aman-Boro rice, 3-crop combinations are Aman-Boro-Aus, Aman-Boro-Jute and Aman-Boro-Pulse. 4-crop combinations are Boro-Aman-Jute-mustard, Boro-Aman-mustrad-aus, Aman-Aus-Boro-tea, Aman-Boro-Jute-wheat, Aman-wheat-Boro-Aus, Aman-Boro-wheat-Aus, and Aman-Aus-Maskalai-Boro (Haque, 2006, p1362).

Because of its tropical location, Bangladesh is able to plant several crops on the same land each year. The crop-growing period is divided into two main seasons, Kharif and Rabi. Crops (such as rice, jute, maize, millets, etc) which are grown during the Kharif season are called Kharif crops and those (such as wheat, mustard, chickpea, lentil etc) grown during the Rabi season are called Rabi crops. The Kharif season extends from May through October, while the Rabi seasons starts from November and continues up to April. In addition to these two main seasons, a transition season called Pre-kharif has been identified. This season starts from March-April and ends in May-June (Haque, 2006,p1362).

2.6.3. Climate change affects the coastal area of Bangladesh

Three major parts of the country’s coastal belt consist of alluvial soil sediments deposited by the Meghna, Ganges, Braughamaputra, Tista, Jamuna rivers and their tributaries. Terraces with elevations of 20-30 cm cover about 8% of the country, while hilly areas with an altitude of 10-1000 m occur in southeastern and northeastern part of Bangladesh. The coastal region covers 29,000 sq. km or about 20% of the country and coastal areas of Bangladesh cover 30% of the cultivable lands of Bangladesh (Rahman and Parkinson, 2007). Ayers and Haque (2008) stated that the Bangladesh coastal area may be the front line of climate change impact and response in South Asian countries.

The coastal belt is playing an important role in increasing in the country's GDP, as one third of GDP is dependent on the country's agriculture sector. While Ali and Wakatsuki (2002) show agriculture contributed 32% to the GDP sector for Bangladesh and 72% of this contribution comes from rice cultivated areas, BBS (2002) declared that the modern varieties of rice are covering about 62% of total rice areas that contribute to about 77% of the total rice production in Bangladesh (BBS,2002, p1184). It is therefore important to show the impact of climate change on rice production in the coastal belt, as rice production plays a major role in the country's GDP.

However, a quarter of the population of Bangladesh lives in the coastal area and the majority of the population is reliant on, or affected by, coastal agricultural activity. For example, Bangladesh could lose 15% of the land mass and up to 30 million of people could be refugees with a 1-meter sea level rise in coastal area of Bangladesh. Such a condition may lead to a decline in the country's GDP from 57% to 27% through the reduction of crop production. The main cause of predicted lower GDP above is for the decreasing of crop production in the coastal area of Bangladesh due to recent climate changes. OECD in 2003 compared the risk of coastal resources with other resources in Bangladesh due to climate as shown in Table 10.

Table 10: Climate risk assessment parameter

Resource/ranking	Certainty of impact	Timing of impact	Severity of impact	Importance of resource
Water resources(flooding)	Medium-high	High	High	-
Coastal resources	High	Low	High	High
Human health	Low-medium	Medium	Medium-high	High
Agriculture	Medium	Low-medium	Low-medium	High

Source: OECD, 2003

On the other hand, Haque (2006) assessed the severity of the impacts of climate change on rice production; his report may be more reliable for showing the impact of climate change on rice production than the OECD comparison. Haque (2006) used data from 4 major districts in

Bangladesh and tried to analyze the type of natural hazards in the coastal belt compared to other districts in Bangladesh, while the OECD report was based on their own project area in Bangladesh. Haque (2006) showed that the Meghna estuary islands are constantly changing shape and position as a result of river erosion and new alluvial deposition. In addition, the most significant hydrological feature in the coastal area of Bangladesh is the seasonal flush flooding (up to 90 cm) which effects about 64% of total coastal belt and high tide during summer season may rise up to 1.3 m above the general ground level for the regular alteration of fall/rise of sea water level. As a result crops are damaged by flooding and high tide as well as salinity intrusion. Dewan *.et.al.*,(2003) showed the historical statistics of damage to crop production (Table 11).

Table 11: Historical damage of crops due to flooding in Bangladesh

Years	Crop damage in central coastal belt (Thousand tonnes)
1953	0.6
1954	0.7
1956	0.5
1962	1.2
1966	1.0
1968	1.1
1969	1.2
1970	1.4
1974	0.4
1980	0.7
1984	1.5
1987	3.2
1988	3.1
1998	4.5

Sources: BBS, 2000

Rahman & Parkinson (2007) tried to analyze the relation between crop production and soil fertility for the changing climate pattern, but their study did not mention any climate change parameter that may affect crop production and they emphasized farmer’s decision making support and economic analysis. However, farmer decision making may depend on the change of

climatic parameters; for example, if farmers cannot sow the Aman rice at the proper time due to the early flooding in the coastal belt region in Bangladesh, this is an important issue for the analysis of the relationship between crop production and climate change in Bangladesh which was ignored in the Rahman & Parkinson (2007) study.

Rahman and Salam (2007) developed a suitability layer for crop production in a few districts (Northern part) in Bangladesh that may able to show the relationship between soil characteristics and crop production under the different situation (high, medium and low level of crop growth suitability). Rahman and Salam (2007) used GIS techniques for presenting the relationship between inundation land type, soil toxicity, depth of ground water level and three basic crop seasons in the northern part of Bangladesh. Although their (Rahman and Salam, 2007) study was short and did not consider other relevant parameters, CCC (2009) used more climate change parameters for showing the adaptation options for climate change in the coastal area of Bangladesh. The CCC (2009) research was only in the western coastal area of Bangladesh. For example, the CCC (2009) study results show the T-Aman rice season is still coping with salinity in the coastal area, as this is a saline tolerant crop but it may be affected by future rainfall changes. It was assumed that if rainfall increases, Boro rice will affected by salinity. However, under the HadC50 and HadC70 scenarios different cultivars of Boro rice yield will decrease by 14-15% and 15-18% respectively. BRRI Dhan45 and BRRI Dhan47 behaved similar but for the latter cultivar yields were higher (CCC 2009, p67).

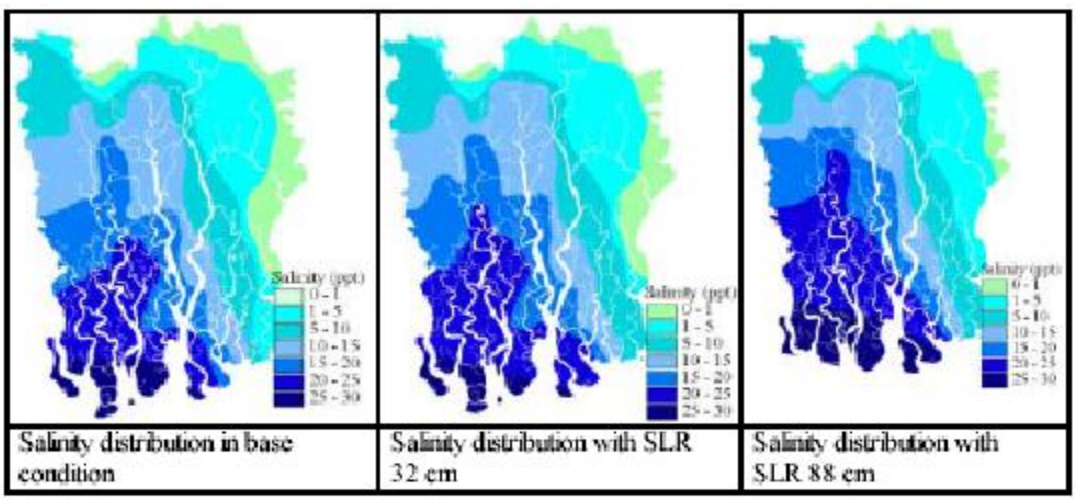
However, DSSAT crop simulation models for overall Bangladesh show an increase of rice production with the increases of temperature, but for both T.Aman and Boro rice, the rises of CO^2 in atmosphere of 515 and 575 ppmv will have a negative influence on rice production (CCC, 2009). In addition, the CROPSUIT model was applied in the South Eastern part of Bangladesh Hassan (2008). The model results considered two distinct sea level rises (Table -12) and suggest a more suitable method for analysis of the impact of sea level rise under different land use scenarios and later CCC (2009) was able to use this suitable method to identify climate risk for sea level rises under various land uses including the elevation scenarios (Fig 8).

Table 12: Area of flooding in Bangladesh under two scenarios

Condition	Area of land class by flood depth (sq km)					
	Dry	0-30 cm	30-90 cm	90-80 cm	180-300cm	>300cm
Year 2000	1058	534	1009	515	200	1
Sea level rise 32 cm	836	444	1007	710	318	2
Sea level rise 88cm	537	279	878	1011	541	71

Sources: CCC, 2009, p19

Fig 8: Scenarios for sea level rises in Bangladesh as predicted



Source: CCC, 2009,p20

In addition, salinity intrusion from sea level rise assists in decreasing rice production through the degradation of soil quality (Hossain, 2010). Coastal inundation reveals that the shoreline retreats as low-lying areas are gradually submerged by ocean water. Rahman, 2008, p 5) show that 11 % (4,107 km^2) of the land area would be inundated by the year 2100 for an 88 cm sea level rise in Bangladesh coastal area. Therefore, a 32 to 88 cm sea level rise can cause surrounding water level of coastal polders to increase by 30-80cm (Rahman, ,2008, p 6) where, OECD (2007,) suggests that “Changes in future flood frequency and extent will impact on agricultural yields but

further analysis is necessary to quantify their impacts" (Tanner *.et.al.*,2007, p50). Meanwhile, the major impact of sea level rise on rice production would cause flooding and salinity intrusion (Table 13) on five categories of land in Bangladesh where, coastal belt fall on F2, F3 & F4 categories, that is the most vulnerable part of Bangladesh (Faysal and Parveen, 2004, p491).

Table 13: coastal belt's flooding scenarios for sea level rise in Bangladesh

Type of floods	Description	Flood depths	Area(Mha)	Nature of flooding
F0	Highland	Not flooded	4.199	Flooded up to 30 cm
F1	Medium highland	30-90cm	5.099	Seasonal
F2	Medium lowland	90-180cm	1.771	Seasonal
F3	Lowland	Over 180cm	1.101	Seasonal(<9 months)
F4	Lowland/very lowland	Over 180cm	0.195	Seasonal(<9 months) or per annual

Sources: Faysal and Parveen, 2004

However, the IPCC (2007) report mentions the shift of a large portion of F2 category land into F3 & F4 by the end of 2050 (Faysal and Parveen, 2004, p492). The Bangladesh coastal belt is also vulnerable to cyclonic storm surge, especially in the central coastal belt area (Shamsudhoha & Chowdhury, 2007). From the historical analysis, the two seasons of cyclonic storm events are May and November within the peak season pre- monsoon (April –May) and Post- Monsoon (Oct-Nov) respectively. In addition, during 1891 to 1990, 700 cyclones occurred, of which 62 were in pre monsoon and 192 in post monsoon periods (Samshudhoha and Chowdhury 2007, p18). The loss of rice production due to cyclones varies annually from $2.4 billion to $4 billion. For example, 12000 hectare of coastal area standing crops were destroyed in cyclone SIDR in 2007 in Bangladesh. With the threat of cyclone, climate change impacts on the coastal area of Bangladesh will have an effect on rice production that need an urgent strategy (global to local) for reducing the future climate risk.

2.6.4. Relationship between temperature rise, rainfall, sea level rise and rice production in coastal areas of Bangladesh

There have been few studies on the Bangladesh coastal belt to show the relationship between different climate parameters and rice production. The complete studies (Roy, 1999; Razzaque & Rafiquzzaman, 2007; Roy *.et.al.*,2009; Sing, 2002; Karim, 2005; Karim and Mimura 2008) looked at the individual impacts of single climatic parameters on crop production rather than a whole set of parameters. Although CCC (2009) covers temperature rise and sea level impacts on rice production in the South Western part of Bangladesh, they are not able to show all the parameter in the same report and it did not cover whole country's coastal belt.

Firstly, temperature rise was emphasized in the studies Karim (2005); Roy *.et.al.*,(2009) and CCC (2009). Karim (2005) reported on how temperature varies among different regions was based on cyclonic storm impact on Bangladesh. Karim (2005) showed that out of 70% of cyclones, 40% of cyclones occur because of a rise of temperature. Roy *.et.al.*,(2009) focus on the moisture stress in the South coastal area of Bangladesh that may cause soil moisture deficit in particular seasons and thus variation of the yield of the main rain fed crops in coastal areas. In addition, temperature rise may increase the need for irrigation that may cause lower ground water level in future and contribute to future salinity. CCC(2009, p5) predicted that temperature would be increased 1.3°C to 2.6°C for the two projection years, 2030 and 2075, respectively. However, the result of crop simulation model by Faysal and Parveen (2004) shows (in Table- 14) the changing pattern of crops due to temperature rises in the Bangladesh coastal belt and CCC (2009) declared that T.Aman can tolerate higher temperature but cannot sustain more than 2˚C increase of temperature in future . However, increase of maximum temperature variation of 4˚C and 2˚C could have negative impacts on Boro and Aman rice production. In addition, a rise in minimum temperature variation of 2˚C and combined effects of maximum and minimum temperature variations can cause the reduction of Boro rice by 10.4% and above 22.87% for 4˚C variation (Basak, 2008).

Table -14: Impacts of predicted temperature change on rice yield in Bangladesh coastal areas

Simulation	HYV Aus		HYV Aman		HYV Boro		Rice Total	
	(10^6 t)	%	(10^6 t)	%	(10^6t)	%	(10^6 t)	%
Base Line 1990 (330 ppm CO_2)	0.77	-	4.02	-	6.26	-	11.05	-
330 ppm CO_2 + 2˚C	0.68	-19	3.48	-13	6.04	-4	9.46	-14
330 ppm CO_2 + 4˚C	0.48	-38	3	-25	5.81	-7	7.99	-28
580 ppm CO_2 + 0˚C	1.01	31	5.02	25	7.75	23	15.01	36
580 ppm CO_2 + 2˚C	0.87	13	4.47	11	7.49	20	15.39	21
580 ppm CO_2 + 4˚C	0.72	-6	4.06	1	7.24	16	12.05	9
660 ppm CO_2 + 0˚C	1.08	40	5.33	33	8.17	30	16.19	47
660 ppm CO_2+ 2˚C	0.94	22	4.76	19	7.95	27	14.56	32
660 ppm CO_2 + 4˚C	0.48	4	4.37	9	7.69	23	13.24	20

Source: Faysal and Parveen, 2004

On the other hand, Karim *et.al.*,(1999) investigated the level of moisture stress on the rice grown in the Boro season under the baseline climate of 1990 and showed that moderate moisture changes of up to 30% can cause the reduction of crop yields by 1% to 4% of the base year 1990 while, higher moisture stress up to 60% will drop yields by 10% to 33% (Faysal and Parveen , 2004)

Secondly, rainfall patterns are changing and winter rainfall is likely to increase by 3.8 to 10.4% by the year 2030 (Roy .*et.al.*,2009). CCC (2009) described the sustainable capacity of T.Aman rice due to rainfall changes and the impact of salinity due to sea level rises results in lower Boro yield. However, CCC (2009) also predicted pre and post monsoon rainfall pattern due to climate risk in future. Monsoon rainfall is also predicted to increase by 2075, but the variation of rainfall pattern is related to this increase. Roy .*et.al.*,(2009) showed the huge changes of post monsoon (6.2-17%) rainfall increase by the year 2030 and 2075 and lower variations of pre monsoon rainfall that can cause an unavailability of water in rice planting periods. In addition, winter rainfall is likely to increase by 3.8 to 10% by the years 2030 and 2075 relatively. Thus, rainfall change may cause problems for growing plant and harvesting of rice in every single year (Sing, 2002).

Thirdly, the coast line is vulnerable to rising sea surface temperature and sea level rise. Generally, the Meghna estuarine area is a flood and cyclone prone area, where sea surface temperature is an important factor for rising flood risk and the increase in storm surge height. For example, Alam (2003) shows the cause and trend (Table-15) of the predicted sea level rise in the Meghna estuarine area in Bangladesh, while, Karim and Mimura (2008) calculated the future sea level rise due to higher sea surface temperature by using DEM data. Karim and Mimura (2008) study showed a 2°C variation of sea surface temperature and 0.3 meter sea level rise increase flood risk by 15% more than current (10%) and depth of flooding would increased by as much as 22.7% within 20km of coast line in the Bangladesh. Karim and Mimura, (2008) assumed maximum water level in the coastal area as well as high flood prone area, flood level and flooding depth in the study area that may overestimate climate risk results for future prediction. However, their study input data was computed with the distance and maximum surge, flooding and depth and was based on only western coastal belt data in Bangladesh because of lack of proper DEM resolution across the whole coastal area in Bangladesh. Karim and Mimura (2008) study considered only climate parameters as an input in their model to identify future climate risk of SST and SLR. Therefore, CCC (2009) used DEM data as an input in their GIS model for the identification of future rice production vulnerable area and future climate change scenario (impacts of temperature rise, sea level rise and salinity intrusion). The results (Table 16) of CCC (2009) study of SLR on rice production show the impacts on the basis of high, medium and low land that was subdivided on the basis of the DEM data. However, the CCC (2009) study indicates it is almost impossible to get a sensible future estimate of SLR due to the sedimentation area in Bangladesh coastal belt, as

> "Predicted 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" (CCC, 2009).

On the other hand, lower predicted values of sea level rise and impacts of climate change on rice production may be ignored, as the IPCC (2007) shows the future sea level rise from 9-88 cm by the year of 2100 and a non linear rate of increase of greenhouse gases in the atmosphere will increase the SST that may raise sea level by 2-20 cm by the year 2025 and from 4-59 cm by the year 2050. Then the net sea level rise will be 4.5-23 cm in 2025 and 6.5 to 44cm in 2050. As a result, the impacts of SST and SLR may be more than present predictions. However, rainfall changes and temperature changes have a major impact on flooding and sea level rises and this is an important issue of flooding and natural disaster in the coastal area of Bangladesh. All of these above impacts of climate risk are important in identifying in the future climate risk for crop production.

Table-15: Increase trend of tidal wave in Meghna Estuary in Bangladesh results from major sea level rise impacts

Tidal station	Region	Longitude(N)	Latitude(E)	Datum (M)	Trend(mm/year)
Hiron Point	Western	21°48	89°28	3.784	4.0
Char Ganga	Central	22°08	91°06	4.996	6.0
Cox’s Bazar	Eastern	21°26	91°59	4.836	7.8

Sources: Alam, 2003, p9

Table 16 (a, b, c and d): CCC study results of SLR impact on coastal belt

Table 16 a: Scenarios of Aman rice non-suitability in future

Scenario	Highly suitable area	Suitable area	Moderately suitable area	Not suitable area
Base	0	84	14	2
32cm	0	60	24	16
88cm	0	12	57	31

Source: CCC, 2009

Table 16 b: Scenarios of Boro rice non-suitability in future

Scenario	Highly suitable area	Suitable area	Moderately suitable area	Not suitable area
Base	10	36	43	11
32cm	0	6	37	57
88cm	0	6	33	61

Source: CCC, 2009

Table 16 c: Paddy production (kg/capita/year) under different sea level rises

District	Paddy production (kg/capita/year) under different sea level rises		
	Base year 2005	SLR 32 cm in year 2050	SLR 32 cm in year 2100
Bagerhat	287	77	5
Khulna	123	52	14
Satkhira	298	161	70

Source: CCC, 2009

Table 16.d : Paddy production (kg/capita/year) under different adaptation options

District	Paddy production (kg/capita/year) under different adaptation options				
	SLR 88	clousre	Augmentaion of Goral flow	Ganges barrage	Embankment rising
Bagerhat	5	132	69	106	2
Khulna	14	136	60	81	30
Satkhira	70	272	165	212	69
Average	30	180	98	133	33

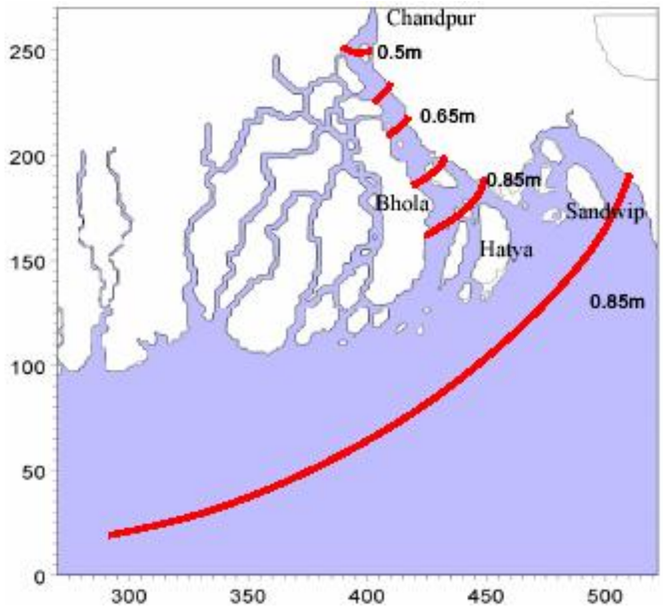
Source: CCC (2009)

Fourthly, sea level rise and salinity intrusion are closely related with each other. In addition, salinity intrusion may also occur because of over irrigation of water & cyclonic storm surge. Karim and Mimura (2008) noted the Bangladesh coastal belt is delineated based on three criteria; tidal fluctuation, salinity intrusion and cyclonic storm surge, Haque (2006) shows the cause of salinity in coastal area of Bangladesh is mainly involved with the movement of salt

through the river channel in the winter season, shrimp cultivation particularly in the south western area, changing shape of estuarine islands and water logging in the dry season in the south western coastal belt. Although there has been limited study on the central coastal belt salinity intrusion, the main cause of central coastal belt salinity intrusion is linked with tidal surge, cyclone, sea level rise and irrigation water (Roy, 1999, p115). However, the impact of salinity is severe in rice production and CCC (2009) suggest that the T.Aman & Boro rice may tolerate 88 cm sea level rise , but *"Crop cultivation in the salinity area is a risky venture, as an increase in the salinity level makes rice crops sterile" (CCC, 2009, p34).* The saline resistant varieties of T.Aman & Boro rice may need maximum rainfall for the increase of production under sea level rise. The CCC (2009) study was based on adaptation options and suggests an increase of T.Aman and Boro rice production may occur under salinity intrusion and sea level rise conditions. Hossain (2006) presented the historical data that shows the quantity or trends of soil salinity in crop yields (4.5-8.5 ds/m) and fallow lands (5.5-15.5 ds/m) in the central coast of Bangladesh can assist to reduce average crop production in future. The CCC (2009) adaptation options for saline tolerant rice may be dependent on the maximum rainfall pattern, as the pumped water salinity varied from 4.25 to 7.00 dS/m and results in the lowest grain yield of Boro production of 4.36 t/ha for the whole Bangladesh coastal belt. On the other hand, medium saline zone pump water salinity varied from 0.8 to 1.5 dS/m and fluctuations of crop production are varied and depend on the rainfall pattern (Hossain, 2006). So, the uncertainty of maximum saline tolerant rice variety is still a question related to adaptation options in Bangladesh coastal belt area.

Therefore, food production in Bangladesh may not improve due to future climate change and the close relationship between temperature rise, sea level rise and salinity intrusion with rice production. PRDI (2009) stated in their climate change brief report that there will be a 10% reduction of rice by the year 2050 using IPCC (2007) simulated similar results. In addition, PRDI (2009) also showed the reduction of rice production under IPCC estimated sea level rise in future in (Fig- 9) and Ali (2005) showed (Table- 17) a four major period of low rice yield in Bangladesh history for the impact of sea level rises in Southwest coastal area of Bangladesh.

Fig: 9- PRDI Sea level estimation under IPCC prediction



Source: PRDI, 2009

Table-17: Decline of rice yield because of soil degradation results from sea level rise impacts

Crop (Months observed)	**1985**	**1990**	**1995**	**2003**
	Area under rice (ha) (% of crop land)			
Aman (HYV); July – November	345.5 (100)	344.6 (100)	332.4 (97.0)	314 (91.9)
Boro (HYV); December - May	200.4 (58)	269.6 (78.2)	122.4 (32.8)	58.2 (17)
Expected total rice production	1373	1689	1679	1673
Observed total rice production	1265	1260	745	522
Decline in rice production due to loss of Area	108	221	670	890
Decline in rice production due to yield loss	-	208	264	261

Source: Ali, 2005, cited in Hossain 2010, p79

2.7. Uncertainty of the model results

Estimates of climate change impacts in the coastal belt area on rice production could be biased depending upon the uncertainties in climate change scenarios, region of study, crop models used for impact assessment and the level of management. Therefore, the importance of showing different uncertainties is necessary while assessing the impacts of possible climate change on crop production.

The Earth's environment is continuously changing due to the rising temperature, solar radiation, cloudiness, but GCM models are less consistent in climate change predictions, particularly on a regional basis (Mitchell *.et.al.*,1995; IPCCC, 2001; Basak *.et.al.*,2009; CCC, 2009). At regional scales this uncertainty is especially observed. For example, IPCC (2001) announced the global temperature rise and sea level rise would be higher by the year 2050 and 2075, but in Bangladesh the scenario is different and much higher by the year of 2025 and 2050 than the IPCC estimation based on various studies (CCC, 2009, Basak, 2008; Basak *.et.al.*,2009, Ali and Wakatsuki, 2002). It should be noted that the projected changes of climate elements by the end of the 21st Century are sensitive to assumptions concerning future concentrations of greenhouse gases (Mall *.et.al.,2006*, p464). The main causes of the uncertainty are subject to upward and downward movements of climate parameters in different regions and in Bangladesh, these uncertainties are caused by a lack of proper research and the input of climate parameters in GCM activity.

Models (GCM, DSSAT3.00) results show the different temperature rise predictions for Bangladesh may result from the use of different methods or use of different data. In 1994 BUP-CEARS-CRU first attempted a study of GCM models for Bangladesh and their result shows a 0.05 ˚C to 2˚C temperature rise by the year 2030 as well as 10-15% increase of precipitation. Karim *et.al.,(*1999) and Habibullah. *et.al.,(*1998) used GCMs and the different prediction results shows the variation of temperature in different projected years. Uncertainty of model results also increased when people started to use models more specifically (regional basis or seasonal

analysis). For example, an ADB (1994) study of 4GCMs (CSIRO9, CCC, GFDLH & UKMOH) shows the increase of monsoon rainfall and decrease of dry season rainfall for 2010 and 2075 respectively. In addition, the ADB study shows 0.3C temperature rise by the year 2010 and 1.5C by the year of 2075.

The uncertainty also varies upon the basis of the projected year. Ahmed and Alam (1998) used the same methods as ADB (1994) and their results show an increase of temperature of 1.3 C to 2.6C by the projection years 2030 and 2075 respectively, dry season rainfall changes are negligible and monsoon rainfall is increased by about 12% and 27% for the respective years 2030 and 2075. However, Mirza (1997) tried to correlate the Ahmed and Alam (1998) results with ADB (1994) study showing that the mean rainfall over Bangladesh would increase with global warming.

Agarwala (2003) used the MAGICC driven SCENGEN database to produce a best estimation ensemble of 11 GCMs and the results were obtained using the IPCC B2 SRES scenario and suggest the increase of annual temperature would be up to 1.4˚C and 2.4˚C by the projection years of 2050 and 2100. In addition, dry season precipitation was projected as 1.7% and 3.0% reductions for the respective projected years, as well as the increase of monsoon precipitation up to 6.8 and 11.8% by the years 2050 and 2100. However, unlike other GCM outputs Chaudhury *.et.al.*,(2005) obtained results using HadCM2 regional model suggesting a high increase in pre-monsoon and winter precipitation in Bangladesh.

Roy *et.al.,(*2009) estimates of the moisture stress on crop production obtained from CROPWAT coupled with MAGIC/SCENGEN in the western region of Bangladesh show the high temperature and rainfall in all seasons and especially unpredictable rainfall at the starting time of planting seasons and resulting irrigation may reduce the crop yield, Basak *.et.al.*,(2009) used the DSSAT3.0 model for calculating impacts of climate change on rice production in several regional areas of Bangladesh including some east and west coastal belt areas.

Bansak.*et.al.,*(2009) found that increasing daily maximum and minimum temperature can reduce crop yields. Variation of rainfall pattern over the growing period of rice also has some negative effects on rice yields. Basak .*et.al.,*(2009) worked on the particular rice variety that shows the reduction of yields of over 20% and 50% for the years of 2050 and 2070. So, although, there are significant uncertainties in the predicted climate parameters, the crop simulation model results show a decline of rice yield for the increases of temperature, rainfall pattern as well as changes of solar radiation. DSSAT modeling system is an effective tool for showing the impacts of climate change on rice production, as all climate parameters can be imputed at the same time in the DSSAT software based on crop production parameters (soil, phosphorus, production, yield, etc).

2.8. Discussion & Conclusions

The current GCMs still have a good deal of uncertainty. The ability of current GCM's in predicting the impact of climate change on rainfall that is still not promising. In addition, there is uncertainty involved in predicting extreme flood and drought events by models. There is a considerable uncertainty in the projected temperature change and rainfall in Bangladesh, as the climate change is different from overall global parameters. Climate change impacts in Bangladesh depend on the location of the area and where close to sea or river area. For example, the amounts of rainfall changes in Bangladesh in the monsoon period is much higher than in pre monsoon seasons for the combined effects of precipitation and sea level rises as well as temperature changes (Basak, 2008, p4). However overall in Bangladesh 60% of rice production is still dependent on monsoon rainfall as well as soil fertility and flooding depth (Sing 2002; Roy .*et.al.,* 2009). Therefore, due to the potential adverse climate impact on agriculture and the dependency of local and regional agriculture on climate parameters, it is necessary to conduct more in-depth studies and analysis to gauge the extent of problems that the country may face in future. So, there is a need to focus on how the possible climate change will affect the intensity, spatial and temporal variability of the rainfall, surface and groundwater availability for irrigation, evaporation rates and temperature in different agro-climatic regions. For this more studies are needed on direct or indirect effect of climate change on crop growth, uncertainties of onset of rainfall, spatial and temporal rainfall variability, duration and frequency of floods, availability of

irrigation, changes in ground water level, soil transformations, crop-pest interaction and submergence of coastal land due to sea level rises under several models or statistical analyses.

Ahmed and Alam (1998) and Mirza, (2005) showed the asymmetry in the temperature in the dry and winter seasons all over Bangladesh; the observed warming was predominantly for the increase of maximum temperature while minimum temperature in winter season was unchanged for the past century. Mirza (2005) also projected that there is likely to be a substantial increase in extreme maximum and minimum temperatures all over the country due to increase in green house gas concentrations. In addition, IPCC (2001, 2007) also reported that global average temperature would be increased by 1.5 -2˚C by the 2030 for the expected green house gas increases. Bangladesh already faces a 0.6m sea level rises in coming decades resulting from rising temperature and the resulting ocean expansion and glacier melting (Karim and Mimura,2008).

The very important finding from an agricultural point of view from the Basak *.et.al.,*(2009) study of the impact of climate change on Boro rice production is the increase of temperature and C02 concentration is helping to increase the rice production but there is a limit of the temperature rises at 6˚C. In addition Roy (2009) shows the rising monsoon season temperature may be good for increasing Boro rice production but this will need irrigation from ground water that makes the situation in future more vulnerable to salinity intrusion and destruction of soil structure (Rahman and Parkinson, 2005). On the other hand, Harun *et.al.*, (2008) showed the historical natural disaster events as well as increase of temperature will lead to more frequent cyclones in the coastal belt that will destroy the crops. However, Karim, (2005); Ali and Wakatsuki, (2005), APEIS, (2006) showed that the sea level rises are causing pre monsoon and post monsoon flooding as well as water logging, flash floods and salinity intrusion that is decreasing crop yield. So, extreme climatic events, abnormal temperature in a specific rice development stage, caution us to identify suitable management options for climate change risk reductions.

The uncertainty of climate change impact is much greater in local areas than in national summary situations like the case of the low-lying coastal belt in Bangladesh. APEIS (2006); CCC, (2009), and Hassan, (2012) particularly show this for climate change impacts on rice production in the western coastal belt and central coastal belt. APEIS (2006) showed the rice production is dependent on monsoon rainfall and in some worst cases of natural disasters, farmers cannot take their rice off from the field. In addition, APIES (2006) also showed that the farmer who plants Aman rice in the pre monsoon seasons with low rainfall results in the higher quantity of husks. However, low yield also has been observed form Boro rice resulting from short length in the paddy field due to the pre monsoon planting. While, CCC (2009) showed the impact of temperature rise, salinity intrusion and sea level rise on three major crops (Aus, Aman and Boro) is much higher along the 53180 km in the coastal belt of Bangladesh, Ahmed (2006) showed the overall crop production in a particular year is reduced for the different planting period chosen by farmers due to current climate risk.

The total average impacts may be positive or negative depending on climate scenarios (temperature variation rising in 2˚C or 4˚C) increased CO^2 concentration. Impacts also vary both qualitatively and quantitatively by crop, level of agro-economic management, region and season. Seasonal (winter, summer, and monsoon) impacts in coastal area of Bangladesh will need to be assessed. Various recent studies (Roy *.et.al.,*2009, CCC, 2009, Hassan, 2012) show the overall negative impacts of climate change on coastal area of Bangladesh by 2025 and 2050. By the year 2100 temperatures will be high and changing monsoon period will extend to the Bangladesh coastal belt. In other words, it can be said that food production will not only be threatened up to 2025 and 2050, but crop production will be a major issue in the years 2080 and 2100.

Chapter 3: Study Area and Methods

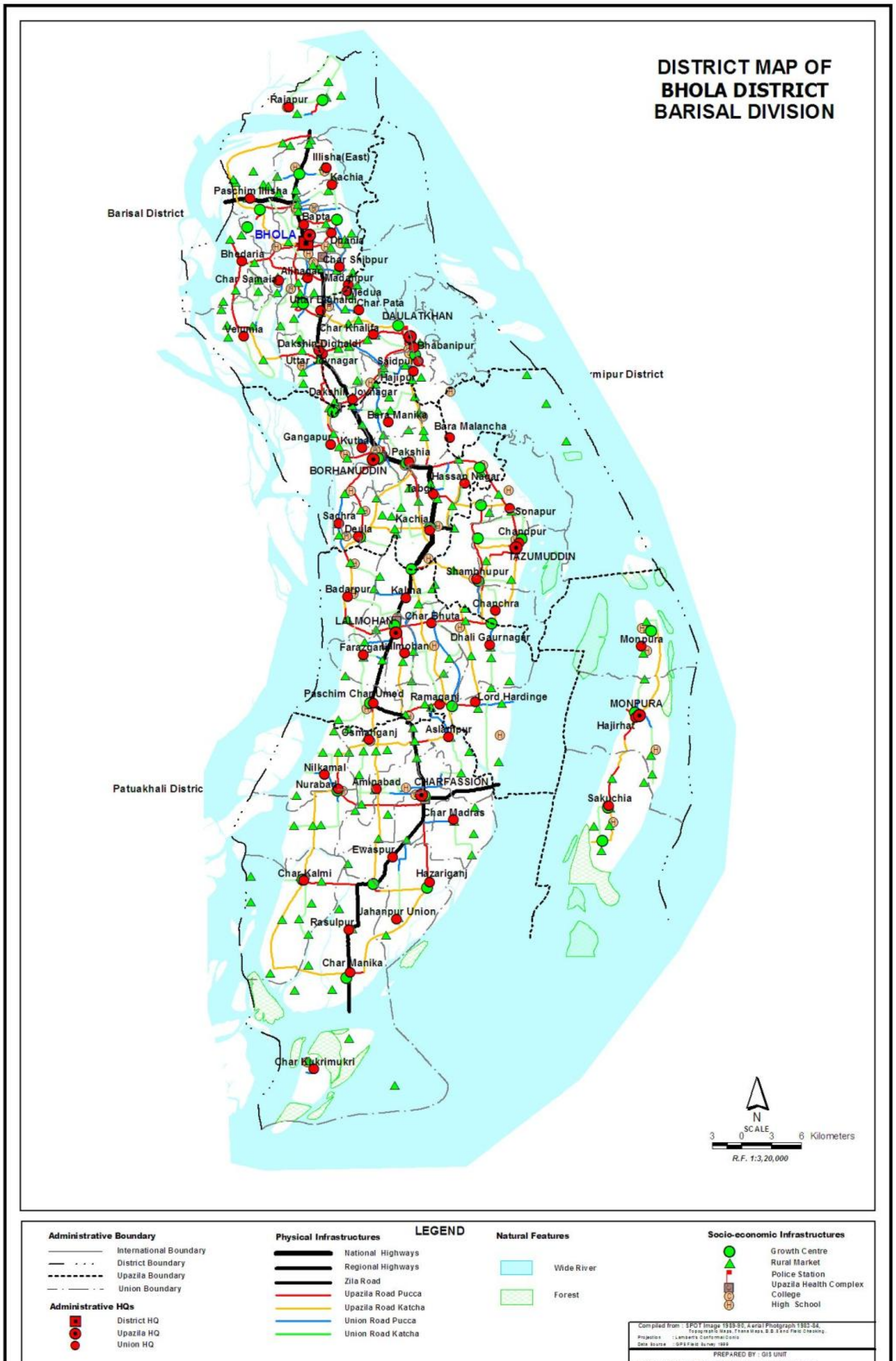
3.1. Introduction

Most rice growing and disaster prone zones were priority for the selection of study area. As this research is going to assess the impacts of climate change on rice production, 'disaster prone area can help to define the happenings of the climate change on food production in the study area. For example, rising temperature and excessive rainfall can show the change of climate pattern. The study location is near to Bhola's southwest coastal belt in Bangladesh and climate change impact is affecting the area with flooding and salinity intrusion most visibly, and with other indirect factors. In addition, the study area is densely populated area in Bangladesh that is important consideration for choosing the study area. The total population of the Bhola island is 1.6 million and their economy depends on the climate, as most of them are farmers.

3.2. Salient features of the study area

The study region comprised a part of the lower catchments of the Young Meghna estuaries in Bangladesh. The area is in the south-west region in Bangladesh (Fig-10). Bhola District is an offshore island with an area of 3403.48 sq km, bounded by Lakshmipurand Barisal districts on the north, Bay of Bengal on the south, Lakshmipur and Noakhalidistricts, Meghna (lower) river and Shahbazpur Channel on the east, Patuakhali district andTentulia River on the west. It lies between 21°-54ˈ to 22°-52ˈ North Latitudes and 90°-34ˈ to 91° East longitude. The study area is situated in the West of Lakshimipur, Ramgati, Alexender, Char Bouya, Maulavir Char, Noakhali,Hatia, Nijhum Dwip areas, East of Barisal Sadar Upazila of Barisal district, South of Ganeshpura Done / River and Mehendiganj Upazila, Bakerganj, Bauphal, Dasmina (Barisal Zila) and Galachipa (Patuakhali Zila) and North of the Bay of Bengal. Annual average temperature varies between highest 32.70C and lowest 11.60 C and annual rainfall is 2360 mm (Hossain, 2010, p17) .The perimeter of the area is 212.50 km. (EGIS, 1997). In addition, the total 340348 ha / 3403.48 km² area in the study area of which 113346 hectare is riverine and 16540 ha is under forest (BBS; 1991).

Fig-10: The map of Bhola district in Bangladesh



Source: LGED , Bangladesh

However, Bhola has many small islands called Char land. Coastal islands and chars are one of the least known geographical entities of Bangladesh for many reasons, e.g, regular erosion and accretion of chars and islands, problems in mapping and information collection, remoteness and inaccessibility of the chars. Information on different chars and islands are collected by different projects and initiatives of government and non-government organizations. The number of char lands in Bhola district is given below.

- Balur Char: No data
- Char Aicha (2463 acres / 997 ha (BBS, 1991).) Demography: Population: 6338 (1991); Households (HHs): 1322: Occupation: Mainly farmer and fishermen
- Char Chakrimara 2764 acres / 1119 ha (BBS, 1991). Population: 814 (1991); Households (HHs): 145: Occupation: Agriculture, livestock and fishing
- Char Darbesh: No data
- Char Dhal: 5 sq km. Population: 10000 (2001), Households (HHs): 1325
- Char Kabir: No data

3.3. Topography & landscape in the study area

The study area is at an average elevation of 3 meters above mean sea level and in gently sloping towards the south. The soil texture is categorized as a dominantly sandy calcareous alluvium type of soil (Table-18).

Table- 18: Soil type information for Island Bhola

Type of soil	Bhola
Sandy (% of land)	6
Sandy Loam(% of land)	77
Loam (% of land)	16
Clay loam(% of land)	1

Sources, LGED, 2009, p17

Generally, the soil is sandy loam to loam in nature with percent of calcareous soil being more than 80%. However, due to river erosion of the main land, it is very common for land to emerge in the middle of the river (called char). The soil condition of the char islands is generally sandy and partially sandy loam that is favorable for certain crops like ground nuts, pulses, etc. In sandy soils farmers grow water melon, sweet gourd, ground nut and in sandy loam sow rice, pulses, wheat. All crops grow well in loamy soil but clay soil is also suitable for rice cultivation. The area is mainly low and medium low land (Table-19) in comparison with the rest of Bangladesh. The available moisture contents top soils in the study region are listed in Table 19.

Table 19: Soil moisture contents in the study area is below

Agro-ecological zone	Inundation land type –Percentages of area in hac			
Young Meghna Estuarine Floodplain	Available soil moisture	High land (%)	Medium(%)	Low(%)
	100-200 mm	0	11.15	12.09
	200-300 mm	0	19.55	1.442
	300-400 mm	0.15	55.14	0.466

Source: BARC, 2010, AEZ (Agro Echological Zones Datasets from BARC)

As the study area is near to the Meghna estuary and it is good for agriculture, the available moisture of soil and silt deposits may contribute to good agricultural production (SRDI, 2007). However, the area is in a low-lying delta region and the risk of flooding is an important issue that may affect agriculture production. The area is vulnerable to flooding according to the flood depth measured in the lower part of Meghna Basin in Bangladesh as shown in Table 20.

Table 20: Flooding depth in the study area

River basin	Percentages of area in hectare			
	Flooding depth	High land	Medium land	Low land
Lower Meghna River Floodplain	No Flooding	0.15%	-	-
	Flooding < 0.3 m	-	30.87%	-
	Flooding 0.30-0.91 m	-	54.96%	-
	Flooding 0.91-1.83 m	-	-	9.92%

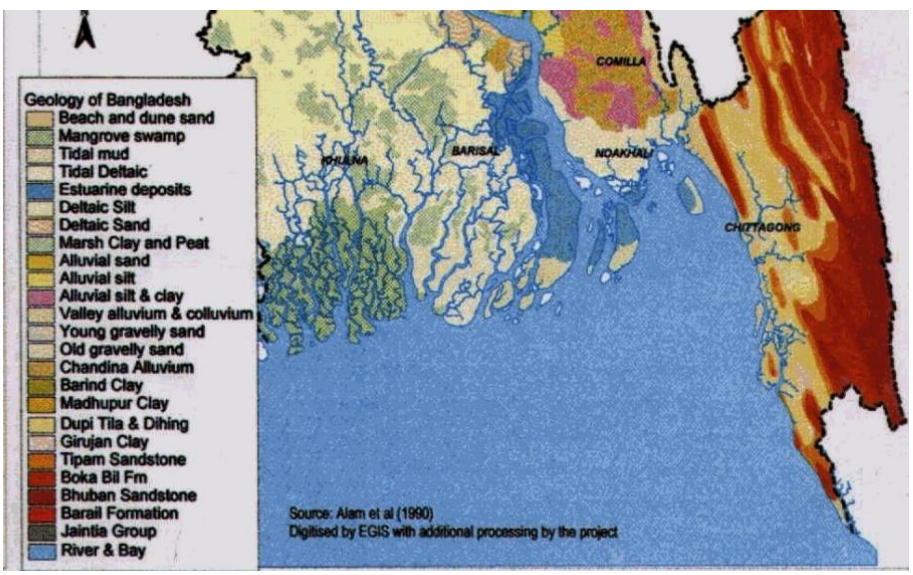
Source: BARC, 2010 datasets from BARC

In addition, the annual average temperature in the study area has a high of 32.7°C and a low of 11.6°C; average annual rainfall is 2506 mm per year (BBSdata-2001). Besides, average wind speed is 2.3 to 3.1 m/s. This area is highly vulnerable to cyclonic disasters (Kumar, *et.al.,* 2004,). However, the lowest low lands are in a flat terrain zone. Therefore, excessive runoff in the river Ganges and Meghna combined with local rainfall can cause over bank spillages as well as floods.

3.4. Geology

According to the published map 1:250000 scales (Fig- 11), the major part of the land in the study area is underlain by estuarine deposits while a small portion in the west is underlain by deltaic silt. The soil is sandy as well as sandy loam type and mostly alluvial land which is good for agriculture.

Fig-11: Geological condition in the study area



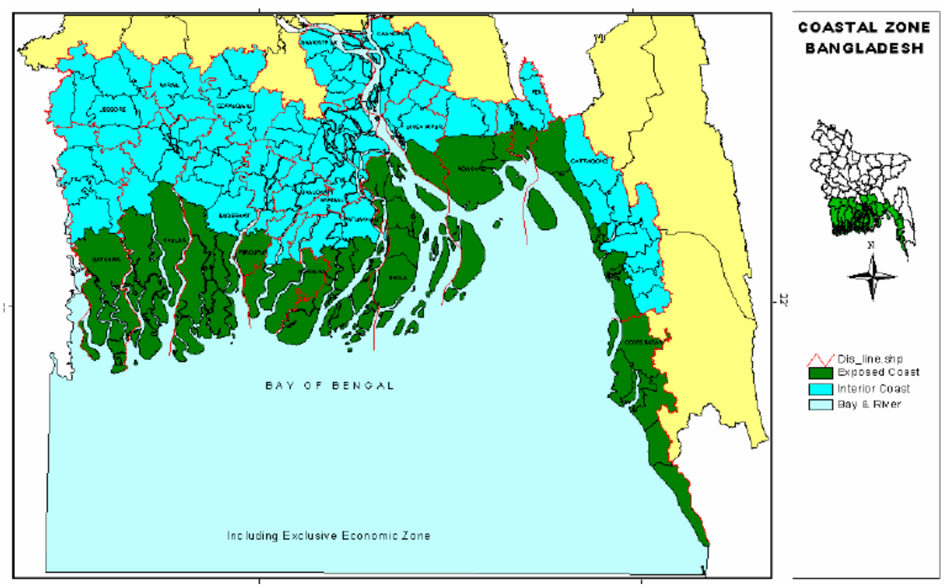
Source: SRDI, 2009

Sediments are deposited at the banks of the rivers which makes more agricultural land and enriches agricultural land too. It helps to produce more crops and maintain ecological balances. However, the area is geographically most volatile, where sediments carried by the rivers and floodwaters are primarily responsible for the formation of the char lands and river bank erosion which can cause changes of river flow.

3.5. Hydrology

Bangladesh is highly vulnerable to climate change and extreme events are common phenomena in coastal exposed areas. As, Bhola is situated in the mouth of the Bay of Bengal and is surrounded by rivers (Fig-12), it is highly vulnerable to natural disasters. Considering elevation alone, even a one-meter rise would swallow about 15 to 20 per cent of Bangladesh's land area, where about 20 million people live today. Such estimates can, however, be misleading, since they leave out some crucial factors (Atiq and Nishat, *2009). Such as, the lack of infrastructure, lack of immediate disaster response by government and economic conditions of farmers etc (CEGIS, 2006)*

Fig :12- Hydrology in coastal districts in Bangladesh



Source: Islam, 2004

The area is physically vulnerable to sea level rise, as tidal surge is increasing (IPCC, 2007). In addition, as the area is situated usually less than three meters above the sea level, the area is vulnerable to sea level rise. However, tidal flooding through a network of tidal creeks and drainage channels connected to the main river system inundates the soil and impregnates them with soluble salts thereby making both the top and subsoil saline. The most significant feature of hydrology in relation to agricultural development is the seasonal shallow flooding (up to 90 cm) which affects about 64% of the total area (SRDI. 2009)). In these areas, floodwater recedes from

October to late December. Depending on the topographical position and drainage facilities, water recedes from about of the 24% of the area within October, from about of the 53% area in November and mid- December and from about 23% area in late December (SRDI, 2009).

3.6. Factors affecting the choice of the study area

3.6.1. Mainly agriculture based economy area

Most of the rural people are poor or extremely poor. Livelihood opportunities include agriculture, fisheries and labor selling. The economic activity of this region is concentrated in crop production, capture fisheries, labor wages (World Bank, 2008).

Livelihood options in the study area are:

- Agriculture – Good crop producing area. All varieties of paddy including Rabi and Kharif I & II and vegetables, etc, are produced. Area is famous for guava fruit and fishing.
- Forest: Mangrove plantation outside embankment and other trees along embankment over a length of hundred kilometers.
- Livestock – (BBS,1983-84) Bovine: 314683, Ovine: 240994 & Poultry: 16725197
- Fishery- Total Ponds: 45,000. Good supplier of fish to other districts including Dhaka City.

(Source: BCAS and Caritas, 2008)

Economy of the study area is mainly dependent on agriculture is shown in Table 21 that involves especially growing aman rice, mung bean, chilli, grass pea, watermelon, hog palm, guava, fishing etc. Paddy, fish, fruits, pulses, soybean and ground nut are exported from this region. However, traditional livestock, poultry and pond fish production exists and commercialization of these products is very slow. Milk production especially buffalo milk production in Bhola is encouraging and the product is consumed in local and regional markets. The vegetable demand of the local market is very high. Most of the time, vegetables are imported from Jessore, Khulna, Magura distrcts. Landless and marginal farmers migrate to other parts of the country during the

drought and monsoon periods due to limited income opportunities in the region. Young women shift to Dhaka as garment and maid workers.

Table 21: Main income generation activities in the study area

District	Agriculture	Fishing	Agricultural laborer	Wage laborer	Business	Service	Others
Bhola	38.74%	5.9%	24.52%	4.67%	9%	4.47%	12.70%

Source: LGED, 2009, p10

Employment opportunities are mainly dependent on the agriculture sector and limited non-farm sectors. More than 80% of households depends on agriculture and they are mainly involved with cereal crop production, where 50% are involved with vegetable production and 15-20% of farmers are involved in pulse/tubers/fruit crops production.

3.6.1.1 Agriculture & cropping pattern in the study area

The area is well known for crop production. Crop production is the main source of food and cash of the study region. The farm household and the crops land in Bhola district are shown in Table 22 (a) and 22 (b). Table 22 shows the cropping type of Bhola district as well as the total cultivable and cultivate land.

Table- 22. a: Farm household and crop land in Bhola district of Bangladesh

District	Farmer HH	Total land (ha)	Single crop	Double crop	Triple crop	Total crop land	Fallow land
Bhola	264,859	409,553	21,699	85,312	76,878	183,889	829

Source: LGED, 2009,p13

Table- 22. b: Amount of land use for cultivating crops in Bhola in Bangladesh

District	Item		
Bhola	Cultivable Land (ha)	Cultivate land (ha)	Cropping intensity
	203,550	180,297	224

Source: LGED, 2009, p13

However, in Table 23 shows the main crops of the study area. These main crops are rice (T-Aman), mung bean, soybean, ground nut, chili, watermelon, tomato, country bean, okra. Aman is the main crop of the region but Boro rice and winter vegetables are growing well in Bhola, because of well irrigation facilities, soil type and land topography are comparatively good in Bhola.

Table- 23: Major crops grown in Bhola regions as well as central coastal region in Bangladesh

District	Present crops	Promising growing crops
Bhola	T-Aman, Mung, Chili, Country bean, Sweet gourd, Snake gourd, Water melon Plane dal, Ground nut,	Teasel gourd, Okra, Cauliflower, Cabbage Cucumber, Maize, soybean,

Source: DAE Annual report,2009; LGED,2009, p14

In the study area, most of the land is under cultivation in kharif II; 30% and 15% of the land is used in the Rabi and Kharif I growing season respectively. Vegetables and fruits are not available in the region in Kharif I &II seasons except for hog palm, guava and betel nut. Pulses such as grass pea, mung bean, lentil and oil crop such as soybean, ground nut, mustard are cultivated especially in the char land. Recently Boro, potato and water melon cultivation and productivity has increased. In Bhola, farmers are practicing intercropping system, such as,

chili/okra plus sweet gourd and potato plus bitter gourd. The pulse production trend is increasing in Bhola (DAE, 2009).

However, the percentages of various crop productions are shown in table 24 on which farmers and local's livelihood options are depends. In addition, table 24b shows the seasons of cropping system in the study area that is mainly depends on climate.

Table-24 a: Percentages of crop production in the study area

Crops		Production quantity (%)
Cereals	Aman	52
	Boro	11
	Aus	9
Pulse		15.34
Spices and Fruits		3.79
Oil seed crops		4.68
Vegetables		1.76
Tuber crops		1.43

Source: DAE annual report, 2009

Table- 24.b: Cropping seasons in the study area

(BARI)	Rabi (October-February)	Kharif 1 (March-June)	Kharif II (July-Sept.)
	Boro	Pulses /Spices /oilseed	T. Aman
	Potato	T.Aus	T.Aman
	Pulses	Sugercane	T.Aman
	Vegetables	T.Aus	T.Aman

Source: DAE Annual report, 2009

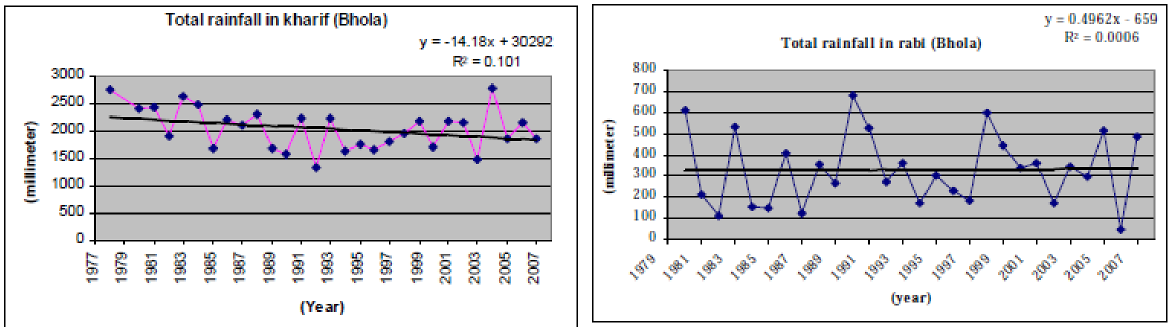
3.6.2. Influence of climate on crop production in the study area

The study area's climate is tropical in nature dominated by the south-west monsoon of the Indian Ocean (Ahmed, 2006, p7). There are three distinct season warm (from March to May), monsoon (June to October) and cool seasons (Nov to Feb) and about 15% of the annual rainfall occurs during March to May mainly as thunder storms often accompanied by strong winds (Ahmed, 2006, p3). The humidity is generally high throughout the period. In on average 75% to 80% of the annual rainfall occurs during the monsoon period (*WARPO- Halcrow et.al*, 2004). Rainstorms of several days duration characterized by relatively slow but steady rain occur during this season. Most of the destructive cyclonic storms with winds of more than 75 Km/h per hour occur during pre-monsoon and post monsoon period, i.e. April-May and November (*WARPO-WARPO- Halcrow .et.al.,2004*). The cool season is generally pleasant and comfortable. Rainfall in this season is infrequent. Increasing trends of maximum temperature in Bhola district is 1.7˚C per 100 years and trend of minimum temperature is 2.06˚C per 100 years (Islam, 2009, p7). So, trends of mean temperature in Bhola are 2.07˚C per 100 years (Islam, 2009, p7). However, there are two major cropping seasons found in the Ganges belt area Rabi and Kharif seasons (Pal, 2010). Temperature and rainfall is important for these two seasons, as plants in the field are growing depending on rainfall pattern and temperature changes.

3.6.2.1. Impacts of rainfall on crop production

The main Rabi and Kharif seasonal crops depends on rainfall. Fig 13 shows the seasonal changes of rainfall of these two seasons that could have impact on rice production. As, growing rice generally pass through the three stages(planting, maturing and harvesting periods), changes of rainfall may show the difficulty in planting and harvesting periods by flash flooding, delay planting or damage of the crops in harvesting periods.

Fig 13: Changes in annual rainfall from 1975-76 to 2005-06 in Bhola district



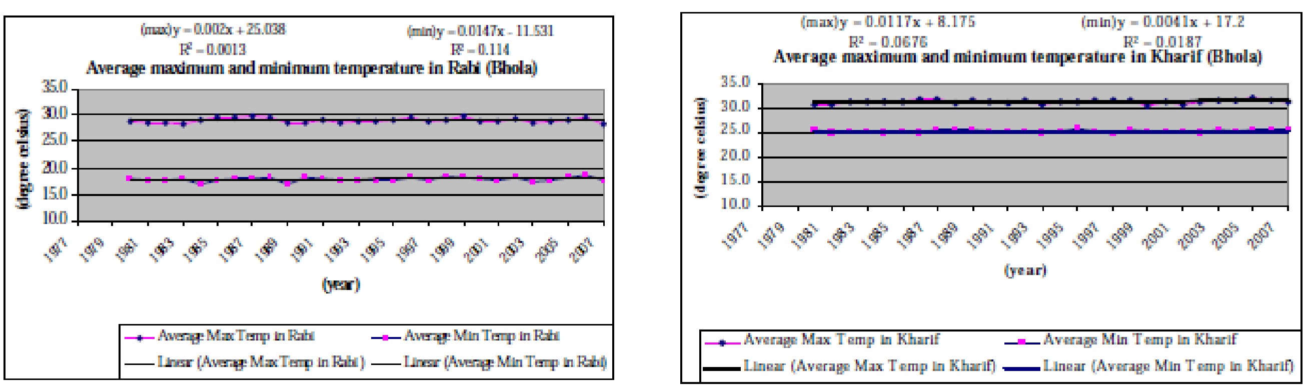
Source: BCAS, 2010, p40

In the Fig 13, total rainfall pattern in both Rabi & Kharif seasons are decreasing and that is affecting the cultivation of rain fed crops.

3.6.2.2. Impacts of temperature on crop production

Temperature increase (both maximum & minimum) in the Rabi and kharif seasons indicates global warming. During the Kharif season, the higher temperature is causing a lack of water in crop fields during the planting periods (Amin, 2001; Atiq, 2009). Fig 14 shows the changes of temperature in Rabi and Kharif seasons in the study area that could have impacts on crop productions.

Fig- 14: Changes in Temperature during 1975-76 to 2005-06 in Bhola district



Source: BCAS, 2010, p38

However, due to temperature rise, Boro plants need irrigation for drought condition in some periods. As this area is beside the coastal belt, ground fresh water level decreased for getting into saline water into silt and cause high level of salinity through the intrusion of saline water in the sandy soils (Dillenburg *et.al.*, 2008).

3.7. Factors affecting rice production in the study area

3.7.1. Climatic factors

Climate change is an important factor leading to changed cropping patterns in the study area that can easily be described from local FGDs (Focus Group Discussion) surveys by SRDI and DAE in 2007. The data showed that the average cropping intensity is not significantly increased in flood plain areas. The main reasons for conversion of agricultural land into non-crop agriculture/other purposes are expansion of water-logged areas, expansion of poultry farm, high market price of fish and poultry due to increased flooding and the destruction of crops by storm surges and salinity intrusion. The findings are shown in below in Table-25:

Table 25-Changing of cropping lands to other uses in the coastal districts (BCAS, 2010)

Agricultural land use	Land Use (ha) (1975-76)	Land use(ha) (2005-06)
Paddy (local varieties)	146970	168735
Paddy (HYV)	6150	118860
Vegetable (Summer)	875	2435
Vegetable (winter)	3200	8812
Pulses	42180	41847
Wheat	620	3414
Sugarcane	2048	397
Jute	515	60

Brickfield	0	130.5
Poultry	-	52
Fish/shrimp culture	13	3227
Gardening	-	1853
Industry	0	0
Houses	-	40
Others	0	280

Source: BCAS, 2010, p56

3.7.2. Water logging & embankment difficulties

Water logging is mainly caused by salinity intrusion and unplanned embankments in the study area. At present, embankments are protecting farmer's fields from tidal waves but the worst storm surges assist the entry of saline water into the fields (Samsuddoha and Chowdhury, 2007, p15). Southwestern embankments might face occasional tidal overtopping, leading to saline water-logging within embanked areas (CEGIS, 2006). When storm surges occur, water enters the fields and causes water logging , also rising sea levels threaten to eat away at the embankments, just as they did 2010 (Kibria, 2011). Table 26 shows the total water logged area and resons for water logging in the study area.

Table-26: Seasonal water logging in the study area

District	Upazila	Water-logged areas (in ha)		Remarks
Bhola	Bhola	1975-76	2008-2009	-Seasonal Submergence -Tidal flooding -Drainage congestion -Faulty sluice gate -Heavy clay
	Bhola Sadar Charfassion	- 2,000.00	2,500.00 3,000.00 5,500.00	

Source: BCAS (2010, p52)

3.7.3. Salinity intrusion

The salinity of surface water is higher in part of Monpura and Charfasion upazilla of Bhola district. Farmers used organic matter mulch as much as possible and used gypsum and potash fertilizer to counteract the soil salinity. They chose rice varieties BRRI 47 Boro and BRRI 41 and BRRI 44 for aman season as saline tolerant varieties. The trends of increasing salinity are shown in Table 27. However, Kharif I group is less productive due to drought and higher salinity. About 2,500, 8,000 and 14,000 km2 of land (with a corresponding percentage of 2%, 5% and 10% with respect to the total land area of the country) will be lost due to SLR of 0.1m, 0.3m and 1.0m respectively (Ali, 2000).

Table -27: Increase of salinity in the study area on the basis of baseline year 1973.

District	Year	Salinity level (dS/m)				Salinity increase over 4 decades	%	Remarks
Bhola		S1	S2	S3	S4	Area(ha)		Burhanuddin, Charfession, Monpura, Lalmohan
	1973	9.18	30.81			54.58	136.48	
	2000	32.44	33.70	26.13	5.27			
	2009	42.11	28.84	20.62	3.00			

S1 = *2.0 – 4.0 dS/m*, S2 = *4.1 – 8.0 dS/m*, S3 = *8.1 – 16.0 dS/m*, S4 = *>16.0 dS/m*

Source: BCAS (2010, p49)

3.7.4. Farmer's observations

Crop growing factors are clear in the Bangladesh Council for Agriculture Studies (BCAS's) FGD (Focus group discussion) study among framers. The farmer's observations have noted on the following climate risk factors affecting crop production in no priority order:

- Frequent drought
- Changes in seasonal rainfall pattern
- Seasonal rainfall

- Long dry spells
- Increase of soil salinity
- Increase of tidal surges

In addition, farmers mentioned that high temperatures are causing problems in growing winter crops as well as increased insect pests on whole seasons. Increased intensity of soil salinity has been observed by the farmers as white crust of salts on the soil surface and crops showing evidence of burning during drier months in the coastal areas due to salinity. Farmers are thus very concerned about climate change issues that are associated with erratic rainfall, temperature rise, short winter, intensity of drought, salinity, tidal surges, submergence, cyclone, tornadoes, etc, in crop production systems. In addition, Table - 28 describe the farmer's opinions and observations about the changes of crop productions due to climate risk as well as type of severity for particular crops.

Table 28: Farmers opinions about the impacts of climate change impacts on crop productions

Pattern of crops	risk	severity	%	Remarks
T.Aman	Drought, flood, erosion Drought, tidal surge Cyclone, river erosion Drought, flood, erosion Drought, flood Tidal flooding Tidal flooding, cyclone	Moderate Moderate Severe Moderate Moderate Moderate Moderate	20-40 20-40 40-60 20-40 20-40 20-40 20-40	Bhola (S): 12,000 ha(drought, flood) Lalmohan:2,500ha ((drought, tidal surge) Monpura : 7,500 ha (cyclone, erosion) Daulatkhan : 5,500 ha (drought, flood) Borhanuddin : 2,000 ha (drought, flood) Tazumuddin : 2,500 ha (tidal flooding) Charfasion : 10,000 ha (flood,

				cyclone)
Wheat	Temperature variation Late winter/short cold period	Severe Severe	40-60 ,,	Due to temperature variation and late winter/ short cold period, the farmers can not cultivate wheat
Maize	Drought Rainfall variation High wind	Severe Severe Severe	40-60	Severe drought/rainfall variation and high wind causing 40-60% yield reduction in maize crop. Maize can not be profitably grown here.
Potato	Temperature variation Short cold period Pests and diseases	Severe Moderate Moderate	40-60 20-40 20-40	Short winter/short cold period, clayey soils, salinity and temperature variation, the cultivation of diamant/ cardinal variety of potato is limited in 5,200 ha.
Pulse	Erratic rainfall Soil wetness Drought Salinity Pests and diseases	Moderate Moderate Moderate	20-40 ,, ,,	Due to mentioned environmental risk factors, cultivation of pulse crops is affected in about 42,200 ha
Oil seed crops	Temperature variation Late winter/short cold period	Severe Severe Severe Moderate Moderate	40-60 ,, ,, ,, ,,	Farmers usually do not cultivate oilseed crops except mustard, sesame and ground nut in some locations (about 16,500 ha) in Bhola Sadar, Lalmohan,

	Clayey soils Salinity			Daulatkhan and Borhanuddin.
Spice crops	Early rainfall Temperature variation Pests and diseases	Moderate Moderate Moderate	20-40 ,, ,,	Farmers usually do not cultivate spice crops except chilli and some onion in some locations (about 21,200 ha).
Jute Sugercane	Temperature variation High rainfall High wind	Severe Severe Severe	>60 ,, ,,	Farmers usually do not cultivate jute and sugarcane due to unfavorable climatic Conditions. Some farmers cultivate some chewing Varieties of sugarcane.
Fruit crops	Salinity High wind Excessive rainfall Pests and diseases	Severe Moderate Moderate Moderate	.40-60 ,, ,, ,,	Due to stormy wind and severe/ moderate salinity in drier months and pests & diseases in monsoon period, the cultivation of fruit crops is severely affected. Water melon and amra is cultivated in some locations (4,000ha).
Irrigated HYV Boro	Drought Cyclone Salinity Pests and diseases	Severe Severe Moderate Moderate	40-60 ,, ,, ,,	The mentioned environmental risk factors causing 40-60 % yield reduction in the cultivation HYV boro crop.
T.Aus	Drought	Moderate	20-40	The mentioned environmental

	Salinity Cyclone Pests and diseases	Moderate Moderate	,, ,,	risk factors causing 20-40% yield reduction in the cultivation of HYV T.Aus crop.
T.Aman	Floods/water stagnancy Drought/salinity Cyclone Pests and diseases	Moderate Moderate Moderate	20-40 ,, ,,	The mentioned environmental risk factors causing 20-40% yield reduction in the cultivation of HYV T.Aman crop.

* Very severe= > 60% yield loss, Severe= 40-60% yield loss, Moderate=20-40% yield loss and Low=< 20% yield loss

Source: BCAS, (2010, pp72)

3.7.5. Other factors

3.7.5.1. Yield gap

The term yield gap has been widely used in the literature for at least the past few decades. Yield gaps are estimated by the difference between yield potential and average farmers' yields over some specified spatial and temporal scale of interest. Yield potential, in turn, can be defined and measured in a variety of ways, which has resulted in lack of consistency in yield gap analysis in the literature (Lobell, *et.al.* 2009).

For every crop, average yield gap varies from 29-53% in the study area. Generally, many farmers would not cultivate rice in out of among three seasons for last 20 years in Bhola district. This may have happened due to the low quality of seed, weak crop management practices and in appropriate harvesting time and techniques. As a result, the gap ranges causes 1.5 to 2 times lower yield than the potential yield. It was found that the scope to increase the cereal yield is low and more for increasing vegetable and pulse yields (Haque, 2006).

3.7.5.2. Economic factors

Rice, watermelon, okra, country bean, mung, soybean, groundnut, etc., are exported to the other parts of the country. This leads to local shortages at certain times. Although the production has increased in the recent years, vegetables are still being imported from other parts of the country in some seasons. It is found that due to residual ground water after the rainy season it is possible to grow early (before winter planting seasons) vegetables in these areas. A few farmers are taking this opportunity to generate more income. If farmers grow and sell early vegetables, this helps them to earn 30% more profit compared to peak season. For example, a country bean sale in the early season earns Tk 25-30/kg, Tk 15-20/kg in middle and Tk 8-10/kg in the late season.

3.7.5.3. Opportunities for farmers to access quality seed

There are two kinds of organization providing high quality seeds in the study area public and non-government organization (private sector). In the public area, Bangladesh Rice Research Institute (BRRI) and Bangladesh Agricultural Development Corporation (BADC) are playing a major role in providing high yielding variety of rice seeds (BARCIK, 2008, p11). NGOs(private sectors) are supplying vegetables and commercial seeds, but not showing any interest in supplying rice, pulses, wheat and oil seeds (BARCIK, 2008, p15). As local farmers are poor, they find it hard to buy good quality seeds. Although government provides a subsidy for buying seeds for poor farmers, it is not enough for them to buy high quality seeds due to their extreme poverty. Percentages of different types of seeds used by local farmers are shown in Table 29:

Table 29: Percentages of the type of seeds used in the area

District	Local seed (%)	HYV seed (%)	Hybrid (%)
Bhola	70	25	5

Source: IDE staff observation and LGED, 2009

3.7.6: High risk of natural disaster in the study area

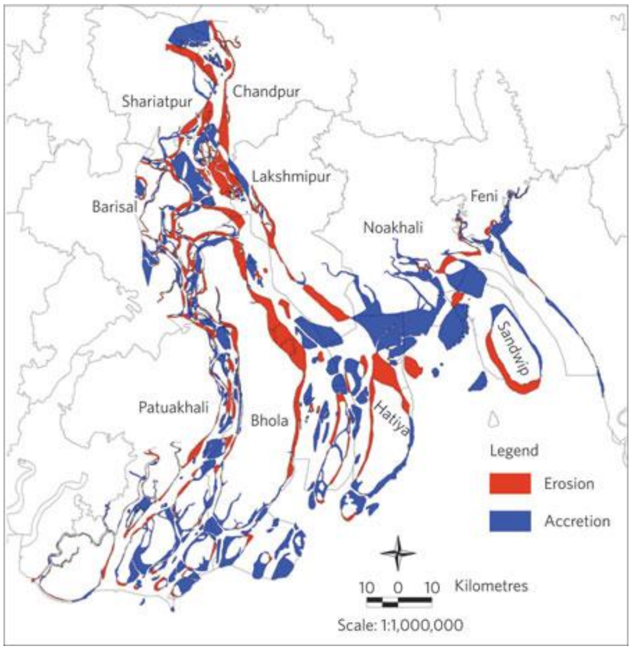
The area is highly vulnerable to natural disasters (flood, drought, river bank erosion and tidal surges) see in Table 30. The area is situated in the lower part of young Meghna basins and lower part of the Ganges belt (Fig-15). Four major rivers cross the area that makes it vulnerable to flooding as well as river erosion. The major cyclones in 1971, 1991, 2007, and 2009 produced remarkable tidal surges. Now flash flooding is a major issue contributing to low crop production. Therefore, natural disasters play an important role for crop production in the study area, as crop production depends on natural climatic conditions. However, temperature and rainfall changes as well as sea level rises are major concern in the study area for future crop production (BARC, 2010).

Table 30: Area is affected by natural disaster in each year.

District	Drought prone area (ha)	Flood prone area (ha)	River bank erosion prone area (ha)	Tidal surge area (ha)
Bhola	9,025	21,485	9,010	15,285

Source: BCAS , 2010

Fig 15: Location of the study area is indicating the vulnerability to natural disasters



Source: CEGIS, 2006

Climate change will almost certainly make these disasters worse, threatening to reverse the coastal belt's progress. Continued warming in the Indian Ocean could see a trend continue of increase in monsoon rainfall, making the annual floods broader, deeper and longer; this could also increase river erosion. Already farmers' responses have shown that the change of cropping pattern and more erratic weather is making it hard for them to maintain the planting of crops in the study area. There is the other risk of future sea level rise which threatens to submerge a substantial part of the study area, to worsen monsoon floods and to help storm surges clear protective embankments (SRDI, 2009).

3.8. Methods

3.8.1. Literature review

The literature review includes a review of journals and reports on climate change impact across Asia and Bangladesh to review the previous researches. This allowed the development of knowledge in assessing aspects of climate change impacts on rice production. Generally, I used international and national journals through the internet and the Wollongong University library. Some journals from Bangladesh were also used to find information on climate change issues in Bangladesh.

3.8.2. Data Collection

Data used in this study area were collected from the Water and Resource Board in Bangladesh (*WARPO*) and Bangladesh Agricultural Resource Council (BARC). For the collection of data, I went through the official procedure including writing applications. Two types of data were collected. Firstly, climate information (daily temperature, rainfall, and sunshine hour) data for the years of 1990 to 2008 were collected. Secondly, rice yield data for the years of 1990-2008 were collected. Individual local rice production data was not available for the year from 1990 to 2008. In Bnagladesh still data is not digitalized fully and it's hard to get local level seasonal crop production data. I used Aman, Aus and Boro rice production data that is available in BARC.

3.8.3. Data analysis

3.8.3.1. Statistical analysis

This research used to show correlation between yield and climate parameters in statistical analysis. Yield against climate parameters in a single graph could help to show any positive or negative relation between climate change and yield. Rice data were in thousands of Metric ton per acre. I converted this data into yield in tonne per hectare. Crop production data for seasonal crops converted to yield that assists to show the amounts of study area's crop production without any crop field information. As, this research used limited data, converting of crop production to

yield helps to show the change of cropping pattern (positive or negative against temperature and rainfall changes) from 1990 to 2008 years.

3.8.3.2. Synthesis of crop production data

The yield data were used to look for correlations with climate data in each rice category (Aus, Aman and Boro). For correlations, Microsoft Excel sheet was used in this research. In excel sheet, it is possible to show the relation between yield and climate parameters in one single graph. Thus, yield against climate parameters can assist to explain how much crop production is changing with the change of temperature and rainfall pattern in 1990 to 2008 years.

3.8.3.3. Description of each seasonal cropping pattern

Aus, Aman and Boro cropping were analysed for 1990 and 2008. Total Aus, Aman or Boro yield in each seasons and climate data stored in excel table for showing co-relationship. The factors that were considered are:

1. minimum and maximum temperature in each season used the highest daily maximum temperature and the lowest minimum daily temperature among first 45 days, first 90 days against total yield in each year (from 1990-2008). This first 45 days and 90 days were taken into consideration for few reasons. Generally, first 45 and 90 days is associated with planting period that is most sensitive with temperature and rainfall. According to my literature review, if too much rainfall in 1st 45 and 90 days, then there have a chance to loss of plants though flooding and damaging leaves. Therefore, total amount of rainfall for 1st 45 and 90 days also count to show the correlation.

2. The highest and lowest temperatures in every cropping season were taken into consideration for showing correlation between temperature and yields.

3. Difference of rice production in each season can be described from the correlation results. The impacts of climate change on rice production and yields against climate parameters

in every year were graphically presented. The graphs can show the change of positive or negative crop yield in the last 18 years against temperature and rainfall.

3.8.4. DSSAT 4.5 simulation model

Outline/explanation of steps followed in the modeling process is presented here. The steps that I followed in using the DSSAT 4.5 model are described below.

3.8.4.1. Collection of minimum datasets

Four minimum data sets were collected from *WARPO* in Bangladesh. These four minimum datasets are maximum daily temperature, minimum daily temperatures, daily rainfalls and daily sunshine data. These minimum data sets were used as inputs to models for reliable solutions. DSSAT software was obtained with the help of Dr. Paul Wilkens of the IFDC. However, no rainfall pattern shows in Boro season. So, only Aus and Aman were considered in simulation modeling.

3.8.4.2. Building the weather mean and running simulation model

Weather means data was created for Bhola districts. Minimum weather data was stored in weather mean with its site observations that include latitude, longitude and elevation of Bhola district. The steps of producing weather mean and simulation modelling are described in following steps:

Step 1: Imported raw data from Excel sheets into weather mean for each climate data set. Then edit dialog box as necessary with right click on the column.

Step 2: Created new climate database and merge data to build new climate stations (Fig 16). File naming convention represents a symbol (AABBNNnn.WTH). Here AA is a institute identifier (Bh), BB is site ID (ol), NN is year of observation (from 1990 to 2008) and nn is a number of years (default=01).

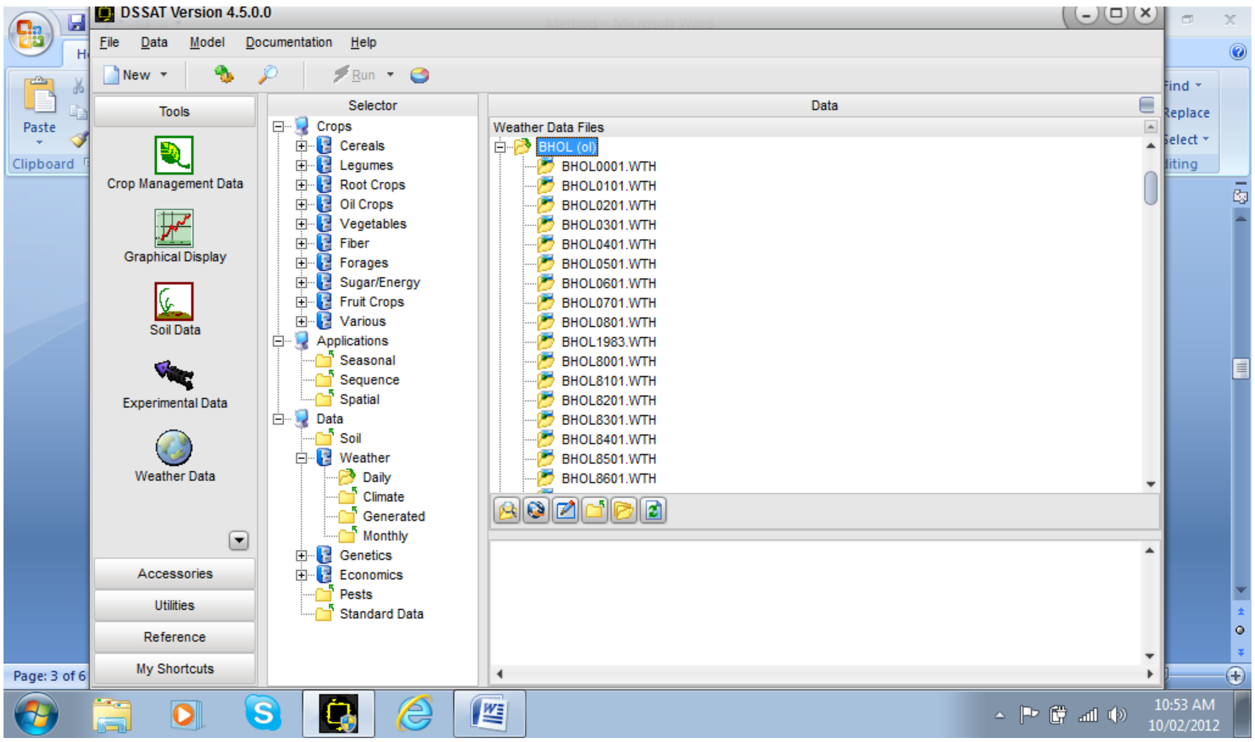


Fig 16: Climate stations

Step 3: New climate station was made and station information was edited as per requirement of this thesis. Then weather station data was saved in station file and it directly saved into DSSAT weather directory (Fig 17). Then I produced 18 (1990-2008) WTH files, which were utilized in the crop models. So, a new climate database was created to store the data in the model.

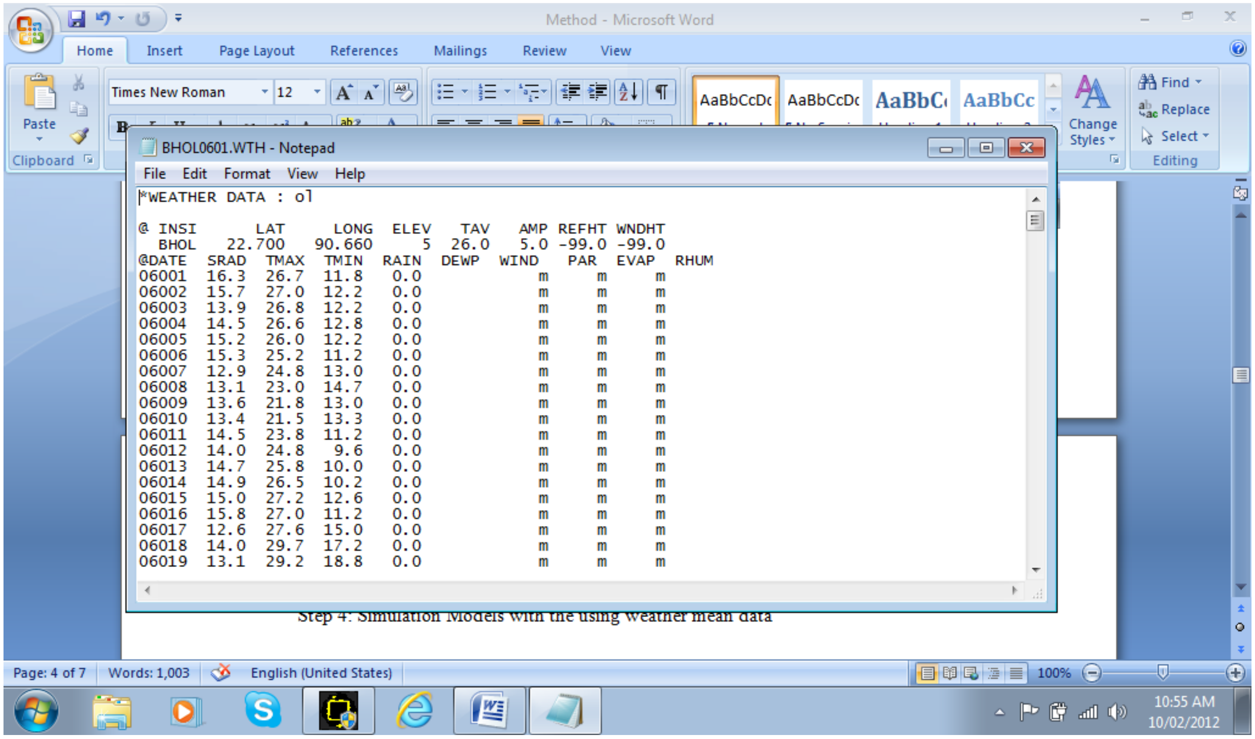


Fig 17: Climate station documentation

Step 4: Simulation Models using the weather mean data

The purpose of Introductory Crop Simulation Model (ICSIM) is to allow the use of crop simulation models based on the DSSAT v 4.5 software packages. In particular, it allowed specifying weather, soil, and main practices to simulate crop growth and yield using any of the crop models and data sets contained in DSSAT v 4.5. The program also automatically computes potential yield. This provides new users with an immediate demonstration of the concept of yield gap analysis. For the simulation of crop yields, the following steps were followed:

- Menu items include four tools (Experimental file, environmental modification, management options and simulations), where, the experimental details window contains Experiment Name, Experiment Identifier, Field Information, and Initial Soil Conditions options (Fig- 18). The Management window allows one to enter management data including planting date, plant population, row spacing, irrigation, fertilizer and harvesting date inputs. In this research, plant population and row spacing information was provided

from BARD in Bangladesh. However, only nitrogen fertilizer data was used for management data in this study.

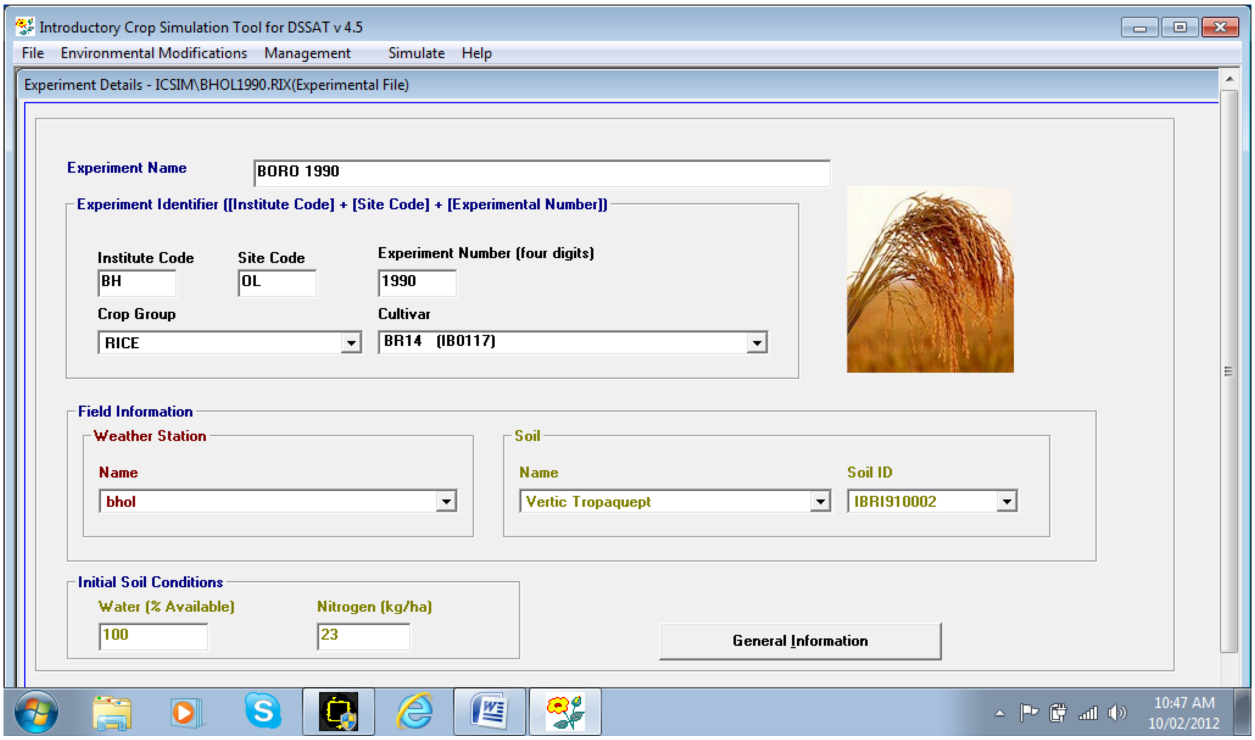


Fig 18: Experimental window

- For analyzing each single season for Aus and Aman rice yields the format of date cell was used to enter new date or expected date results for a single season. The format to enter the date is MM/DD/YY (or MM/DD/YEAR). Any day after this date, daily weather values can be changed according to the modifications entered into the other slots on this window (Fig 19 and Fig 20). This allows one to simulate an expected rice yield at 45, 90 and 120 days after planting. In this research, I used four different environmental variables for simulation. These environmental variables and their units are day length (hour); maximum daily temperature (°C); minimum daily temperature (°C); daily rainfall (mm). According to my literature review, nighttime temperature could cause the damage

of flower in the plants. So, the increase of 2˚C minimum temperature in Aus and Aman season’s were simulated to show the potential of yield risk due to climate change. However, IPCC (2007) estimation of 2˚C temperature rise was taken into consideration in this modelling system. So, prediction of future yields may draw the future climate risks on food security..

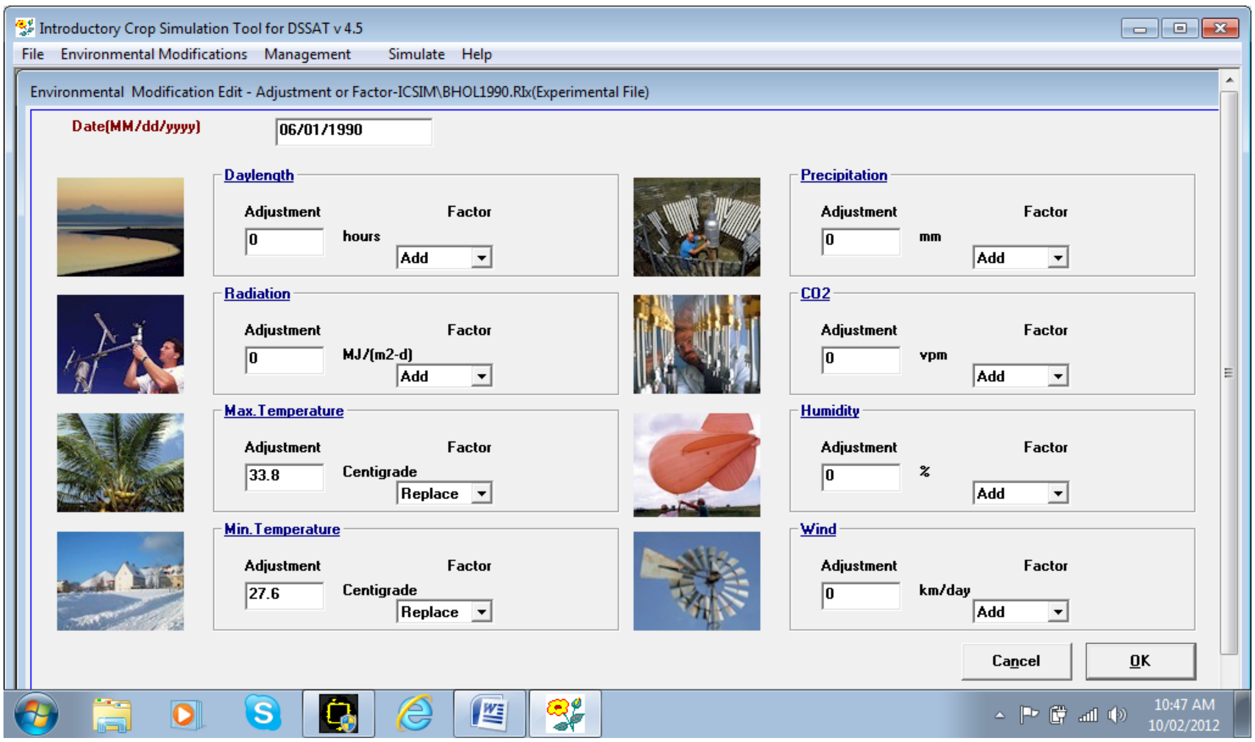


Fig 19: Climate window

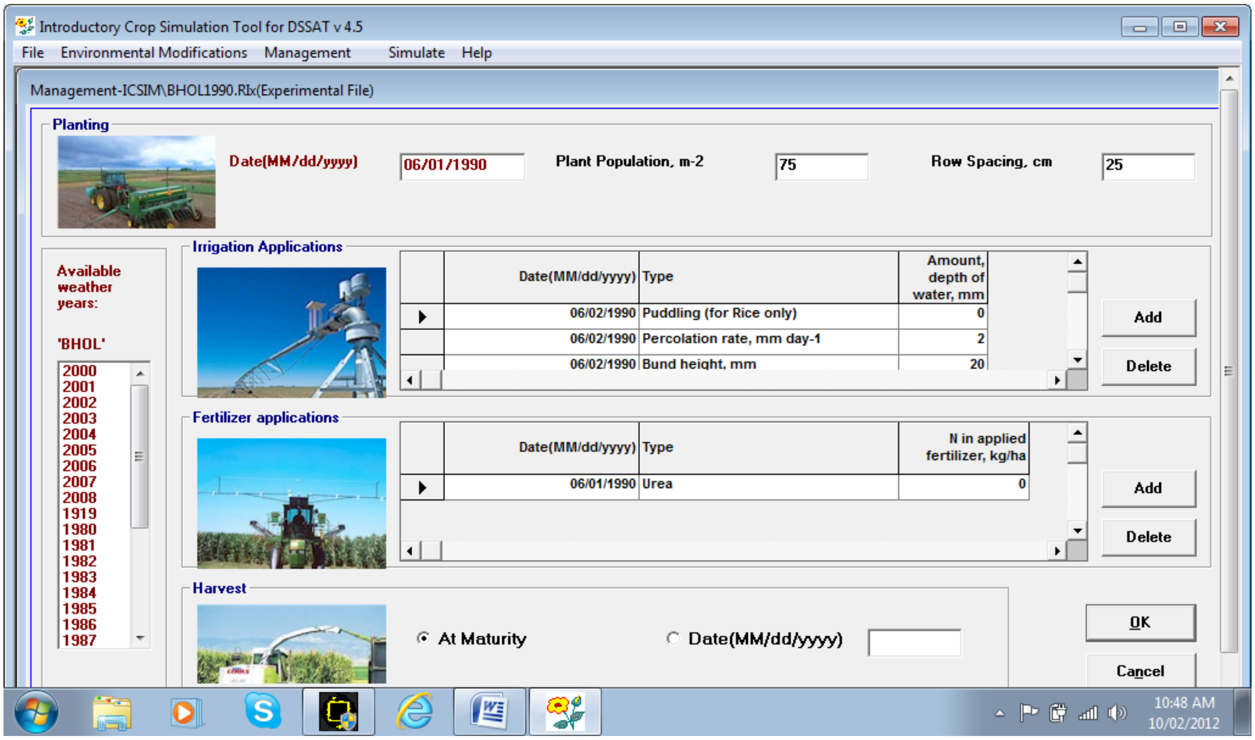


Fig 20: Management data

- By clicking on the Simulation menu button, the file being created or edited will be saved and the crop selected will be simulated using the crop models in DSSAT v.4.5.

- Analyzing results: After simulation, windows (example fig-21) showed the options for viewing, printing, and graphing results. In this research, I use plant grow out options for getting graph and results.

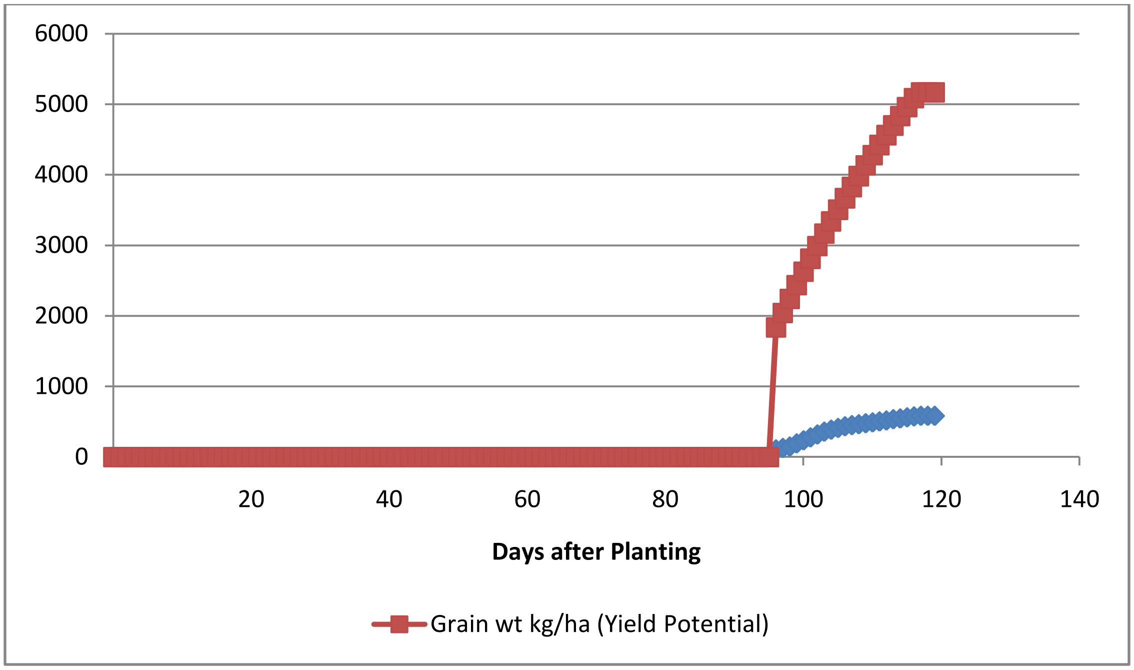


Fig 21: The result of climate model data

Chapter 4: Results and Discussions

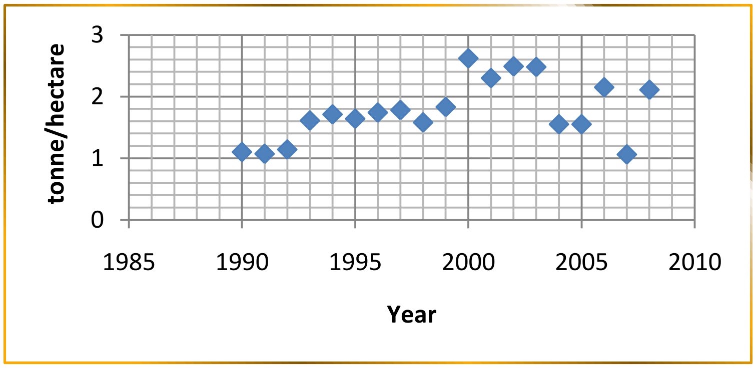
4.1. Introduction

This chapter will describe the study findings as well as the limitations of the study. The study used only two sets of climate parameters (temperature and rainfall) and yield data for the overall Bhola study region. The results will show the overall impact of climate change based on total yield. Impacts of climate change in each season can be analysed through the seasonal yield.

4.2. Rice production

The results that have been used are from 1990 to 2008 data sets. The daily rainfall and temperature are from the district has been used in this research. Therefore, it is assumed that the available temperature and rainfall data is able to represent the impacts of climate on rice production due to the major influence of temperature and rainfall on plant growth that has been described in the literature review. The rice production data are from 1990-2008 shown in Fig 22. The total production by year gradually increased from 1990 to 1993 and from 1994 to 1999, with the exception of 1998 when it slightly decreased. The decrease of crop productions in 1998 may have happened because of a big flood that covered 64% of total area in Bangladesh (Rahman and Parkinson, 2007) However, from 2000 to 2008 production fluctuated and this may have happened for several reasons. The reasons include the recent high frequency of floods which are a result of sea level rise as well as changes of rainfall pattern that may impact the growth of plants (Karim and Mimura, 2008).

Fig 22: Rice production in Bhola district (tonne/hectare) from 1990-2008



Rainfall has a major impact on plant growth. Heavy rainfall sometimes sinks the small plants as well as destroys the flowering growth of the plants (Ahmed and Alam, 1998). However, temperatures have direct and indirect impacts on plant growth.

Drought conditions and night time temperature changes may create some obstacles to flowering of the plant and directly or indirectly impact on other components of plant growth.

4.2.1. Seasonal impacts of climate parameters on rice production

In the study area, three major types of rice data has been used in this research. However, fallow land constraints are an issue, but the study area is producing more than one fourth of the total rice output in Bangladesh (BARC, 2010). The three major types of rice grown in three seasons are characterized by three different types of tropical climate seasons is winter, summer and rainy seasons. It is important therefore to focus on the amount of each season's rice production, which is linked, to the changing pattern of rice yield due to changes of climate parameters. However, in this research only two climate parameter (temperature and rainfall changes) have been used due to the lack of data for other climate parameters. In addition, although some local varieties of rice are produced in the study area, for rice data sets, the three major types that are available in BARC data sets (**Appendix-2**) have been used in this research.

The planting period is important for good rice production. Temperature and rainfall have a major impact on planting periods. Both low and high temperatures are not good for rice development as well as the fluctuation of humidity (Rahman, 2011). In addition, low temperatures at the germination and seedling stages may cause poor plant stand establishment (Lal,*et.al.*, 2011). However, water in the form of rainfall causes planting delays, disease and harvest problems in the Delta (Rosenzweig and Hillel.1995; and Atlas, 2011).

4.2.1.1. Season 1: Aus rice productions

The planting period of Aus rice is mid February to Mid April, growing season is mid April to mid May and harvesting period is mid May to mid July. The planting period of Aus rice is linked with the end of winter and the harvesting period is in the middle of the flooding season. Fig 23 shows the average Aus rice production per year from 1990 to 2008. Year 2000 was the highest Aus rice production year in the study area. A little fluctuation of Aus production is shown from

1990 to 1999, while a big variation occurs from 2000 to 2008. In 2007 there is the lowest level of Aus production in the area. The season of Aus rice is particularly changing as drought and fallow land yield constraints are increasing. The planting season is affected by high temperature, as the country is facing pre summer in February. Sometimes, wild storms are starting earlier and this can cause the destruction of Aus rice plants

Fig 23: Bhola district's Aus rice yields (tonne/hac) from 1990-2008

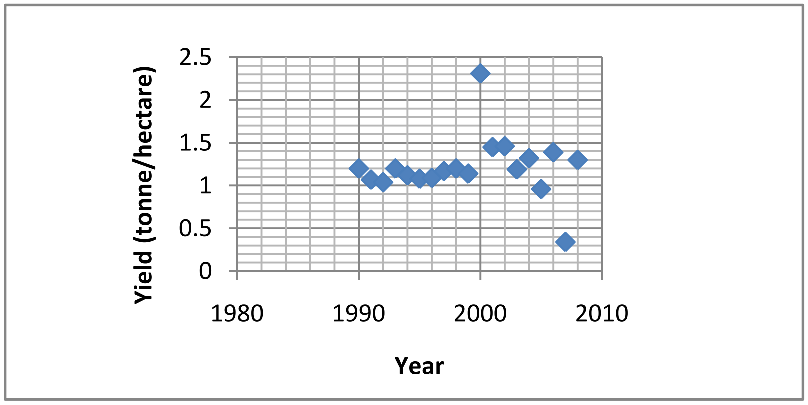


Figure: 23 shows the high fluctuation of yield from 2000 to 2008. From 2001 to 2008 Aus production increased except the year 2007. The increase of yield may be a result of using fertilizer or increase of growing high yielding variety of Aus rice in the study area, as Bangladesh has been using high yielding variety of rice from 1990 and it spread dramatically.

- **<u>Temperature variations & rainfall patterns</u>**

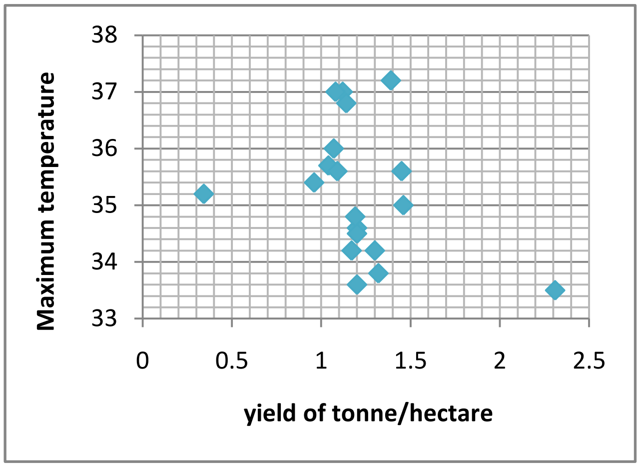
Aus growing season experiences higher temperatures with minimal diurnal fluctuation, moderate humidity during the reproductive stage, but with occasional scanty rainfall during the early plant growing period. This climatic condition is very conducive to higher vegetative growth of the crop with the lowest partitioning coefficient and development of pests and diseases (Sattar, 2007).

- **<u>Temperature</u>**

The results of maximum and minimum temperature were examined for 1st 45 days from the planting date and 1st 90 days from the planting date as well as for the whole season. Yield per

hectare against maximum and minimum temperature shows the changing yield based on 10 years data for the Aus planting period. Fig 24 shows the maximum temperature against yield of rice production over the years from 1990-2008.

Fig: 24-1st 45 days for Aus rice in Bhola effects of maximum temperature on yield



In Figure 24, 33.3˚C temperature shows overall good yield (2.3tonne/ hac) in compare to other highest temperature in this figure. However, increase of 2˚C temperature variation may not significant impacts on rice, as between 34˚C to 36˚C yield production range between 1-1.5 tonnes per hectare.

Fig 25: 1st 45 days minimum temperature effect on Aus rice production in Bhola

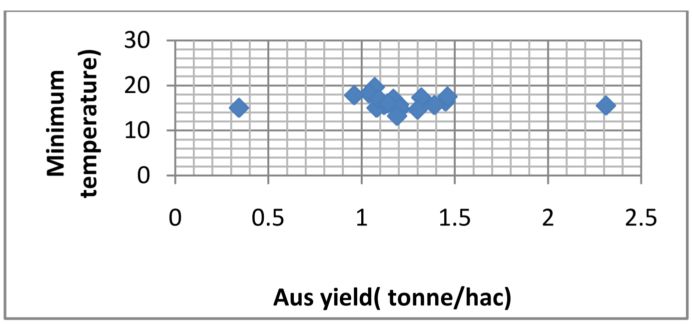


Fig 25 shows there are no major yield changes with minimum temperatures change during the 1st 45 days after planting. Yield of Aus production is high between 15˚ to 20˚C, where in one case is different shows the low productions of less than 0.5 tonne/ha. This may have happened in one year from major climate events such as a cyclone, floods or river erosion. There is no significant change between 1st 45 days, 90 days and completely seasonal production against maximum and minimum temperature, as this season is the cool season, and temperature is relatively constant.

However, the country is experiencing higher temperatures in recent years and the range of increase rate observed from 1˚C to 2˚C in many recent seasons.

- **<u>Rainfall patterns</u>**

Fig 26: 1st 45 days total rainfall effect on Aus rice production in Bhola

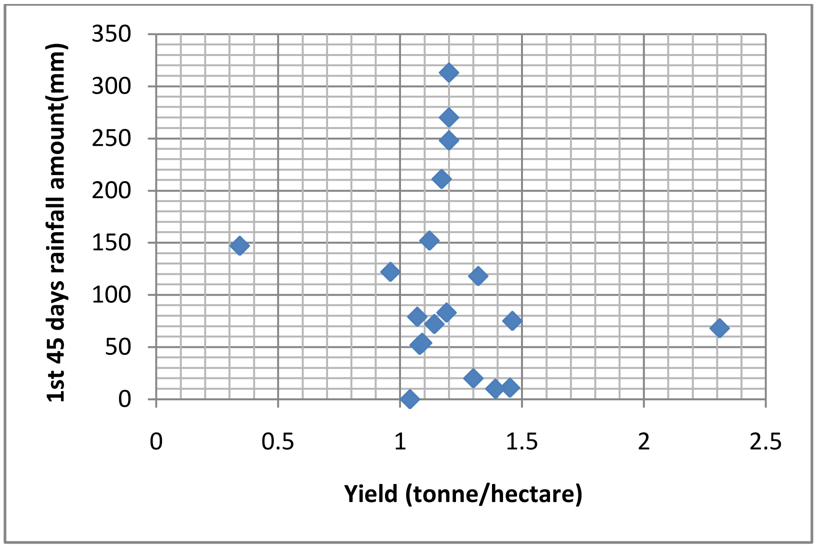


Fig 26 shows the effect of varying amount of rainfall in 1st 45 days of Aus production on yield. As this is a end of winter season, rainfall amount is not high and generally varies from 50 to 150 mm. However, some years shows the high rainfall amounts, but production is constant from 1.25 to 1.5 tonne/hac. Although there is low amount of rainfall in early planting periods , this weather is suitable for vegetative growth and there are few negative impacts on rice production. However, people are interested to grow late winter vegetables rather than the traditional Aus variety, as the amount of Aus rice production is not so profitable. This may cause the low rice production trends in future in this season.

Fig 27: 1st 90 days rainfall effect on Aus rice production in Bhola

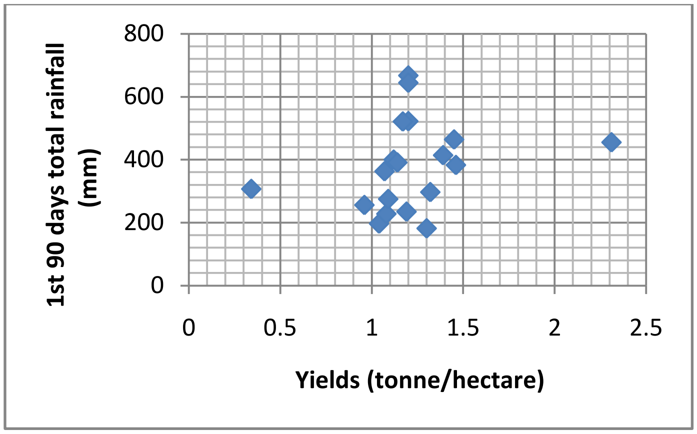


Fig 27 shows the total amounts of 1st 90 days rainfall against yield of production. Yields are high with the range of 200-400 millimeter rainfall. No major changes are shown except two cases where up to 400 millimeter and the highest yields production is 2.3 tonne/hectare. However, in one case it is showing less than 0.5 tonne/hectare with 300-millimeter rainfall. The total planting time is normally about 90 days. So, no major change is shown between this yield of the whole planting seasons and those for the 1st 90 days.

- **General discussions**

Assessment of the impacts of temperature and rainfall patterns on Aus rice production shows no relationship. Although Aus rice planting is dependent on temperature and rainfall, the yield data overall in the study region may not depend only on temperature and rainfall directly. Other factors may include soil salinity, water logging, sea level rise, seed quality,etc. However, the whole yield data sets have been collected for the overall regional basis rather than for a local level. Local level data availability might show more clear relationship between temperature and rainfall with Aus rice yield.

There are no big variations between 1st 45 days temperature (maximum and minimum) and 1st 90 days temperatures (maximum and minimum) as well as the whole Aus planting season. However, year 2000 shows 1˚C variation of maximum temperature, may not enough for the justification of climate change variation of maximum temperate (1st 90 days) on yield production over the last 18 years.

The difference of total rainfall amount between 1st 45 days and 90 days after planting Aus plants has been observed in this research. As 1st 90 days rainfall pattern is much higher than in 1st 45 days, sometimes-excessive rainfall due to changes of climate pattern might have negative impacts on rice growth in some years. Excessive water in the field due to excessive rainfall or flash flooding can destroy the growth of rice plant in early stage. However, minimum rainfall (250-300 mm) needs to grow plant of aus rice in planting season for good or average yields.

The overall impact of climate change on Aus rice production in the study area (1990-2008) has been a decline of yearly Aus production. However, there have the limitations of showing the production of local Aus variety; overall yield of Aus production in the study area is decreasing (Sen, 2004, p2). This may have happened because the lack of water, unseasonal flooding or two times of flooding as well as cyclonic storm surges.

4.2.1.2. Season 2: Aman rice production

The full monsoon season crop is Aman in lowland ecosystem known as T. Aman, cultivated during July to December. The crop experiences heavy rainfall and high temperature during the vegetative stage and low nighttime temperature often associated with drought during the reproductive stage. However, the limited occurrence of drought is found once in five years during the Aman season (Haque, 2006, p1463), annual drought of various intensities affects about 2.3 million ha of T. Aman rice in the whole of Bangladesh (Karim, 1999).In addition, medium flooded (flooding depth ranges from 0.3-0.9 meter) area have low a risk for harvesting and less sensitive to photoperiod, but water logging and salinity becomes a difficulty at the harvesting time. Although in the past strong photoperiod sensitive verities were grown which mature after the field dries up, the recent extreme climate conditions at the end of the Aman harvesting stage is contributing to low production (Haque, 2006).

Planting time is very important due to recent extreme climatic events for Aman rice and sometimes farmers cannot follow the appropriate planting Schedule Plus various socio-economic factors may cause planting to be delayed. This late planting may cause yield decline (Razzaque and Rafiquzzaman, 2007).

Fig 28: Yield of Aman rice production in the Bhola district from 1990- 2008

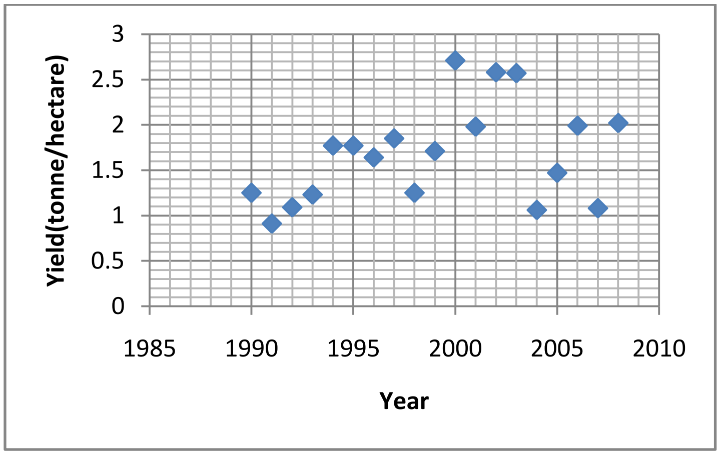


Fig 28 shows the yield of rice production from the year of 1990 to 2008. Aman rice production is increasing and it starts to increase from 1994. However, some years like 1998, 2004, 2006 and 2007 show lower yields. Great fluctuations have been observed from 1999 to 2008. The frequency of natural disasters has also increased from 1995 (Harun *et.al.*, 2008). Now, farmers are using HYV Aman seeds and they are producing more rice in small yields. So, production trend is generally increasing except in some years when there are lower yields.

- **Temperature variation & rainfall pattern**

Impacts of maximum and minimum temperature are a serious concern for the growth of Aman rice. Mahmood..*et.al.*,(2004) reported that significant reductions of Aman yield in wet seasons have been observed due to the delay of planting date beyond 1st of June. In addition, DSSAT 4.0 model predicts that rainfall will be high (11.5mm/day) for the month of April to May in 2050 that may cause serious delays for planting Aman rice, as water is not sufficient in these months for growing plants (Basak .*et.al.*,2009). So, changes of temperature and rainfall not only cause the negative impacts of rice yield, but could also make yield more sensitive to planting time.

- **Temperature**

Fig-29: Maximum temperature in 1st 45 days of growth against rice yield in Bhola district (1990-2008)

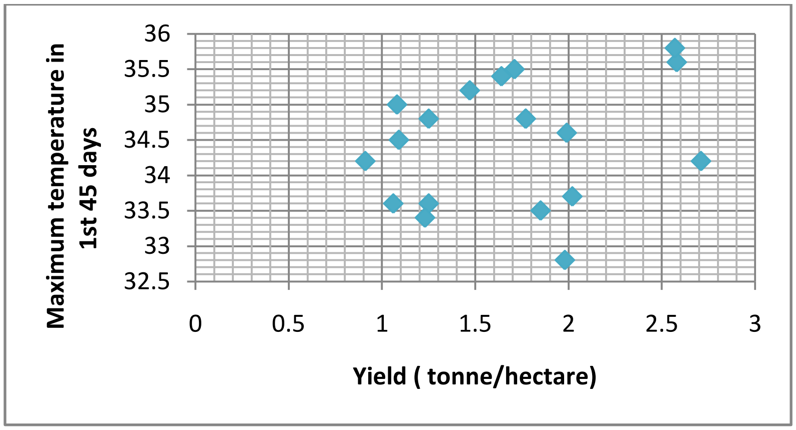


Fig 29 shows a great fluctuation of yields with maximum temperature. Maximum temperature varies from 32.4 to 35.8˚C. Fig 30 also shows no pattern for the relationship between yields and climate pattern. CO^2 concentration and high temperature are good for photosynthesis and that is why during planting periods high temperature leads to large yields. However, 2008 shows low temperature with extreme rainfall and flooding.

Fig 30- Minimum temperature in the 1st 45 days of growth against rice yield in Bhola (1990-2008)

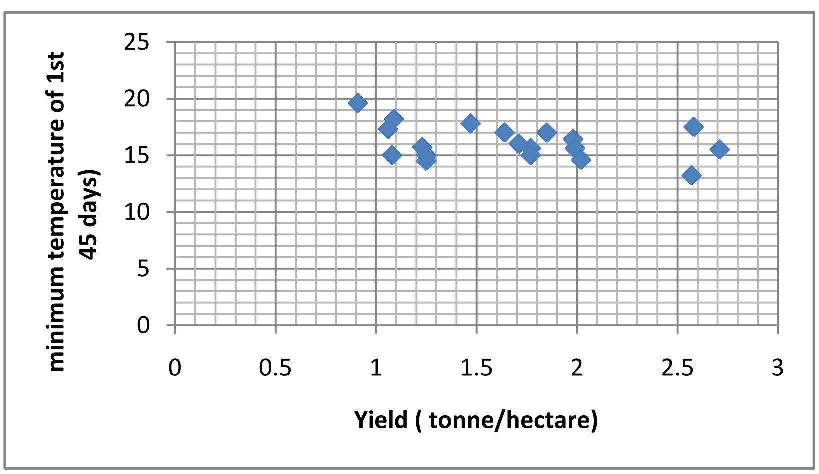


Figure 30 shows the general consistency of minimum temperature in 1st 45 days of Aman rice growth. There is no major variation of minimum temperature in that season, as the temperature varies from 13˚C to 19˚C. This shows that whole temperature remains within central area of the graph and yields can vary by 2-3 times there is a weak negative co-relation between production and minimum temperature in first 45 days of growth.

Fig-31: Minimum temperature 1st 90 days against rice yield in Bhola district

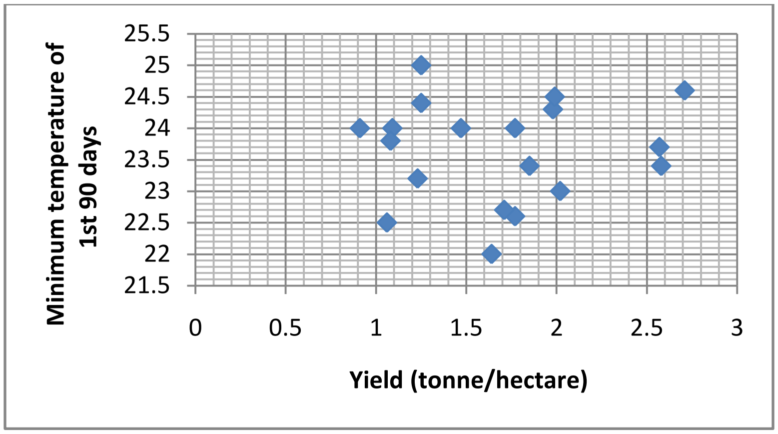


Fig 31 shows no co-relation between minimum temperature and yield. However, some cases show the low yields and this may have happened because of major natural disasters as well as farmer's behavior. Farmers may delay for planting due to lack of money, early excessive rain or water stagnation in the field.

- **Rainfall**

Fig32: Rainfall in the 1st 45 days growth against yield of rice in Bhola(1990-2008)

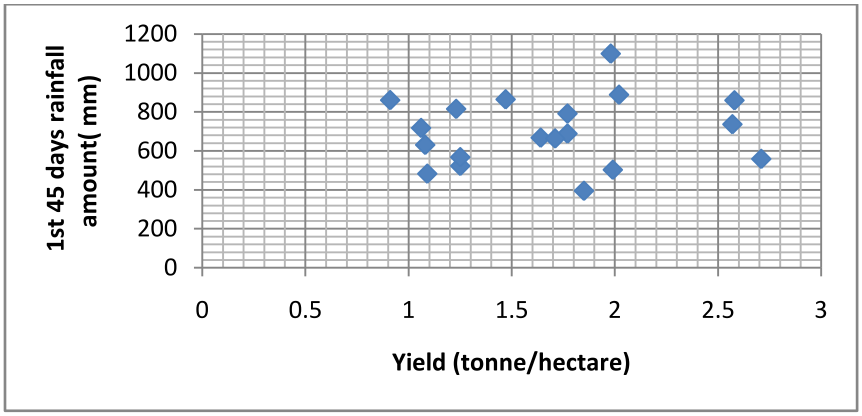


Figure 32 shows no general trends between the rainfall amount in the 1st 45 days growth and yields. The figure shows the maximum amount of rainfall varies between 400 to 1100 mm in 1st 45 days of the Aman planting seasons. The major difference between the amounts of rainfall may lead to more water in the field during planting periods. This may responsible for delaying rice planting and sometimes for washing away of plants with flood water that can reduce yields.

Fig 33: Rainfall in 1st 90 days of growth against rice yield production in Bhola(1990-2008)

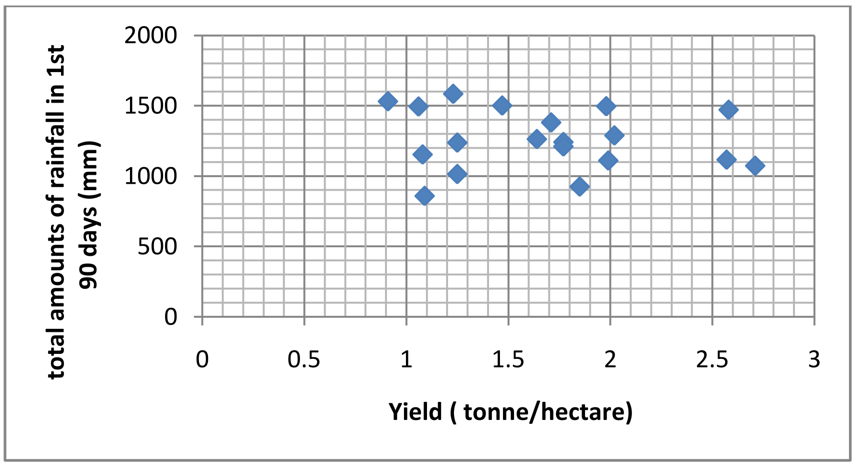


Figure 33 shows a weak negative co-relation between total amount of rainfall in the first 90 days of growth and yields. However, the growth trends of Aman rice generally depends on water quantity in the field . So, good rainfall is important for good Aman rice production.

General Discussion

The data do not show any significant correlations of impacts of temperature and rainfall on yields. However, in the study one general rice data set for Aman is used rather than many local Aman rice data due to the lack of data access. In addition, in this research no seasonal map for rice production is produced and no accurate geographical boundary of the area for rice cultivation in last 18 years has also found.

The 1st 45 days minimum temperature variation in the study area is more than 2˚C that may play a major role because of the impact of minimum temperature on rice production (Peng *et al*,

2004). In addition, maximum temperature variation in the 1st 45 days is does not exceed 3˚C that is within the limits of IPCC predictions. However, no major difference is shown between 1st 90 days maximum temperature and 1st 45 days maximum temperature patterns.

There is a major difference between 1st 45 days total rainfall amount (<1000 /mm) and 1st 90 days total rainfall amount (800-1600 /mm), as Aman is planted in the rainy season. The starting rainfall condition of 1st 90 days total rainfall is 900 mm that is much higher than in 1st 45 days rainfall starting amount (250 /mm). This means that Aman rice is growing better with the availability of water. However, excessive rainfall can cause flash flooding that may destroy crops in the field.

The overall impacts of temperature and rainfall parameter on Aman seasons are important, as Aman is growing in rainy seasons. Although the high rainfall amount shows possible overall positive trends of rice production, the excessive rainfall in 3 cases (1990, 1994 and 1999) shows the negative impact on rice production. The negative impacts due to excessive rainfall may include flash floods and water stagnation during planting periods of Aman seasons. However, no overall temperature impact on Aman rice was found due to a lack of co-relation between maximum and minimum temperature with yield. But the overall impact of climate change on rice production due to temperature and rainfall changes needs to considered more deeply, as great fluctuation of yield production against maximum and minimum temperature as well as rainfall pattern is observed in many seasons.

4.2.1.3. Season 3: Boro rice production

Boro is growing in winter period when no rainfall pattern shows in Bangladesh. Therefore, availability of irrigation water is a necessary pre-condition for growing Boro rice. So, during the planting time water is important, as farmers generally use irrigation facilities for cultivating Boro rice. Farmers often delay the Boro planting in order to shorten the growth duration, reducing production costs, particularly irrigation water. Although BARRI released relatively shorter growth duration Boro verities, farmers are not using appropriate technology for irrigation rather using an early transplanting method which is subjecting the crop to cold damage during the flowering stage and thus realizing poor harvests. However, the country's target Boro rice

production in Bhola district consisted of a medium level (60-100 thousand hectare in a year). So, the study area is playing a major role for producing Boro rice that is important for the overall yield in a year. Among the three seasons, the region is now depending on Boro rice production, as farmers can grow more rice in a limited area by irrigation and fertilization in dry seasons. However, there have been some negative impacts of unplanned irrigation and over use of fertilizer, Boro rice production is depending on other factors (irrigation, fertilizer, soil salinity, etc) rather than temperature and rainfall directly.

Fig 34- Boro rice production in tonne per hectare from 1990 to 2008 in the Bhola district

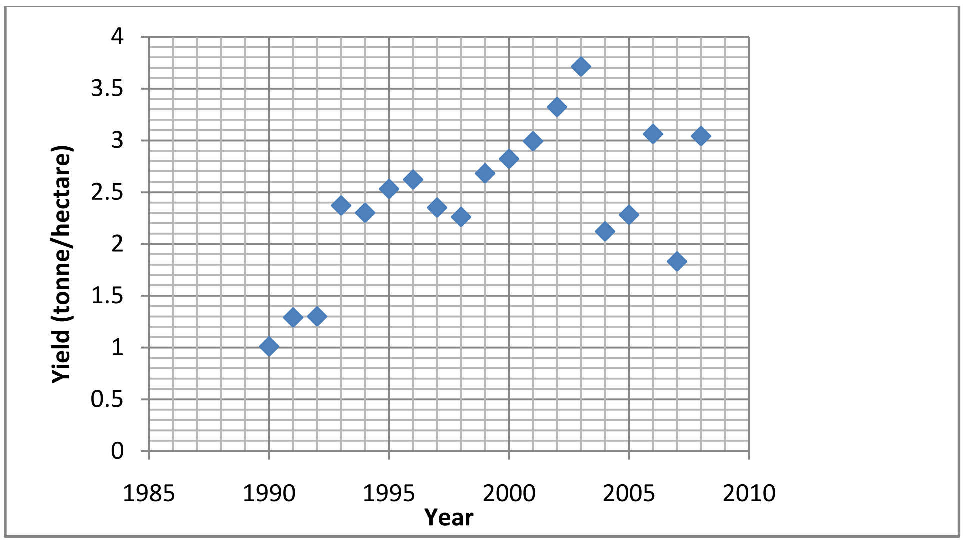


Fig 34 shows the total yield production in Boro reasons from 1990 to 2008.Boro yields have risen clearly from 1991.However, Boro yields gradually increased from 1991 to 2002 with little fluctuation in 1997 and 1998. From 2005 to 2008 big fluctuations in Boro rice production were noted and this may have happened because of the changes of climate, but more likely other factors like salinity, drought and irrigation water availability.

- **<u>Temperature variations & Rainfall patterns</u>**

Both the CERES and DSSAT models show a decline of yields for Boro rice by 2050 and 2070 with rising temperature and rainfall (Basak *et. al.*, 2009).. In addition, the vegetative stage and a part of the reproductive phase will face the highest water levels in the field in the Boro season. However, the combined effects of maximum and minimum temperature could cause negative impacts on Boro rice productions. DSSAT model results show the decline of Boro rice

production by about 15.5% with the increases of maximum and minimum temperatures (Basak .*et.al.*,2009; Basak, 2008). There is a strong modeled relationship between grain yields and maximum and minimum temperature (Peng,.*et.al.*,2004). However, the future demand for water in the dry seasons is under threat due to changes of rainfall amounts (Wahid, 2005).

- **Temperature**

Fig-35: Maximum temperature in the 1st 45 days of growth against Boro yields in Bhola(1990-2008)

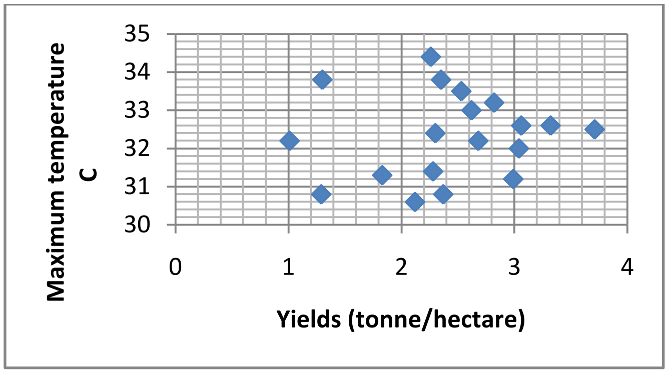


Fig 35 shows the yield production of Boro rice against maximum temperature of 1st 45 days after planting Boro rice with no patterns. The maximum temperature varies between 30.3˚C to 34.1˚C. However, IPCC predict that maximum temperature variation will be 4˚C higher by 2050 and 2070.

Fig-36 : minimum temperature in the 1st 45 days growth against before yield in Bhola (1990-2008)

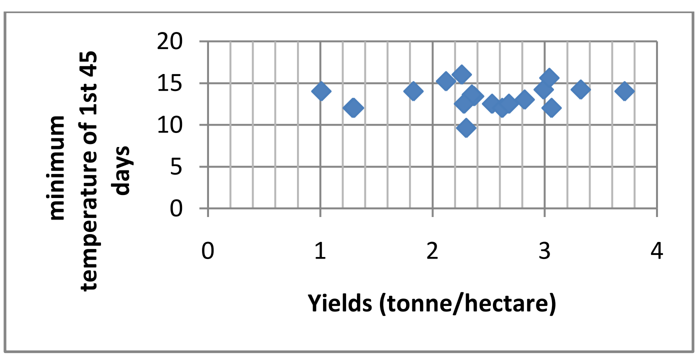


Fig 36 shows 1st 45 days minimum temperature against Boro rice yield, where minimum temperature varies from 8.6˚ to 15.8˚ C. However, IPCC stated that minimum temperature variation would be 2˚C higher by 2050 and 2070. The figure shows no correlation, as in some cases shows higher minimum temperature may lead to higher yield production and in some cases shows high minimum temperature may lead to lower yield production.

Fig-37 : Minimum temperature in the 1st 90 days growth against Boro yield in Bhola(1990-2008)

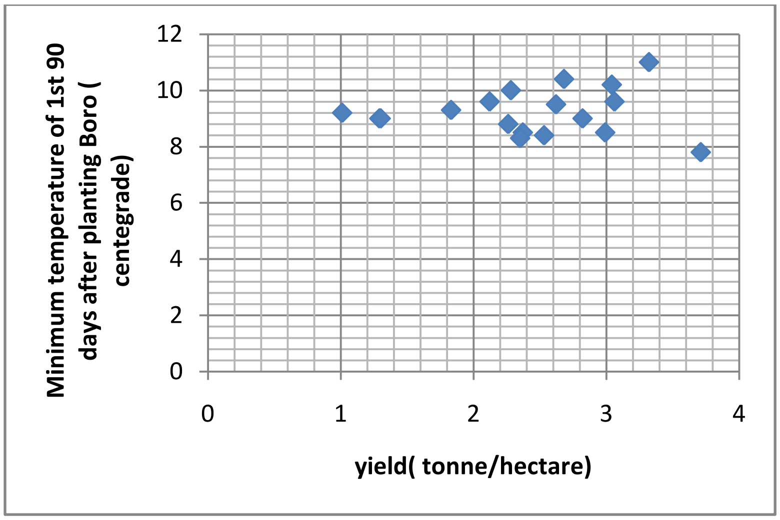


Figure 37 shows the minimum temperature of 1st 90 days of Boro rice planting period against yield. The variation of minimum temperature during the 1st 90 days is 7.9˚C to 10.8˚C. However, 8-10˚C minimum temperature lead to average 2-3 tonne/hectare of yield production, in one case of 7.9˚C shows highest yield productions in the study area. There is no correlation between yield and minimum temperature in the study area based on the data.

- **Rainfall**

Fig -38: Total rainfall in the 1st 45 days of growth against Boro yield in Bhola (1990-2008)

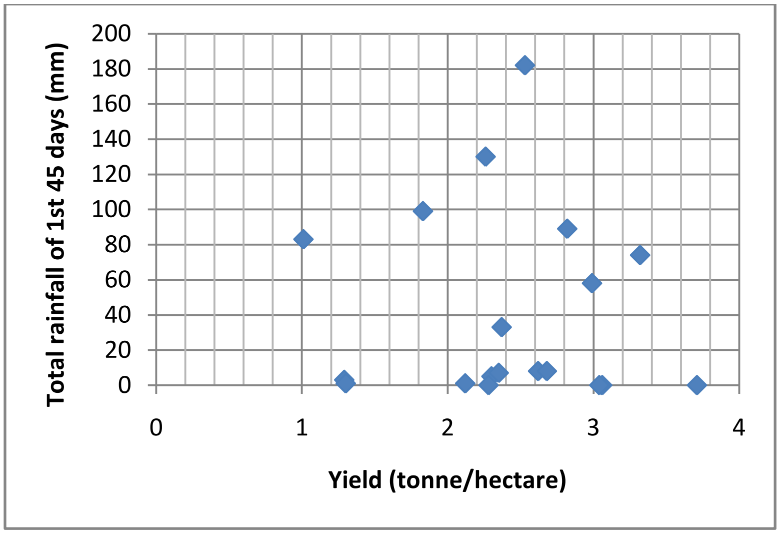


Figure 38 shows the total amount of rainfall against Boro rice yield from 1990 to 2008 in Bhola district. Low rainfall shows yield during the planting period of more than 2 tonne/hectare. The limit of high rainfall (60-80/mm) shows high yields. Therefore, Figure 39 shows has no correlation between yield and rainfall pattern, as Boro needs irrigation.

Fig- 39: Total rainfall in the 1st 90 days of growth against Boro yield in Bhola(1990-2008)

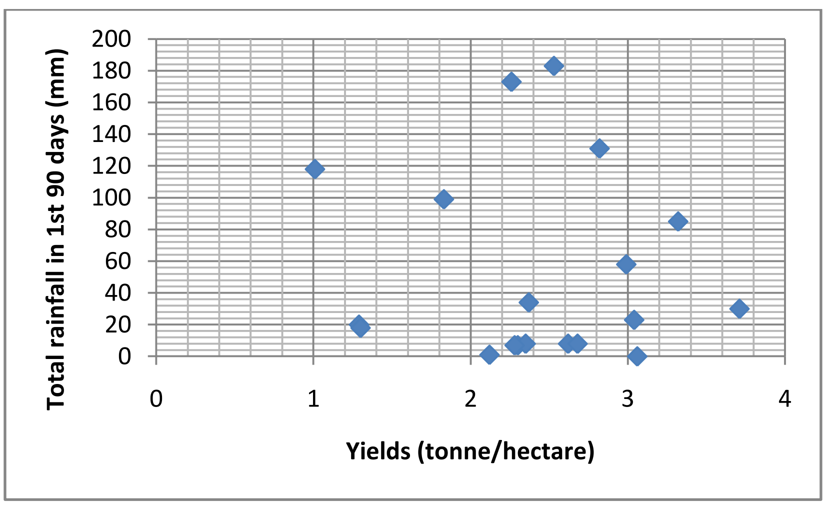


Figure 39 shows the total amount of rainfall in 1st 90 days against Boro rice yield from 1990 to 2008. This shows no correlation between yield and rainfall. However, total amount of rainfall

varies from 0 to 170/mm which can play a major role in delaying farmer's planting or farmer's irrigation policy, as farmers may not need much ground water if there is sufficient rain.

- **General discussion**

Seasonal variation of temperature and rainfall have limited or no co-relation with yields (1990-2008). The study is not able to show the impact of climate risk on seasonal yields as one single average Boro rice data set has been used in this study rather the more local profitable or high yielding varieties. So, one Boro yield data in Boro season and one planting date of Boro rice is not able to show in detail the impact of temperature and rainfall changes on Boro yields. In addition, the change of local variety of Boro rice is important for showing the change of yield, as farmers may use a local climate tolerant Boro variety in the study area. Therefore, the overall Boro production is increasing in the study area and this may be the result of farmers using high yielding varieties of rice.

There is no major difference of temperature between 1^{st} 45 days maximum and 1^{st} 90 days maximum temperature except in one year. In addition, 1^{st} 45 days minimum temperature and 1^{st} 90 days minimum temperature have few variations that need consideration. However, only based on minimum daily temperature variation, it is very hard to analyse the impact of minimum temperature on crop production. Night temperature is important for the analysis of impact of minimum temperature on flowering, but the study did not show any night time temperature impact on yield particularly due to the lack of flowering data.

As Boro is a dry season rice, the total amount of seasonal rainfall is generally low. This low yield may happen for the change of climate and changes of seasonal pattern. However, the research is not able to describe about the cause of seasonal changes in climate properly and the pattern of climate due to the lack of other climate parameters data sets. Other parameters that could be important includes salinity, water logging, crop field water availability, drought conditions.

The overall impact of daily temperature on Boro yields shows no trend with temperature change and no trends with the change of rainfall. However, yield may increase due to irrigation and use of high yielding varieties.

4.3.1. Simulation crop growth model

Generally, crop growth simulation models can be used to simulate crop growth and yields based on a number of observed data (e.g, soil, weather, fertilizer, season, and spatial, etc, data). They enable users to try in any specific management combinations for the simulation of a number of crops. In addition, they help users to show the seasonal analysis, crop rotation and spatial analysis for a number of crops based on historical observed data. However, wide ranges of physical and topographical data are used for the DSSAT modeling to simulate crop yield. The greater the data availability, the more accurate the simulation results obtained under the DSSAT modeling system.

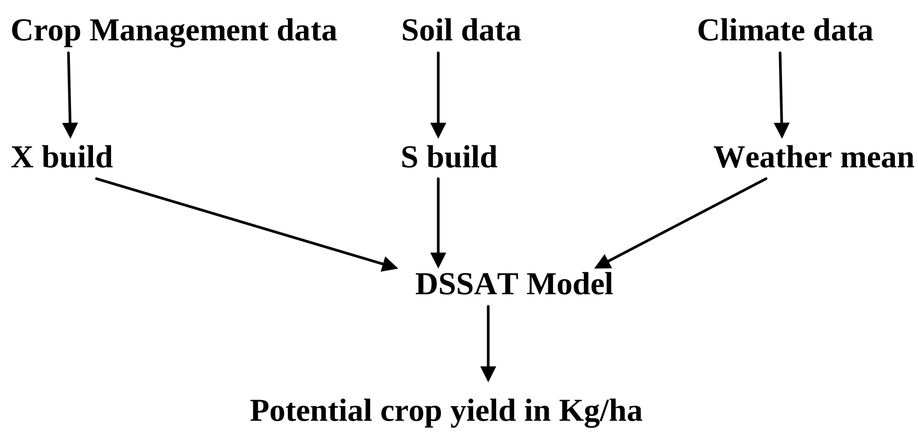
The goal in this study of the use of the DSSAT4.5 model system is to find the potential crop yields in the study area. The historical weather data was used as inputs to calculate the potential rice yields. In addition, planting available data and soil type variability have been used. In this study, three types of historical climate data (18 years from 1990-2008) have been used the temperature (maximum and minimum), rainfall and sunshine data.

4.3.2. Method of simulation

Weather and sunshine data (18 years) were obtained from WARPO in Bangladesh. A new weather station Bhola has been created by using DSSAT 4.5(**Appendix: 3**) and then all the climate data including sunshine data on a yearly basis were imported. In addition, crop cultivation is defined by the process of crop biological growth that consists of distinct, chronologically sequential phases. Thus, various sequential stages data and weather mean data input are important to calculate potential crop yield in DSSATv4.5 model. The ICSIM (Introductory Crop Simulation Model) tools in the DSSAT v4.5 model system can run crop models based on management input, planting date, fertilizer input, harvesting date, and weather data. In addition, ICSIM tools in the DSSAT modeling system have been widely used for assessing climate change impacts under a range of weather and soil conditions (Curry. *et. al.*, 1995; Jones. .*et.al.*,2003).

Hoogenboom..*et.al.*,(2004) have provided a detailed description of the model. The steps involved in the DSSAT modeling system are displayed in figure 40 .

Fig 40: Steps in the simulation process using the DSSAT modeling system



Sources: Hoogenboom..*et.al.*,2004

4.3.2.1. Selection of rice variety

Selection of cultivar and rice is important to allow the model to respond to diverse weather and management conditions. The Boro rice variety BR14 (IB0117) was selected in the present study because the genetic coefficients for this variety are available in the DSSAT modeling system. The BR14 (IBO117) rice variety was also selected for the Aman rice variety simulations.

4.3.2.2. Crop Management Data

In the model, crop management data required include planting method, transplanting date, planting distribution, plant population at seedling, plant population at emergence, row spacing, fertilizer application rate and irrigation application and frequency. Where possible these data collected from the Bangladesh Rice Research Institute (BRRI). Two planting dates (days of the

year 90 and 120) used. The major crop management input data used in the model for all simulations in the present study are shown in Table31.

Table1 31: Crop management input data

Crop management data		Rice	
Management input		Aus	Aman
Planting date		March to May	July to September
Population(m^{-2})		75	75
Irrigation data	Puddling for rice only	0	0
	Percolation rate (mm/day)	5	2
	Bund height mm	150	20
Fertilizer(kg/ha)	Nitrogen	25	25
Row spactng(cm)		25	25

Source: BARC datasets, 2010

4.3.2.3. Description of soil input

The most common soil identified is the Vertitropaquent (Soil Survey Staff, 1975, p745) database. This soil data is based on the 10 km soil database developed by Kern (1994, 1995). The database includes soil physical properties (particle size distribution and organic carbon) down to 1.5 m soil depth. The CROPGRO-rice model computes a daily soil water balance as a function of rainfall and soil water holding characteristics of each layer (drained upper and lower soil water holding limits).

4.3.2.4. Weather mean data

CROPGRO-Rice requires daily sunshine (hour/day), maximum and minimum temperatures (°C), and rainfall (mm/day) data. Weather data consists of the minimum dataset (maximum and minimum temp, sunshine and rainfall in this study). After observation of daily data (, weather file structure has been made. In the study, the local area weather file structure is named BHOLNNnn.WTH. Here BH is the institution ID, Ol is the site ID, NN is the year of observation

and nn is number of years (default=01). The new station information is stored (**Appendix-4**) in a PRM climate project files and data is normally imported in the Excel format to DSSAT units that are used by the DSSAT crop models. In addition, data can be edited by exporting from DSSAT and filling any missing data. The individual year of the weather data is saved in a station. Then weather mean variables for maximum and minimum temperature, sunshine and rainfall are identified through the generated weather mean data in weather station. All data are then saved in a climate file for the interaction of data management and climate analysis in the DSSAT modeling system, that enables running the simulation of crop yield.

4.3.2.5. Simulation Runs

The predictions have been made using a fixed concentration of atmospheric CO^2 of 379 ppm (the value reported for the year 2005 the Fourth Assessment Report of IPCC 2005), rainfall application (860 mm in 14 applications), fertilizer rate (0 to 125 kg/ha in 3 applications of nitrogen) and for a planting date of July for Aman and April for Aus . Soil data and climate data were selected on a location basis.

However, the SRES emission scenarios and climate models (INCCA Model, 2000-2007) considered the projected global mean surface temperature rise in a range from 1.8°C (with a range from 1.1°C to 2.9°C for SRES B1) to 4.0°C (with a range from 2.4°C to 6.4°C for A1) by 2100. Based on the Fourth Assessment Report of the IPCC (2005), the assumptions of maximum and minimum temperatures considered were 20˚C and 40˚C. According to the literature review, a critical parameter for rice crop cultivation is the minimum temperature, thus using the models a simulation was made of the potential rice yield under the increase of highest minimum temperature. This study examined the effect of an increase of 2˚C in the minimum temperature for Aus and Aman rice, as this is considered the likely change over the next 50 years.

4.3. 3.Simulation results

Two major types of rice (Aus and Aman) have been used in the simulations of potential yields (kg/hectare) using the DSSAT4.5 model system. Another rice season (Boro) where underground

water irrigation is used cannot be modeled in the DSSAT modeling system, as detailed irrigation rate data is not available.

4.3.3.1. Outcomes based on actual observed data

Observed Aman and Aus season's weather data have been used to find the potential rice yield over the 18 years (from 1990-2008) in the study area. However, only one planting date is used in DSSAT modeling for Aus and Aman yield. So, the outcomes **(Appendix-5)** may not therefore fully reflect the Aman and Aus potential yields as farmers may use different times to plant their crops on the basis of their particular circumstances.

4.3.3.1.1. Potential Aman and Aus rice yields

The predicted Aus yield data are shown in Table 32. From the model simulation, it is observed that over the years of 1990 to 2008 the maximum Aus rice production in the Bhola district has been found to be 4000 kg/ha and the minimum is 3200 kg/ha. On average, the maximum yield is more than 3500 kg/ ha in the study area; this is much higher than the actual yields reported.

The predicted Aman yield data are also shown in Table 32. From the model simulation it is observed that maximum Aman rice production for the Bhola district has been found to be 5750 kg/ha and the minimum is 3600 kg/ha over the years of 1990 to 2008. The average maximum yield is more than 4500 kg/ ha in the study area; and again this is much higher than the actual yields reported.

Table 32: Predicted Aman and Aus rice yields for the Bhola district of Bangladesh using the DSSATv4.5 model

Year	Potential Aman yield(1000kg/ha)	Potential Aus yield(1000kg/ha)
1990	5.1	3.2
1991	5.6	3.5
1992	4.5	4
1993	4.7	3.9
1994	4.4	3.4
1995	4.4	3.4
1996	3.8	3.6
1997	4.9	3.8
1998	3.6	3.2
1999	3.6	3.7
2000	5.02	3.4
2001	5.1	3.7
2002	4.9	3.7
2003	4.9	3.9
2004	4.7	4.2
2005	4.3	3.9
2006	3.7	3.7
2007	4.7	3.5
2008	5.1	4

4.3.3.2. Outcomes based on modeling with an increase in minimum temperature of 2°C.

In Bangladesh, low temperatures induce two types of damage to rice cool injury and changes due to diurnal changes of low (night) and high (day) temperature. The critical limits of low temperature for a rice crop at agronomic panicle initiation (API), reduction division (RD) and anthesis are respectively 18˚C for cool injury, 19˚C for low(night temperature) and 22˚C for high minimum daytime temperature. However, as noted earlier (literature review) an increase in the minimum temperature can cause changes in rice production; this was therefore included in the simulated DSSATv4.5 model system for an increase in minimum temperature of 2˚C. The results reported in Table-3 for rice production for both Aus and Aman rice varieties in this study area.

4.3.3.2.1. Potential Aman and Aus yields under conditions of increased minimum temperature.

The maximum simulated yields of Aus under the conditions of having an increase of 2˚C in the highest minimum temperature shows in Table 33. Aus rice yields declined between 800 to 1000 kg/ha based on data from 1990-2008. The Aus rice-planting season normally starts from March/April and the highest minimum temperatures varied from 26 to 30˚C between the years of 1990 to 2008. The highest minimum temperature observed to be much higher in the last 6 years (from 2002 to 2008) than in the earlier years (1990 to 2001). Therefore, increase of minimum temperature is expected to cause an impact on rice production in future but other factors may also be important, e.g., change of soil properties/ changes of nitrogen fertilizer rate/ lack of water caused by lowering water table depth etc (Piao..*et.al.*,2010, p48-49).

Table 33 also contains the maximum simulated Aman yields under the conditions with an increase of 2˚C in the highest minimum temperature. The results show the lowering of rice yields by 875 kg/ha to 1200kg/ha based on the data for 1990 to 2008 for Aman rice. However, Aman rice planting season starts from November and the highest minimum temperature varied from 18 to 23˚C between 1990 and 2008. The highest minimum temperature was observed to be much higher in the years 2003 to 2008 than in the past. Therefore, the changes of minimum temperature at nighttime can influence rice production in the future because of cold injury to the plant for rice (Cho and Oki, 2012). In addition, recent weather changes in the study area results in early winter or long-term winter in the study area. These changes can cause damages during rice flowering in the study area (Peng. *et. al.*, 2004). In this study, only the increase of the highest minimum temperature of 2˚C has been used in the DSSAT4.5 modeling system; this may not show all the minimum temperature impacts on rice production. However, the impact of minimum temperature can reduce the yields in the study area. The rising of temperature in the ground can cause the increase of daytime minimum temperature and in this report the DSSAT 4.5 modeling system shows the low yields under the highest minimum temperature. So, further study on low minimum temperature may show more accurate results for yields due to the changes of minimum temperature resulting from climate changes.

Table-33: Modeled potential yields for Aman and Aus rice from 1990-2008 in the Bhola district with the increase of 2˚C in the highest minimum temperature.

Year	Potential Aman yield with increase minimum temperature(1000kg/ha)	Potential Aus yield with increase minimum temperature(1000kg/ha)
1990	4.9	3.0
1991	5.2	3.3
1992	4.0	3.7
1993	4.1	3.6
1994	3.7	3.3
1995	3.6	3.0
1996	3.5	2.9
1997	4.6	3.4
1998	3.3	2.9
1999	3.2	3.4
2000	4.7	3.1
2001	4.8	3.2
2002	4.4	3.5
2003	4.1	3.7
2004	4.5	3.8
2005	3.7	3.6
2006	3.2	3.5
2007	4.3	3.4
2008	4.7	3.2

4.3.4. Discussion of the modeling result

In this study the DSSATv4.5 model used minimal crop management input data. Generally, no plant genetic co- efficient or soil data has been tested in the study area due to a lack of data. In addition, the planting date for Boro and Aman rice has been assumed to be only one date. Only one transplanting date and one date of nitrogen, fertilizer use has been used for the simulations. Moreover, these limitations need to be considered in the DSSAT modeling system in future.

The simulation can be improved by the use of soil data that would allow the more accurate estimation of soil related parameter in the DSSATv4.5 model system. In addition, more than one cultivar and other transplanting dates and fertilizer rates input could also improve the results. Harvesting date changes and water table depth data input may used to get more specific result that allow for crop damage in the flood seasons. Despite these limitations, seasonal analysis is important to show the impact of particular seasonal climate changes on rice production in the study area.

4.4. General discussion of the results

Actual yields (average 2.5 tonne /ha for Aman, 3.4 tonne /ha for Boro and 2.0 tonne /ha for Aus) in the study area were generally low compared to the whole world range (4tonne/ha) of rice yields (Abbasi, 2012). However, in Bangladesh an average rice yield is 1.25 tons per hectare for local varieties (Aus rice), 4.5 tonne/hac for Boro rice and 2.8 tonne/hac for Aman rice (Hussain, 2012). Actual yields show no minimal correlation with temperature changes or rainfall changes. There is the possibility of other factors, such as; sea level rises, land erosion, drought, and excessive flooding as well as temperature and rainfall changes affecting rice production. The possibility of flooding due to rainfall or sea level rise contributing to the low yields cannot be ignored. In addition, modeling study did not consider any detailed soil properties that can have major impact on rice production. Soil factors influencing yield also vary with temperature change, salinity intrusion and rainfall patterns.

Since the study area is situated beside the Bay of Bengal there is a strong chance of major impact from salinity intrusion and sea level rises that has been investigated by researchers in Bangladesh for long time. As this study only identified temperature and rainfall patterns, it is difficult to say which climatic factors can have the major responsibility of the low yields.

Global temperature change can cause the sea level rise due to the ice melting and expansion of sea water and thus may cause severe floods in low-lying areas. Because of sea level rise, saline

water can enter low lying areas with flood water and cause the damage of soil properties (e.g; structure material activity). All climate factors are directly or indirectly related with each other for changing the pattern of rice growth climate (changes of soil pattern, flash flooding, and inundation of land, severe flooding, longer time and more frequent flooding, sea level rise, seasonal changes of rainfall pattern) that can cause damage to crops. It is therefore important to analyse soil properties and sea level rise to try and assess the maximum possibility of the climate change impact on rice production in this area.

At the same time, the economic condition of the local population should not be ignored in any analysis of climate change impact on rice production. Sometimes farmers face severe economic crisis and copping with climate conditions is very hard for them. For example, a farmer's capacity to purchase better seeds and plants at the right time depends on their income level. Sometimes a disaster in a previous cropping season makes it impossible to buy plants or seeds at a particular time due to the loss of a previous season's income. They are very often obliged, therefore to take loans from rich people at high interest (more than 60% interest) rates that can cost them all the profits. This loss of income is also putting pressure on them for purchasing seeds or plants for the next cropping season. Therefore, one big disaster in a year makes farmers' incomes vulnerable with continuous decrease in the purchasing capacity for seeds and plants; this is making it harder for them to cope with poverty that is a major economic issue contributing to low yields in the study area. So, economic effects of climate change also need to be considered, but were not completed in this study.

In the DSSAT 4.5 modeling system, potential yields for two cropping seasons are shown to be much higher than actual yield data. This study used only temperature, rainfall and sunshine data for producing weather mean as other data were not available of that time. On the other hand, with full data availability the DSSAT model could be used to better estimate the actual predicted rice.

According to the literature review (Chapter-2), a rise in the minimum temperature can cause a lowering of rice production. The DSSAT model data show such reductions (~10%) in the

potential yields due to a rise of 2°C in the minimum temperature in the study area. This lowering of production under rising minimum temperatures indicates the possibility of reductions in actual yield with the expected climate change.

Any yield reduction will be very important for this region as it will affect food supply and income. The main livelihood options for this region are based on agriculture and rice production is playing an important role for the income from the agricultural sector. In this study only three sets of general (Aus, Aman and Boro) yield data have been used as this was available from BARC in Bangladesh. Farmers could use higher yielding varieties that can provide higher yields than the three traditional (Aus, Aman and Boro) varieties. In addition, if funding can be found for farmers then they could use more fertilizers to produce more rice. The only fertilizer option used in the DSSAT models in this study was one level of nitrogen. Therefore, the use of more detailed soil and fertilizer information in the DSSAT model may provide more accurate yield information in the study area.

Sea level rise and disaster frequency are important factors when considering crop yield estimation or when trying to estimate the loss of rice production in the study area. The area has a high rate of saline intrusion and if sea level rise occurs as predicted, more salinity issues are likely contribute to a greater loss of rice production, as the sea level rise is responsible for the long-term inundation of the land, flooding depth and intrusion of saline water into the land. In addition, in the frequency of disaster can contribute to more damage to and loss of crops. Storm surges and flash flooding can cause the destruction of crops and if these disasters become more frequent that will add to income vulnerability for farmers. Thus, sea level rise mapping through ARC GIS or similar approaches can help to analyze the flooding depth of the land and thus estimate the vulnerability of currently suitable land for rice production.

Chapter 5: Conclusions and Recommendations

5.1. Conclusions

Generally, rice yield and rice production depend on various factors such as, climate conditions, soil quality, planting methods and practices, irrigation facilities, etc. The historical rice yield data can show changes of rice yield due to climate variables especially in Southeast Asia. Therefore, future climate risk is now a major concern for rice yield in Bangladesh especially in low-lying areas.

Identifying present climate trends was an objective of this research. However, the achievement of this first objective outcome was not satisfactory for showing the trends of present climate trends. As ,IPCC(2007) declared that global temperature is expected to rise by 2.2°C ~ 3.0°C and precipitation is forecasted to increase by 3% ~ 8% (Christensen. ***et. al.*** 2007), the research tried to show the impact of climate change on rice yield in the chosen study area. The current climate situation was observed from the daily weather data over the last 18 years. Generally, temperature starts to rise in recent years. However, changes of rainfall pattern and excessive pre and post monsoon rain were observed in the chosen study area. So, climate change trends are expected to decline rice yield.

A quantitative analysis of the impact of climate trends on rice yield is the second objectives of this research. The research used climate data to try and examine the correlation between climate trends and yield. This statistical method could be useful to show the high or low trend of rice yield due to climate changes. As, temperature and rainfall change are important factors for rice yield, correlation between yield and temperature or rainfall may show a quantitative change in rice yield due to climate change. However, no good correlations between yield and climate parameters, the best results show no or weak correlation between yield and climate parameters. The research is able to achieve its goal partially for the assessment of impacts of climate patterns on rice yield. Better results might be achieved with more exact yield data from field investigation rather then using average data. Moreover, other environmental factors, e.g; soil management, sea level rise could affect yields.

Climate is changing in all over the world and it is now treating food production. The third objective in my research is to show the predicted climate risk on rice yields. Simulation method was used to assess the projected climate change affect on rice yield. Models operate with various management, planting and climate data in one file. DSSAT modeling system can perform with climate data, management data, yield data, fertilizer, and other variables also. This research used daily temperature, daily rainfall and daily sunshine data for climatic condition and only nitrogen fertilizer data for management input. Other data were not available and the result of the simulation may not be very accurate for the study area. However, the overall simulation result can indicate the consequences of climate impacts on rice production. The results show low rice yield of 800 to 1000 kg/hectare if the highest minimum daily temperature will increase in 2 degrees based on the simulation climate data in last 18 years (1990-2008). With more management data inputs we could get a better picture of climate risk on rice yield. However, the result of simulation model indicates the low yield due to temperature and rainfall. The result indicate that projected climate change can make a major impact on yields in low-lying delta areas in Bangladesh.

Generally, this research was based on secondary data (rice production, climate daily data). However, rice production is related to water supply in the planting period, flooding in the rainy seasons, pest management in the harvesting time and soil fertility. In addition, high temperature demands more water supplies in the field due to the high rate of evaporation. So, irrigation or drainage facility is important to meet the demand for water in the field for high yield. However, as the soil condition in the research area is sandy soil or clay soil, the river erosion and surface rainfall pattern is important for rice production. Both mean temperature and variability of temperature can also affect rice yield. In addition, soil fertility management is also important for good crop growth, and it was not possible to investigate this perspective in the study area.

The study area is low lying and close to the Bay of Bengal. Due to global warming and sea level rise, the area is facing more flooding and river erosion than in the past and thus may be a major cause of low yields. However, temperature and rainfall are playing a strong role in rice

production as sea level rise, flooding, etc are at least partially the result of changes of temperature and rainfall.

5.2. Recommendations

The outcome of the research has not completely resolved the issues, as further research will be needed in future to investigate climate change impacts on rice production in Bangladesh. Following areas of research will need to be further developed:

- Data for this research was limited. Generally farming system studies need to look at soil, water, land management strategies and technologies. This research model only used daily weather data. Further research should include more detail on soil management, water, land management and technology to improve the accuracy of climate model results.

- To understand the potential risks of future food production, more detailed local and regional scale rice production data must be taken into consideration to get better relationship between rice yields and climate pattern.

- Flooding is important factor reducing rice yields as observed in my research. No detailed flood information data were available for any in depth analysis. However, more flooding data could be considered by mapping flood zones and risk of flooding zones in future through GIS techniques. Therefore, flooding maps for recent years and flood return periods should be considered in further research.

- Salinity intrusion is an important factor leading to reduced rice yields, as this research showed negative with salinity impact on rice yield from the review. In the DSSAT, modeling system, in depth soil management data can show the effect of changing soil properties and this could lead to better results of future risk to rice yields due to salinity. .

- Economic factors are important for farmers. Most recent research into agriculture in Bangladesh is associated with climate factors. Very little research has focused on the understanding of adaptation strategies for men and women in disaster prone areas. Further research may focus to understand men’s and women’s adaptation, mitigation and challenges to cope with climate risk in the study area.

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Appendices

Appendix 1: The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES)

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Appendix 2: Rice production data sets from BARC

A. Total Crop Production Data for 1990-2008 from BARC in the Study Area

Year	Yield/thousand acre	Production per thousendsM.t	Yield(Tonnes/hectare
1990	1036	779	1.1
1991			1.07
1992	1137	919	1.14
1993	1155	987	1.61
1994	1176	982	1.711
1995	1202	630	1.64
1996	1132	627	1.74
1997	679	998	1.78
1998	133	662	1.58
1999	1389	909	1.83
2000	1471	1091	2.62
2001	1512	1007	2.3
2002	1466	1038	2.49
2003	1416	1022	2.48
2004	1427	914	1.55
2005	1497	1100	1.55
2006	1330	739	2.15
2007	1040	686	1.06
2008	984	1016	2.11

Here, Yield (Tonnes /Hectare) = $\frac{\text{Total Production}}{\text{Acre X 2.47}}$

B. Total Yield in Aus, Aman and Boro Seasons in the study area

Year	Aus(B.Aman)	T.Aman	Boro
1990	1.2	1.25	1.01
1991	1.07	0.91	1.29
1992	1.04	1.09	1.3
1993	1.2	1.23	2.37
1994	1.12	1.77	2.3
1995	1.08	1.77	2.53
1996	1.09	1.64	2.62
1997	1.17	1.85	2.35
1998	1.2	1.25	2.26
1999	1.14	1.71	2.68
2000	2.31	2.71	2.82
2001	1.45	1.98	2.99
2002	1.46	2.58	3.32
2003	1.19	2.57	3.71
2004	1.32	1.06	2.12
2005	0.96	1.47	2.28
2006	1.39	1.99	3.06
2007	0.342	1.08	1.83
2008	1.3	2.02	3.04

Appendix3: Weather station data of Bhola

Rainfall of BMD

Datatype : Excel 8.0

BUNDLE INFORMATION

Table Name : CodeRainfallBMD

ID	FIELD	FIELD_NAME	UNIT
1	DateTime	Data Capturing Date	
2	StationId	ID of Each Station	
3	TsValue_Old	Original Time Series Value collected from Source	MiliMeter (mm)
4	TsValue_Updated	Time Series Values Updated (All negative values,Records with abnormal high value are deleted)	MiliMeter (mm)

Sunshine Hours, BMD

Datatype : Excel 8.0

BUNDLE INFORMATION

Table Name : CodeSunshineHour

ID	FIELD	FIELD_NAME	UNIT
1	DateTime	Data Capturing Date	
2	StationID	Id of Each Station	
3	TsValue_Old	Original Time Series Value Collected from Source	Hour
4	TsValue_Updated	Time Series Values Updated (Values > 14.2 are deleted)	Hour

Temperature Data of BMD

Datatype : Excel 8.0

BUNDLE INFORMATION

Table Name : TemperatureCode

ID	FIELD	FIELD_NAME	UNIT
1	DateTime	Data Capturing Date	
2	MaxTemp_Old	Original Time Series Value Collected from Source	Degree Centigrade (°C)
3	MaxTemp_Updated	Time Series Values updated (All 0 Values,Values Greater than 44.2°c,All Negative Values,Values Less than 1,and Values with Other Obvious Error are Deleted)	Degree Centigrade (°C)
4	MinTemp_Old	Original Time Series Values Collected from Sou	Degree Centigrade (°C)

		rce	
5	MinTemp_Updated	Time Series Values Updated (All 0 Values,Values Greater than 44.2°,All Negative Values,Values Less than 1 and Values with Other Obvious Error are Deleted)	Degree Centigrade (°C)
6	StationID	ID of Each Station	

Appendix 4: Bhola Station Information

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* CLIMATE:ol

@ INSI      LAT     LONG  ELEV   TAV   AMP  SRAY  TMXY  TMNY  RAIY
  BHOL   22.700   90.660     5  26.0   5.0  15.2  30.4  21.7  2342
@START  DURN  ANGA  ANGB REFHT WNDHT SOURCE
  1980    27  0.25  0.50 -99.0 -99.0 Calculated_from_daily_data
@ GSST  GSDU
     1   365

*MONTHLY AVERAGES
@  MTH  SAMN  XAMN  NAMN  RTOT  RNUM  SHMN  AMTH  BMTH
     1  13.7  25.6  12.5   8.3   1.0   -99 0.250 0.500
     2  16.2  28.4  16.0  30.9   2.9   -99 0.250 0.500
     3  17.8  31.8  20.9  57.8   3.9   -99 0.250 0.500
     4  19.1  33.0  24.1 120.5   7.3   -99 0.250 0.500
     5  17.9  32.8  25.2 263.3  12.3   -99 0.250 0.500
     6  14.6  31.6  26.0 474.4  19.6   -99 0.250 0.500
     7  14.0  30.8  25.9 456.3  24.7   -99 0.250 0.500
     8  14.4  31.2  26.0 383.2  23.5   -99 0.250 0.500
     9  13.6  31.3  25.7 314.0  17.5   -99 0.250 0.500
    10  14.2  31.7  23.9 183.0   8.6   -99 0.250 0.500
    11  14.2  29.8  19.3  42.8   2.0   -99 0.250 0.500
    12  13.0  26.9  14.4   7.1   0.8   -99 0.250 0.500

*WGEN PARAMETERS
@  MTH  SDMN  SDSD  SWMN  SWSD  XDMN  XDSD  XWMN  XWSD  NAMN  NASD ALPHA  RTOT   PDW  RNUM
     1  13.8   0.7  11.2   0.0  25.7   1.9  23.7   0.0  12.5   2.1 0.119   8.3 0.022   1.0
     2  16.5   0.7  13.6   0.8  28.7   2.0  26.3   1.9  16.0   2.9 0.475  30.9 0.070   2.9
     3  18.0   0.7  16.3   0.8  32.2   1.8  29.5   2.3  20.9   2.7 0.402  57.8 0.067   3.9
     4  19.2   0.7  18.7   0.8  33.5   1.3  31.5   2.0  24.1   1.7 0.288 120.5 0.146   7.3
     5  18.4   0.7  17.0   0.7  33.5   1.5  31.8   1.9  25.2   1.4 0.152 263.3 0.258  12.3
     6  16.2   0.7  13.8   0.6  32.8   1.6  30.9   1.8  26.0   1.0 0.449 474.4 0.379  19.6
     7  15.4   0.7  13.6   0.6  31.8   1.3  30.6   1.5  25.9   0.8 0.260 456.3 0.611  24.7
     8  15.7   0.7  14.1   0.6  31.9   1.3  30.9   1.4  26.0   0.8 0.518 383.2 0.642  23.5
     9  14.4   0.6  13.1   0.7  32.2   1.4  30.7   1.8  25.7   0.7 0.746 314.0 0.340  17.5
    10  15.1   0.7  12.0   0.8  32.2   1.4  30.3   2.1  23.9   1.8 0.447 183.0 0.144   8.6
    11  14.5   0.8  10.0   0.9  30.0   1.5  27.8   3.2  19.3   2.4 0.621  42.8 0.036   2.0
    12  13.1   0.8   9.5   0.0  27.0   1.5  24.4   0.0  14.4   1.8 0.165   7.1 0.018   0.8

*RANGE CHECK VALUES
@      SRAD  TMAX  TMIN  RAIN  DEWP  WIND  SUNH   PAR  TDRY  TWET  EVAP  RHUM
MIN :   0.5 -30.0 -40.0   0.0 -40.0   0.0   0.0   5.0 -40.0 -40.0   0.0   0.0
MAX :  85.0  40.0  30.0 600.0  40.0 500.0 100.0  85.0  40.0  40.0  15.0 100.0
RATE:  70.0  20.0  20.0 500.0   5.0 300.0  90.0  70.0  20.0  20.0  15.0  75.0

*FLAGGED DATA COUNT
@BEGYR BEGMN BEGDY ENDYR ENDMN ENDDY
  1980     1     1  2008    12    31
@        TOTAL   RAIN   TMAX   TMIN   SRAD   SUNH   DEWP   WIND    PAR   TDRY   TWET   EVAP   RHUM
Total  : 42368  10592  10592  10592  10592      0      0      0      0      0      0      0      0
Valid  : 42367  10592  10592  10591  10592      0      0      0      0      0      0      0      0
Missing:     0      0      0      0      0      0      0      0      0      0      0      0      0
Error  :     0      0      0      0      0      0      0      0      0      0      0      0      0
Above  :     1      0      0      1      0      0      0      0      0      0      0      0      0
Below  :     0      0      0      0      0      0      0      0      0      0      0      0      0
Rate   :     0      0      0      0      0      0      0      0      0      0      0      0      0
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BHOL0001.WTH

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*WEATHER DATA : ol

@ INSI      LAT     LONG  ELEV   TAV   AMP REFHT WNDHT
  BHOL   22.700   90.660     5  26.0   5.0 -99.0 -99.0
@DATE  SRAD  TMAX  TMIN  RAIN  DEWP  WIND   PAR  EVAP  RHUM
00001  12.4  25.5  12.0   0.0         m     m     m
00002  13.0  26.0  12.0   0.0         m     m     m
00003  12.8  25.0  12.5   0.0         m     m     m
00004  11.2  24.8  12.4   0.0         m     m     m
00005  11.3  23.5  11.2   0.0         m     m     m
00006  12.5  24.5  10.8   0.0         m     m     m
00007  12.6  23.0  10.4   0.0         m     m     m
00008  13.6  23.6  10.2   0.0         m     m     m
00009  13.9  23.8   9.4   0.0         m     m     m
00010  14.1  26.0  10.5   0.0         m     m     m
00011  13.9  28.0  11.5   0.0         m     m     m
00012  13.3  28.4  12.4   0.0         m     m     m
00013  14.1  29.0  13.4   0.0         m     m     m
00014  15.3  29.8  14.2   0.0         m     m     m
00015  13.2  28.0  16.0   0.0         m     m     m
00016  13.9  28.0  16.8   0.0         m     m     m
00017  14.8  25.6  13.8   0.0         m     m     m
00018  16.0  23.6   9.0   0.0         m     m     m
00019  14.8  24.5  10.2   0.0         m     m     m
00020  14.3  27.0  11.4   0.0         m     m     m
00021  10.8  26.8  18.0   0.0         m     m     m
00022  12.6  27.8  18.4   8.0         m     m     m
00023   9.8  22.8  17.0   0.0         m     m     m
00024  11.9  26.6  16.0  34.0         m     m     m
00025  15.9  26.3  14.8   0.0         m     m     m
00026  16.1  27.6  13.6   0.0         m     m     m
00027  16.6  28.5  13.0   0.0         m     m     m
00028  16.4  28.0  13.0   0.0         m     m     m
00029   9.8  25.5  15.6   0.0         m     m     m
00030  14.4  24.2  14.5   0.0         m     m     m
00031  15.6  25.8  12.8   0.0         m     m     m
00032  16.7  26.8  12.5   0.0         m     m     m
00033  15.3  25.7  13.0   0.0         m     m     m
00034  10.6  27.0  17.2   0.0         m     m     m
00035  10.6  27.2  19.6   0.0         m     m     m
00036  10.0  27.0  19.0   1.0         m     m     m
00037  13.2  25.2  17.4   2.0         m     m     m
00038  13.2  27.0  18.8   0.0         m     m     m
00039  16.2  26.8  17.6   1.0         m     m     m
00040  11.6  25.6  15.2   0.0         m     m     m
00041   7.1  22.5  18.1   0.0         m     m     m
00042  17.9  26.8  14.2   2.0         m     m     m
00043  11.3  26.4  15.2   0.0         m     m     m
00044  12.6  27.2  15.8   0.0         m     m     m
00045   9.5  25.2  18.5   0.0         m     m     m
00046  18.3  25.8  16.0   0.0         m     m     m
00047  18.5  26.5  11.6   0.0         m     m     m
00048  14.7  26.2  11.0   0.0         m     m     m
00049   7.7  22.8  16.8   0.0         m     m     m
00050  14.9  26.5  12.0   2.0         m     m     m
00051  14.6  27.5  13.0   0.0         m     m     m
00052  10.7  27.5  15.0   0.0         m     m     m
00053  17.0  28.4  14.3   0.0         m     m     m
00054  18.6  28.5  14.4   0.0         m     m     m
00055  16.5  28.0  15.4   0.0         m     m     m
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00056	13.0	27.5	15.0	0.0	m	m	m
00057	13.8	26.8	17.2	0.0	m	m	m
00058	18.6	28.0	14.2	0.0	m	m	m
00059	17.5	28.7	14.0	0.0	m	m	m
00060	17.2	28.5	14.8	0.0	m	m	m
00061	12.6	29.5	15.5	0.0	m	m	m
00062	9.1	29.5	20.6	0.0	m	m	m
00063	13.2	30.0	22.7	0.0	m	m	m
00064	13.1	30.0	22.8	0.0	m	m	m
00065	14.7	30.6	22.8	0.0	m	m	m
00066	12.0	29.0	21.6	0.0	m	m	m
00067	14.1	30.7	23.0	0.0	m	m	m
00068	12.3	30.0	22.2	0.0	m	m	m
00069	14.6	29.0	19.5	12.0	m	m	m
00070	16.5	31.2	20.5	0.0	m	m	m
00071	14.0	30.7	20.7	0.0	m	m	m
00072	12.7	31.0	21.6	0.0	m	m	m
00073	11.0	30.4	24.5	0.0	m	m	m
00074	10.8	29.5	23.5	1.0	m	m	m
00075	14.0	30.6	20.3	48.0	m	m	m
00076	16.5	30.6	23.2	0.0	m	m	m
00077	18.0	31.5	17.6	0.0	m	m	m
00078	14.3	30.2	20.0	0.0	m	m	m
00079	11.1	30.5	21.5	0.0	m	m	m
00080	14.2	31.8	23.4	0.0	m	m	m
00081	20.4	33.2	20.6	0.0	m	m	m
00082	20.4	33.4	18.0	0.0	m	m	m
00083	12.3	32.2	18.2	0.0	m	m	m
00084	13.8	32.5	20.2	0.0	m	m	m
00085	16.1	31.5	20.4	0.0	m	m	m
00086	9.4	32.2	19.8	0.0	m	m	m
00087	15.4	31.8	20.3	0.0	m	m	m
00088	13.7	33.5	18.2	0.0	m	m	m
00089	9.9	32.6	20.5	0.0	m	m	m
00090	9.0	30.0	21.8	0.0	m	m	m
00091	15.2	32.5	22.2	0.0	m	m	m
00092	21.6	33.2	23.4	0.0	m	m	m
00093	16.6	33.0	25.2	0.0	m	m	m
00094	13.2	32.0	26.0	0.0	m	m	m
00095	17.1	32.7	25.5	0.0	m	m	m
00096	15.3	32.4	26.1	0.0	m	m	m
00097	11.6	32.0	26.0	0.0	m	m	m
00098	13.3	31.6	25.5	0.0	m	m	m
00099	18.9	32.8	25.5	0.0	m	m	m
00100	21.0	32.6	25.6	0.0	m	m	m
00101	11.4	33.5	26.3	0.0	m	m	m
00102	20.4	33.6	25.0	0.0	m	m	m
00103	19.2	33.1	22.0	1.0	m	m	m
00104	22.7	32.8	24.0	0.0	m	m	m
00105	20.3	32.6	24.5	0.0	m	m	m
00106	20.3	31.8	21.6	6.0	m	m	m
00107	23.1	31.5	21.0	10.0	m	m	m
00108	21.5	32.8	24.3	0.0	m	m	m
00109	22.9	32.8	22.8	8.0	m	m	m
00110	21.1	33.0	25.5	0.0	m	m	m
00111	21.1	31.5	25.8	0.0	m	m	m
00112	20.2	32.0	21.0	3.0	m	m	m
00113	19.6	33.4	23.8	12.0	m	m	m
00114	21.5	31.6	23.8	0.0	m	m	m
00115	18.8	32.8	25.5	4.0	m	m	m
00116	22.1	31.6	20.2	31.0	m	m	m
00117	16.7	27.0	20.5	18.0	m	m	m

00118	17.9	32.3	20.2	23.0	m	m	m
00119	19.6	33.0	22.3	10.0	m	m	m
00120	18.2	33.5	27.8	0.0	m	m	m
00121	21.0	33.0	22.0	0.0	m	m	m
00122	16.8	32.4	27.6	0.0	m	m	m
00123	11.9	30.8	21.0	25.0	m	m	m
00124	22.7	31.0	19.1	62.0	m	m	m
00125	9.8	31.2	23.3	0.0	m	m	m
00126	10.3	30.7	24.3	0.0	m	m	m
00127	15.6	30.0	25.6	1.0	m	m	m
00128	25.2	30.5	22.6	10.0	m	m	m
00129	19.6	32.2	24.4	0.0	m	m	m
00130	23.2	34.0	24.8	0.0	m	m	m
00131	24.2	34.8	26.4	0.0	m	m	m
00132	24.2	34.6	25.2	0.0	m	m	m
00133	21.4	35.0	27.0	0.0	m	m	m
00134	23.4	36.2	26.4	0.0	m	m	m
00135	20.5	35.7	27.6	0.0	m	m	m
00136	22.2	35.2	27.0	0.0	m	m	m
00137	9.9	31.5	27.8	0.0	m	m	m
00138	13.9	32.7	26.4	0.0	m	m	m
00139	19.5	33.8	24.4	27.0	m	m	m
00140	10.1	31.0	27.3	0.0	m	m	m
00141	14.6	30.8	24.0	5.0	m	m	m
00142	12.3	29.8	25.4	0.0	m	m	m
00143	13.3	31.0	25.0	20.0	m	m	m
00144	11.6	29.4	25.2	3.0	m	m	m
00145	13.2	31.0	25.5	5.0	m	m	m
00146	10.3	33.0	27.0	10.0	m	m	m
00147	11.5	32.6	25.3	1.0	m	m	m
00148	10.0	30.4	22.4	0.0	m	m	m
00149	10.0	29.2	22.3	81.0	m	m	m
00150	13.9	30.1	21.8	9.0	m	m	m
00151	17.9	33.0	24.0	9.0	m	m	m
00152	18.8	32.6	23.0	11.0	m	m	m
00153	19.5	33.4	25.6	5.0	m	m	m
00154	17.5	33.5	26.8	0.0	m	m	m
00155	18.9	33.5	27.4	1.0	m	m	m
00156	14.5	33.5	28.0	0.0	m	m	m
00157	24.3	32.5	26.6	0.0	m	m	m
00158	11.2	30.2	25.2	10.0	m	m	m
00159	12.1	29.5	25.4	29.0	m	m	m
00160	10.0	28.5	25.0	10.0	m	m	m
00161	18.8	32.4	25.0	25.0	m	m	m
00162	10.0	31.2	24.6	144.0	m	m	m
00163	10.0	28.2	24.6	5.0	m	m	m
00164	10.0	27.6	26.0	1.0	m	m	m
00165	10.0	31.2	24.0	34.0	m	m	m
00166	14.3	32.5	27.0	0.0	m	m	m
00167	10.0	31.2	25.8	1.0	m	m	m
00168	19.3	31.8	25.8	5.0	m	m	m
00169	20.2	33.0	26.8	2.0	m	m	m
00170	19.9	31.0	27.2	0.0	m	m	m
00171	10.9	30.0	25.8	6.0	m	m	m
00172	10.7	30.5	24.5	24.0	m	m	m
00173	19.3	31.8	26.5	6.0	m	m	m
00174	15.6	31.8	25.5	4.0	m	m	m
00175	10.6	30.7	24.5	14.0	m	m	m
00176	10.0	30.8	25.5	30.0	m	m	m
00177	11.2	27.8	24.8	5.0	m	m	m
00178	19.6	32.0	22.6	45.0	m	m	m
00179	18.9	31.7	25.8	0.0	m	m	m

00180	15.3	31.2	25.4	7.0	m	m	m
00181	18.9	31.0	25.8	0.0	m	m	m
00182	18.0	32.0	26.3	3.0	m	m	m
00183	17.1	32.5	26.0	24.0	m	m	m
00184	21.6	33.0	26.7	3.0	m	m	m
00185	21.6	33.5	26.5	0.0	m	m	m
00186	24.1	34.2	27.0	0.0	m	m	m
00187	19.3	33.2	27.0	0.0	m	m	m
00188	17.7	32.8	27.5	0.0	m	m	m
00189	13.9	31.5	26.6	1.0	m	m	m
00190	11.0	30.0	26.6	0.0	m	m	m
00191	13.7	31.8	25.0	17.0	m	m	m
00192	16.6	30.8	26.0	26.0	m	m	m
00193	20.2	32.7	26.5	2.0	m	m	m
00194	15.2	30.8	26.5	6.0	m	m	m
00195	16.0	31.0	25.5	12.0	m	m	m
00196	15.1	31.0	26.0	40.0	m	m	m
00197	19.7	31.8	26.4	2.0	m	m	m
00198	22.6	31.6	26.6	10.0	m	m	m
00199	16.9	31.5	26.2	3.0	m	m	m
00200	9.9	28.6	25.6	25.0	m	m	m
00201	9.9	25.7	25.0	35.0	m	m	m
00202	9.9	28.0	24.5	64.0	m	m	m
00203	10.4	29.0	25.3	56.0	m	m	m
00204	17.6	30.2	25.6	1.0	m	m	m
00205	12.9	31.2	24.0	35.0	m	m	m
00206	9.9	27.4	26.3	0.0	m	m	m
00207	13.3	29.0	24.8	30.0	m	m	m
00208	10.5	29.8	25.4	0.0	m	m	m
00209	14.1	30.0	25.2	2.0	m	m	m
00210	10.6	30.0	24.8	20.0	m	m	m
00211	21.0	31.2	25.8	1.0	m	m	m
00212	12.1	31.0	26.2	3.0	m	m	m
00213	13.7	30.5	24.5	14.0	m	m	m
00214	9.8	31.6	26.0	6.0	m	m	m
00215	9.8	29.5	23.6	9.0	m	m	m
00216	9.8	30.2	25.2	32.0	m	m	m
00217	11.3	34.0	26.8	0.0	m	m	m
00218	19.5	33.4	25.4	2.0	m	m	m
00219	17.0	33.4	27.7	0.0	m	m	m
00220	20.6	32.0	27.0	2.0	m	m	m
00221	21.9	32.2	27.0	0.0	m	m	m
00222	15.6	32.0	27.4	5.0	m	m	m
00223	18.6	30.8	25.0	8.0	m	m	m
00224	14.6	31.2	26.8	1.0	m	m	m
00225	9.6	29.5	24.5	1.0	m	m	m
00226	9.6	27.8	24.0	34.0	m	m	m
00227	10.4	28.5	25.2	25.0	m	m	m
00228	9.6	29.0	24.2	34.0	m	m	m
00229	11.1	30.4	26.0	0.0	m	m	m
00230	17.1	31.5	25.5	3.0	m	m	m
00231	20.2	31.8	26.5	1.0	m	m	m
00232	23.0	32.0	26.7	0.0	m	m	m
00233	10.9	30.8	25.0	0.0	m	m	m
00234	15.8	32.0	26.0	14.0	m	m	m
00235	22.8	33.2	26.0	0.0	m	m	m
00236	20.4	32.5	27.2	0.0	m	m	m
00237	19.3	33.4	27.2	0.0	m	m	m
00238	22.4	35.5	27.6	0.0	m	m	m
00239	20.6	32.6	24.5	14.0	m	m	m
00240	16.8	32.5	27.2	0.0	m	m	m
00241	15.6	32.0	27.0	0.0	m	m	m

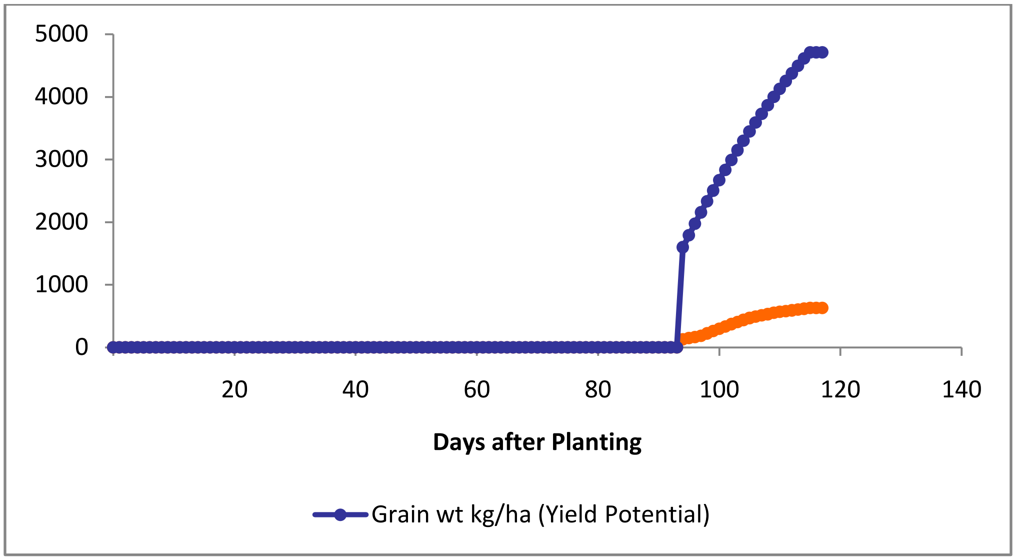
00242	9.8	30.5	27.2	4.0	m	m	m
00243	9.3	28.6	26.0	31.0	m	m	m
00244	9.2	30.2	26.0	7.0	m	m	m
00245	9.2	30.2	24.8	9.0	m	m	m
00246	9.5	30.0	26.4	0.0	m	m	m
00247	9.2	30.5	25.8	10.0	m	m	m
00248	9.1	29.5	24.5	1.0	m	m	m
00249	17.8	31.0	24.2	57.0	m	m	m
00250	17.5	31.0	26.5	3.0	m	m	m
00251	11.7	31.0	25.6	1.0	m	m	m
00252	17.1	31.8	25.8	3.0	m	m	m
00253	11.8	31.0	25.8	0.0	m	m	m
00254	11.2	31.2	26.0	13.0	m	m	m
00255	11.0	32.4	26.7	0.0	m	m	m
00256	11.5	34.0	27.2	0.0	m	m	m
00257	10.2	31.0	27.6	0.0	m	m	m
00258	14.7	31.5	27.5	0.0	m	m	m
00259	8.8	31.2	26.2	6.0	m	m	m
00260	8.8	31.2	26.0	7.0	m	m	m
00261	10.5	31.2	26.2	0.0	m	m	m
00262	8.7	31.0	25.0	30.0	m	m	m
00263	8.7	29.5	24.0	35.0	m	m	m
00264	8.6	28.6	25.2	10.0	m	m	m
00265	11.5	32.0	25.5	8.0	m	m	m
00266	12.6	33.2	24.6	0.0	m	m	m
00267	8.8	31.8	25.6	0.0	m	m	m
00268	10.5	31.8	24.8	0.0	m	m	m
00269	12.4	32.0	25.0	12.0	m	m	m
00270	12.5	32.6	25.2	1.0	m	m	m
00271	10.9	33.2	25.0	0.0	m	m	m
00272	14.7	34.5	25.3	0.0	m	m	m
00273	11.1	34.6	26.2	0.0	m	m	m
00274	10.5	33.7	26.0	0.0	m	m	m
00275	8.2	27.6	25.5	0.0	m	m	m
00276	8.2	29.6	24.3	6.0	m	m	m
00277	13.2	33.0	25.0	0.0	m	m	m
00278	10.0	32.0	25.5	0.0	m	m	m
00279	14.8	33.0	24.5	0.0	m	m	m
00280	9.4	33.0	25.2	0.0	m	m	m
00281	8.0	28.2	25.6	0.0	m	m	m
00282	13.6	32.8	24.5	0.0	m	m	m
00283	14.1	33.4	24.8	0.0	m	m	m
00284	17.9	33.4	25.0	0.0	m	m	m
00285	18.4	35.5	25.5	0.0	m	m	m
00286	14.5	34.5	25.0	0.0	m	m	m
00287	12.3	34.0	26.5	0.0	m	m	m
00288	13.0	34.5	25.5	0.0	m	m	m
00289	16.0	35.2	26.4	0.0	m	m	m
00290	13.1	34.5	26.4	0.0	m	m	m
00291	7.6	30.2	26.5	0.0	m	m	m
00292	10.5	32.0	25.6	3.0	m	m	m
00293	10.6	33.2	25.5	2.0	m	m	m
00294	15.9	35.4	26.0	0.0	m	m	m
00295	12.0	33.6	26.0	0.0	m	m	m
00296	12.0	33.4	24.0	1.0	m	m	m
00297	11.8	33.5	25.0	0.0	m	m	m
00298	11.3	33.2	24.6	0.0	m	m	m
00299	12.8	33.0	23.8	0.0	m	m	m
00300	8.1	31.2	24.4	0.0	m	m	m
00301	7.2	25.2	23.2	41.0	m	m	m
00302	7.2	26.6	22.8	85.0	m	m	m
00303	7.8	24.8	20.6	1.0	m	m	m

00304	13.6	29.2	19.4	0.0	m	m	m
00305	15.7	30.5	21.0	0.0	m	m	m
00306	17.4	32.0	22.0	0.0	m	m	m
00307	17.7	33.2	22.5	0.0	m	m	m
00308	16.2	33.0	22.2	0.0	m	m	m
00309	16.1	33.0	21.5	0.0	m	m	m
00310	17.3	32.0	21.4	0.0	m	m	m
00311	15.3	31.5	22.5	0.0	m	m	m
00312	14.8	31.4	21.2	0.0	m	m	m
00313	17.0	31.2	20.5	0.0	m	m	m
00314	13.9	31.0	20.0	0.0	m	m	m
00315	14.5	31.4	20.5	0.0	m	m	m
00316	15.6	31.6	20.5	0.0	m	m	m
00317	16.5	31.2	19.6	0.0	m	m	m
00318	16.3	31.2	19.6	0.0	m	m	m
00319	15.2	30.0	19.6	0.0	m	m	m
00320	15.7	31.0	19.4	0.0	m	m	m
00321	15.7	31.4	18.2	0.0	m	m	m
00322	15.3	30.6	18.0	0.0	m	m	m
00323	14.8	30.8	18.0	0.0	m	m	m
00324	11.7	30.2	18.8	0.0	m	m	m
00325	8.6	29.0	19.6	0.0	m	m	m
00326	12.9	30.5	18.6	0.0	m	m	m
00327	12.1	30.7	18.6	0.0	m	m	m
00328	13.6	30.4	18.8	0.0	m	m	m
00329	10.1	30.5	18.6	0.0	m	m	m
00330	11.1	29.0	18.2	0.0	m	m	m
00331	11.5	29.5	17.6	0.0	m	m	m
00332	8.6	28.2	17.5	0.0	m	m	m
00333	6.2	20.2	17.4	0.0	m	m	m
00334	7.6	25.3	15.8	89.0	m	m	m
00335	14.5	29.0	16.4	0.0	m	m	m
00336	12.8	28.5	16.8	0.0	m	m	m
00337	11.4	27.5	17.0	0.0	m	m	m
00338	14.1	26.8	13.0	0.0	m	m	m
00339	13.7	26.8	12.8	0.0	m	m	m
00340	13.2	26.6	13.2	0.0	m	m	m
00341	13.7	27.4	13.3	0.0	m	m	m
00342	13.5	27.4	14.5	0.0	m	m	m
00343	12.6	27.3	15.0	0.0	m	m	m
00344	13.7	27.0	13.3	0.0	m	m	m
00345	12.7	26.8	13.7	0.0	m	m	m
00346	9.9	28.0	13.4	0.0	m	m	m
00347	10.0	27.5	12.6	0.0	m	m	m
00348	11.2	26.2	13.4	0.0	m	m	m
00349	12.7	26.6	13.0	0.0	m	m	m
00350	9.3	26.4	13.0	0.0	m	m	m
00351	12.4	26.8	13.6	0.0	m	m	m
00352	11.9	27.0	13.2	0.0	m	m	m
00353	10.8	27.2	13.4	0.0	m	m	m
00354	9.9	27.5	13.5	0.0	m	m	m
00355	9.6	27.5	13.5	0.0	m	m	m
00356	11.1	27.6	13.4	0.0	m	m	m
00357	12.5	28.5	13.4	0.0	m	m	m
00358	12.2	27.6	14.2	0.0	m	m	m
00359	14.2	27.6	13.5	0.0	m	m	m
00360	12.3	27.7	13.0	0.0	m	m	m
00361	11.0	27.3	13.8	0.0	m	m	m
00362	13.2	28.0	13.5	0.0	m	m	m
00363	14.8	28.8	14.0	0.0	m	m	m
00364	15.2	27.5	12.8	0.0	m	m	m
00365	15.2	26.7	12.0	0.0	m	m	m

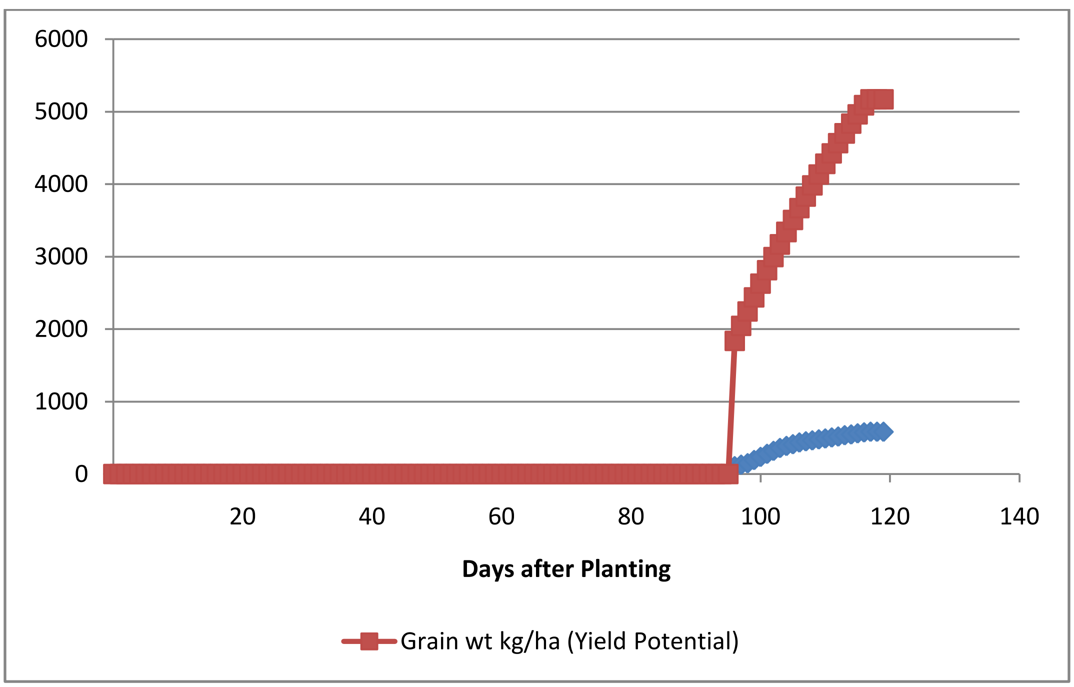
00366	15.2	27.0	12.0	0.0	m	m	m

Appendix 5: Outcomes of the Model

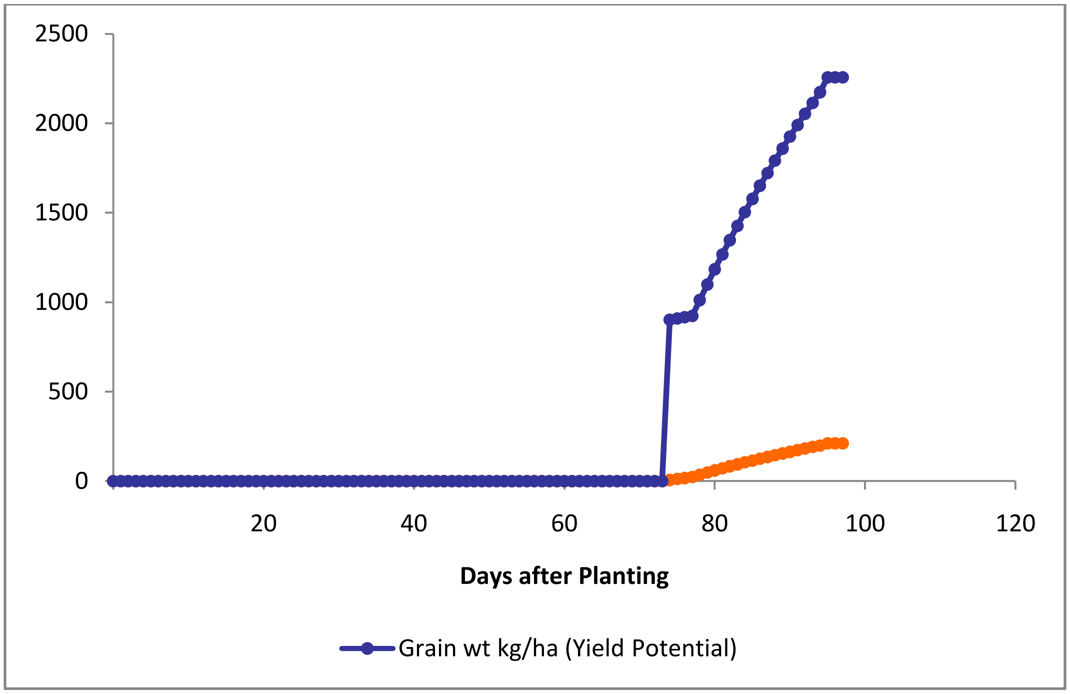
1990 Potential Aman Yield with actual measured temperature



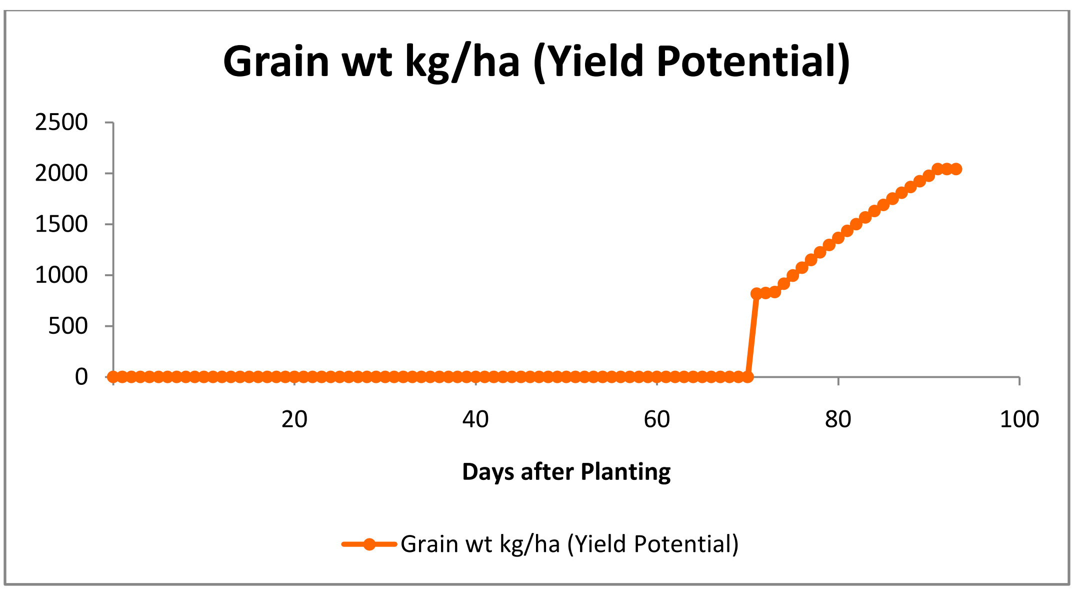
1990 Potential Aman yield with the increased of minimum measured temperature



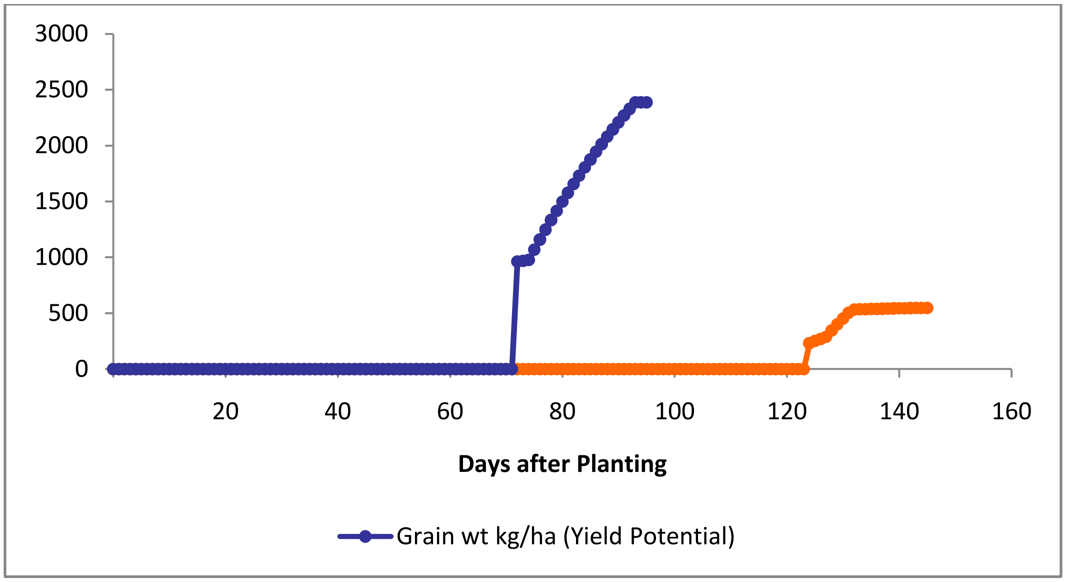
1991 Potential Aus yield with actual measured temperature



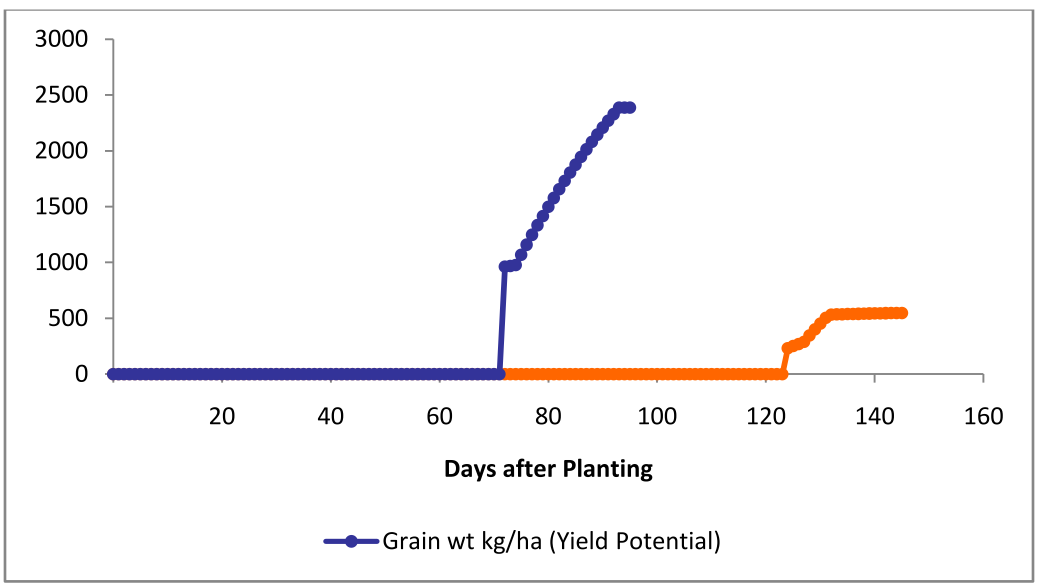
1991 Potential Aus yield with the increase of minimum measured temperature



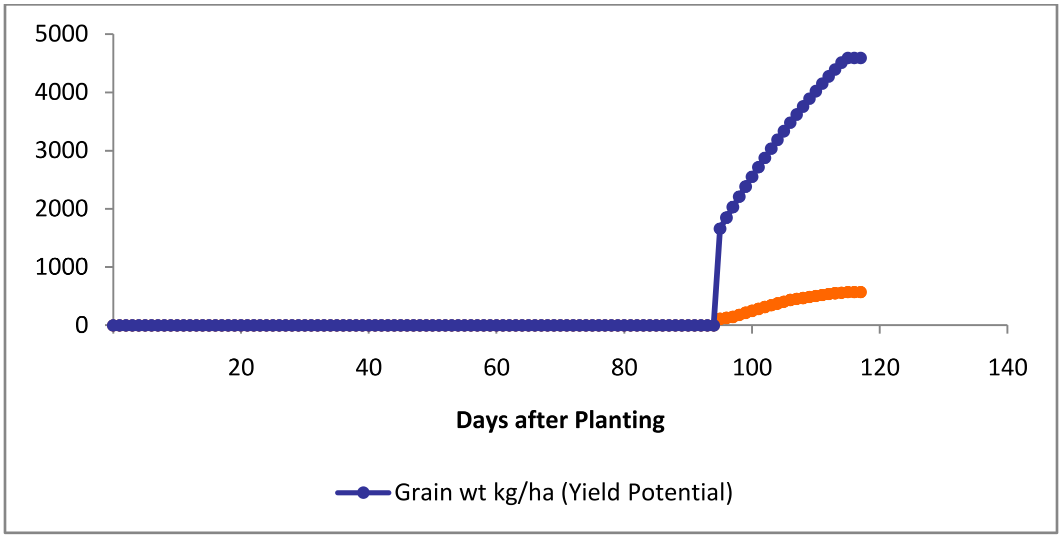
1992 Potential Aus yield with actual measured temperature



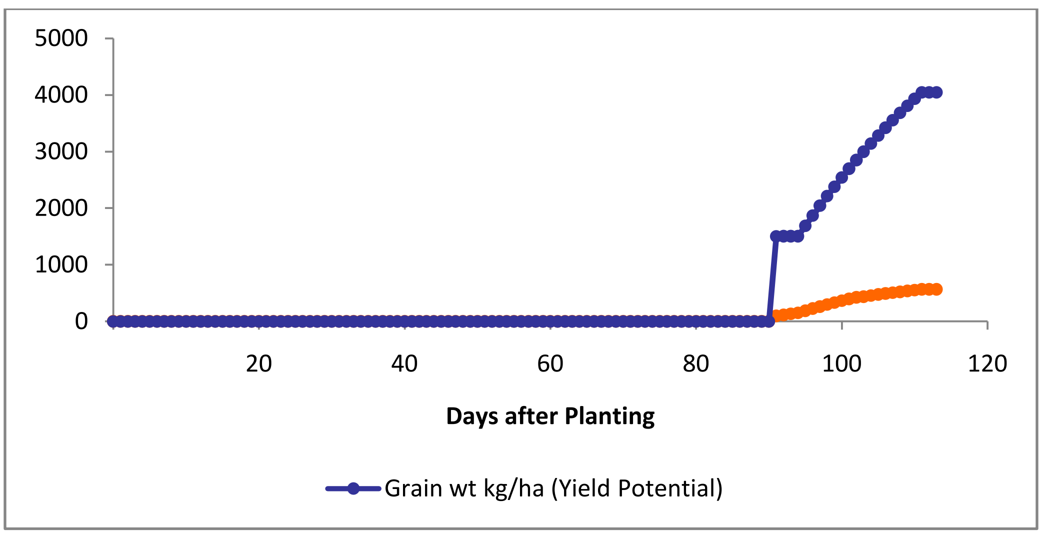
1992 Potential Aus Yield with increase minimum measured temperature



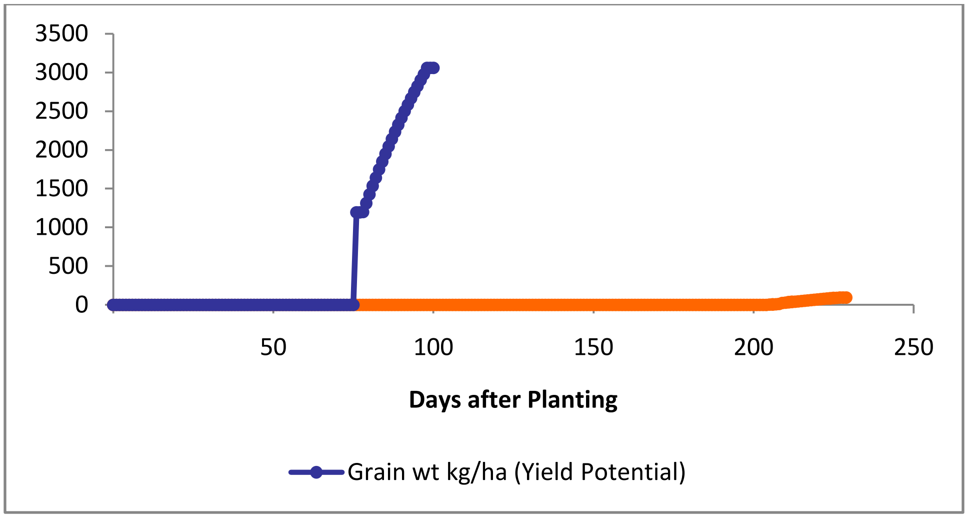
1992 Aman with actual measured temperature



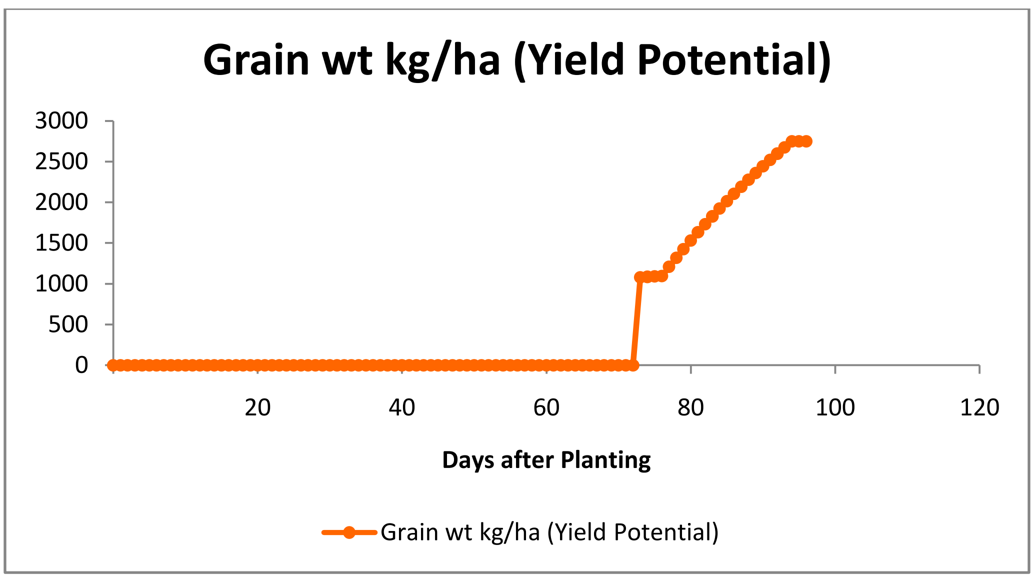
1992 Aman with increase minimum measured temperature



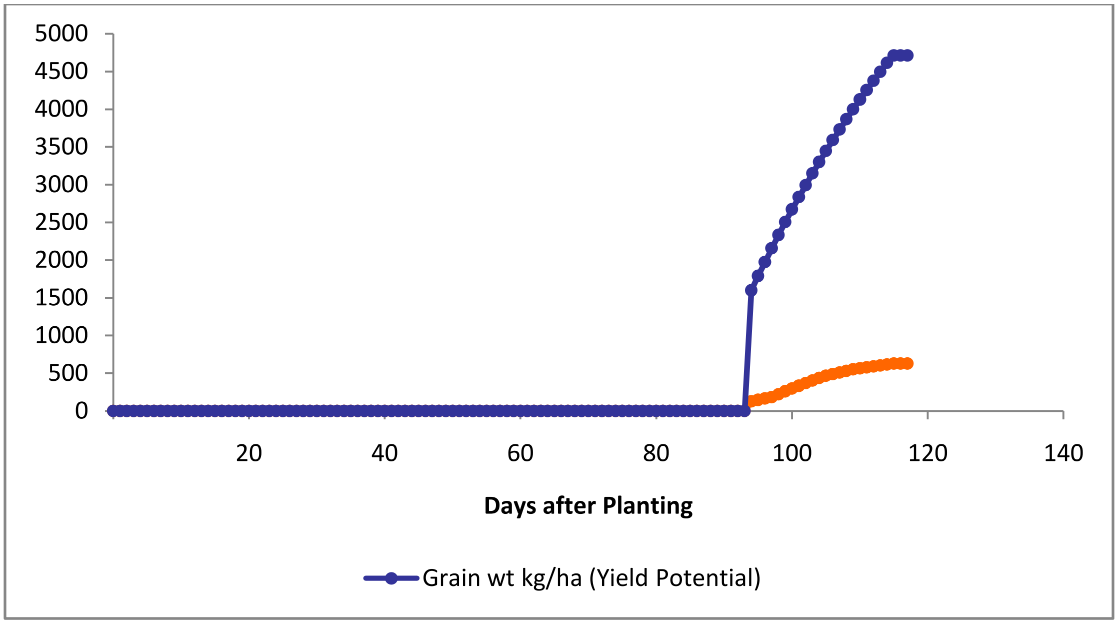
1993 Aus yield with actual measured temperature



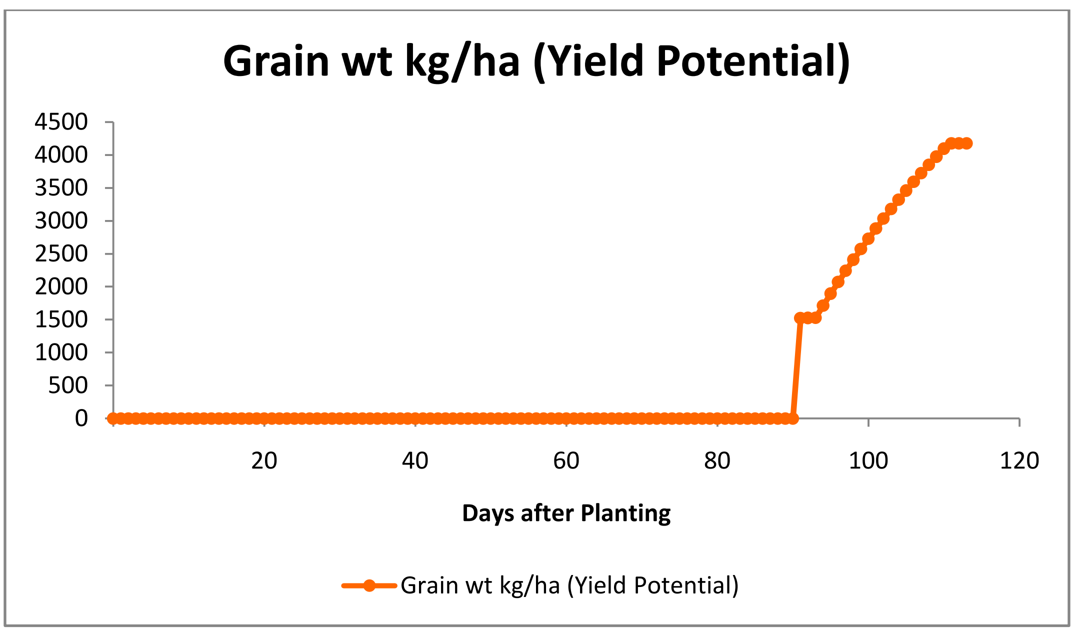
1993 Aus yield with increase minimum measured temperature



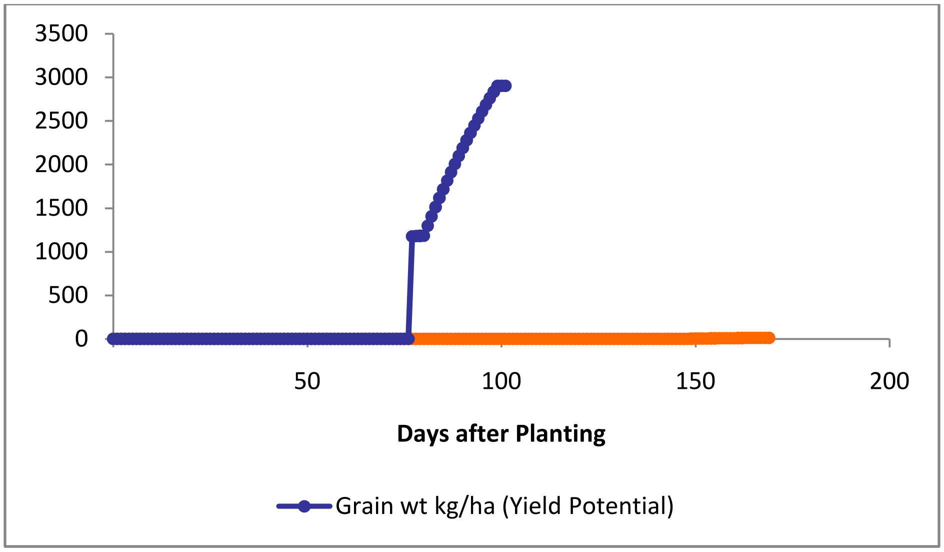
1993 Aman yield with actual measured temperature



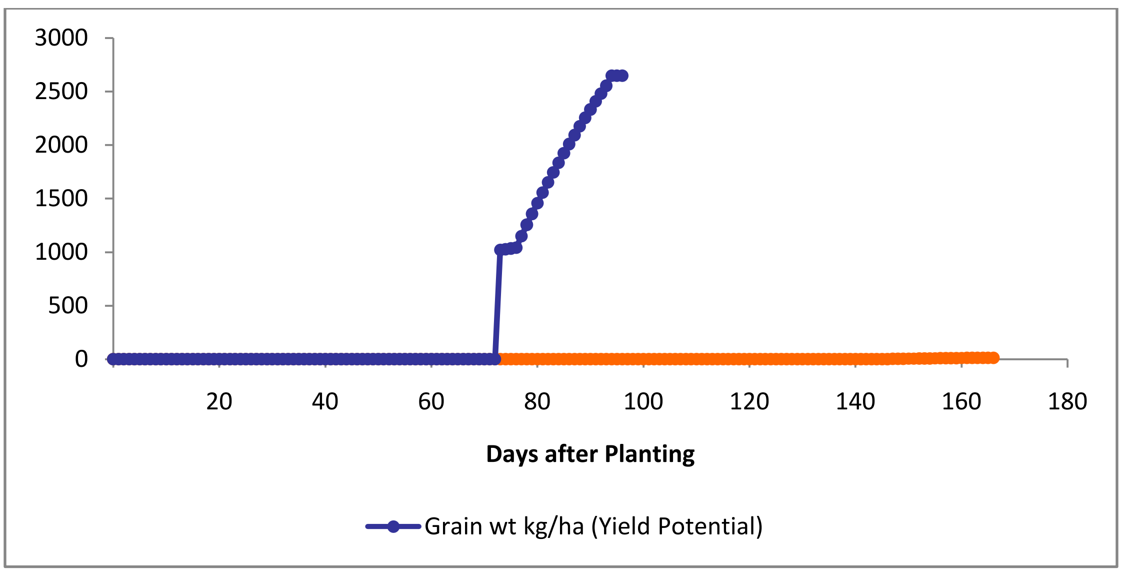
1993 Aman yield with increased minimum measured temperature



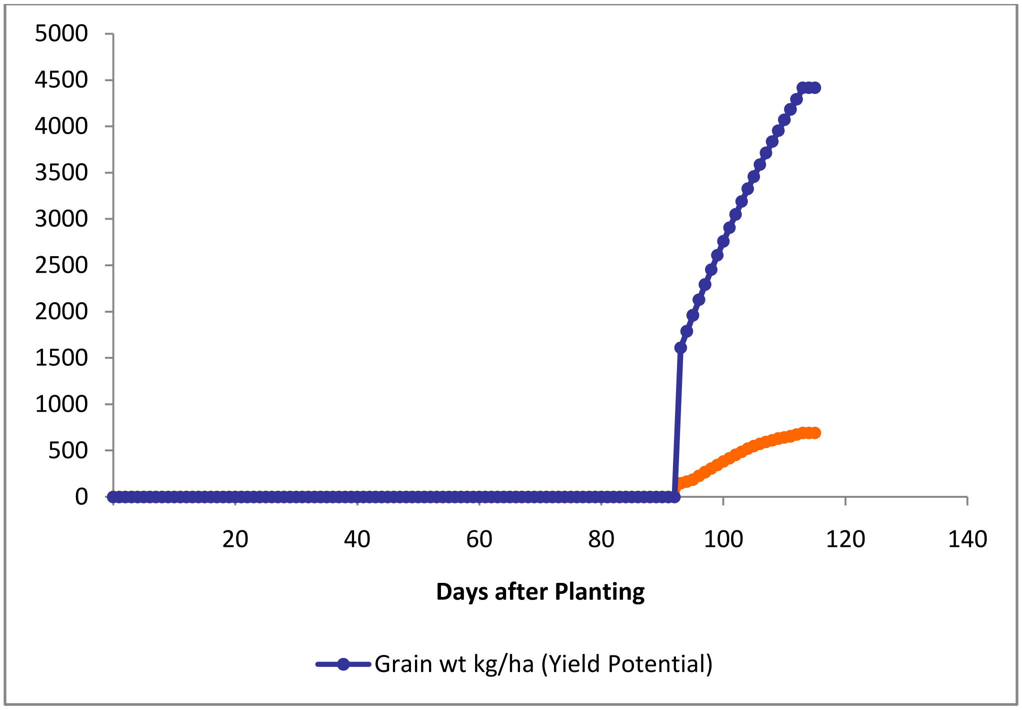
1994 Aus yield with actual measured temperature



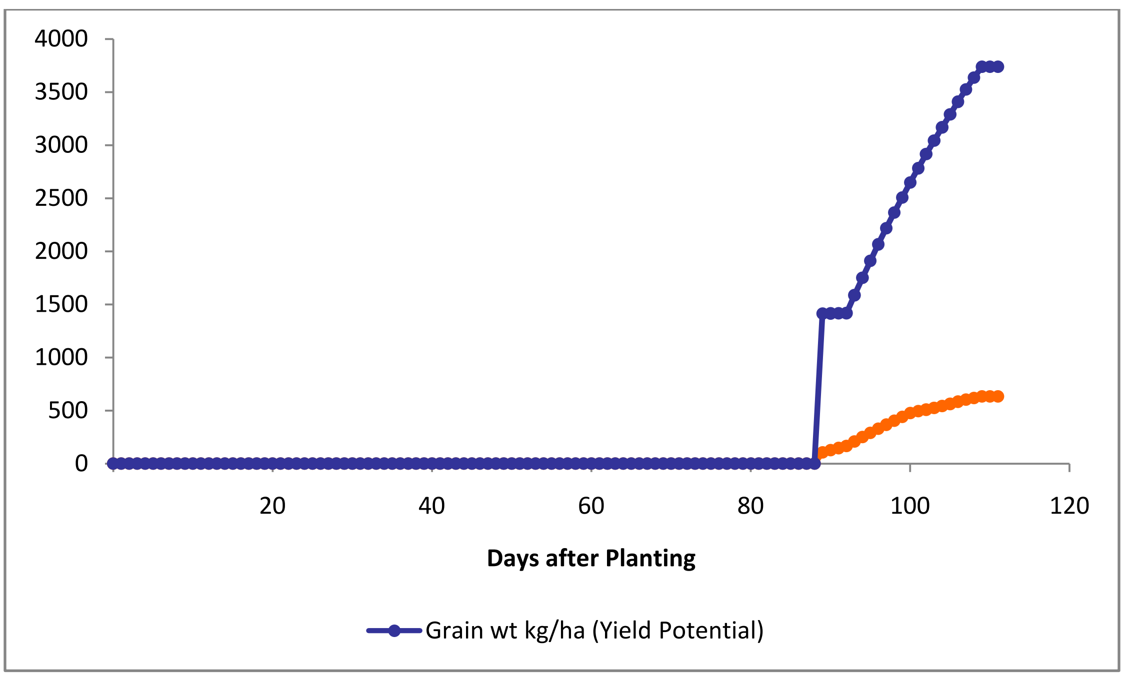
1994 Aus yield with increase of minimum measured temperature



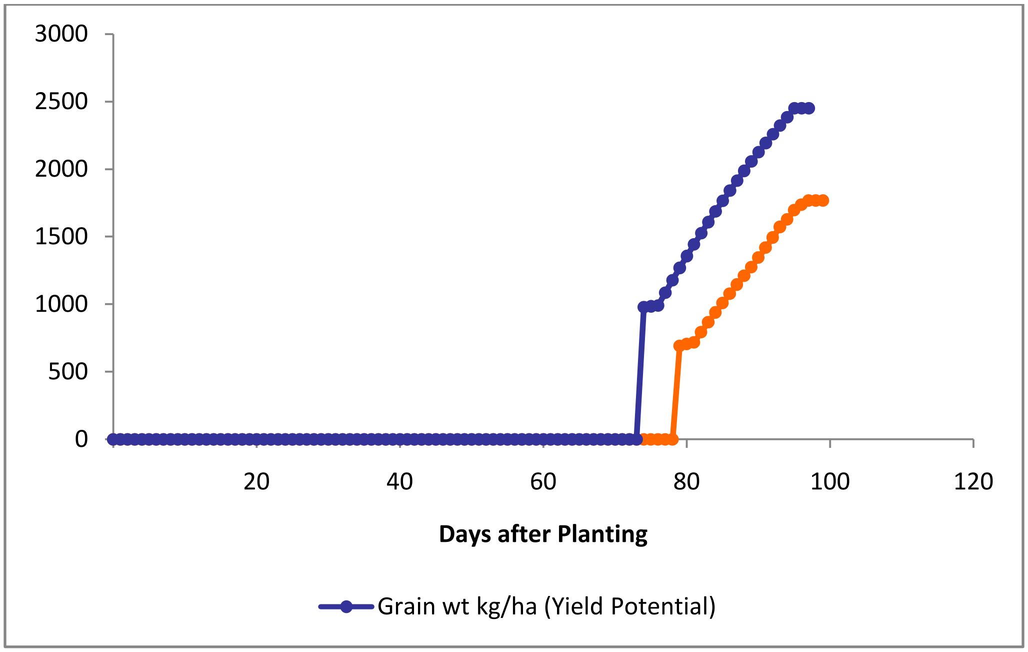
1994 Aman with actual measured Temperature



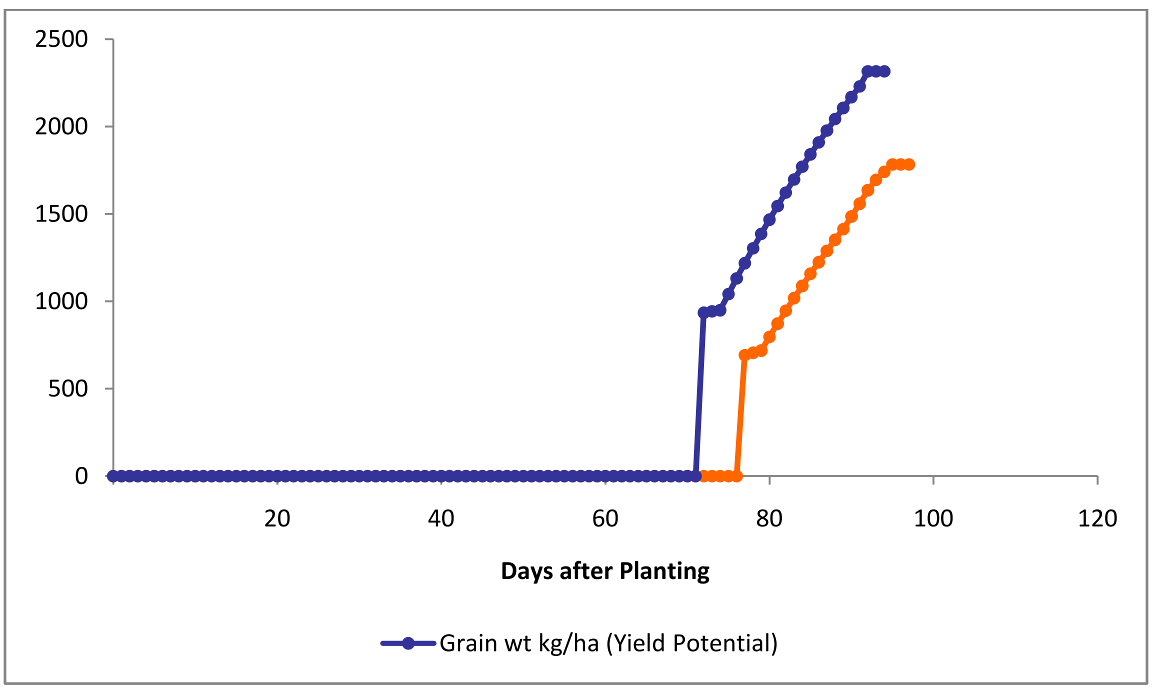
1994 Aman with increase of minimum measured temperature



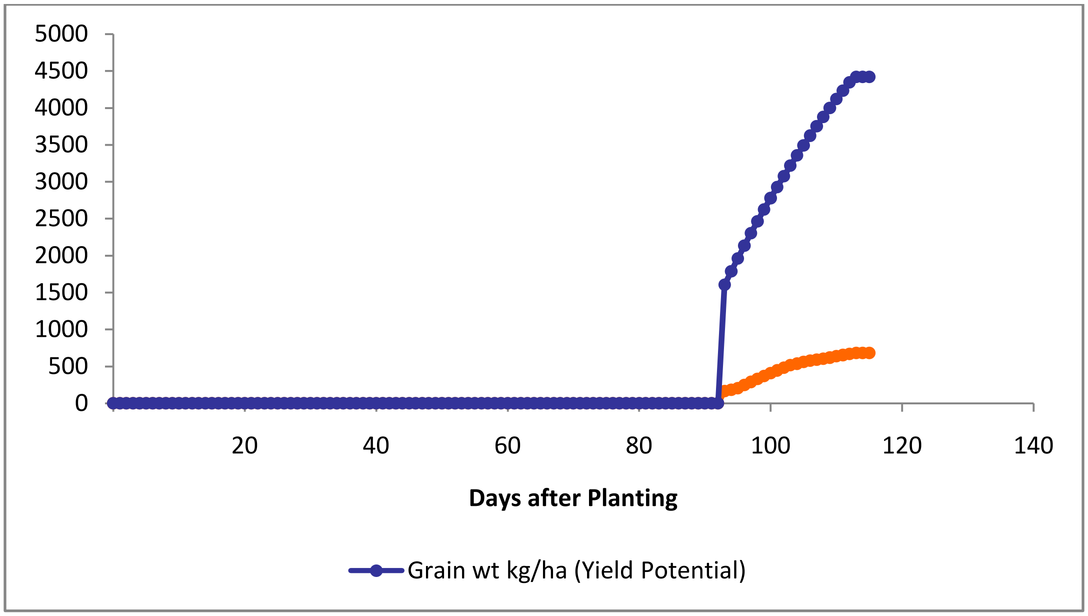
1995 Aus yield with actual measured temperature



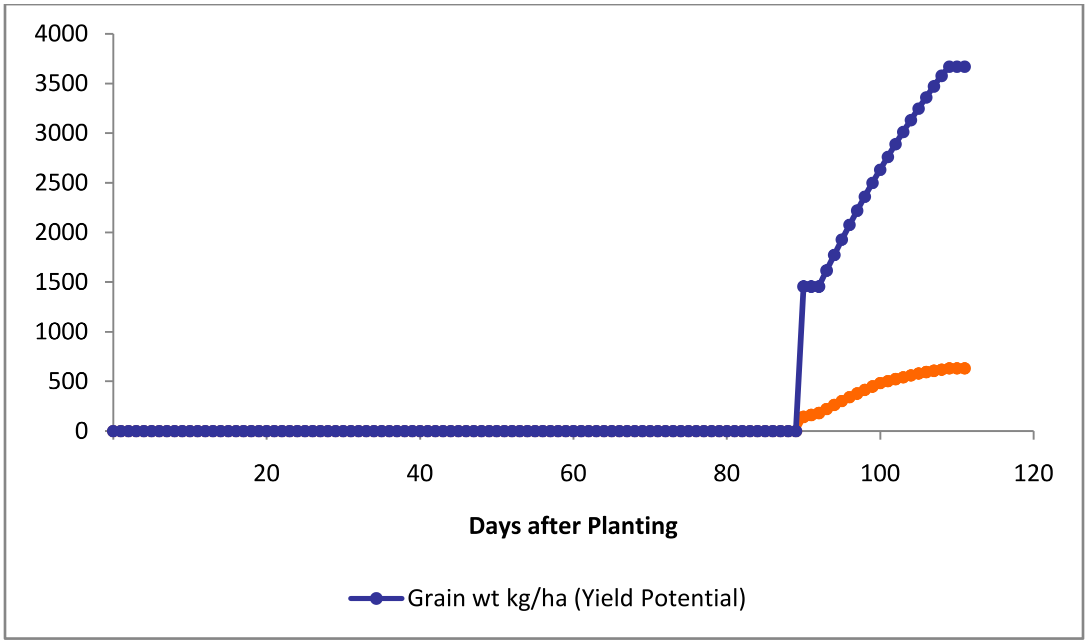
1995 Aus yield with increase of minimum measured temperature



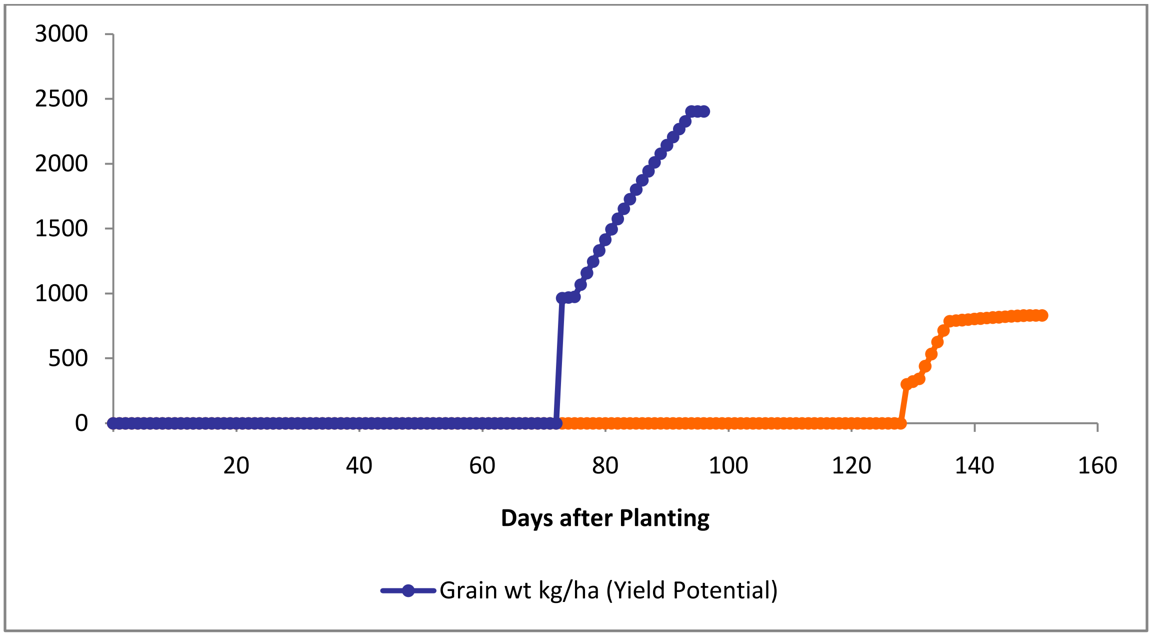
1995 Aman yield with actual measured Temperature



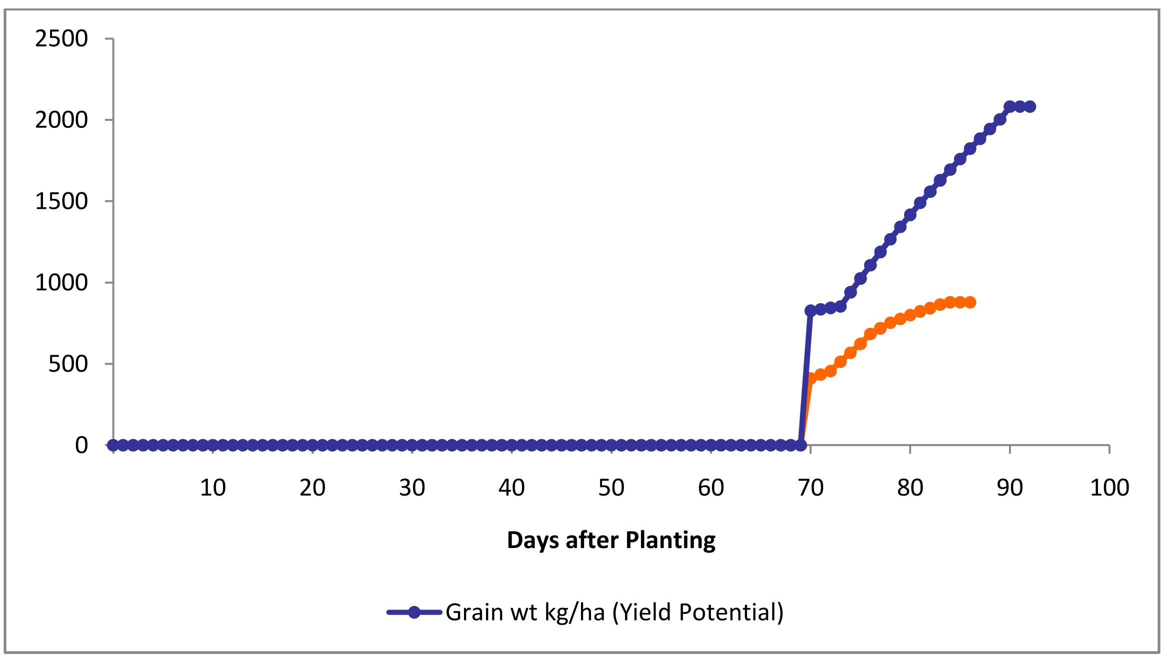
1995 Aman yield with increase of minimum measured temperature



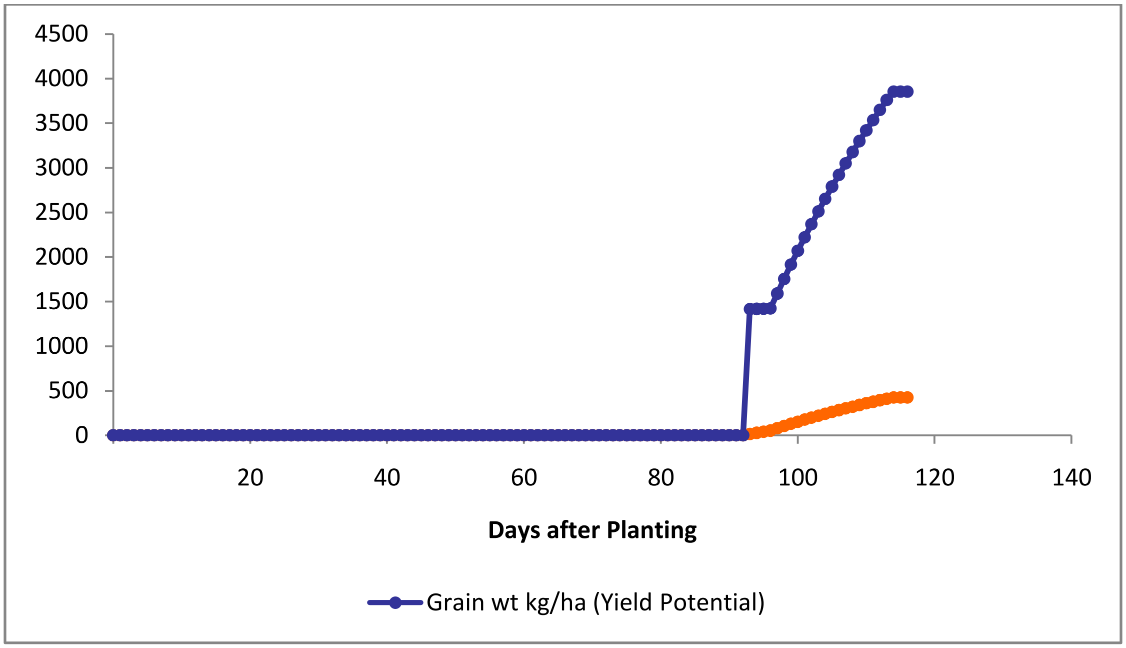
1996 Aus yield with actual measured temperature



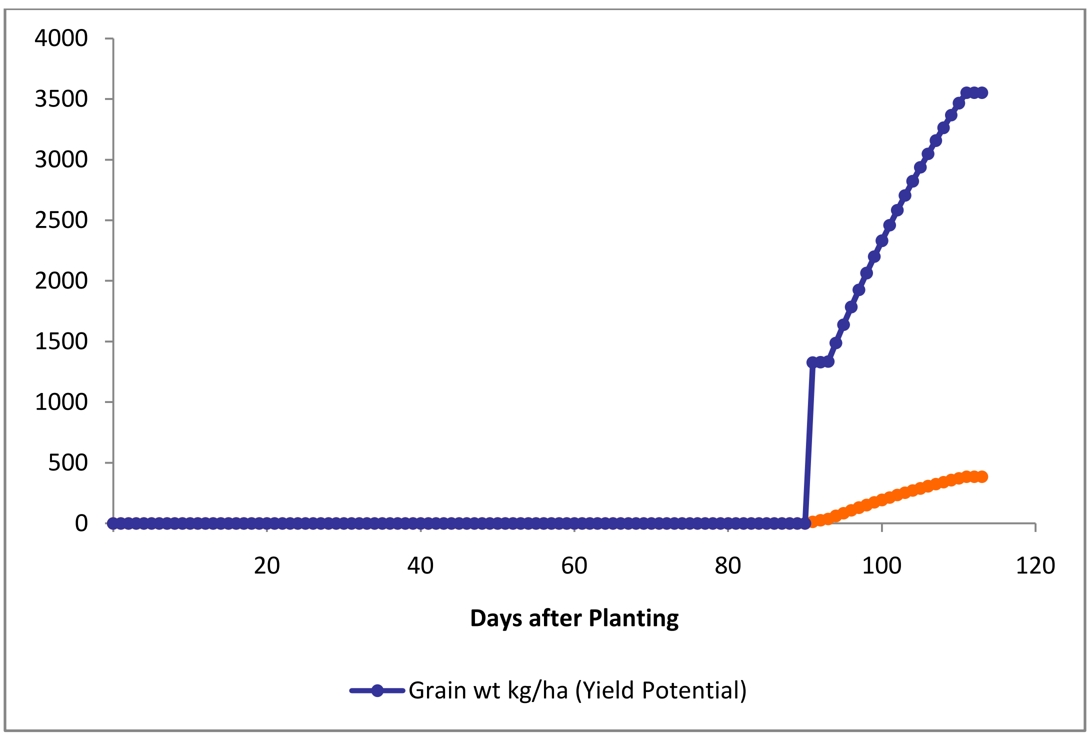
1996 Aus yield with increase of minimum measured temperature



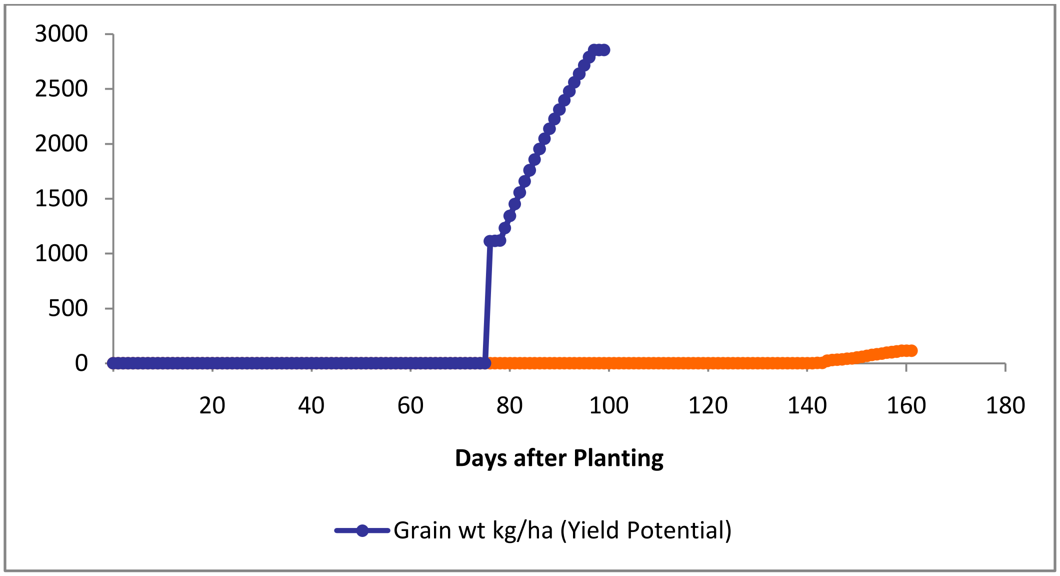
1996 Aman yield with actual measured Temperature



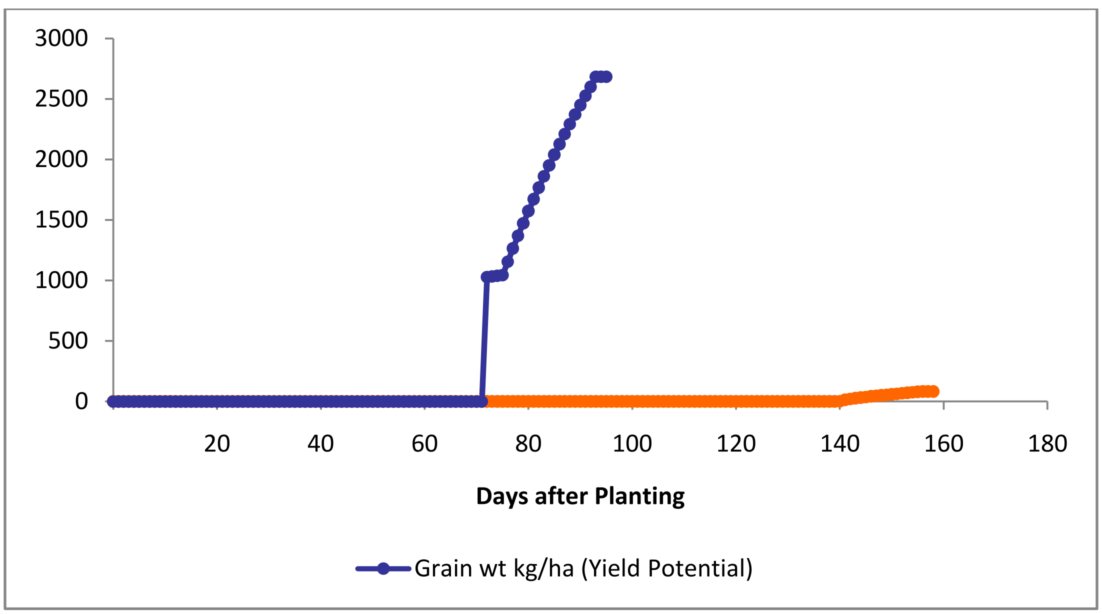
1996 Aman yield with the increase of minimum measured temperature



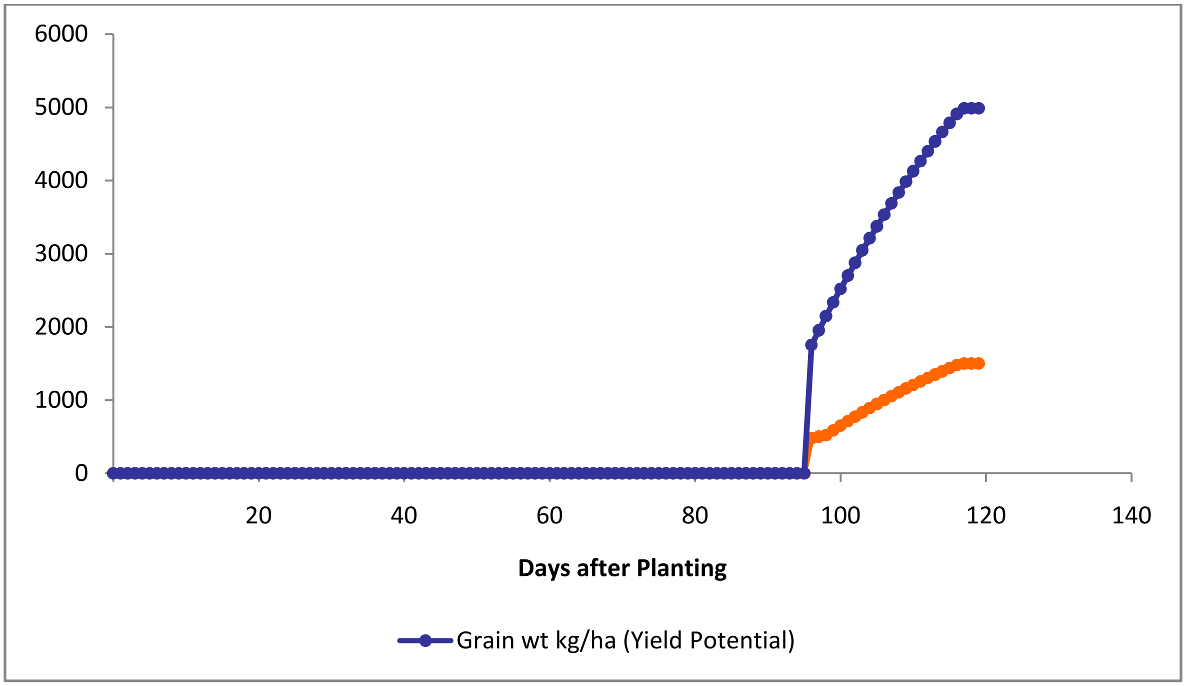
1997 Aus yield with actual measured temperature



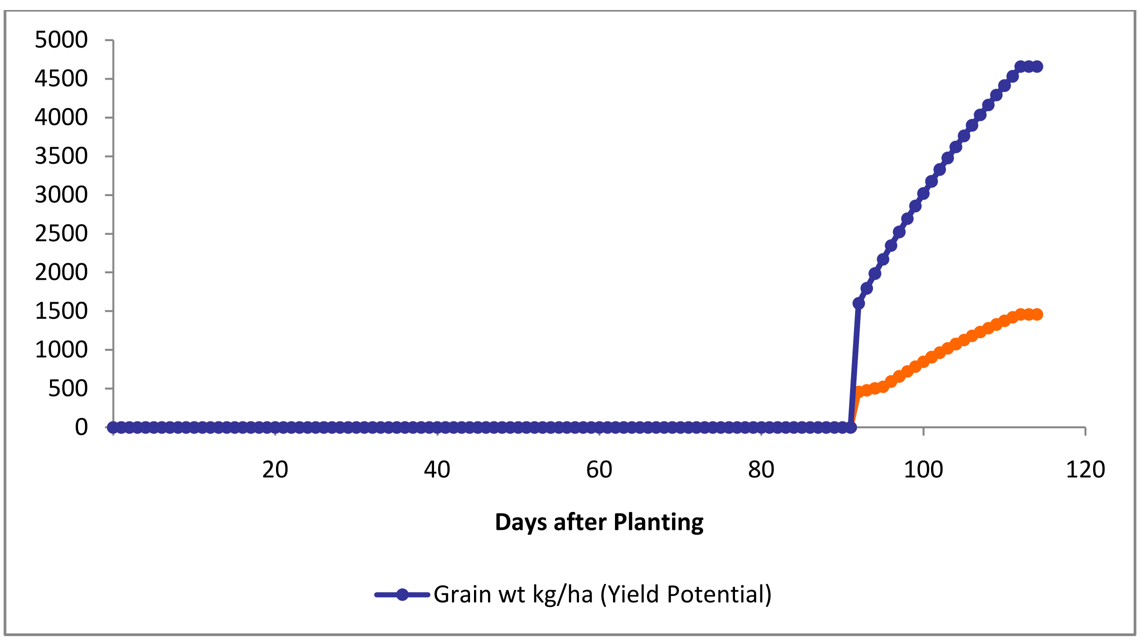
1997 Aus yield with increase of minimum measured temperature



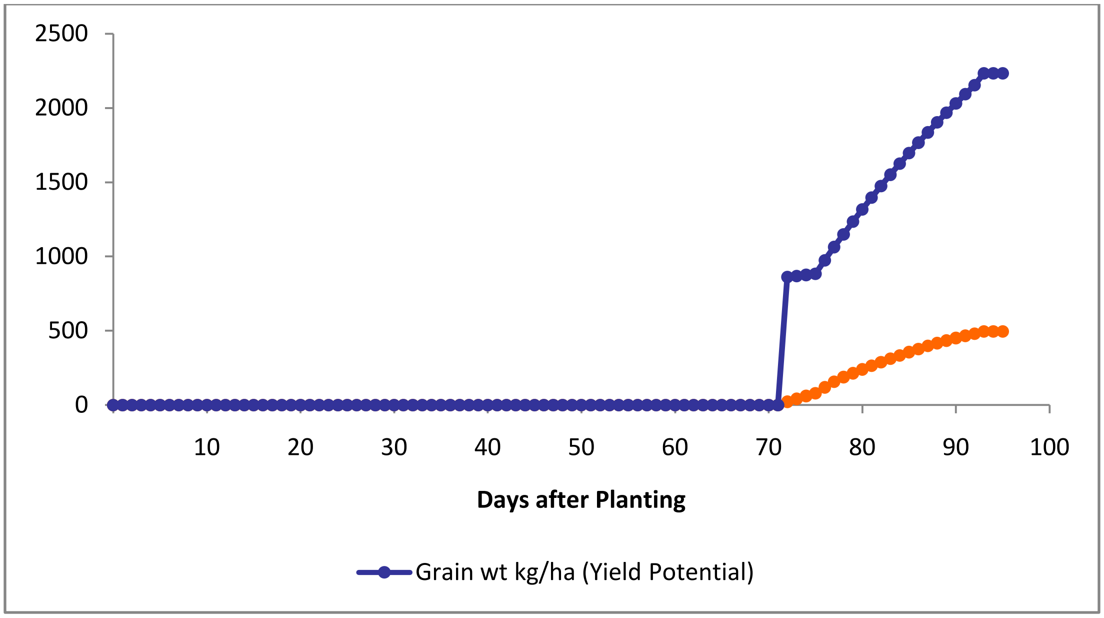
1997 Aman yield with actual measured Temperature



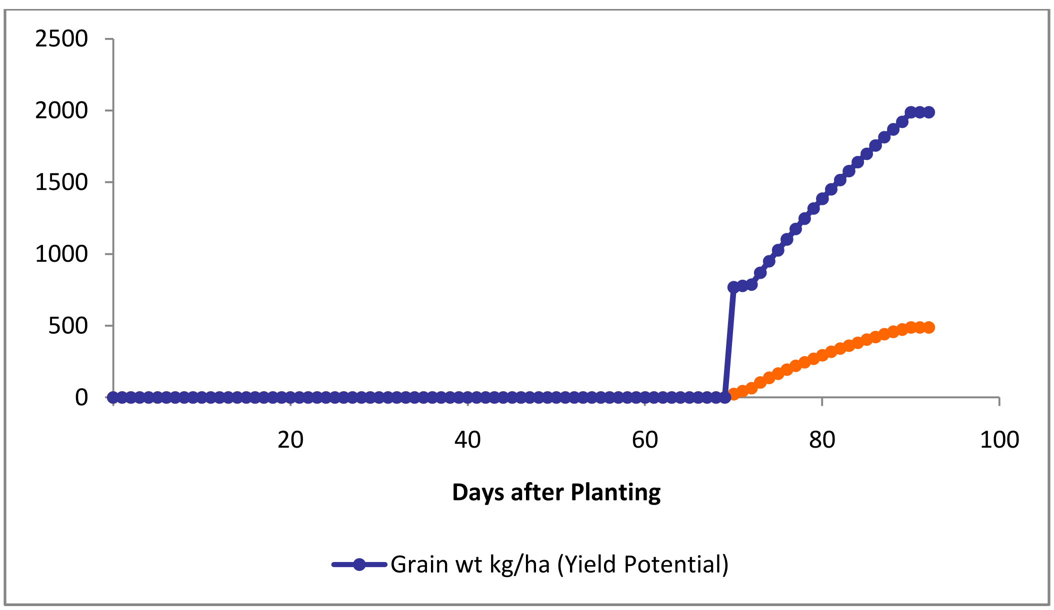
1997 Aman yield with increase of minimum measured temperature



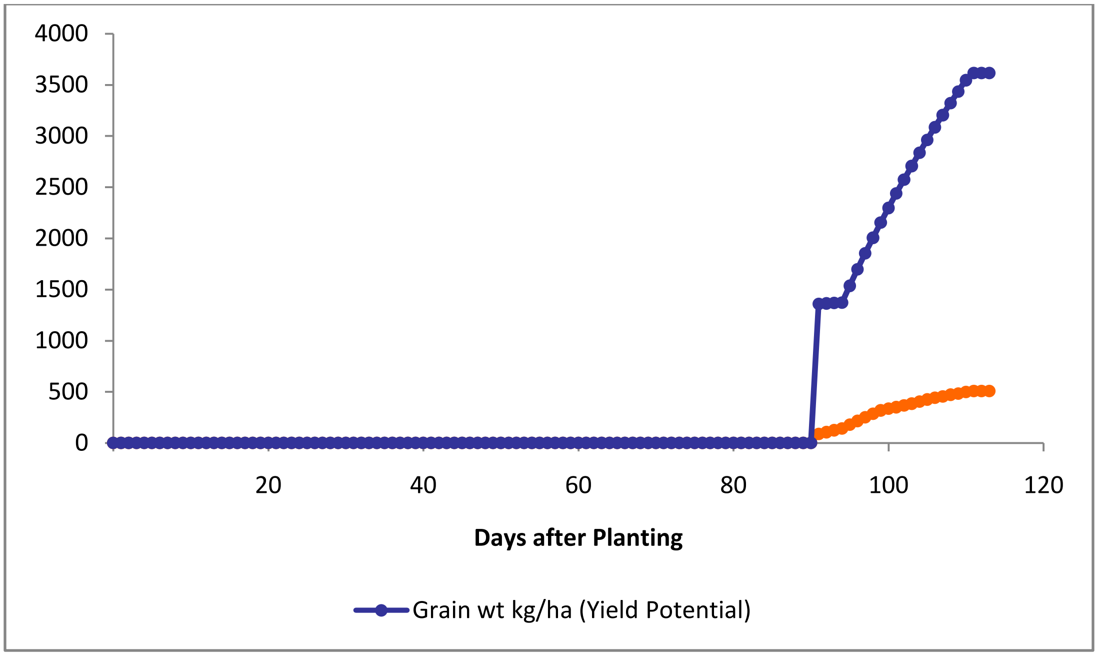
1998 Aus yield with actual measured temperature



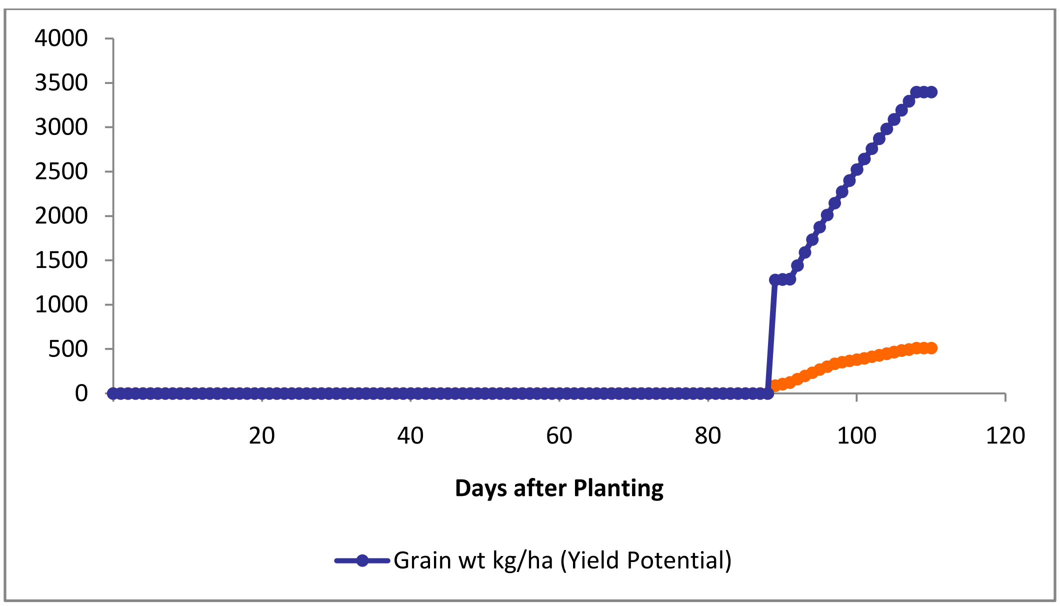
1998 Aus yield with Increase of minimum measured temperature



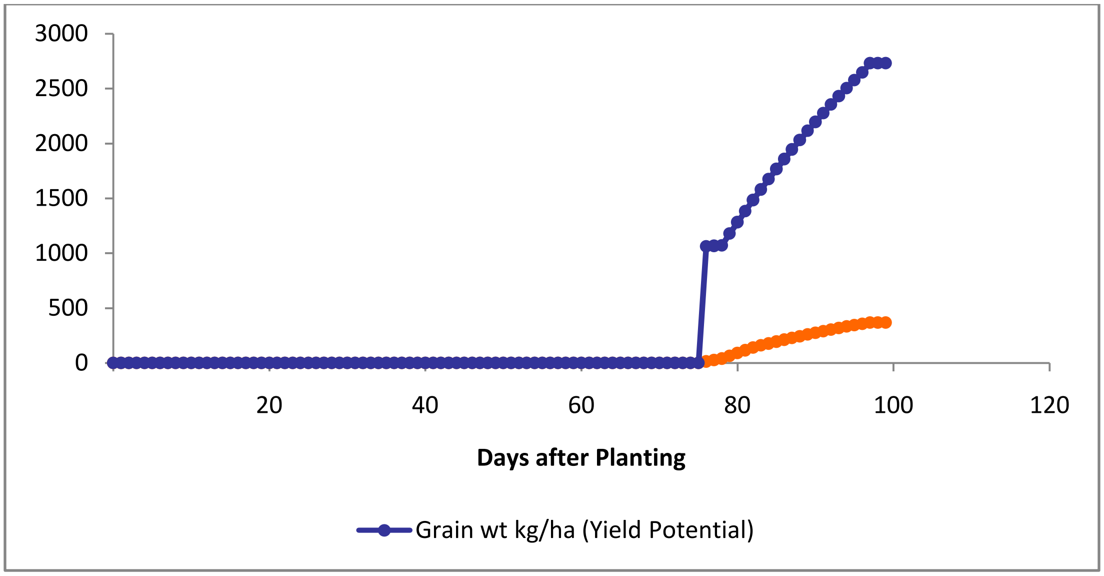
1998 Aman yield with actual measured Temperature



1998 Aman yield with increase of minimum measured temperature



1999 Aus yield with actual measured temperature



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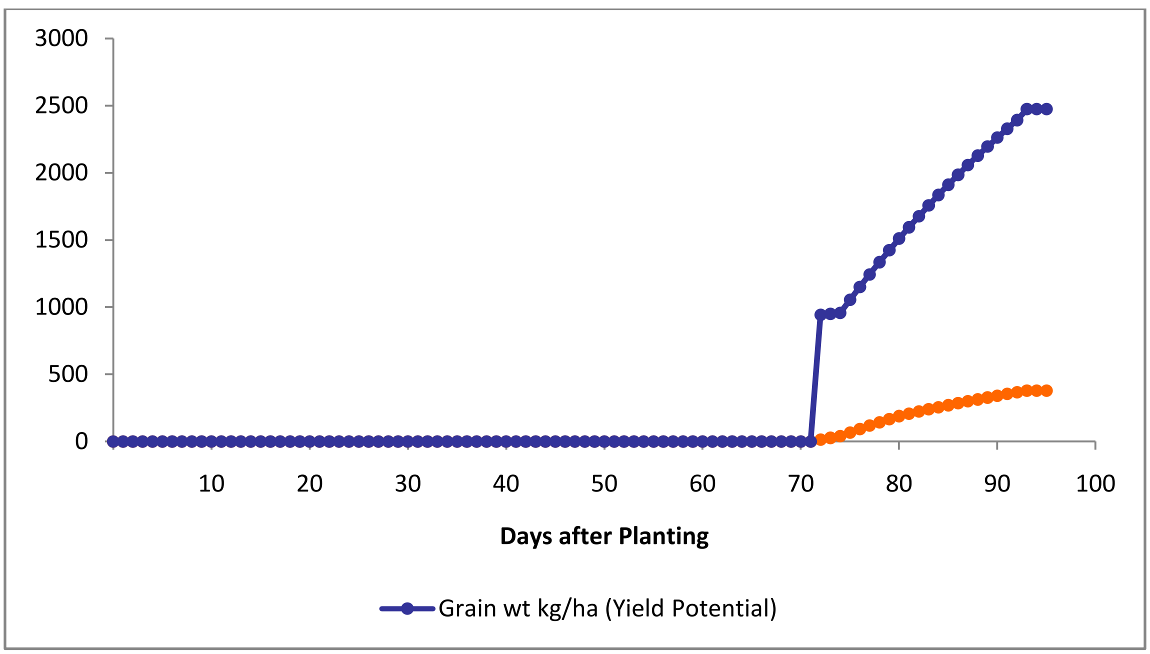

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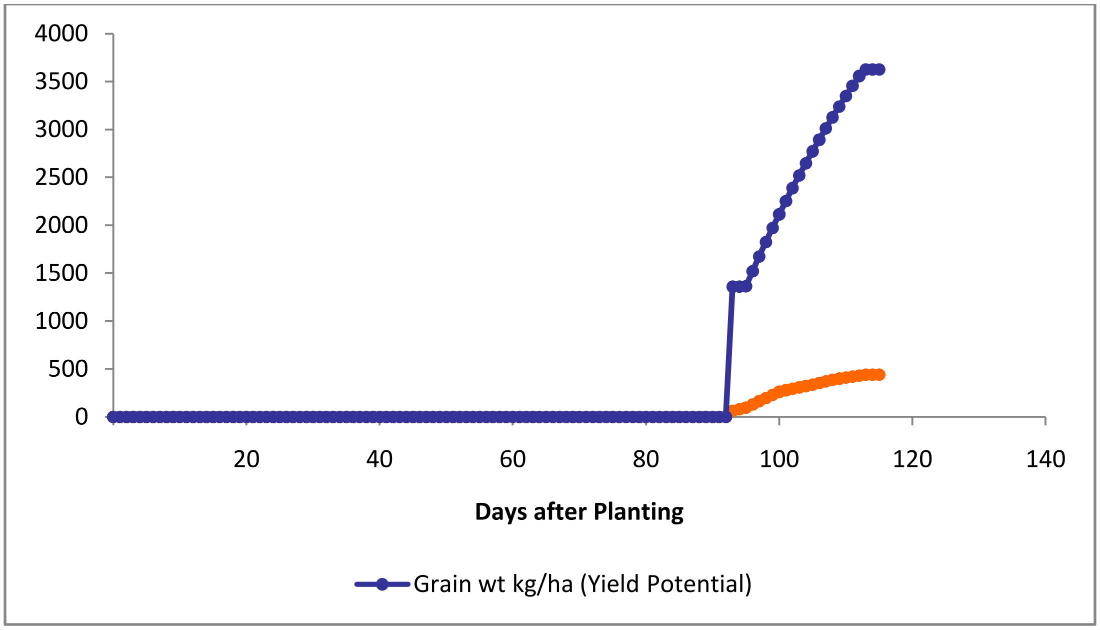

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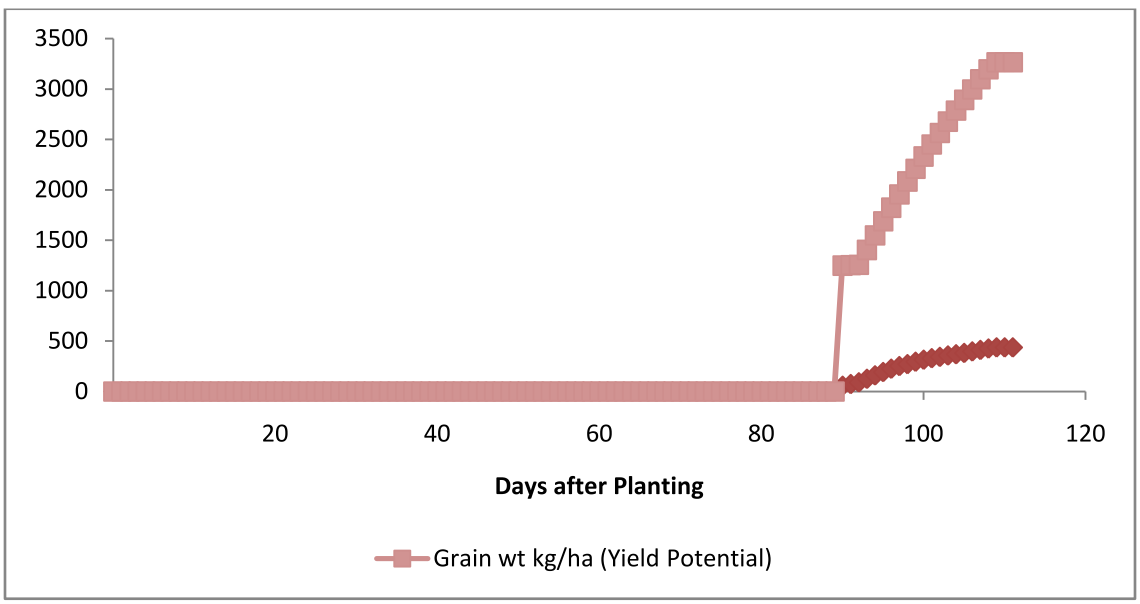
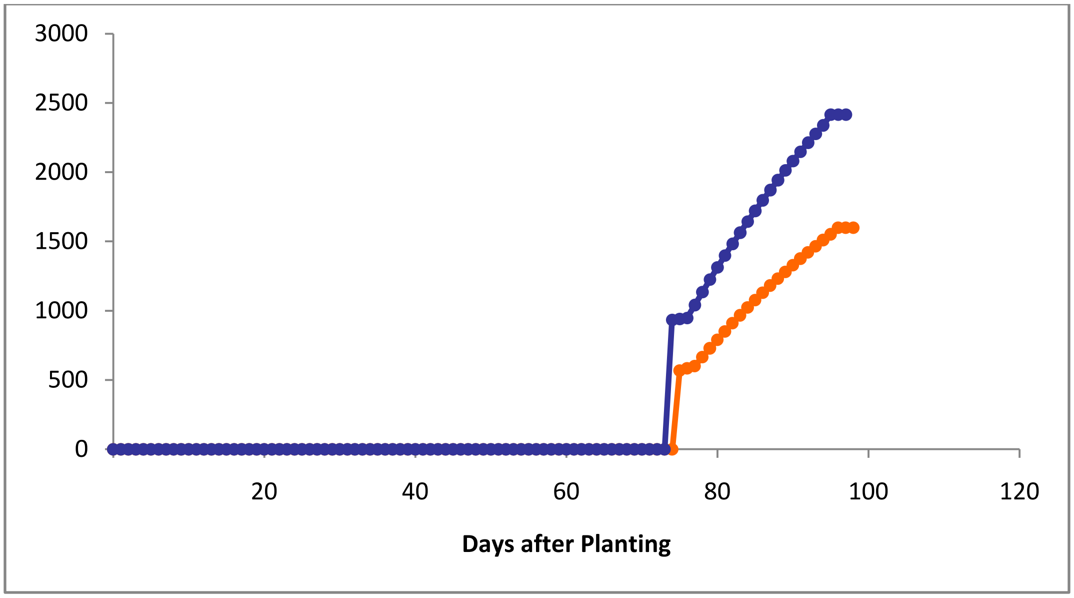


2000 Aus yield actual measured temperature



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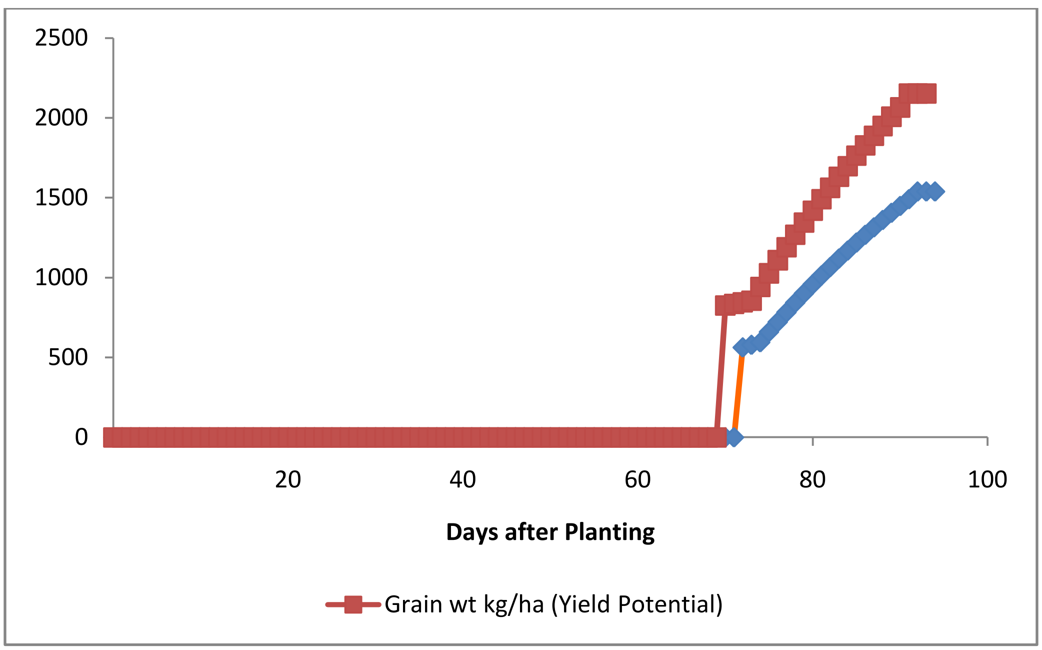
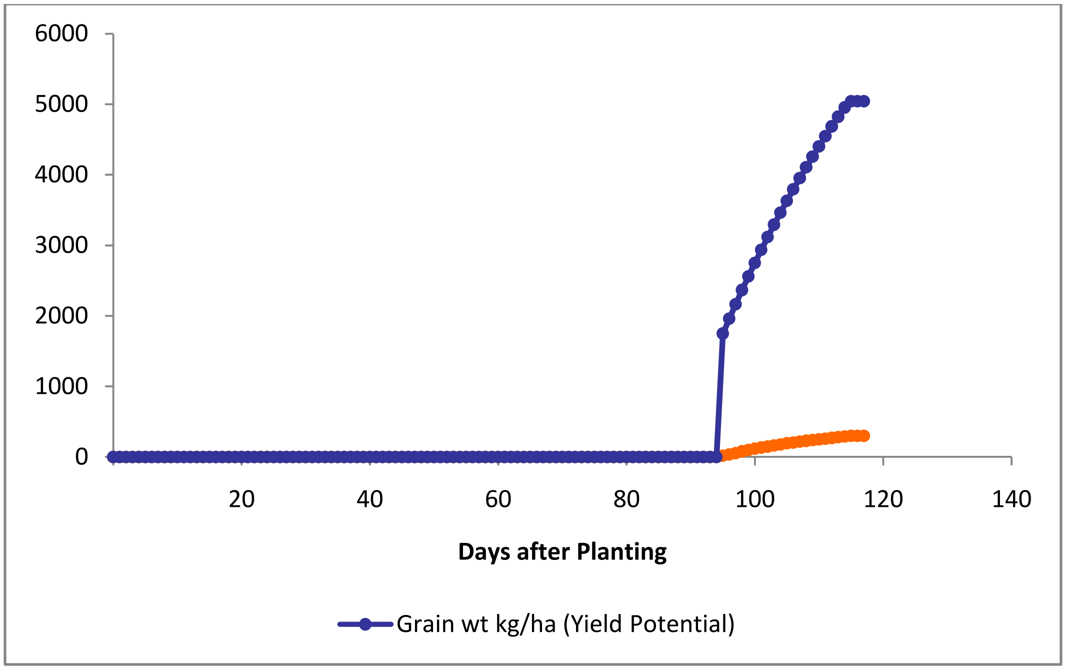
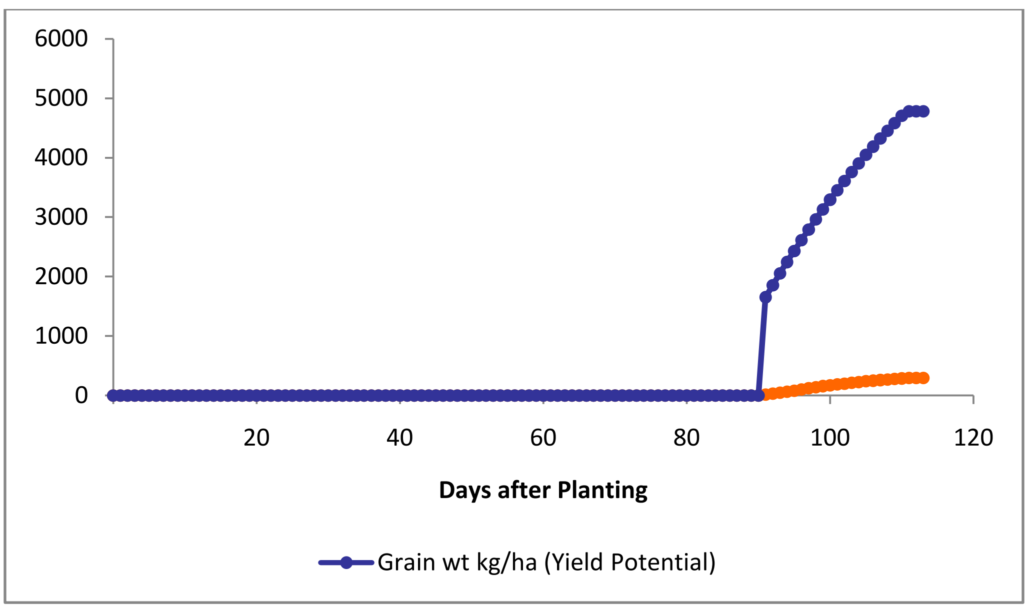


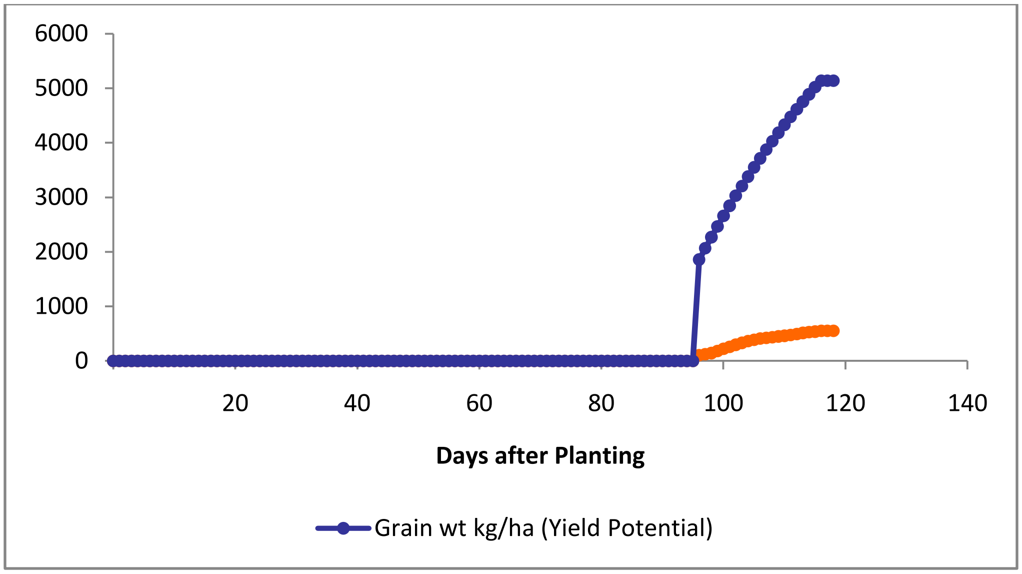
2000 Aman yield with actual measured temperature



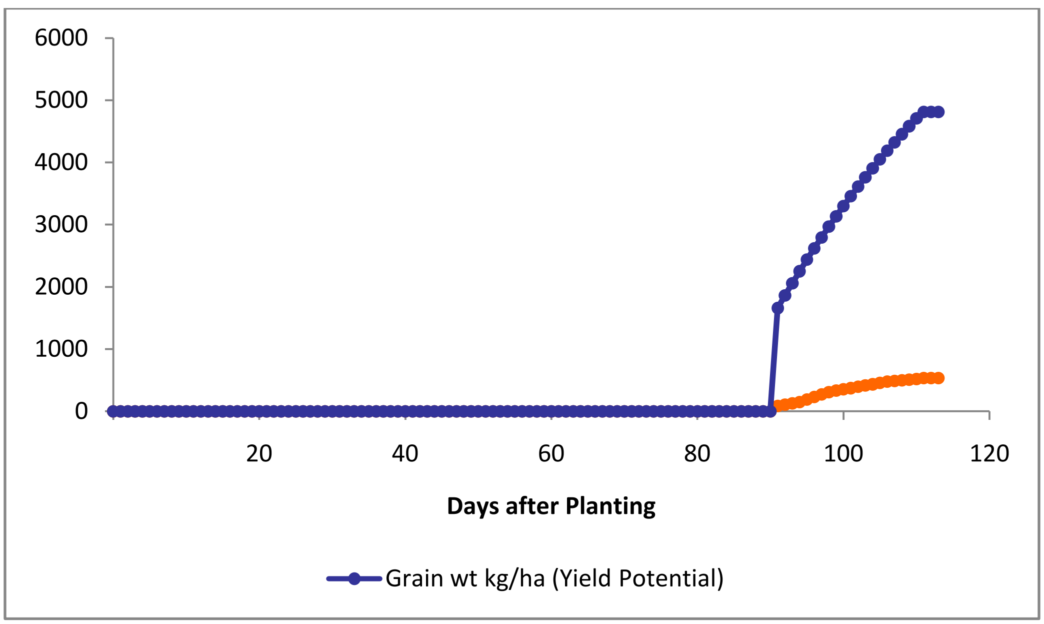
2000 Aman yield with the increase of minimum measured temperature



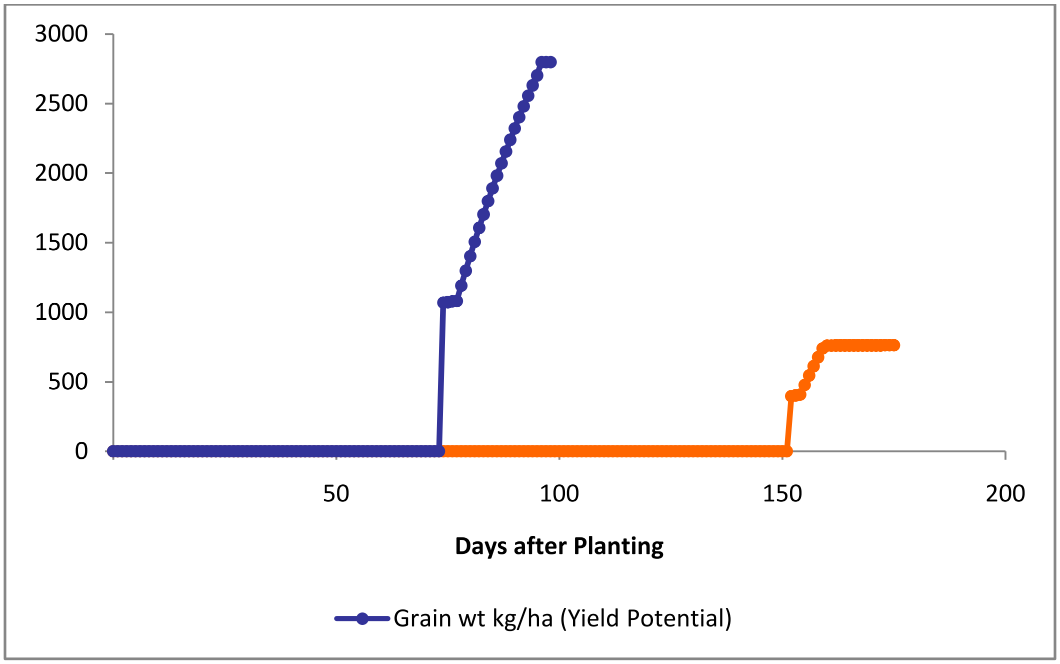
2001 Potential Aman yield with actual measured temperature



2001 potential Aman yield with the increase of minimum measured temperature



2002 Potential Aus yield with actual measured temperature



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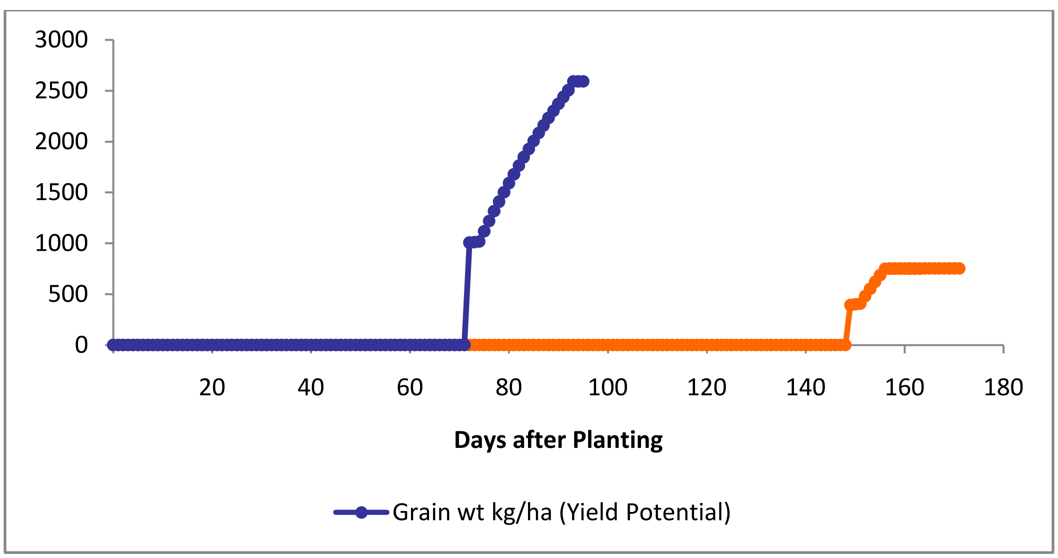
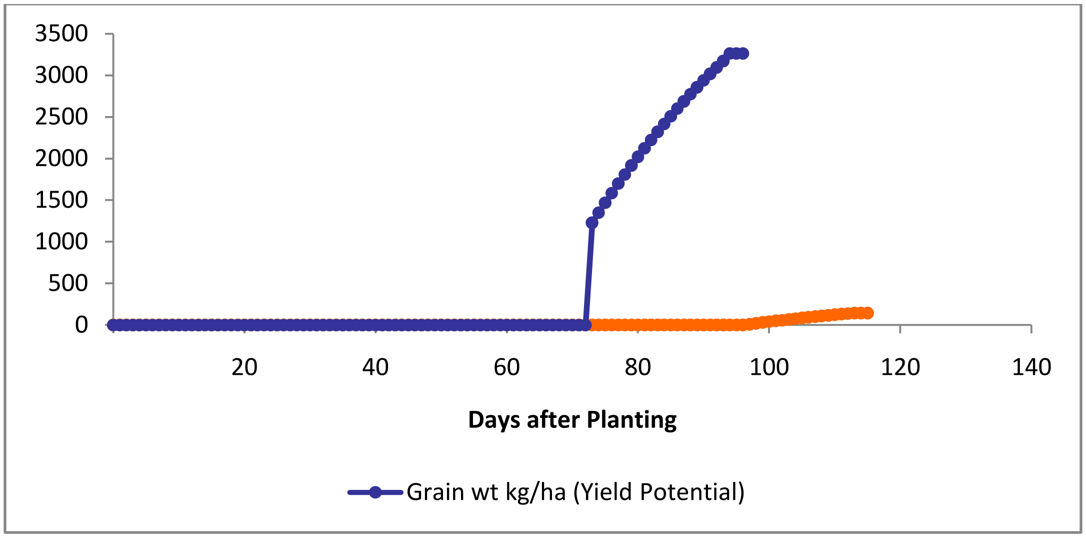
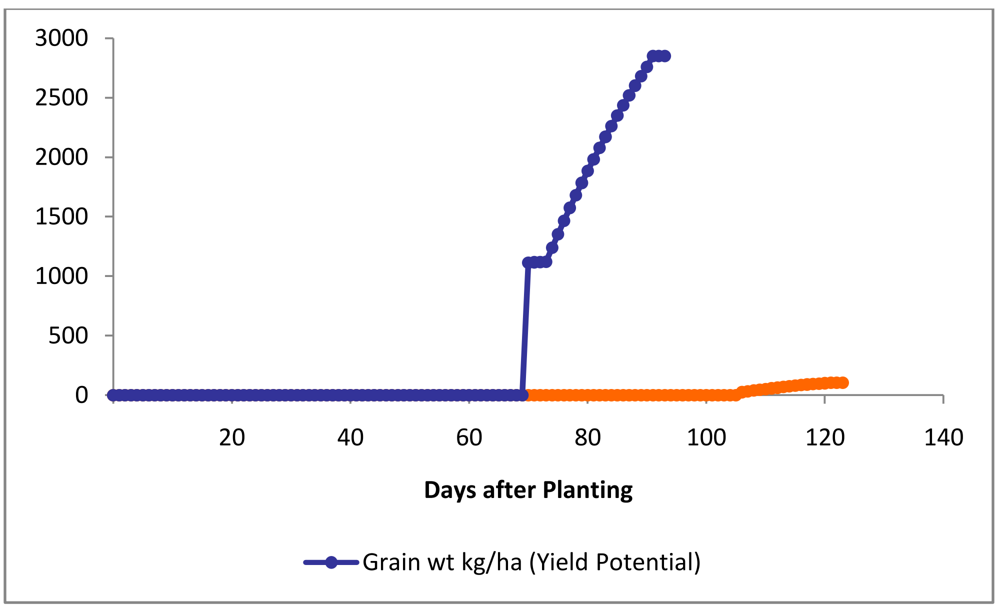


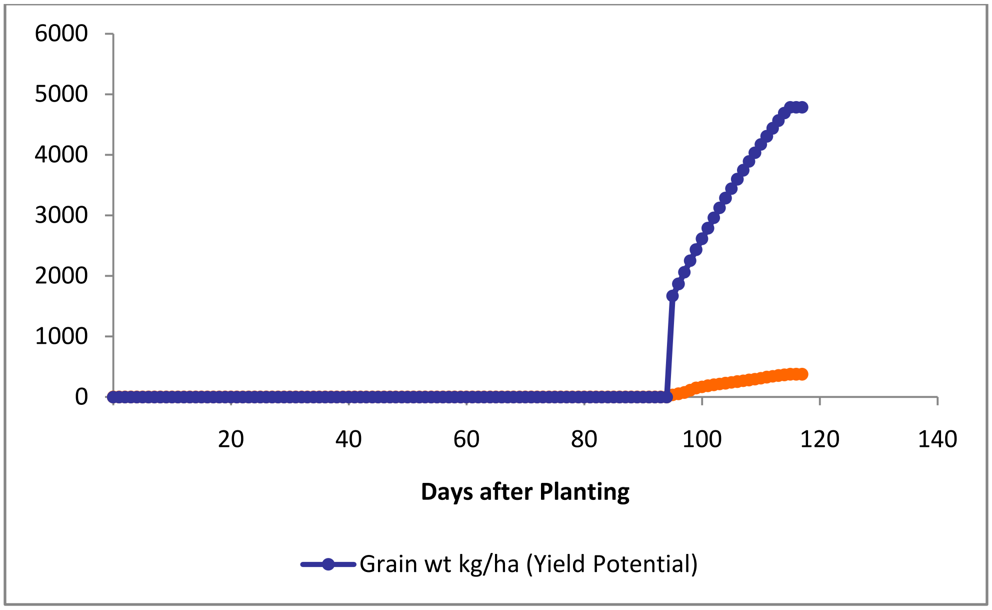
2004 Aus yield with Actual measured temperature



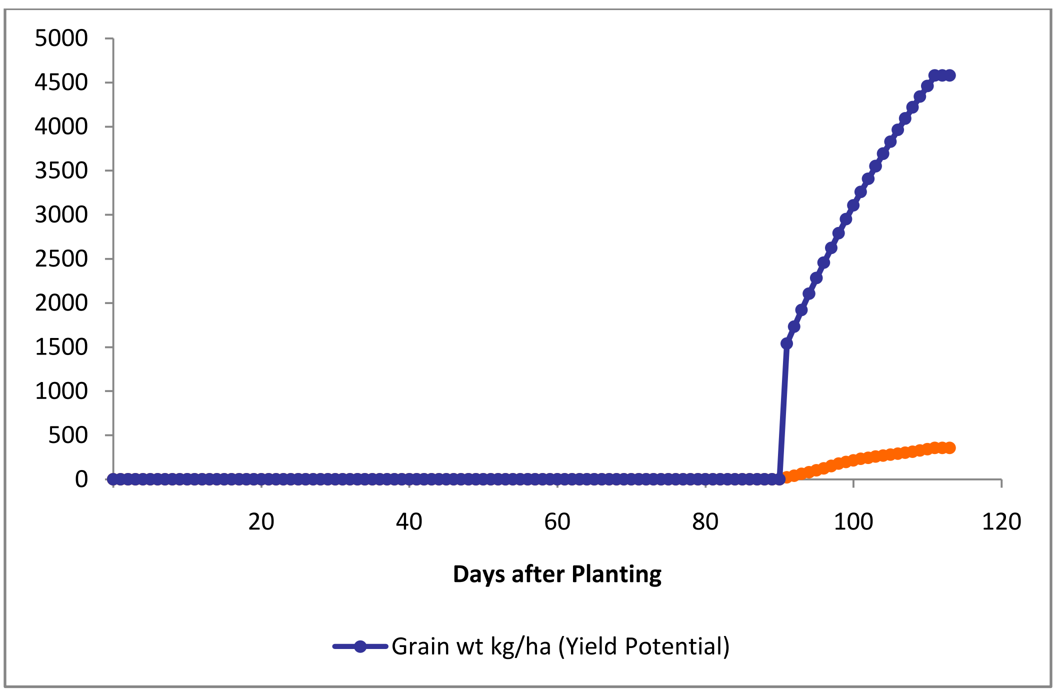
2004 Aus yield with the increase of minimum measured temperature



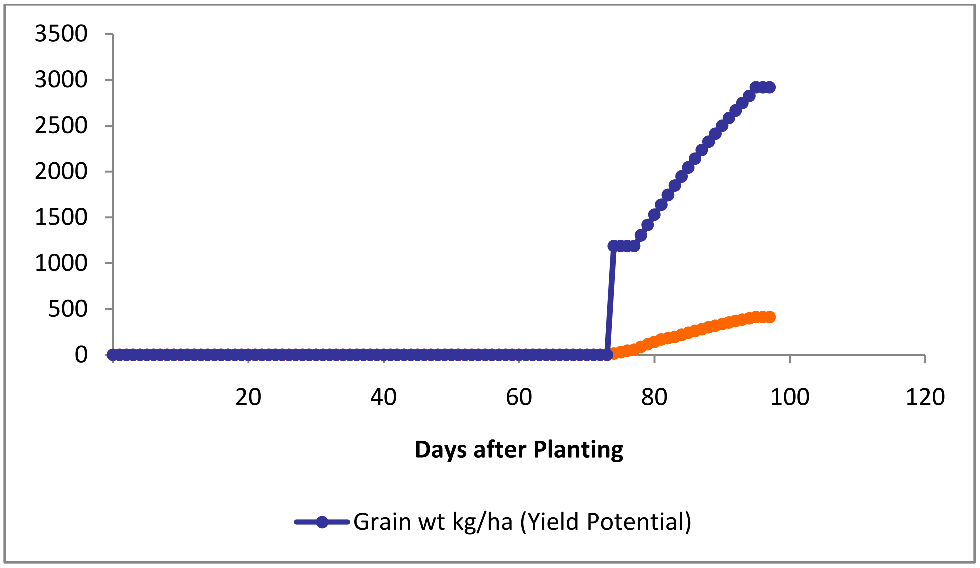
2004 Aman yield with actual measured temperature



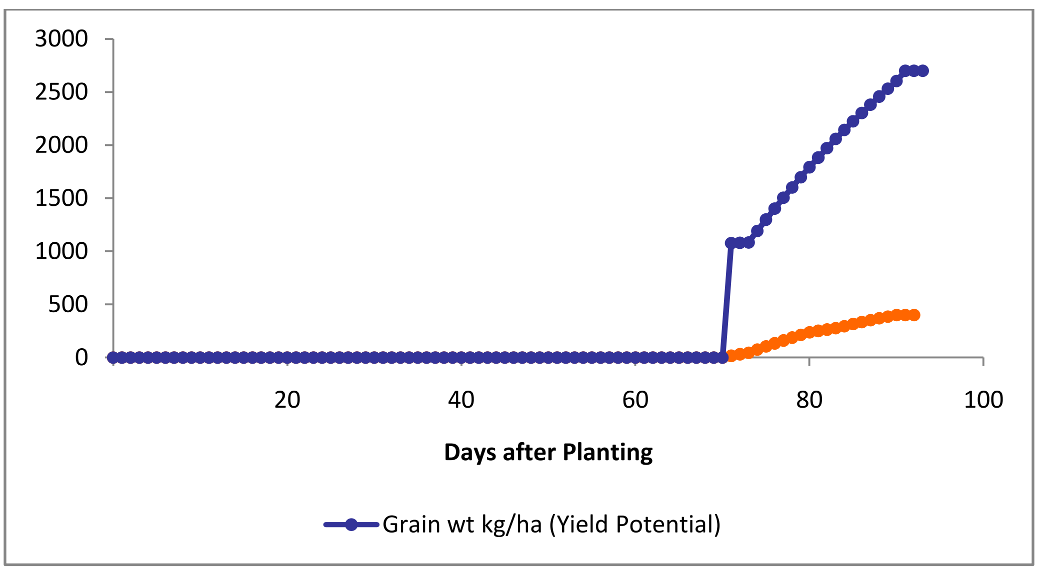
2004 Aman yield with the increase of minimum measured temperature



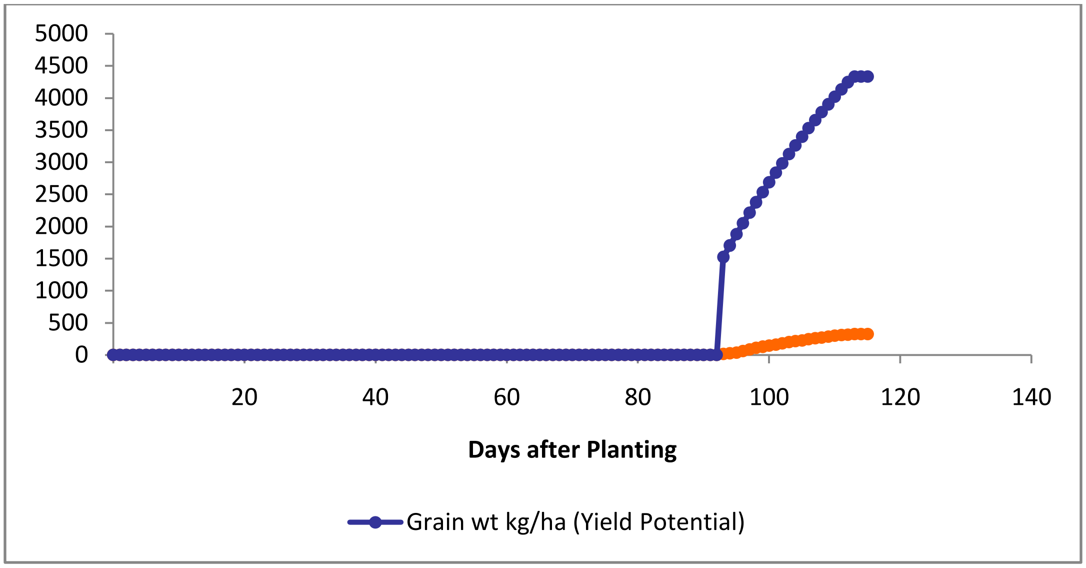
2005 Aus yield with actual measured temperature



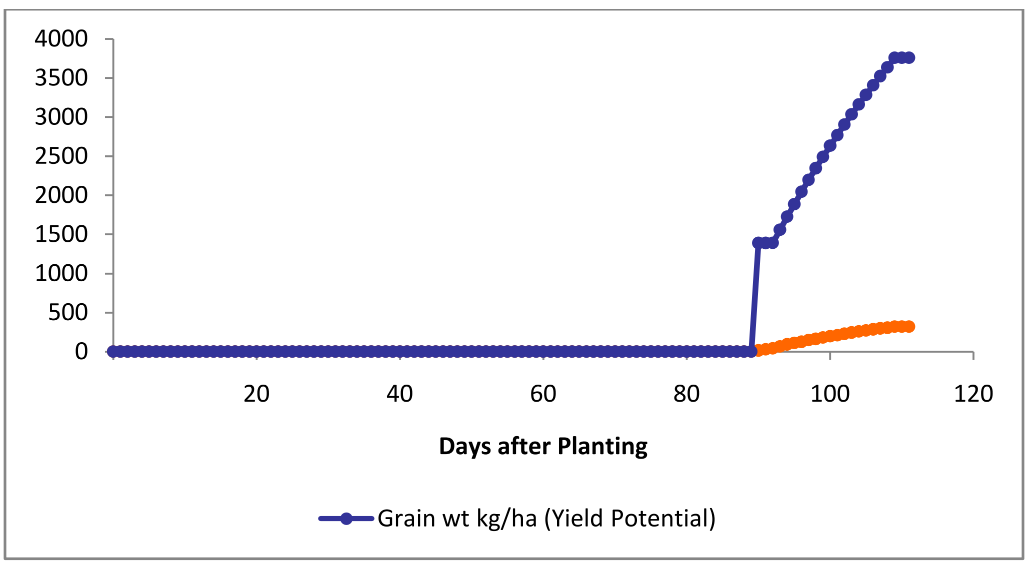
2005 Aus yield with the increase of minimum measured temperature



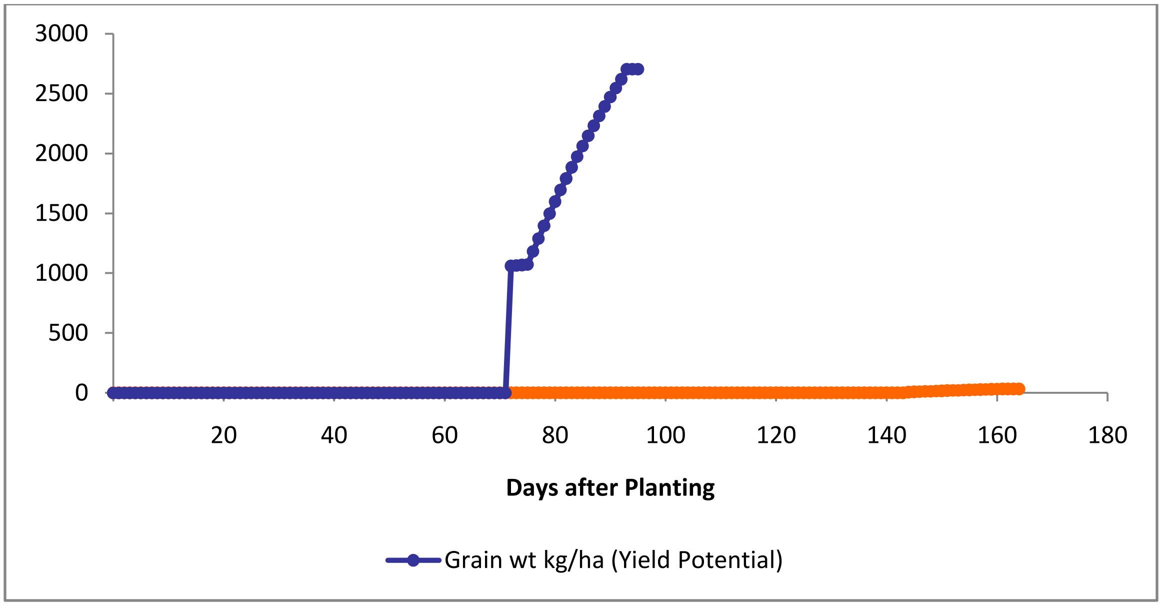
2005 Aman yield with actual measured temperature



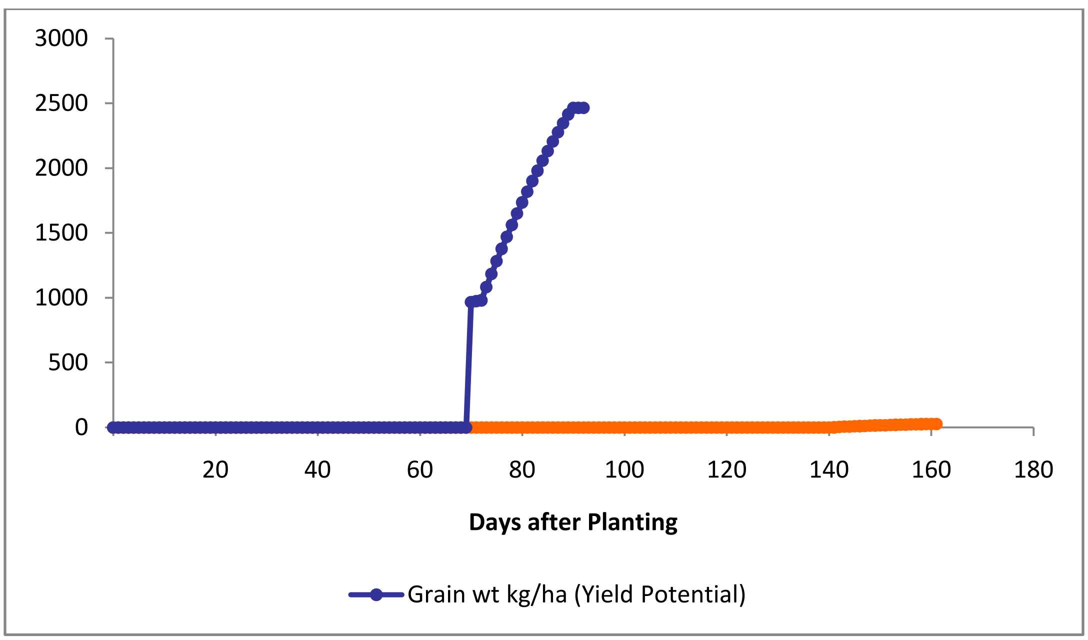
2005 Aman yield with the increase of minimum measured temperature



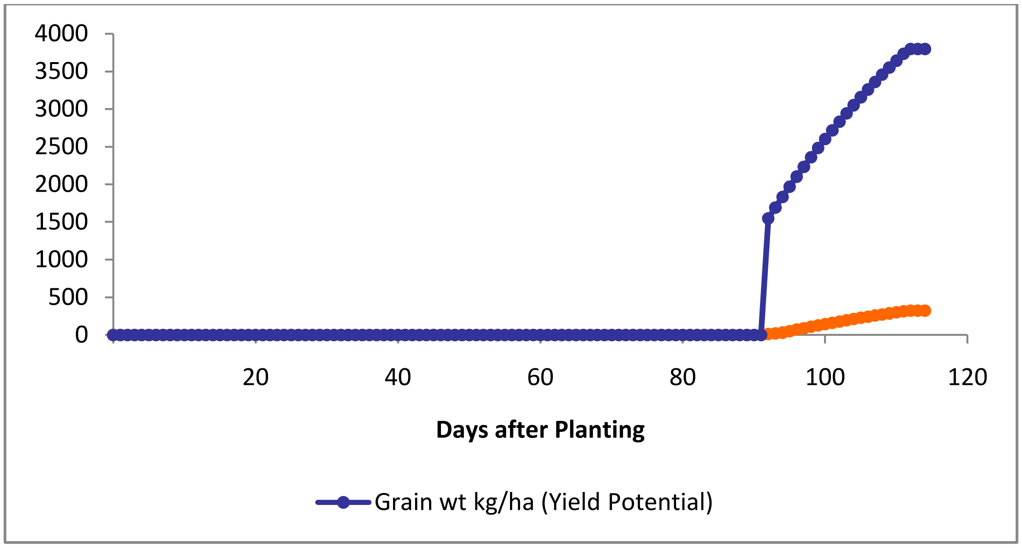
2006 Aus yield with actual measured temperature



2006 Aus yield with the increase of minimum measured temperature



2006 Aman yield with actual measured temperature



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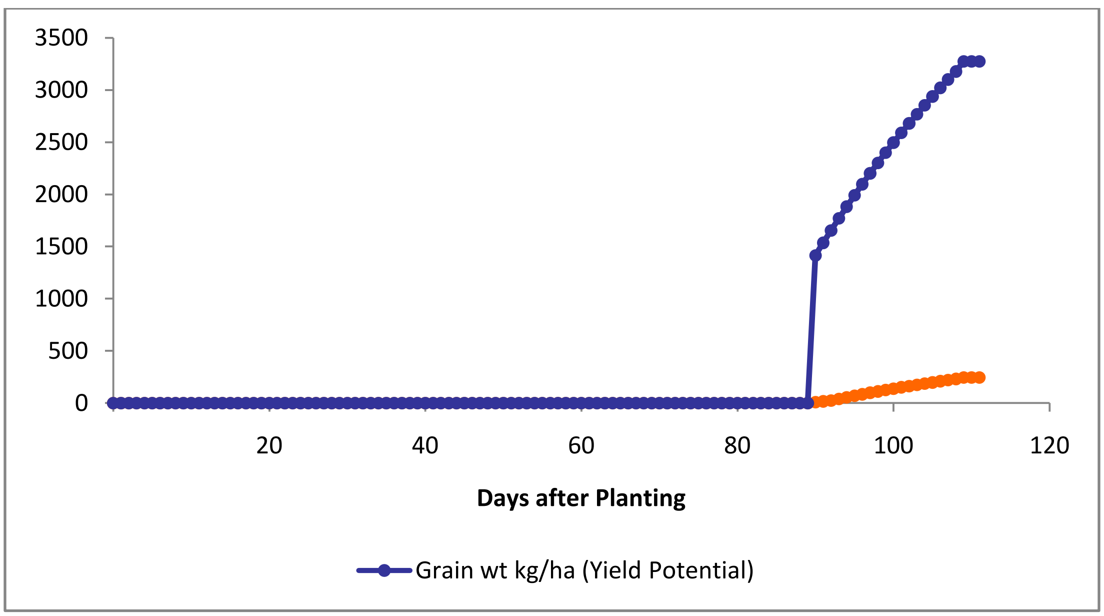
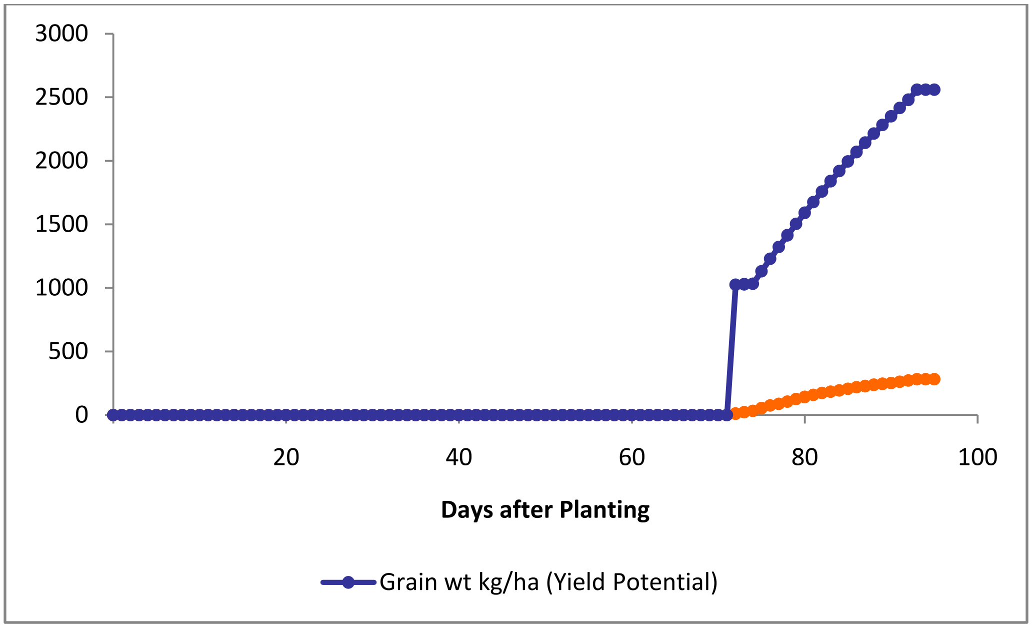
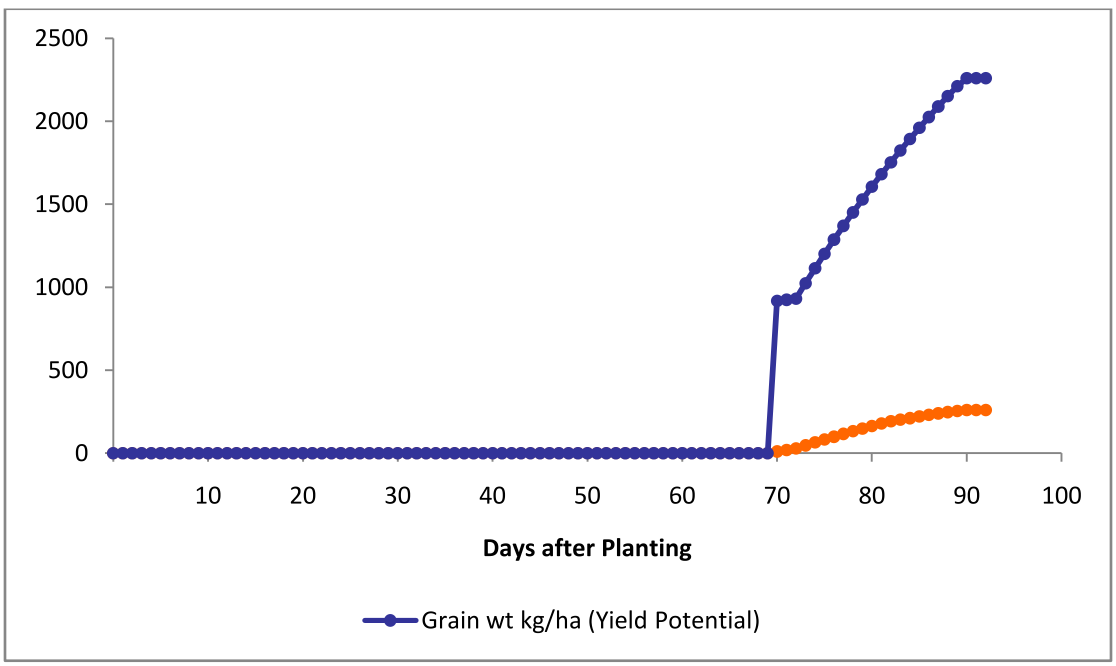


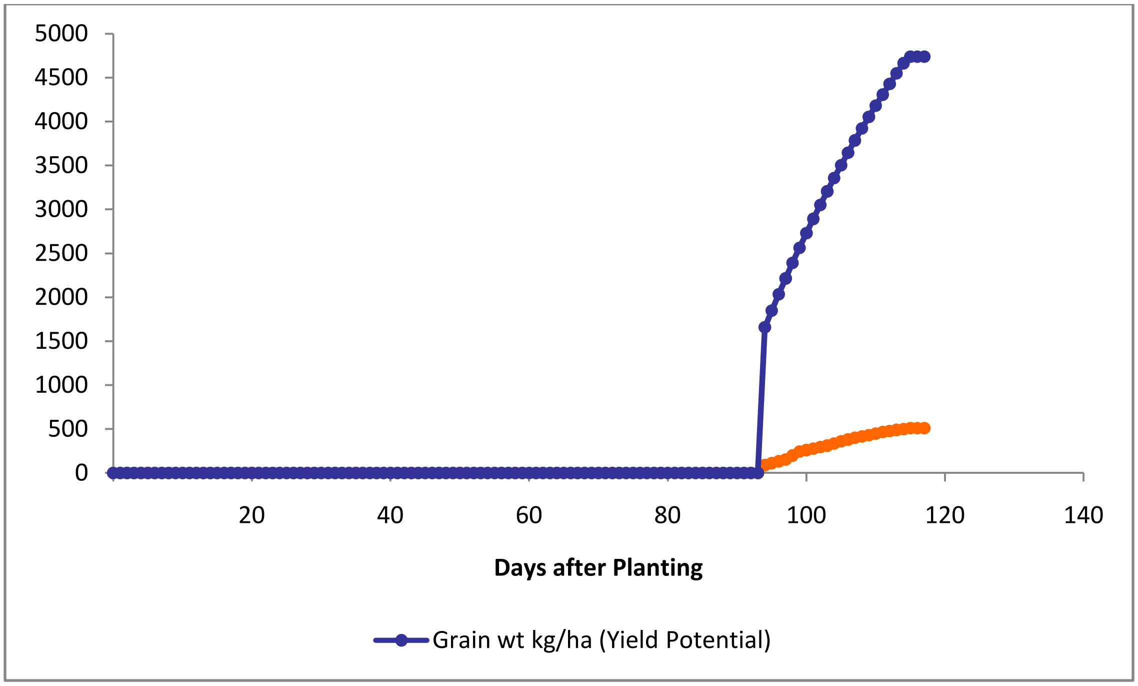
2007 Aus yield with actual measured temperature



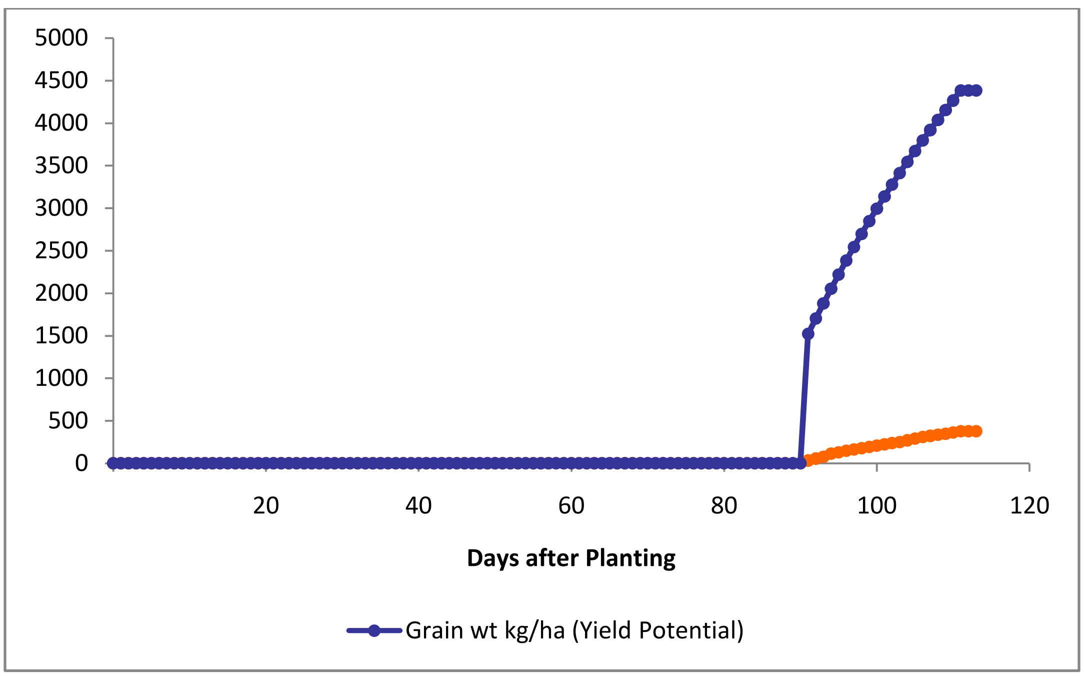
2007 Aus yield with the increase of minimum measured temperature



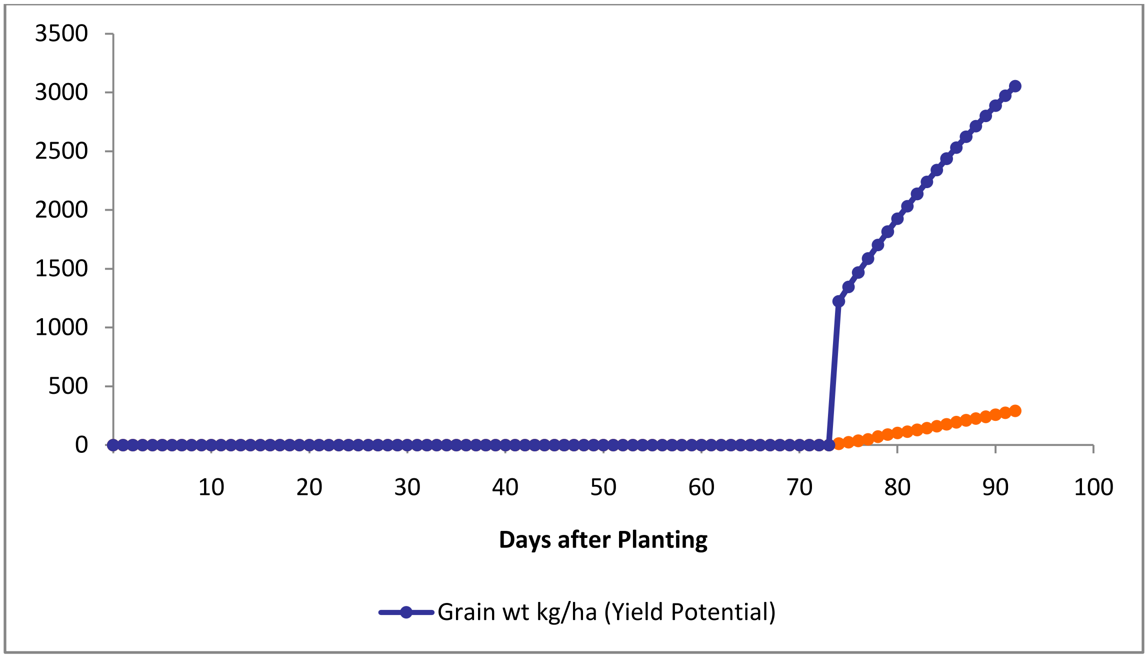
2007 Aman yield with actual measured temperature



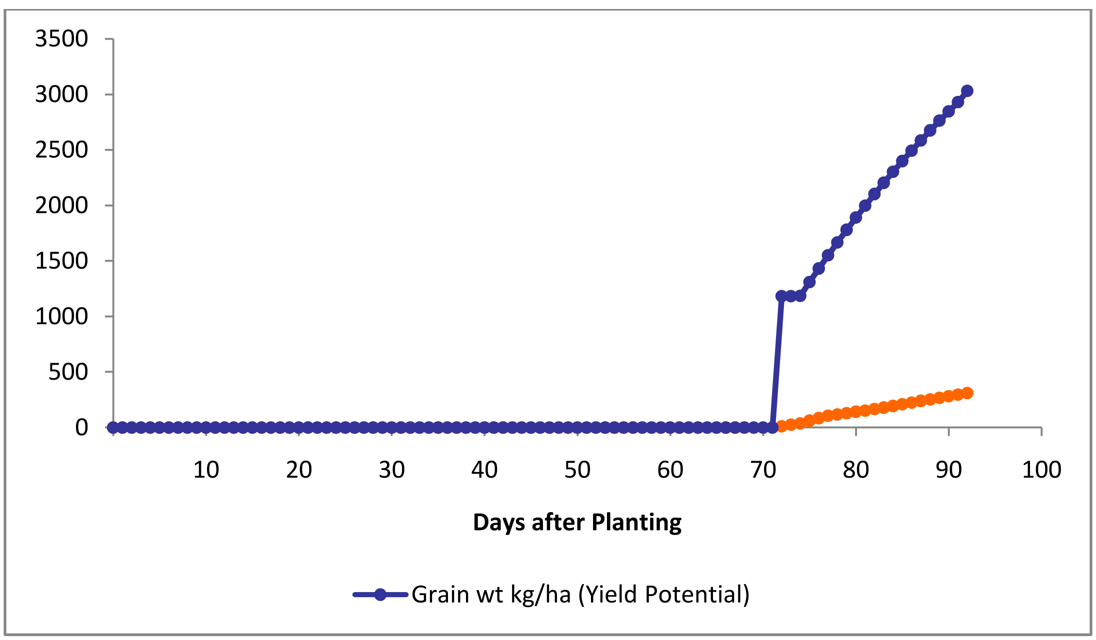
2007 Aman yield with the increase of minimum measured temperature



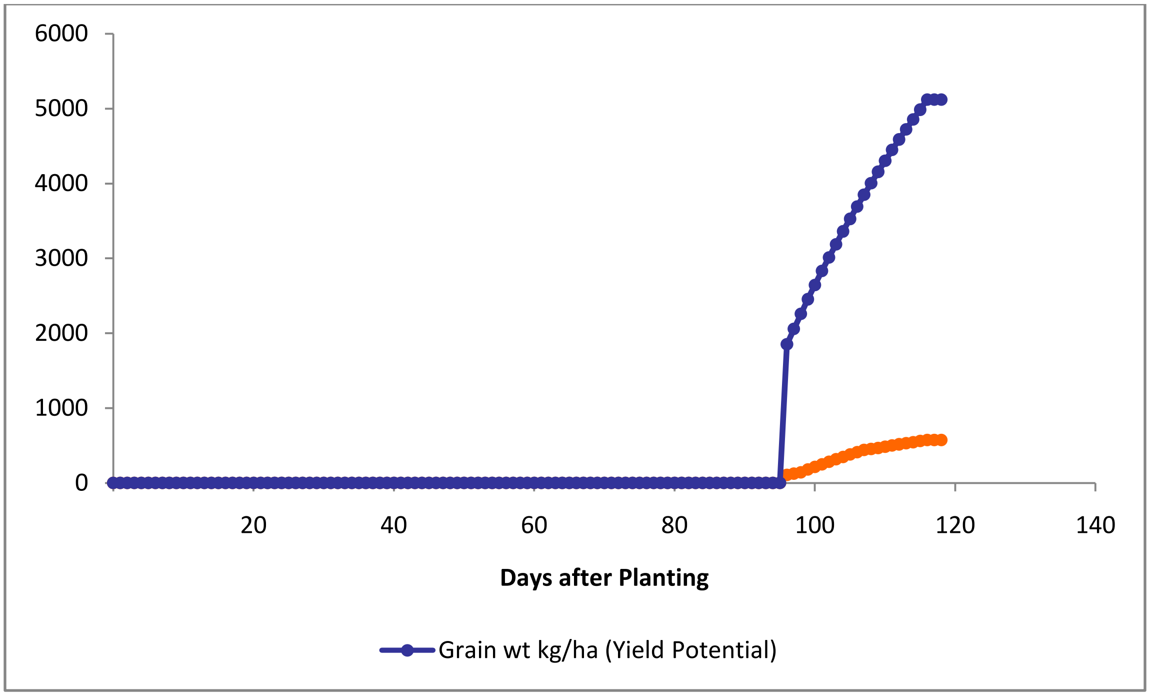
2008 Aus yield with actual measured temperature



2008 Aus yield with the increase of minimum measured temperature



2008 Aman yield with actual measured temperature



2008 Aman yield with the increase of minimum measured temperature