Austin Publishing Group

Rice Production Under Changing Climate scenarios

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Published Date: January 08, 2020

Abstract

Rice is a staple cereal crop for more than half of the global population. The changing climate, such as high Carbon Dioxide (CO_2), rainfall, and temperature have direct and indirect impacts on the soil-rice-plant atmosphere. Rice accounts for 2.7 percent of the value added in agriculture and 0.6 percent of Gross Domestic Production (GDP) in Pakistan. The optimum temperature required for growth of rice is 22-28 °C whereas, it is estimated that by the end of the twenty-first century, the surface air temperature will increase around 1.4–5.8 °C. This increase in surface means temperature during sensitive stages of rice production may reduce rice yields drastically. The high CO_2 levels reduce the rice productivity. These climatic impacts can be minimized through the proper management system and adaptation. The adaptation practices may include the shift of sowing dates, selection of appropriate stress tolerant variety specific to the agricultural zone, and water conservation strategies. The agronomic management suggests early sowing of rice cultivars or selection of early maturing cultivars to avoid high temperatures during grain filling. In this chapter, the threats of climate shift and climate change on rice characteristics, including its growth, quality, yield, and various other physiological, morphological, and biochemical mechanisms are discussed. The comparison of different management and adaptation practices and their limitations are also highlighted. The mitigation and adaptation strategies for food security dealing with climatic stressors under different rice simulation models are discussed.

Keywords: Climate; Temperature; Rice; Rainfall; CO2; Agriculture; climate shift

Abbreviations: CIAT: Climate-Smart Agriculture; CSA: Climate-Smart Agriculture; FACE: Free-Air CO_2 Enrichment Facility; FAO: Food and Agriculture Authority; FOT: Flower opening time; GDP: Gross Domestic Production; GHGs: Green House Gases; IPCC: Intergovernmental Panel on Climate Change; IRRI: International Rice Research Institute; LAI: Leaf Area Index; NGDP: National Gross Domestic Production; WG: Working Group

Introduction

The climate change refers to the variation in a climatic condition such as intensity and frequency of rainfall, temperature, and humidity level over some time. This change might be due to natural variability or as a result of anthropogenic activities [1,2]. Climate change in the form of higher temperatures, reduced rainfall, and increased rainfall variability, reduces crop yields and net farm revenues and threatens food security in low income-based economies, including African countries [3]. At the recently concluded 10th Session of IPCC WG II and the 38th session of IPCC in Yokohama, Japan, the world was warned that climate change impacts are leading to shifts in crop yields, decreasing yields overall and sometimes increasing them in temperate and higher latitudes. In light of these, some indigenous communities are changing seasonal migration and hunting patterns to adapt to changes in temperature

Climate Change Scenarios and Food Security

The simulation of climate change indicates a severe threat to the agricultural sector in developing countries [2]. According to the report of Climate-Smart Agriculture [4], the changes in monsoon and higher temperature are considerable challenges for the agriculture sector of Pakistan. This sector contributes 25% in National Gross Domestic Production (NGDP), involving 42% of the labor force [4]. About two third of the total population in Pakistan earn its livelihood through agriculture sector so the decline in cereal productivity may result in adverse impacts on their livelihood [2,5].

Pakistan is one of the most vulnerable countries of climate change due to its low adaptive capacity, and it is ranked 8th on the vulnerability index from 1995 to 2014 [6-8]. The productivity of major crops such as wheat, rice, cotton, and sugarcane is greatly affected due to climatic variations and extreme climatic events such as severe droughts from 1999 -2003, [5]. The global food security is threatened due to climatic changes, population growth, rapid urbanization, and a shift towards more meat consumption [6]. Pakistan is the 6th most populous country, and it ranks 78 out of 113 countries in Global Food Security Index. Therefore, the agricultural production needs to be increased by 70% by adaptive measures such as biotechnologies to create more productive crops and ensure food security (Brown and Funk, 2008; Tester and Langridge, 2010).

Effect of climate change on rice production

According to the [7], the climate change may cause tremendous damage to the rice production if it is not managed correctly. Less supply of rice with an increase in demand will not only create the food insecurity, but it will also affect the global food economy. Among the impacts of climate change are increase in temperature, increase in frequency, intensity, and duration of extreme climate events such as droughts, floods, and tropical storms; changes in the intensity, timing and spatial distribution of rainfall; soil degradation; and sea level rise resulting in loss of agricultural land and saltwater intrusion. Rising sea level may amplify soil salinity, displace areas for crop production, and reduce rice production in a sizable portion of the highly productive rice land in deltas. Drought affects all stages of rice growth and development. The strong effects of drought on grain yield are mainly due to the reduction of spikelet fertility and panicle exsertion. Frequent drought not only reduces water supplies but also increases the amount of water needed for plant transpiration. The most significant

Table 1: Critical temperature ranges required at various growth stages of rice

Growth Stage	Critical Temperature (^{0}C)		
	Low	High	Optimum
Germination	16-19	45	18-40
Emergence of Seedlings	12	35	25-30
Rooting	16	35	25-28
Leaf elongation	7-12	45	31
Tiltering	9-16	33	25-31
Anthesis	22	35-36	30-33
Ripening	12-18	>30	20-29

(Source: FAOSTAT, 1998)

Temperature

Increase in air temperatures during the grain-filling stage of rice will decrease grain yield and reduce its quality. Temperatures above the optimal growth temperature impair dry matter production due to reduced grain size [9]. Increases in both carbon dioxide levels and temperature will affect rice production. Higher carbon dioxide levels typically increase biomass production, but not necessarily yield. Higher temperatures can decrease rice yields as they can make rice flowers sterile, meaning no grain is produced. Higher respiration losses linked to higher temperatures also make rice less productive. The different predictions for elevated temperature, carbon dioxide levels, changes in humidity, and the interactions of these factors make forecasting future rice yields under these conditions challenging. IRRI research indicates that a rise in night-time temperature by 1 degree Celsius may reduce rice yields by about 10%. The effect of the expected rise in temperature as a result of reduced length of the growing season and increased maintenance respiration rates, such that the two factors canceled each other out [10-14].

CO_2 and other GHGs

The CO2 concentration in the atmosphere affects plant productivity in three significant ways, i.e. increase in photosynthesis, reduce in stomatal aperture and density which causes a reduction in stomatal conductance and transpiration and reduction of dark respiration [15]. Therefore, the increased CO2 levels are beneficial to vegetation [10].

Rice plants exhibit phenotypic plasticity in Flower opening time (FOT) in response to the concentration of atmospheric CO_2. Elevated [CO2] (E-[CO_2]) increases the temperature of rice panicles, which results in advance FOT. A study conducted by [16] indicates effect of E-[CO2] on FOT in rice using a Free-Air CO2 Enrichment Facility (FACE) where [CO_2] was increased by about 200 μmol mol^{-1}above the ambient level (A-[CO_2]) resulted in advanced FOT due to an increase in panicle temperature arising from a reduction in leaf stomatal conductance.

In rice plants, the respiratory CO_2 efflux and O_2 uptake in leaves change in response to the growth CO_2 concentration ([CO_2]). This degrees of change varies upon the cellular processes such as nitrogen (N) assimilation and accumulation of organic acids to growth [CO_2]. However, the underlying mechanisms remain unclear. A study conducted by [17] examined the respiratory characteristics of two rice varieties leaves with different yield capacities at different growth stages under ambient and elevated [CO_2] conditions at a FACE. The leaf CO_2 efflux rates decreased in plants grown at elevated [CO_2] in both varieties and were higher in high-yielding Takanari than in Koshihikari. The leaf O_2 uptake rates showed little change concerning growth [CO_2] and variety. The increased water temperature did not significantly affect the CO2 efflux and O2 uptake rates.

sea level rise

According to the International Rice Research Institute (IRRI), it is predicted that sea level may rise on an average rate of 1 m by the end of the 21st century due to the melting polar ice caps and glaciers. Rice production is vast in low lying deltas as well as the coastal regions of Asia, sea level rise. Predicting the effect of high sea-level on rice production in vulnerable areas is involved as the entire hydrology of the delta will be affected; sediment discharge and shoreline gradients will also be changed.

Flooding

Rice is unique in its characteristics as it can thrive in wet conditions where other crops fail to grow. However, the uncontrolled flooding is a problem, because rice cannot survive if I submerged under water for long periods. Flooding caused by sea-level rise in coastal areas and the predicted increased intensity of tropical storms with climate change will likely hinder rice production. At present, about 20M hectares of the world's rice-growing area are at risk due to the flooded at submergence level, especially in major rice-producing countries such as India and Bangladesh.

Climate change is likely to increase the frequency and intensity of flooding events in rice-growing areas. Currently, those areas which are not exposed to flooding, are predicted to experience floods.

Water Scarcity

An abundant amount of water is required for proper growth of rice. Low levels of rainfall or no rainfall for a week in upland paddy areas and for about two weeks in shallow lowland paddy fields can reduce rice production. According to the findings of IRRI (2018) average, rice yield reduction in rainfed, drought-prone regions has ranged from 17 to 40% in severe drought years, leading to a loss in production, food scarcity and related economical loses.

In South and Southeast Asia, water scarcity directly affects approximately 23 million hectares of rainfed rice production regions. In Africa, drought affects about 80% of 20 million hectares of rainfed lowland rice. Moreover, the climatic studies predict that drought also affects rice production in Australia, China, USA, and other countries.

Salinity

Salinity is associated with higher sea levels. As this will bring saline water further inland and expose more rice-growing areas to salty conditions. Rice is only moderately tolerant of salt and yields can be reduced when salinity is present. As sea-level rises, the effects of salinity can permeate throughout the whole deltas and fundamentally change hydrological systems. Higher salinity has indicated negative effects on rice productivity [18,19]. A number of studies have been conducted to analyze the impacts of higher salinity on various components on rice growth cycle including establishment, panicles, tillers and spikelets per plant, Leaf Area Index (LAI), floret sterility, individual grain size, and timing of heading [20,21]. Severely salt-stressed rice seedlings have smaller and lesser tillers; less root mass; and shorter, thinner, paled (less chlorinated) leaves compared to control plants not exposed to salinity [21]. [20] found a decrease in the LAI in different varieties of rice with an increase in salinity level. Research indicates that the percentage of sterile florets in panicle increases with increasing salinity, which results in a reduction of rice yield [21,22]. Salinity is also associated with the delay in flowering and reduction of productive tiller number, fertile florets per panicle, weight per grain, and overall rice grain yield [22].

The scarcity of irrigation water is recognized as a global threat in rice cultivars, which forces them to adopt irrigation water management systems that may result in increased salinity and yield reductions. While salt concentrations in field water have been shown to vary depending on water management, the distribution and build-up patterns of dissolved salts are unclear.

Adaptation and mitigation of climatic Impacts through smart climate agriculture

According to the Climate Smart Agriculture (CSA) report of 2019 rice alone accounts for 50 % of total GDP. It is simulated that in upcoming years (2020-2050) the percentage points will increase by 23.6%. Rice is the third most cultivated crop in Pakistan, followed by wheat and cotton and accounts for 8% of the total area harvested with a productivity of 5802 kg/ha (FAO, 2017). According to the studies until 2050, the total rice harvested area will increase by a factor of 3. However, the rice productivity will decrease by 5.7% mainly due to the increase in temperature.

According to the Climate Smart Agriculture (2017), the proposed adaptation techniques to overcome the climate change impact on wheat productivity includes:

i. Direct Seeding

ii. Measurement of correct timings for harvesting and

iii. Alternate Wetting and drying

These changes are being analyzed (Adopted) only by less than 30% of Punjab and Sindh predominantly by large scale farmers. The direct seeding and correct timing of harvesting (measuring proper grain moisture) lead towards 1.6 and 1.1 ranks on Climate smartness level (out of 10).

Table 2: Smartness assessment for rice ongoing CSA practices by production implemented in Pakistan

CSA Practices	Region and adaptation ratio (%)	Predominant farm scale	Climate Smartness	Impact on CSA Pillars
Direct Seeding	<30%	Large	1.6	Productivity: Increase yield by maintaining optimum conditions for plant development Adaptive: promotes the efficient use of scarce resources such as water Mitigation The practices may contribute to reactions in GHG emissions by reduced use of fossil fuel
Correct timing of harvesting (measuring proper grain moisture)	<30%	Large	1.1	Productivity: Increases in household income and profit due to higher yield. Adaptation: Reduces the risk to extreme climate conditions, without compromising production and quality of produce. Mitigation: Provides moderate reduction in GHG emissions per unit of food produced

Conclusion

There is Climate change has adverse effects on rice production, especially in South Asian countries. Several factors such as a rise in temperature, rainfall intensity, increase in GHGs, and salinity of soil can lead to a decrease in rice production. The water scarcity and flooding will also decrease rice production. These challenges will become more intense in the future as the simulation of mid-century and end-century shows that climatic patterns will be intensified. Therefore, appropriate adaptation and management plan is required to overcome these climatic challenges. The smart climate agriculture suggests that adaptation and mitigation practices such as direct seeding, measurement of correct timings for harvesting and alternate wetting and drying can increase rice production and also reduce GHGs.

Future Aspect

Agro-climatic modeling is used for the simulation of related climate impacts on future crop production. These simulations are run on the bases of different management practices such as the application of fertilizers, pesticides, insecticides, use of different irrigation techniques, and many other factors. Several experimental studies have been conducted to analyze the impact of modifications in the environment and their effects on productivity. However, there is a need to explore the future trend in the productivity of rice, especially from the economic point of view. Moreover, the study of climatic trends may also indicate which areas are more suitable and increase the productivity of rice.

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