Rajshahi University journal of social science and business studies ISSN 2309-0944 (Print)
Vol. 29 (2021), pp 1-16 ISSN 2408-8811 (Online)
DOI: https://doi.org/10.64102/rujssbs.0468

The Impact of Climate Change on Agriculture and Production Efficiency

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Abstract

Climate change is a major concern in the contemporary world, and it poses a growing threat to global agricultural production and food security. Agriculture is intrinsically sensitive to climate variability and change, whether caused by natural or human activity. This paper attempts to understand the impact of climate change on agriculture and crop productivity, with a special focus on Bangladesh. It has been written based on a systematic literature review of previous studies, published reports, climate models, and prediction data. Climate change events—higher temperatures, rise of sea level, changing rainfall patterns, salinity intrusion, land degradation, extreme weather events, and ecosystem disruption—could reduce agricultural output and impede progress toward achieving food security. Finally, the loss of agricultural production due to climate change can have an impact on the entire food supply chain, including food availability, access to resources for acquiring food, food consumption, and food stability. Therefore, there is a need to carry out such investigations to examine the impact of climate change on agricultural productivity and ensure food security for the growing population.

Keywords: Climate change, Agriculture, Crop production, Food security, Bangladesh.

Introduction

Climate change denotes to the fact that the greenhouse gas emissions from modern industry are causing the climate to warm up that could have potential distressing consequences for the future (Giddens, 2009). The continued growth of greenhouse gas emissions could reduce food production and possibly lead to large-scale famine, migration, conflict, and death (Brammer, 2019). Agricultural productions are always sensitive to climate, and their production systems are likely to be affected by adverse climatic events. The events of climate change—rising temperatures, extreme weather, changing rainfall patterns, water crisis, rising sea levels, salinity intrusion, drought, flood, cyclone, precipitation, land degradation, and the disruption of ecosystems—could interrupt agricultural productivity and obstruct progress towards ending hunger, malnutrition, and poverty (Cheeseman, 2016; Gornall *et al.,* 2010; Spijkers, 2011). In addition, climate change affects biophysical factors, including animal and plant development, water systems, soil fertility and moisture, biodiversity, and nutrient cycle, which ultimately affect the agricultural production process (Herrero *et al.,* 2015; Saha & Barmon, 2015). Gornall *et al.,* (2010) revealed that extreme heat and shortage of water can interrupt crop growth and reduce productivity; climate variation affects irrigation and soil quality; and sea level rise reduces the availability of arable land, and extreme events, like flood, drought, cyclone,

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can terminate harvests. Climate change has also an impact on pest reproduction, development, spread, and survival, and consequently on the percentage of crop losses. Downing (1993:491) noted that climate change affects agriculture in four ways: "(i) the direct effects of increased concentrations of carbon-dioxide; (ii) through changes in climatic averages; (iii) the effects of altered weather patterns, including extreme episodes; and (iv) the secondary effects on social and economic systems."

The demand of food is expected to increase by around 300% by the year 2080 due to higher population growth, and there will be further pressure on food security because of production falls caused by climate change (Cline, 2008). It is predicted that climate change could raise temperatures by 0.4–2.0°C by 2030, 1.0-6.0° by 2070 (Hughes, 2003) and 3.5–5°C by 2100 (Ravi, 2012), while Easterling *et al.,* (2007) predicted that even a 2°C rise in global mean temperatures by 2100 would destabilize current farming systems. According to Knox *et al.,* (2012), the effect of climate change in Africa and South Asia is significant for millet, sorghum, wheat, maize, but equivocal for rice, cassava, and sugarcane. World Bank (2013) reported that rice and wheat yields in Asia have fallen by about 8% for each 1°C temperature rise since the 1980s. Hertel *et al.,* (2010), applying a computable general equilibrium (CGE) model, claimed that South Asian countries, especially India, Pakistan, and Bangladesh, are likely to be adversely affected concerning their economic efficiency and trade in relation to climate change and food production. A systematic analysis of climate changes in crop yields in South Asia indicated that average crop yields could drop by 8% by the 2050s (Knox *et al.,* 2012). Similarly, the IPCC (2007a) claimed that agricultural crop production in South Asia could fall by 30% by 2050 following the effects of rising temperatures and hydrological disruption. All of these figures indicate that, in South Asia, there could have a significant decrease in wheat and rice yields, which could incur a loss in farm-level net revenue.

As a developing country, Bangladesh faces many other challenges, including a high incidence of poverty, malnutrition, frequent disasters, environmental degradation, agricultural management practices, and many others. In addition, climate change could make this region more vulnerable and negate the country's attempts in achieving sustainable development goals (SDGs) by causing a decrease in agricultural production and finally affecting food security, although Bangladesh contributed only 0.14% of the total global CO2 emissions and ranked 67th globally (Ahsan, 2011). Few researches assess the impact of climate change on food production, especially rice, in Bangladesh (Karim *et al.,* 1996; Sarker *et al.,* 2012; Ruane *et al.,* 2013; Amin *et al.,* 2015). According to Delta Plan (2018), under the business as usual scenario (BAU) scenario, yearly paddy production would fall by 1.60% in 2050 and 5.1% in 2100. It is estimated that the cumulative effects of temperature, rainfall, floods, cyclones, and sea level rise by 2050 might cut annual monsoon and dry-season rice production in Bangladesh by 1.5–3.5% and 5.5% respectively (Brammer, 2019). In addition, the frequency of intense rainfall has increased in Bangladesh, causing severe floods, landslides, debris, and mud flows, and finally affecting agricultural production.

In addressing the goals of the 2030 Agenda on SDGs, it is essential to address the impact of climate change, which will require a profound transformation of agricultural and food systems. There needs to be a comprehensive study to find out the impact of climate change on agriculture and its productive components. This paper attempts to understand the nexus between climate change and agricultural production efficiency. It assesses the different adverse climate events and their consequences on agricultural production efficiency. This paper has been prepared based on secondary data collected from different sources, including published and unpublished articles, research reports, government and non-government documents, statistical synopses, and so on. As a part of secondary research, a systematic review has been done to write this paper. All sorts of steps of systematic review, including problem selection, identifying research sources, collection of existing data, compiling and comparing data, summarizing and analyzing data, and writing the report, have been followed to complete this study.

The Impact of Climate Change Events on Agriculture and Crop Production

Temperature and precipitation

Climate change is expected to raise mean, maximum, and minimum temperatures in many parts of the world, while temperature is widely regarded as one of the most critical factors affecting the growth and development of crop yields. High temperatures and heat stress alter photosynthesis and cell respiration, which cuts the life cycle and reduces crop production. It is expected that countries in low-latitude (tropical and sub-tropical) regions would generally be at risk of decreased crop yield at even 1 to 2°C of warming (McCarthy *et al.,* 2007). Moderate warming (increases of 1 to 3ºC in mean temperature) benefits crop and pasture yields in temperate regions, while it is likely to have negative impacts in tropical and seasonally dry regions, particularly for cereal crops (FAO, 2008). However, a warming of more than 3ºC is expected to have negative effects on agricultural production in all regions (IPCC, 2007b). Moreover, temperature rises may increase the need for irrigation, which may cause a lower groundwater level in the future and reduce crop production.

Asseng *et al.,* (2013) revealed that global wheat yield reductions will be 6% per degree of warming. A World Bank (2013) noted that rice and wheat yields in Asia had declined since the 1980s by approximately 8% for every 1°C temperature increase, and agricultural production in South Asia could fall by 30% by 2050 (IPCC, 2007b) and by 15% in India by 2030 (World Bank, 2013) due to the effects of increasing temperatures. Hossain and Silva, (2013), applying geophysical fluid dynamics laboratory (GFDL) model, assumed approximately 17% and 61% fall in rice and wheat production in Bangladesh, respectively, under a 4°C change in temperature. Another study found that for every 1°C increase in maximum temperature at vegetative, reproductive, and ripening stages, there was a decrease in *Aman* rice production by 2.94, 53.06, and 17.28 tons, respectively (Islam *et al.,* 2008). Furthermore, moderate temperature may have little impact on monsoon season (*kharif*) crops, whereas winter (*rabi*) crops could have decreased yields due to substantial temperature increases and greater uncertainty in rainfall. It is estimated that a minimum temperature of 15ºC is needed for the production of temperate crops such as wheat that are grown in Bangladesh. On the other hand, temperatures of 40ºC interfere with the pollination of rice, which is important for *Boro* paddy production in Bangladesh (Brammer, 2019). A rise in the maximum temperature variation of 4˚C and 2˚C could hurt *Boro* and *Aman* rice production. So the changing pattern of temperature will certainly hamper the production of wheat and rice in Bangladesh, which are the two main crops.

Sea level rise and salinity intrusion

Anthropogenic greenhouse gas emission since the Industrial Revolution have caused global warming, resulted in accelerated ice sheet melt and an increased rate of sea level rise. More than 70% of our planet is ocean, and nearly half of the world's population lives within 200 kilometers of coasts (Hinrichsen, 1998). Sea level rise increases the vulnerability of coastal and low-lying arable lands. It is expected to increase sea level by more than 1m by the end of this century (Rahmstorf, 2007), which could result in the inundation of large tracts of low-lying coastal agriculture land. It affects agriculture in many ways, including floods, cyclones, dam damage, and salinity intrusion and so on. It also decreases the terminative energy and germination rate of plants (Rashid *et al.,* 2004). Salinity intrusion caused by sea level rise decreases agricultural production by causing the shortage of fresh water and soil degradation. It is widely considered that Bangladesh is a flat alluvial plain that will be overwhelmed contour after contour as sea level rise due to global warming, displacing a large number of people. Singh *et al.,* (2000) showed that the mean tidal level at Hiron Point, Char Changa, and Cox's Bazar increased by 4.0 mm/yr, 6.0 mm/yr, and 7.8 mm/yr, respectively, which is much higher than the global rate. It is estimated that Bangladesh is expected to lose 30% of its food production by 2050 as a result of rising sea levels (MoEFCC, 2022).

More than 30% of the cultivable land in Bangladesh is in the coastal area, and about 0.87 Mha out of 2.85 Mha of coastal areas are affected by different degrees of soil salinity (Khan *et al.,* 2011). Based on IPCC reports and available sea level rise studies, the National Adaptation Programme of Action (NAPA) for Bangladesh recommended a sea level rise of 14, 32, and 88 cm for the years 2030, 2050, and 2100, respectively (MoP, 2020). Ravi (2012) predicted that a possible sea level rise between 15 and 38 cm by the 2050s would allow saline water to enter inland that would ultimately displace some 35 million people around the Bay of Bengal. Karim and Mimura (2008) showed that a 2°C variation in sea surface temperature and 0.3 meter sea level rise increase flood risk by 15% more, and the depth of flooding would increase by up to 22.7% within 20 km of the coastline in Bangladesh. Under a moderate climate change scenario, crop loss from salinity intrusion might be approximately 0.2 million tonnes per year (Delta Plan, 2018). CCC (2009:34) noted that "*T. Aman* and *Boro* rice may tolerate 88 cm of 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." *T. Aman* and *Boro* rice, which are saline-resistant, may require the most rainfall to improve production as sea levels rise. A study conducted in Satkhira found that, due to salinity intrusions, rice production in 2003 was 1,151 metric tons less than that in 1985, corresponding to a loss of 69% (Ali, 2006). In Bangladesh, over 1 million hectares of cultivable land are already affected by salinity intrusion caused by slow and rapid-onset events, e.g., the net cultivated area in Satkhira decreased by 7 percent from 1996 to 2008 (MoEFCC, 2022).

Rainfall pattern and water crisis

Climate change has important implications for water availability (Milly *et al.,* 2005), glacier melting, groundwater recharge, flooding (Kleinen & Petschel-Held, 2007), and geomorphic processes, including erosion, slope stability, channel changes, and sediment transport (Dennis *et al.,* 2003). The United Nations Department of Economic and Social Affairs (UNDESA) predicted in 2014 that current climate change scenarios would result in nearly half of the world's population living in areas of high water stress by 2030 (Islam & Wong, 2017). The changing rainfall pattern causes low crop production and creates food insecurity for the world's rising population. It is estimated that more than 80% of total global crop production is supplied by rainfall, and therefore changes in rainfall patterns will affect agricultural production (Olesen & Bindi, 2002). The changing rainfall pattern may cause moist temperate regions to become wetter and dry parts to become dryer. It can also affect soil moisture and soil erosion rates, which are important for crop production. Moreover, severe rainfall can cause flooding and water logging that ultimately result to production loss. Most South Asian climate models indicate increasing rainfall throughout the pre-monsoon, monsoon, and post-monsoon seasons, with decreasing rainfall during the winter season. It is estimated that Bangladesh may face 10-15% more rainfall by 2030, and it will lead in crop failure and production decline. It is estimated that a 1 mm increase in rainfall at the vegetative, reproductive, and ripening stages decreased *Aman* rice production by 0.036, 0.230, and 0.292 tons, respectively (Saha & Barmon, 2015). Haque (2006) showed that the fluctuation of rainfall patterns and the uncertainty of flooding damaged the *Aus* and *Aman* crops, and he further claimed that heavy rains slowed down *Aman* transplanting and produced flash floods, which washed away the standing crops.

The world's hydroelectric power and water supply systems depend on different components of the hydrological cycle, including evaporation, condensation, precipitation, and many others. Climate change creates the greatest pressures on the hydrological cycle, and it reduces water availability in many regions of the world. As a result, prolonged and repeated droughts due to a shortage of water result in the loss of productive assets, which jeopardize the sustainability of agriculture-based livelihoods. In addition, drought and deforestation due to water scarcity can increase the risk of fire, resulting loss of the vegetative cover required for grazing and fuel wood. The availability of good-quality water for crop irrigation at specific times of the year will have a detrimental impact on food supplies. Freshwater availability in India is predicted to decrease by 47% in 2025 (Spijkers, 2011), and India's major river basins are likely to face a water deficit by 2050 as a consequence of climate change (Garg & Hassan, 2007). The agricultural production of Bangladesh is highly dependent on irrigation. The north-western part of Bangladesh experiences droughts yearly, which are mainly the result of adverse climate change impacts, such as decreasing rainfall and rising temperature. Decreasing trends of rainfall in winter and pre-monsoon reduce *Aman* yields; both broadcast and transplanted, and delay pulse and potato sowing. *Boro*, wheat, and other dry-season crops are similarly impacted by climate variability and water crisis on a regular basis.

Degradation and loses of agricultural land

Soil resources are limited, unevenly distributed, and prone to degradation as a result of land overuse, mismanagement, and climate change. Land degradation is a downward trend in land conditions caused by direct and indirect human-induced processes, including anthropogenic climate change. Climate change events, high atmospheric carbon dioxide concentrations (400 ppm) combined with rising air temperatures (2-4°C or higher), will have a considerable impact on soil characteristics and fertility, food quantity and quality, and environmental health (Qafoku, 2015). Changes in soil carbon dioxide concentrations caused by climate events have an impact on soil organic matter content and soil quality, resulting in soil deterioration. Soil deterioration is primarily caused by water erosion, wind erosion, soil organic matter loss, nutrient loss, and soil fertility. In addition, droughts, heat waves, desertification, salinity intrusion, sea level rise, waterlogging, and seasonal precipitation are significant drivers of land degradation and it is predicted to increase as a result of climate change. Climate changes induce direct and indirect effects on land degradation in agricultural environments, including potential increases in heat stress on vegetation, changes in soil moisture, increases in soil erosion by wind and rain, soil nutrient loss, increases in evapotranspiration rates, soil salinization, and an overall decline in vegetation and biomass (Li & Fang, 2016; Webb, 2017). All of these factors influence the lands drying-rewetting cycles, which have a direct impact on "microbial nitrogen (N) turnover rates in soil by changing the water content and the oxygen partial pressure" (Gschwendtner, 2014). All of factors are exacerbating the challenges that affect global agricultural production and food security. The Millennium Ecosystem Assessment marked land degradation among the world's greatest challenges due to climate change, which is impeding the achievement of optimum agricultural production (Runólfsson & Ágústsdóttir, 2011). Climate models predict increased evapotranspiration and lower soil moisture levels that would result in agricultural land becoming unsuitable for cropping and tropical grassland becoming increasingly arid (IPCC, 2007b).

Moreover, agricultural land will be lost due to coastal inundation and soil salinization, which will also have a substantial impact on crop production in the coastal regions. It is revealed that countries at medium and low latitudes may suffer from different levels of potentially arable land loss (Zhang & Cai, 2011). The rising temperature and less precipitation cause land loss due to redcued soil moisture, increased aridity, increased salinity, and groundwater depletion. Furthermore, the increase in sea level due to polar ice-melting may reduce the availability of arable land. The loss of arable land is expected in Africa, South America, Europe, and India by 0.5–18%, 1–21%, 11–17%, and 1.7–3.6%, respectively (Zhang & Cai, 2011). Bangladesh may lose 15% of its land mass, and over 30 million people could become refugees if sea level rises by one meter. The total available arable land in Bangladesh stood at 8.5 million hectares (Mha) in 2020 (MoP, 2020) and it is reported that about 1.74 Mha of land in Bangladesh is prone to soil erosion, and land degradation in part from deforestation, both in hills and plains, occurring now at 5–6% annually (Khan *et al.,* 2011). For example, in the southern region, rising salinity has ruined around 170,000 acres of agricultural land during the last three decades.

Furthermore, riverbank erosion accounts for about 40 per cent of the land loss in about 1,200 km of riverbanks (MoP, 2020). Finally, it might cause the country's GDP to fall when crop production falls. Addressing land degradation is critical for developing resilient agroecological systems that protect biodiversity and satisfy global food demand.

Drought intensity

Climate change induces drought in climate-vulnerable regions. Climate models estimate that up to 50% of the earth's surface will be experiencing regular drought by the end of the twenty-first century (Reed & Stringe, 2016). The effect of drought intensity will significantly influence agriculture, particularly crop productivity, water resources, and livestock. Throughout a drought, average rainfall decreases during crop's critical growth periods, causing soil moisture shortages. Drought stress may outweigh the growth benefits of higher CO2 levels unless irrigation is increased to compensate for the soil moisture deficit. Ray *et al.,* (2018) investigated the effect of drought on the agricultural yield of four major crops (cotton, corn, winter wheat, and sorghum) and found that if drought periods increased in the future, crop yields would tend to drop.

Droughts affect 3–4 million acres of land each year in Bangladesh, and the Bangladesh Agricultural Research Council (BARC) estimated that 4.2 million acres of land are vulnerable to droughts of varying severity (Islam & Rashid, 2011). Drought occurs in Bangladesh, having a substantial impact on agricultural production. For example, the consecutive droughts of 1978 and 1979 directly affected 42% of cultivated land and reduced rice production by an estimated 2 million tons (Brammer, 1987). Similarly, the drought of 1994–1995 reduced rice and wheat production by 3.5×10 6 tons (Rahman & Biswas 1995). Drought in 1997 and 2006 caused a reduction of around 1 million tons and 25%–30% crop reduction, respectively (Rahman *et al.,* 2007). It is claimed that drought affects about 2.3 Mha land in the summer season and 1.2 Mha land in the dry season. During the summer season, the *Aman* rice crop is affected, resulting in the reduction of about 1.5 mt of rice, which is about 8% of the total annual production (Khan *et al.,* 2011). Depending on the intensity of drought, the estimated yield reduction of different crops varies from 10 to 70% (Karim *et al.,* 1990). There is also a close relationship between drought stress and monsoon rains, as soil moisture content influences the rains. Drought primarily impacts the pre-monsoon and post-monsoon seasons. The failure of the monsoon frequently results in decreased yields and starvation in drought-affected areas. It was estimated that the drought conditions in the northwestern part of Bangladesh had led to a shortfall in rice production of 3.5 million tons in the 1990s (Saha & Barmon, 2015). The drought that occurred in Bangladesh in 2009 was widely interpreted as evidence of climate change (Brammer, 2019). A severe drought is projected to cause more than 40% damage to *Aus*. Each year, during the *Kharif* season, drought causes substantial damage to the *T. Aman* crop, which covers around 2.32 million ha. In the Rabi season, 1.2 million ha of cropland faced droughts of various magnitudes (FAO, 2007). Brammer (2019) noticed the risk of drought in the pre-*kharif* season (when *Aus* rice and jute are sown) and at the end of the humid period (when the *Aman* rice crop matures).

Figure 1: Impact of Climate Change on Agricultural Assets, Crop Production and Food Security

Climate Change Events	Impact on Agricultural Assets	Impact on Crop Production	Impact on Food Security
Temperature	• Changes in suitability of land; • Loss of biodiversity and land fertility; • Melting glacier; Increased evapo-transpiration; • Changes in vectors and natural habitat; • Decrease ground water level; • Reduce human labour productivity;	• Crop development and yield impacted; • Shorten the life cycle of crop production; • Reduce food crops production and livestock; • Reduce quantity and reliability of yields; • Risk of drought; • Risk of wild fire;	• Reduction in food supply; • Increase price; • Impact on income; • Higher intake liquids; • Food poisoning; • Affect human health;
Precipitation	• Loss of perennial crops and vegetative for grazing; • Loss of livestock due to water stress; • Change in soil moisture; • Change in suitability of land for crops; • Changes in vectors and natural habitats;	• Adversely impact on growth processes; • Decline in yields; • Changes in irrigation equipment; • Lack of water for irrigation; • Unable to tune cropping systems;	• Instability of food supply; • Scarcity of water for food processing; • Pressure on grain reserve; • Impact on global supply, trade and market; • Increase/decrease in food import/export;
Extreme events (storm, flood, cyclone, heavy rain fall, drought)	• Damage embankments; • Damage to roads, bridge, storage structures, processing plants; • Pollution of water supply used in processing food; • Shortage of fuel for food preparation; • Loss of soil organic strength, fertility, nutrients, and moisture; • Increase water born livestock diseases; • Crisis of water; Soil moisture shortage; Loss of land; • Degradation of land; Increase aridity; Land erosion;	• Loss of production; • Damage to standing crops; • Loss of stored crops; • Possibility of lower yields in flooded agricultural areas; • Increase soil erosion reducing future yields; • Reduction in quantities of food; • Reduction in quality food production;	• Increase food aid dependency and food price; • Loss of farm income; • Increase starvation and malnutrition; • Changes in food processing; • Consume less preferred food; • Disruption of food supply chain; • Increase water born health risk; • Conflict over food distribution;

Climate Change Events	Impact on Agricultural Assets	Impact on Crop Production	Impact on Food Security
Sea level rise	• Salinity intrusion in crop land; • Changes in recharge rates for underground aquifers; • Loss of crop land; • Crisis of fresh water; • Increase vulnerability of coastal crop land;	• Decrease the germination rate of plants; • Increase soil degradation; • Lack of optimum water for irrigation; • Salt water intrusion in crop land; • Loss of multi-various crop production;	• Impact on local food security; • Decrease crop productivity; • Increase local food price; • Threatening the viability of fisheries; • Resulting in vegetation shifts.
Rainfall pattern and water crisis	• Land erosion and land slope; • Changes in hydrological cycle and water channels; • Increase sediment transportation; • Change in the quantity and quality of groundwater; • Depletion of water resources; • Increase flooding and waterlog; • Increase in wild-fire danger;	• Production fall due to excessive rainfall; • Production fall due to shortage of rainfall; • Untimely rainfall; • Lack of water in irrigation; • Increase production cost; • Impact on water reservation for production; • Changes in crop pattern, crop breeding;	• Crisis of fresh water for drinking; • Scarcity of water for food processing; • Changes in food demand and preferences; • Suffer from malnutrition • Risk of dehydration; • Need more invest on water;
Pest and disease contamination	• Increase diseases of livestock; • Outbreak of plant diseases; • Weed growth; • Loss of soil fertility;	• Constraints to agricultural production; • Increase crop development time; • Poor quality production; • Increase production cost; • Over utilization of pesticides;	• Initiate a vicious circle of infectious diseases; • Affect crop yield, quality and safety; • Unsafe and of inappropriate nutritive value; • Suffer from food born disease; • Risk of ill health from eating spoiled food;

Pests and diseases outbreak

Farmers are continually concerned about crop losses caused by animal pests, fungal and bacterial diseases, viruses, and weeds. It is claimed that roughly 30–40% of global production for the major food crops is lost due to these factors each year (Oerke, 2006). Climate change and extreme weather would expedite the spread of pests, insects, and diseases, and food security will be jeopardized. Moreover, seasonal variability and weather disruption influence the presence of agricultural pests and diseases. Global warming, rising temperatures, and heat waves affect pest incidents, weed growth, and plant diseases. Temperature rise has direct impact on pest reproduction, survival, spread, and population dynamics, as well as pest-environment-natural enemy connections. Pests and diseases affect not only yields but also the nutritional quality and health outcome. It is claimed that the temperature rise will expand the spread of many agricultural pests and diseases by increasing insect populations' capacity to survive and attack crops, diminishing production (Chijioke *et al.,* 2011). Crop weeds, insects, and diseases are projected to spread to higher latitudes (Rosenzweig *et al.,* 2001). In particular, CO2-temperature and CO2-precipitation interactions are regarded as essential determinants in influencing future plant damage from pests (Easterling *et al.,* 2007). Moreover, water shortages in the soil can lead plants to lose biological functions, making them more susceptible to pests and diseases. Skendži´c (2021:1) noted that "climate change can result in an expansion of their geographic distribution, increased survival during overwintering, increased number of generations, altered synchrony between plants and pests, altered interspecific interaction, increased risk of invasion by migratory pests, increased incidence of insect-transmitted plant diseases, and reduced effectiveness of biological control, especially natural enemies". Surveys on pests and disease have been conducted in different agro-ecological areas of Bangladesh since 1980s. So far, 32 diseases and 175 insect pests have been reported on rice, of which 10 diseases and 20 insect pests have the potential to cause economic damage to the crop (Haq *et al.,* 2011). As climate change worsens the pest problem, so the strategies of future pest managements are critical. These include climate and pest population monitoring, updated integrated pest management tactics, and the use of modeling prediction tools.

Flood, storm, and cyclone

The frequency and severity of floods are affected by changing temperatures, rainfall patterns, melting snow and ice, and storm precipitation. Flood causes more frequent and severe disruptions to food production as a result of climate change. Douglas (2009:128) identified four major distinct implications of climate change in line with flood events; "(i) the timing of the occurrence of floods may change with a possible change in the seasonality of the hydrological cycle; (ii) an increase in monsoon precipitation may increase the magnitude and duration of floods; (iii) changes in the timing of peak flood flows descending the major rivers may alter the likelihood of synchronization of flood peaks of the major rivers; and iv) increases in the magnitude and duration of floods will lead to dramatic modifications of land use patterns." The worst floods will inundate croplands and make a greater part of the population vulnerable to famine, starvation, malnutrition, and possibly death. Bangladesh is one of the most flood-victim countries in the world and the Bay of Bengal is a favourable breeding ground for tropical cyclones. The most critical part of climate change in Bangladesh is the potential change in monsoon precipitation, which lead the country into water-related disasters. It is estimated that nearly 1.23 and 5.05 Mha of croplands are severely and moderately flood-prone, respectively (Khan *et al.,* 2011). Crop damage results from significant rainfall-induced flooding, flash floods, and riverine flooding. The monsoon-planted *Aman* rice crop is far more susceptible to floodwaters (Mirza, 2002). Ericksen *et al.,* (1993) stated that stable floodplain land provides good crops in normal years, but Kharif crops are vulnerable to high floods (bonya). This vulnerability can be mitigated through irrigation (dry *rabi* season) and flood control (wet *kharif* season). In 1974, about 0.6 million metric tons of crops were damaged due to floods and it cost the lives of 1.0–1.5 million people (Douglas, 2009). The 1988 flood caused a reduction of agricultural production by 45% (Karim *et al.,* 1996). According to the Department of Agriculture Extension (DAE), a flash flood submerged 141,000 hectares of farmland in six north-eastern districts in 2017, affecting around 423,000 farmers (MoEFCC, 2022).

Global warming is expected to increase the frequency and magnitude of storms and cyclones due to rising ocean temperatures, which are thought to drive cyclone development in the subtropics. Bangladesh is vulnerable to cyclonic storm due to its coastal regions, especially in the central coastal belt area. Bangladesh is affected by a severe tropical cyclone every three years on average. These storms typically originate in the months preceding and following the monsoon, intensifying as they move north across the warm seas of the Bay of Bengal. They are accompanied by powerful gusts of more than 150 kph and can cause storm surges up to seven meters high, causing major damage to human and animal life, agriculture and livestock, and houses (BCCSAP, 2009). There are two seasons of cyclonic storm: pre-monsoon (April–May) and post-monsoon (Oct–Nov). A total of 700 cyclones occurred between 1891 and 1990, of which 62 were in the pre-monsoon and 192 were in the post-monsoon periods. The annual loss of rice production due to cyclones ranges from $2.4 billion to $4 billion; for example, cyclone SIDR in 2007 destroyed 12000 hectares of standing coastal area crops (Siddika, 2013) with an economic impact of $1.7 billion (Habiba *et al.,* 2015). Cyclones will cause significant loss to the crop production, particularly to rice production in the coastal area of Bangladesh.

Discussion

Climate change is a global phenomenon, especially for developing countries. It is defined as any change in climate throughout time that modifies the configuration of the global atmosphere, whether caused by natural climatic variability or human action. Despite advances in agricultural research and technology, agriculture remains completely dependent on climate events. Climate change has a direct impact on crop production by altering agro-ecological conditions, as well as an indirect impact on income, distribution, and agricultural demand. As a result, the effects of climate change on agricultural production have become a major concern, particularly in delta regions, vulnerable coastal belts, and climate-dependent agriculture-based countries. In addition, climate change would worsen food production in places already prone to famine and malnutrition. It affects agriculture and its production efficiency by impacting temperature and precipitation, sea level rise, salinity intrusion, rainfall patterns, land grade, climate events, and other bio-diversity issues in line with crop production. The interaction between climate change and agriculture are well established and it leads to the production, distribution, processing, preparation, and consumption of food. Climate change is expected to have a direct impact on agricultural productivity and food growth rates, as well as global food security. It will impact the entire food supply chain and food system affecting food availability, access to resources for purchasing food, food priority and distribution, food usage, and food supply stability. The world's population is anticipated to reach 9.1 billion by 2050 (Charles *et al.,* 2010), and it will be needed to increase food production by 70–100% to feed the growing population (World Bank, 2008). Following climate change, expanding food production to feed an ever-growing population presents a significant problem. It is assumed that the population of developing countries, which are already food insecure, is likely to be multiplied by global climate change.

Moreover, agriculture provides both food and income. A significant number of people living in developing countries depend on agriculture, and their livelihood and income-generation activities are fully agriculture-centered. Moreover, as producer as well as consumer they are the victim of climate change events. Under these circumstances, small farmers who produce, process, and consume food directly from their field, are most likely to be affected due to production failure. Moreover, smallholder farmers have limited adaptive capability, and they will have severe consequences on agricultural production, as well as a high sensitivity to extreme occurrences. Under the above circumstances and in adopting the goals of the 2030 Agenda on SDGs, it is essential to address the impact of climate change, which will require a profound transformation of food and agriculture systems. As a result, investigations are required to assess the impact of climate change on food security and sustain agricultural production in order to secure the expanding population's food security.

Conclusion

Agriculture and food security are critical areas where intervention under climate change should be most effective. There are many studies of the projected impacts of climate change on crop yields. Despite the uncertainty in climate change impact research and the shortcomings of climate models, it is obvious that climate implications on food security would be significant. Different extreme climate events would jeopardize agricultural production and hinder sustainable development goals to achieve zero hunger. The direction and severity of climate change would lead to a decline in agricultural production and negatively impact food security across diverse geographies and societies. Under the circumstances, comprehensive impact evaluation on climate change, agricultural production, food security assessment, and adaptation strategies need to be strengthened. Adaptation measures must focus on various aspects of climate change that affect agricultural production, including sustainable resource and disaster risk management, water management, warning systems, crop insurance, and incentives for farmers to adopt better agricultural and land use practices.

In this sense, more comprehensive studies and research are required to better understand the potential challenges the world may face in the future. Action will need to take precedence over knowledge, with choices and reviews based on emerging research and consensus.

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