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Climatic Change Concerns in Bangladesh Agriculture

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Review Article

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Abstract: Wide range of inter-annual climatic variability and frequent occurrence of extreme climatic events is a great concern. There is a need to assess the impact of such events on agriculture and to suggest suitable agri-management options for sustenance. The appropriate regional based agro-advisory needs to be established for the farmers and other stake holders. Inter-annual climatic variability has to be linked through growth and yield of crops and cropping systems in various production environments of Bangladesh. Climate change is a global concern, and we must identify vulnerable regions as well as identify suitable mitigation and adaptation strategies through various agronomic and management options to sustain the agricultural production. Development of climate resilient agriculture is of paramount importance. Agri-response must be evaluated in relation to future climate change scenarios, in which crop modelling can play an effective role. With the help of crop simulation tools, assessment can be made for newer production centres and identifying suitable resource management options for maximizing production. Impact of climate change needs to be worked out on regional scales by integrating crop models with relational layers of bio-physical and socio-economic aspects. For this purpose use of geographic information system (GIS) and remote sensing tools is needed. In this review article, we have discussed about the inter-annual climatic variability and occurrence of extreme climatic events in Bangladesh and their association with agricultural production system. In this paper, we have demonstrated the potential of crop models viz. INFOCROP, DSSAT to assess the impact of this climatic variability and its change on growth and yield of crops and cropping systems and thereby suggesting appropriate management options for sustenance.
Keywords: Climatic variability, climate change, extreme/episodic events, impact on agriculture, crop simulation tools.

INTRODUCTION

A large number of people in Bangladesh depend on agriculture, which is strongly affected by seasonal weather patterns and extreme/episodic climatic events. The country has made tangible progress in food production in the recent past, but the emerging impacts of extreme events are posing serious threats to food security. Sustaining food security for growing population is a major concern in Bangladesh. Developing climate resilient agriculture through adoption of suitable agricultural production practices and inputs management options need to be evolved. Rice, wheat, maize, potato, vegetables, jackfruit, mango, banana, papaya and pineapple are playing dominant role in Bangladesh. Rice is still the most important agricultural crop in Bangladesh, which covers more than 75% of the land area and its production registered a long term [1] steady annual growth rate of 2.8%. Only potato has, to an extent, shown a similar trend of increased area. Farmers prefer growing crops of high market demand despite most farmers operate under subsistence level.

Despite a steady growth in agriculture as well as in food production, Bangladesh has been facing persistent challenges in achieving/sustaining food security. This is mainly due to natural disasters and fluctuations in food prices. Food security worsens with inter-annual shortfall in food grain production caused by climatic variations and natural disasters such as cyclones, floods, and tidal surge, drought and insect and pest attacks.

Major Concerns

Crop agriculture in Bangladesh is constraints by multifaceted events (Fig. 1). Regional temperature variations and rainfall dictates rainfed agriculture, while irrigated agriculture depends on mostly ground/surface waters. The pattern of rainfall will bring changes in timing of drought. Drought in November adversely affects rainfed late planted lowland rice at the ripening stage, but excessive rainfall results in delayed winter non-rice crop establishment. Increasing moisture stress in early pre-monsoon significantly affects Aus rice production. Moisture stress by 30 percent may result in 1 to 4 percent yield reduction of dry season irrigated rice, while yield reduction will be 10 to 33 percent at 60 percent moisture stress condition.

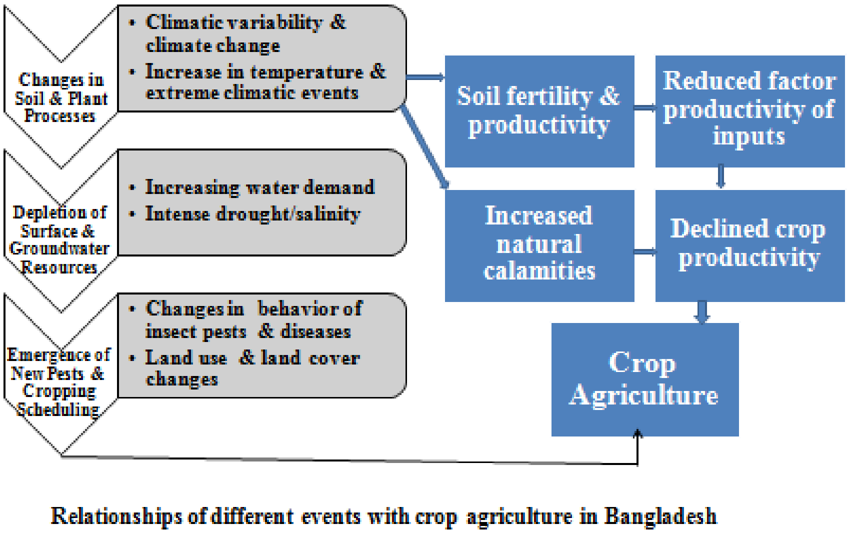

Fig-1: Association of Agricultural System's response to various biotic and abiotic components

Climate variability and rapidly changing land use and land cover change are significantly influencing insects/pests dynamics and there is always a need to innovate and identify appropriate pest control options for sustainable agriculture. There is a need to identify insects/pests hotspots and develop pest population forewarning tools, which can subsequently be linked to crop growth models for yield reduction looses associated with crops and cropping systems.

Degradation of productive lands is key concern for coastal agriculture, due to salinity intrusion and sea level rise. Soil productivity in these regions is declining and thus causing to add more fertilizers and other inputs for sustained crop production. Although newer and improved crop varieties are released by research institutions, but their performance show reduced factor productivity of various resource and management.

North-east and central region of the country is facing frequent flooding and this situation will be aggravated due to increased rainfall, melting of Himalayan glaciers in future. Prolonged floods would tend to delay wet season rice planting resulting in significant loss of potential production as observed in 1998 and 2007. The 1988 flood caused reduction of agricultural production by 45% and approximately 1.2 million acres of crops were destroyed or partially damaged in 2007 floods and estimated damage over $1 billion.

Bangladesh Climate

Bangladesh has a humid, warm tropical climate. Four prominent seasons are: pre-monsoon (March–May), monsoon (June-early October), post-monsoon (late October to November) and winter (December–February). The mean annual rainfall varies widely across locations ranging between 1200 mm and 5800 mm. The average annual rainfall in the country is about 2,200 mm. About 80% of the rainfall occurs from May to September. Seasonal and spatial variations in surface temperature are also substantial. The key features relating to geophysical conditions and climate change interface are: about 10% of the country is less than one meter above sea-level while one-third is under tidal excursions; 32% of the country is situated along and near the coast, accommodating 28% of the country's inhabitants; a vast network of rivers, channels and floodplains.

Pre-monsoon is hot with a maximum temperature of 31-33°C and extreme maximum temperature could be about 44^{o}C in the country depending on location (Fig. 2). Evaporation rate is relatively higher and occasional heavy rainfall observed from March to June. Monsoon is both hot and humid, brings heavy torrential rainfall throughout the season.

About four-fifths (over 70%) of the mean annual rainfall occur during monsoon. The mean monsoon maximum temperature is about 31.5°C and minimum about 25.2°C (Fig. 2). Post-monsoon is short-lived and the season is characterized by withdrawal of rainfall and gradual lowering of night-time minimum temperature. Winter is relatively cooler and drier, with the average maximum temperature ranging from 26.4°C to 28.2°C and average minimum of 12.4°C to 15.2°C (Fig. 2). The extreme minimum temperature can be 3.4°C to 5.0°C depending on locations of the country. The lowest temperature is generally observed in northern part of the country.

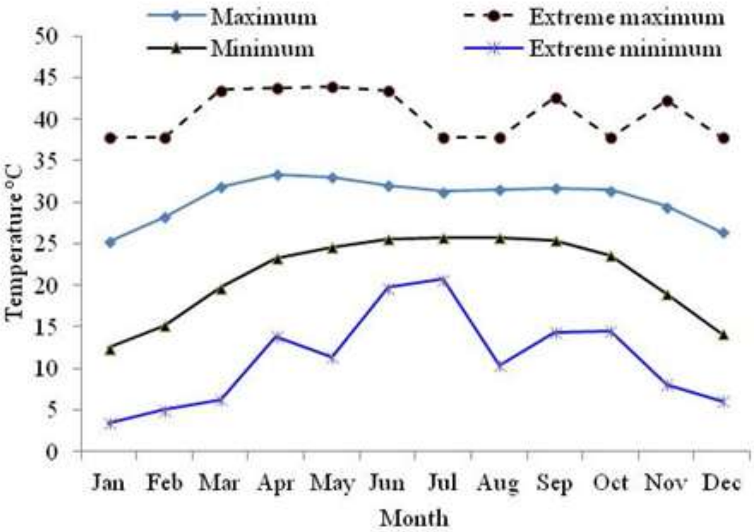

Fig-2: Temperature patterns in Bangladesh during 1948 to 2013 (BARC, 2016)

The climate of the country is strongly influenced by monsoon. Though Bangladesh occupies only 7% of the combined catchment area of the Ganges-Brahmaputra-Meghna river basin, the country has to drain out 92% of the flow into the Bay of Bengal. Too much water in the monsoon period affects different sectors, livelihoods and food security. Climate change scenario projections show mean monthly rainfall may significantly change over normal in future. Monsoon rainfall may increase by 11% by 2030 and 27% by 2070. Also, the general rise in surface average temperature will increase by 1.3 degree C by 2030 and 2.6 degree C by 2070. The number of rainy days will increase by about 20 days.

Extreme/Episodic Events

Floods

In an average year, approximately one quarter of the country is inundated. Bangladesh has experienced six severe floods during last 25 years. In 2007 (July-August and September), two successive and damaging floods inundated the country in the same season. Flash floods can also be a problem in north-eastern and south-eastern regions of the country in the scale of the severe flooding in 2004 and 2007. Flash flood hits *Haor* areas few days earlier than 40-50 years back in recent years [2].

Droughts

About 2-7 million ha area is vulnerable to annual drought. About 18% of the Rabi crops and 9% of the Kharif crops are highly vulnerable to annual drought problems. Bangladesh experienced severe to moderate droughts in 1973, 1978, 1979, 1981, 1982, 1989, 1994, and 1995. Drought 2009 was characterized by 21% less rain in Monsoon period (June-August).

Increase in Soil and Water Salinity

Out of about 1.689 million hectares of coastal land about1.056 million ha are affected by soil salinity of various degrees. Saline area in 1973 was 0.833 m ha, whereas in 2000 was 1.02 m ha. About 35510 ha salinity area of different classes has increased from 2000-2009 AD [2].

Cyclone

A severe tropical cyclone hits Bangladesh, on average, every 3 years. Super cyclone *SIDR* November 15, 2007, Cyclone *Nargis* - 02 May 2008; Cyclone *Rashmi* - 27 October 2008; Cyclone *Aila* - 26 May 2009 were the major ones in the recent decades.

Climate Change and Climatic Variability

Climate change due to atmospheric build up of greenhouse gases (GHG) is a reality. The IPCC assessments and numerous other reports suggest adverse effect of climate change on economic sectors [3, 1, 4]. Severe weather events will have dire social, economic and economic consequences posing threat to global food security.

Farmers and farming communities have survived over generations by mastering the ability to adapt changing climatic conditions and extreme weather events, although crop yields in some areas have already started to decline due to warmer conditions. One of the recent studies has provided detailed analysis of the magnitude of threats that Bangladesh faces due to climate change impact and opportunities of increasing productivity in crop sector [5]. Making a general assessment of the vulnerability, point application studies carried out vulnerability assessment of the climate change and also suggested adaptation strategies for sustainable agricultural production [6-8]. Reviewing the likely impact of climate change, a recent study suggested the possible strategies for sustaining and improving production under abiotic stresses for adapting rice to climate change [9].

Char Lands

Riverine *char* lands are considered as hotspots for climatic hazards. Although chars belong to floodplains, these chars are erosion prone and top soil moisture holding capacities are poor– both these characteristics make the lives and livelihoods of the poors miserable. The characteristics for the Char land ecosystem are: (i) increased severity of bank/edge erosion, (ii) increase in extent and duration of floods, high intensity floods occurring more frequently, (iii) sudden sand casting makes the soil unsuitable for preferred cultivation, (iv) erosion-induced losses and damages, (v) increased spreading of disease vector. Research and development efforts are going on to identify suitable land use types and appropriate management options for agri-sustenance.

Sea Level Rise and Salinity Intrusion

The projected sea level rise (SLR) along the coastal areas of Bangladesh will be about 88 cm by the year 2100. Recent studies by SRDI, Bangladesh indicate significant increase in saline area. Total salinity affected area increased from 0.833 million ha to 1.056 million ha during the past four decades. A World Bank study showed 10 cm, 25 cm and 1 m rise in sea level by 2020, 2050 and 2100 in Bangladesh affecting 2%, 4% and 17.5% of total land mass, respectively. The SLR will have compounding effects on coastal drainage and erosion. The mixing zone between fresh water and saline water will also be shifted. Embanked coastal agricultural areas will be at higher risk of tidal surge and subsequent inundation with saline water. Based on the ground survey information on the dynamic coastal area of Bangladesh, some recent studies suggest possible area-specific mitigation measures to counter predicted rates of sea-level rise [10]. Increase in soil salinity may lead to decline in yield of high-yielding-variety rice and reduce the income of farmers significantly in coastal area. Climate change will cause significant changes in river salinity in the southwest coastal region during the dry season (October to May) by 2050 resulting in shortages of drinking and irrigation water and cause changes in aquatic ecosystems.

Water Resources Availability

Farmers in South Asia, including Bangladesh, use up to 90% of the available fresh water. Water demand for crop agriculture is projected to rise in warmer climate bringing increased competition between agriculture and urban as well as industrial users. Falling water tables and the resulting increase in the energy needed to pump water will make the practice more expensive. Of the total irrigated area, shallow tubewell contributed 65.5% and deep tubewell 14.9%, during 2006-07. These huge withdrawals have depleted underground water reserves because it was not replenished by rainfall or surface water flows [11, 12]. World’s most groundwater depletions are observed in northern India up to the Assam and northern Bangladesh [12-14].

Low river flow condition starts to occur in the post-monsoon period and continues till early April, March being the critical month, and during this time surface salinity penetrates further inland due to lack of adequate flushing. Under climate change scenarios low flow conditions are likely to aggravate with the possibility of withdrawal of appreciable rainfall in winter.

No research has so far been attempted to analyze susceptibility of riverbank erosion in reference to increased flood vulnerability under global warming. Similarly, no serious attempt has so far been made to examine how sedimentation would be affected due to increased flood vulnerability under climate scenarios. Bangladesh is the outlet of all the major upstream rivers and the average annual sediment load that passes through the country to the Bay of Bengal ranges between 0.5 billion to 1.8 billion tons. All rivers in Bangladesh are alluvial and highly unstable.

Forestry/Biodiversity

Bangladesh has a diverse range of forest ecosystems, including savannah, bamboo, freshwater swamp forests and mangroves. The Sundarbans of Bangladesh, a world heritage site, is the single largest mangrove area in the world, comprising an area of 577,00 ha, and housing one of the richest natural gene pools. A total of 425 species have been identified there, the most notable of which is the Bengal tiger, which is endemic to the area. Climate change will have a detrimental impact on all of the forest ecosystems in Bangladesh, and the Sundarbans are likely to be the worst affected. The changes in temperature and water resources with climate change will result in direct pressure on many climate-sensitive species, and cause increased erosion and deterioration of soil quality in may upland forested areas. Increased rainfall intensity will cause enhanced erosion upstream and cause sedimentation. Saline intrusion is already a major problem in the Sundarbans; however it should be noted that climate change will also cause an increase in freshwater flows from the major distributaries with increased precipitation, and the extent to which this may offset salinity intrusion is uncertain. The Sundarbans also offer subsistence to around 3.5 million inhabitants who live within and around the forest boundary. The inundation and intruding salinity are interrupting traditional practices in the Sundarbans.

Climate Change and Agriculture

Agricultural crops of Bangladesh are influenced by temperature, rainfall, humidity, day-length etc. It is also often constrained by different disasters such as floods, droughts, soil and water salinity, cyclone and storm surges. Several studies indicated that climate is changing and becoming more unpredictable every year in Bangladesh. Its variability extreme weather events are being experienced more frequently than ever before. These changes in the physical system of the country will directly affect a number of major productive systems that include (a) crop agriculture, (b) livestock production, (c) aquaculture and fish production, (d) coastal shrimp production, and (e) forest and vegetation.

Using climate data from four general circulation models (GCMs) a recent study evaluated the impact of climate change on agriculture in Bangladesh by 2050 [15]. The results indicate that adaptation efforts in Bangladesh should include adjusting planting dates, using improved cultivars better suited for climate change, improving fertilizer application, exploring increased maize production, and bolstering flood and pest protection for farmers. Apart from such broad-based analysis and studies, specific works on crop response to climatic variability and global climate change have been [16-18]. However, the studies and assessment of climate change and its impact on Bangladesh agriculture is, however, scanty and systematic research on agriculture relating to climate change and adaptation mechanism and strategies aiming at developing climate resilient agriculture for Bangladesh is rather inadequate. There is a need to carry out regional based studies to evaluate the climate change impacts on agriculture.

Temperature Rise and Crop Production

Analysis of long term climatic data shows a fair degree of inters- and intra seasonal variations in temperature changes in Bangladesh. Air temperature generally shows an increasing trend over the years. SAARC Meteorological Research Center showed decreased mean temperature in pre-monsoon season, but in other seasons generally increased temperatures were reported [19]. The average monsoon maximum and minimum temperatures showed an increasing trend annually at 0.05°C and 0.03°C, respectively. Maximum and minimum temperatures in winter season (December, January and February) showed a decreasing and an increasing trend annually at 0.001°C and 0.016°C, respectively. Increase in temperature would greatly affect the productivity of temperature sensitive crops, especially rabi crops in Bangladesh. The production of wheat might drop 32% by the year 2050. Under a severe climate change (4^oC temperature rise) scenario, the potential shortfall in wheat and potato production could be very high [20]. Rise of 1 to 2^oC temperatures in combination with lower solar radiation would cause rice spikelets sterility. High temperature was found to reduce yields of HYVs of aus, aman and boro rice. Changes in temperature, humidity and radiation, have great effects on the incidence of insect pests, diseases and microorganisms. A change of 1^oC in the air temperature, changes the virulence of some races of rust infecting wheat.

Minimum temperature during January and maximum temperature in February determine the wheat yield. Wheat yield decreases by 400 kg/ha per 1^oC increase in maximum temperature and 0.5 hr in sunshine. Wheat must have 60 days with minimum temperature of $<15^oC$ for adequate tillering and panicle development. Any decrease in the length of this cool period is considered to lead a proportionate decrease in yield [21, 22]. Bangladesh grows nearly 9.0 million tons of potato, 0.9 million tons of oilseed and 0.8 million tons of pulses. All these crops require temperature between 18-25^oC. These crops are highly sensitive to fog, cloud and change in humidity. These crops are predicted to be abandoned with rising temperatures. There is a need to assess the growth and yield response of crops and cropping systems to temperature changes and evolve the dated production functions to evaluate the effects of temperature stress in various critical stages of the crop growth on subsequent yield.

Rainfall Variations and Agri-response

Annual rainfall ranges from 1200 mm in the west to over 5000 mm in the east and north-east. Analysis of long term rainfall data fails to provide any consistent trend. However, the most remarkable change in rainfall is the change in the duration of rainy season. Trend analysis from historic records reveals that duration of rainy season shortened but the total annual rainfall remains more or less. This suggests that heavy rainfall occurs within short period (June-early October) accounting to about 72% of total rain was in monsoon. Precipitation extremes will result in increased rainwater flooding.

IPCC [23] suggested that it is rather the erratic behaviour of rainfall pattern that will affect crop production most. Variation in the onset and withdrawal timing of monsoon will affect crop production adversely. Atmospheric Brown Cloud (ABC) or the thick cloud cover enveloped over Indo-Gangetic Plain (IGP) is attributed to delaying the onset of monsoon [24]. Farmers in North-west Bangladesh could not transplant rice seedlings because of delay in the onset of monsoon in 2009. Frequency and intensity of such rainfall uncertainty is predicted to be increased. Rainfall over the IGP has decreased by about 20% since the 1980s. It is anticipated that the current sufferings due to lower water availability in the dry season will be accentuated not only by climate change, but also by increase in demand exerted by increased population.

Drought and Response to Crops

It is claimed that as high as 47% area of the country is drought vulnerable, where 53% of current population live. Meteorological, hydrological and agricultural droughts affect production. Most of the droughts primarily occurred in pre-monsoon and post-monsoon seasons, but in some extreme cases the pre-monsoon droughts had extended into the monsoon season due to delayed onset of the monsoon rains, e.g. the 1979 drought. The dry zone in Bangladesh is located along the country's north-west and south-west border (Rajshahi, Bogra, Pabna, Dinajpur, Rangpur and Kushtia districts) having mean annual rainfall of 1,250-1,750 mm between May-June and September-October.

Drought of different intensities in the monsoon, dry and pre-monsoon seasons cause damage to 2.32 million ha of rice and 1.20 million ha of dry season upland crops annually. Droughts are associated with the delayed onset or the early recession of the monsoon rains and with intermittent dry spells coinciding with critical crop growth stages. Yield reductions due to drought vary from 45-60% in rice and 50-70% in upland crops in very severe drought situation. Yield loss of rice due to slight drought is from 10-30% and might be up to 70-90% under severe drought. Drought of 1981 and 1982 affected the production of monsoon rice resulting in a shortfall of 0.5 and 0.3 million tons respectively. Drought of 2006 in north-western districts reduced crop production 25-30%. During 1960 and 1991, a total of 19 droughts occurred in Bangladesh [2].

Pre-monsoon drought is called Rabi and pre-Kharif drought since it affects both Rabi and Pre-Kharif crops [8]. The commonly affected major crops include high yielding Boro rice, Aus rice, wheat, pulses, sugarcane, and potatoes. Significant damages can occur where irrigation possibilities are limited. Post-monsoon drought is also known as Kharif drought as it affects Kharif crops. Aman rice is the most common Kharif crop that is affected by post-monsoon drought as its reproductive stage is severely constrained by shortage of available moisture.

Mitigation and Adaptation Strategies

There are several mitigation and adaptation practices that can be effectively put to use to overcome the effects of climate change with desirable results. These practices fall under broad categories of crops/cropping system-based technologies, resource conservation-based technologies and socio-economic and policy interventions. The key adaptation strategies in agriculture are: promotion of climate resilient crops (salinity tolerant, submergence and drought tolerant varieties); short duration and early crops; change in cropping patterns in the context of changes in seasons and weather patterns; better farm management through new information dissemination, motivation and technological innovation; water and disaster risk management; and improving R&D in agriculture.

Agriculture offers promising opportunities for mitigating GHGs emissions through carbon sequestration, appropriate soil and land-use management, and biomass production. Major mitigation strategies in the agricultural sector are: introduction of crops that take less water, which are drought, flood and salinity tolerant; local varieties of crops that take less chemical inputs; changes in tillage practices; efficiency in farming machineries; energy efficiency, reduce energy uses for irrigation, promote renewable energy for irrigation; efficient use of water and reuses of water; use of organic manure instead of chemical fertilizers; agro-forestry; increasing efficiency in post harvest activities and storage; local varieties of livestock that needs less feeds and emit less GHG; promotion of small family farms instead of large, mechanized commercial farms.

Government Initiatives to Meet the Challenges of Climate Change

Over a dozen of ministries and their line agencies are involved in addressing climate change issues in Bangladesh. The Ministry of Environment and Forest (MoEF), Ministry of Food and Disaster Management (MoFDM) and Ministry of Agriculture (MoA) are the key national actors in relation to addressing climate change, agricultural development and food security. The government of Bangladesh has already formulated National Adaptation Programme of Action (NAPA) following the guide line of the UNFCCC. Bangladesh has also formulated the Climate Change Strategy and Action Plan (BCCSAP) to address climate change impacts as well as to promote climate resilient development in the country.

The Bangladesh climate change strategy aims to support the Bali Action Plan [1] of the UNFCCC. The BCCSAP is built on six pillars (thematic areas of interventions) of which five are related to management of climate change impacts and one is related to mitigation through low carbon development. The pillars are: a) Food security, social protection and health, b) Comprehensive disaster management, c) Infrastructure,

d) Research and knowledge management, e) Mitigation and low carbon development, and f) Capacity building and institutional strengthening. BCCSAP puts the highest priority on food security.

Research Priorities for Meeting Climate Change Impacts on Agriculture in Bangladesh

- Assessment and characterization of climatic variability and climate change
- Soil and plant processes as influenced by climatic variability and climate change
- Compilation of databases for soil, climate, common cultivars, agronomic and management practices, other bio-physical and socio-economic scenarios, acreage and production delineation, yield gaps and options to narrow down the yield gap, dynamics of insects/pests for subsequent use in crop simulation models for applications viz. Climate change, NRM, yield forecasting etc.
- Calibration and validation of crop simulation models
- Vulnerability assessment for agri-production in relation to climatic variability/climate change
- Mitigation/adaptation strategies for agri-production in relation to climatic variability/climate change

Crop Simulation Models for Climate Change Impact Analysis

Crop simulation tools (viz. INFOCROP, DSSAT) help in evaluating the impact of climate change and its variability on growth and yield of crops, possibly through better prediction of associated soil and crop processes. Characterization of inter-annual climatic variability can be evaluated through growth and yield of crops and cropping systems [21, 25, 26]. Potential use of remote sensing and GIS tools could be vegetation and net primary productivity monitoring (spatio-temporal changes); effective linking of various bio-physical and socio-economic aspects with crop simulation models for NRM, yield estimates and climate change studies and effective in geo-spatial analysis for assessing agri-production through various biotic and abiotic stresses.

Future climate prediction models (GCMs and RCMs) provide the scenarios of global as well regional climate change, in terms of changes in temperature, precipitation, solar radiation, CO_2 concentration. Currently numerous models are being used by scientists across the world with varying degrees of confidence levels in predictive capacities. There is a strong need of regional calibration and validation of the RCMs for providing the gridded information on regional scales. These scenarios are to be linked with the relational layers of other bio-physical and socio-economic inputs along with crop simulation tools for evaluating the impact of climate change on soil and crop processes, subsequently could be used for vulnerability assessment and identifying suitable mitigation options for climate change controls and adaptation strategies for agri-sustenance.

Researchers developed models for analyzing climate change impact and predicting crop behaviour under changing climate and variable climatic conditions, albeit most models were developed and validated for crops growing under temperate climates. Initial projection suggested that rise in atmospheric CO_2 concentration and concomitant increase in temperature would increase crop yields, particularly of C_3 crops [23, 27, 28]. A large gain in photosynthesis and rice yield by raising CO_2 level to 600 ppm using OTC [29] was later on challenged by conducting more sophisticated FACE experiments with a greater resemblance to the actual conditions of production [30].

Among the three rice crops in Bangladesh, Boro rice yield will be affected most due to climate change. Boro rice yield is predicted to be reduced by 5.4% in 2050 [31], both higher maximum and minimum temperature could decrease Boro-rice yields due to spikelet sterility and higher respiration losses. Although higher CO_2 levels in the future would balance the detrimental effects of increased temperatures to some extent but it would not be able to offset them. The model simulations also suggest that changes in rainfall pattern may also adversely affect on rice yield.

Wheat is the second most important cereal crop in Bangladesh. When the winter is prolonged, the yield of wheat is increased substantially. Recent study assessed variability of Bangladesh's agricultural sector in 16 sub-regions using multi-factor impacts analysis framework [32]. Rice and wheat production were simulated in each sub-region using biophysical CERES models. Increased temperatures generally reduced production across all scenarios. Mustard, a cool loving crop, yield decreases with the increase in temperature. Mungbean is a major pulse crop in Bangladesh because of its short growth duration, photo-insensitivity and high temperature tolerance.

Worldwide research in climate change impacts on agriculture has shown that changes in the climate represent a significant new source of risk and management challenges to food production. Our understanding of the underlying mechanisms would lead us broad range of management options and technological interventions for adaptation options in agriculture. Investment in flood protection, planting different crops, development of crop varieties tolerant to drought, heat and salinity, agronomic management such as early planting to avoid terminal drought, bed planting or growing crops on the dyke to avoid tidal flood, integrating rice-fish culture, early warning systems, etc. can be considered. Conservation tillage, for example, can be used both as adaptation and mitigation measures while benefiting the farmers. However, in order for re-orienting farming and farming practices adapting to climate change requires collective actions by scientists, producers, extension leaders, agribusiness and policy makers.

Site specific resource and inputs management for enhanced agricultural production always remains a priority. The decline/stagnant yields are being noticed. There is a need to break the yield barrier either through breeding or through adoption of appropriate inputs options. Imbalanced use of fertilizers and faulty water management practices has lead to rapid land degradation. There are concerns of land degradation, ground water table decline, newer insects/pests emergence. There is a need to sequester carbon content in the soils, which primarily can be through crop residue incorporation in soil, adoption of suitable land preparation/tillage options and practicing organic farming.

Regional based technical coefficients for yield dependence of crops on seasonal temperature should be developed. We should also aim at stage specific dependence through development of dated production functions, as commonly reported for water use-crop yield relationship. Seasonal rainfall relationship with yield of crops over various growing regions should be developed, for subsequently linking with the climate change scenarios. Optimization of N-input in relation to extent of water availability through irrigation is important to sustain crops' yield, and it is conveniently possible through use of simulation models. With adequate moisture supply situation, higher N-input will provide benefits, whereas with limited amount of water availability, relatively lower amount of nitrogen fertilizer is required.

Yield gap analysis (through potential/attainable/actual yield of important crops) for quantifying the factors responsible for the gap and thereby suggesting agronomic and management options for narrowing down the gap will help in enhancing the agricultural productivity. In literature, various researchers have demonstrated this exercise for crops by using crop simulation models. How far the inter-annual climatic variability play a role in this process, is important for Bangladesh production environments. The probable radiation-temperature interaction, CO_2-temperature interaction, aerosol layer phenomenon also need to be linked with important crops of this region. The studies on climate change impacts showed that temperature has so far had a much greater effect on crop yields than precipitation. So, it might be more important to breed heat tolerance into future generations of crops than to make them capable of surviving with less water.

Given the climate change a reality and its possible impact on agriculture, it would necessary to support farmers and farm operators to have taken adequate preparation to adapt to and cope with climate change. Targeted and appropriately conceptualized climate knowledge can increase overall preparedness and lead to better social, economic and environmental outcomes. Increased preparedness to better manage risk arising from weather or climate related events will lead to better social, economic and environmental outcomes. Such increased preparedness can be aided by forecasts. Statistically based climate forecasting has become an important component in managing climate variability risks in agriculture. Seasonal climate forecasting (SCF) aids in tactical, short-term decision making in order for better agricultural risk management. Agricultural producers can more readily be able to adapt to climate change by learning from climate variability [33], if SCF takes into account information related to climate change.

Scientists of agricultural research institutions including agricultural universities and private sector organizations developed and disseminated technologies for enhancing crop production in Bangladesh. The pace of agricultural research accelerated beginning early eighties that still continues. However, research into climate change and its impact on agricultural production in the country remains nearly unattended. To effectively meet the challenge of climate change, farmers require dependable forecasting of seasonal climate events and knowledge of the impact of extreme weather conditions on crops. Scientists working towards developing crop varieties and agronomic practices adaptable under climate change require knowledge and skill of creating climate scenario that will happen in future, and simulating the impact thereof on the crops. Unfortunately, many of our scientists do not have academic training on climate science and climate change impact on agriculture [34].

CONCLUSIONS

Inter-annual climate variability is significant in Bangladesh. Probability of occurrence of extreme climatic events has increased over the past few decades. There is a need to evaluate the impact of climate change and its variability on growth and yield of crops. There is need to evaluate the overall system's response in relation to climate change. Crop simulation models are effective tools for assessing the crops' yield. We need to identify suitable adaptation and mitigation strategies for meeting the challenge of climate change and extreme/episodic climatic events. There is strong need to integrate climate change issues in agricultural policy, strategies and programs; improve knowledge generation, technology, R & D and information dissemination structure at all levels. Improvement of capacity for planning and implementation of adaptation and mitigation projects in agriculture and food systems as well as find synergies and co-benefits needed.

REFERENCES

1. Nordhaus, W. D. (2007). A review of the Stern review on the economics of climate

change. *Journal of economic literature*, *45*(3), 686-702.
2. Agrawala, S., Gigli, S., Raksakulthai, V., Hemp, A., Moehner, A., Conway, D., ... & Martino, D. (2005). Climate Change and Natural Resource Management. *Bridge over troubled waters: Linking climate change and development*, 85-132.
3. Beddington, J. R., Asaduzzaman, M., Fernandez, A., Clark, M. E., Guillou, M., Jahn, M. M., ... & Wakhungu, J.. (2012). Achieving food security in the face of climate change: Final report from the Commission on Sustainable Agriculture and Climate Change.
4. Schellnhuber, H. J., & William, H. (2012). Turn Down the Heat: Why a 4 C Warmer World Must be Avoided. A Report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics. *International Bank for Reconstruction and Development*.
5. Asaduzzaman, M., Ringler, C., Thurlow, J., & Alam, S. (2012). Investing in crop agriculture in Bangladesh for higher growth and productivity, and adaptation to climate change.
6. Tschakert, P., & Dietrich, K. (2010). Anticipatory learning for climate change adaptation and resilience. *Ecology and society*, *15*(2).
7. Ahmed, A. U., Huq, S., Karim, Z., Asaduzzaman, M., Rahman, A. A., Alam, M., ... & Chowdhury, R. A. (1996). Vulnerability and adaptation assessments for Bangladesh. In *Vulnerability and Adaptation to Climate Change* (pp. 141-159). Springer, Dordrecht.
8. Karim, Z., Hussain, S. G., & Ahmed, A. U. (1999). Climate change vulnerability of crop agriculture. In *Vulnerability and adaptation to climate change for Bangladesh* (pp. 39-54). Springer, Dordrecht.
9. Wassmann, R., Jagadish, S. V. K., Heuer, S., Ismail, A., Redona, E., Serraj, R., ... & Sumfleth, K. (2009). Climate change affecting rice production: the physiological and agronomic basis for possible adaptation strategies. *Advances in agronomy*, *101*, 59-122.
10. Brammer, H. (2014). Bangladesh's dynamic coastal regions and sea-level rise. *Climate Risk Management*, *1*, 51-62.
11. Custodio, E. (2002). Aquifer overexploitation: what does it mean?. *Hydrogeology journal*, *10*(2), 254-277.
12. Tiwari, V. M., Wahr, J., & Swenson, S. (2009). Dwindling groundwater resources in northern India, from satellite gravity observations. *Geophysical Research Letters*, *36*(18).
13. Rodell, M., Velicogna, I., & Famiglietti, J. S. (2009). Satellite-based estimates of groundwater depletion in India. *Nature*, *460*(7258), 999.
14. Wada, Y., van Beek, L. P., van Kempen, C. M., Reckman, J. W., Vasak, S., & Bierkens, M. F. (2010). Global depletion of groundwater resources. *Geophysical research letters*, *37*(20).
15. Thomas, T. S., Mainuddin, K., Chiang, C., Rahman, A., Haque, A., Islam, N., ... & Sun, Y. (2013). *Agriculture and adaptation in Bangladesh: Current and projected impacts of climate change* (Vol. 1281). Intl Food Policy Res Inst.
16. Al-Amin, A. Q., & Filho, W. L. (2011). An overview of prospects and challenges in the field of climate change in Malaysia. *International Journal of Global Warming*, *3*(4), 390-402.
17. Haque, M. M., Hamid, A., Khanam, M., Biswas, D. K., Karim, M. A., Khaliq, Q. A., ... & Uprety, D. C. (2006). The effect of elevated CO 2 concentration on leaf chlorophyll and nitrogen contents in rice during post-flowering phases. *Biologia plantarum*, *50*(1), 69-73.
18. Rai, H. K., Sharma, A., Soni, U. A., Khan, S. A., & & Kalra, N. (2004). i Simulating the impact of climate change on growth and yield of. *Journal ofAgrometeorology*, *6*(1), 1-8.
19. Rahman, A., & Alam, M. (2003). Mainstreaming adaptation to climate change in least developed countries (LDC). *Bangladesh Country Case Study*.
20. Karim, Z. (1996). Agricultural vulnerability and poverty alleviation in Bangladesh. In *Climate Change and World Food Security* (pp. 307-346). Springer, Berlin, Heidelberg.
21. Aggarwal, P. K., & Kalra, N. (1994). *Simulating the effect of climatic factors, genotype and management on productivity of wheat in India. IARI Publication*, New Delhi, India, 156p.
22. Aggarwal, P. K., & Kalra, N. (1994). Analyzing the limitations set by climatic factors, genotype, and water and nitrogen availability on productivity of wheat II. Climatically potential yields and management strategies. *Field Crops Research*, *38*(2), 93-103.
23. Reilly, J. M. (Ed.). (2002). *Agriculture: the potential consequences of climate variability and change for the United States*. Cambridge University Press.
24. Ramanathan, V., & Carmichael, G. (2008). Global and regional climate changes due to black carbon. *Nature geoscience*, *1*(4), 221.
25. Aggarwal, P. K., Kalra, N., Chander, S., & Pathak, H. (2006). InfoCrop: a dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments. I. Model description. *Agricultural systems*, *89*(1), 1-25.
26. Aggarwal, P. K., & Kalra, N. (1994). Analyzing the limitations set by climatic factors, genotype, and water and nitrogen availability on productivity of wheat II. Climatically potential yields and management strategies. *Field Crops Research*, *38*(2), 93-103.
27. Mendelsohn, R., Nordhaus, W. D., & Shaw, D. (1994). The impact of global warming on agriculture: a Ricardian analysis. *The American economic review*, 753-771.

28. Iglesias, A., Garrote, L., Quiroga, S., & Moneo, M. (2012). A regional comparison of the effects of climate change on agricultural crops in Europe. *Climatic change*, *112*(1), 29-46.
29. Hamid, A., Haque, M.M., Khanam, M., Hussain, M.A., ... & Uprety, D.C. (2003). Photosynthesis, growth and productivity of rice under elevated CO_2. *Indian J. Plant Physiol.*, *8*, 253-258.
30. Ainsworth, E. A., & McGrath, J. M. (2010). Direct effects of rising atmospheric carbon dioxide and ozone on crop yields. In *Climate Change and Food Security* (pp. 109-130). Springer, Dordrecht.
31. Piao, S., Ciais, P., Huang, Y., Shen, Z., Peng, S., Li, J., ... & Friedlingstein, P. (2010). The impacts of climate change on water resources and agriculture in China. *Nature*, *467*(7311), 43.
32. Ruane, A. C., Major, D. C., Winston, H. Y., Alam, M., Hussain, S. G., Khan, A. S., ... & Rosenzweig, C. (2013). Multi-factor impact analysis of agricultural production in Bangladesh with climate change. *Global Environmental Change*, *23*(1), 338-350.
33. Meinke, H., Wright, W., Hayman, P., & Stephens, D. (2003). Managing cropping systems in variable climates. *Principles of field crop production*, *4*, 26-77.
34. Kalra, N., Chakraborty, D., Sharma, A., Rai, H. K., Jolly, M., Chander, S., ... & Sehgal, M. (2008). Effect of increasing temperature on yield of some winter crops in northwest India. *Current science*, 94(1): 82-88..