Physical consequences of climate change on agriculture: Causes and effects

Abstract

Climate is the most important predictor of agricultural productivity. Concerns about the potential impact of climate change on agriculture have motivated considerable research developments in the last few decades. The research on the physical consequences of climate change on agriculture, such as changes in crop and livestock yields, as well as the economic ramifications of these potential yield going on quite aggressively. The current review examines the information and data associated with impact of climate change on agricultural productivity and sustainability for solving this complex problem. The global food and nutrition security are at risk due to consequences of climate change. Since the beginning of the industrial revolution, emissions from human activity, primarily from changes in land use, have resulted in a huge increase in the amount of greenhouse gases in the atmosphere. This rise is altering the climate, and it will only get worse throughout the course of the 21st century. Since agricultural systems are especially susceptible to climate change (CC), efforts to increase crop productivity while also maximizing resource efficiency and reducing environmental impact may not be successful. Not only productivity, the population of microbes and their enzymatic activities in soil are also impacted by climate change. Different strategies and technologieslike zero tillage, site specific nutrient management, application of efficient irrigation system (drip) etc. are helpful to avoid the effect of climate change on agriculture and ultimately increase productivity.

Keywords: Agricultural productivity, ClimateChange,Sustainable production, Efficiency, Greenhouse gases

Introduction

Climate is a significant factor influencing agricultural productivity. Over the last decade, interest in this topic has driven a significant corpus of research on climate change and agriculture (Anh et al., 2023). The term "climate change" refers to notable variations in the long-term averages of meteorological indicators, like temperature and precipitation. It is anticipated that climate change will affect hydrologic balances, input supply, productivity in agriculture and cattle husbandry, and other aspects (Balasundram et al., 2023). The atmospheric emission of "greenhouse" gases, such as carbon monoxide (CO), carbon dioxide

(CO_2) methane (CH_4), and nitrous oxide (NO) enhancing the global warming rapidly (Anh et al., 2023). There has been 150% increase in the concentration of greenhouse gases such as methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O), since 1750 which signifies change in gaseous composition of atmosphere. Emissions of carbon dioxide, the largest contributor of greenhouse gases, increased from 22.15 billion metric tons in 1990 to 36.14 billion metric tons in 2014 (Malhi et al., 2021). Earth's surface and atmosphere release thermal radiations, which are absorbed by these infrared active gases, primarily carbon dioxide (CO_2), ozone (O_3), and water vapor (H_2O) (Cui, 2020). Increase in greenhouse gases resulted rise in average global temperature 0.15–0.20 C every decade, and from 1975 to 2021, total temperature growth was 1.4–5.8° C. Globally, the average temperature of land has increased by 1.32–0.04 C from 1951–1980, but the average temperature of the ocean has increased by 0.59–0.06 C (Mukhopadhyay et al., 2021). To uphold the disastrous effect of global warming we have to limit the temperature rise within 2°C over pre-industrial levels and to achieve the target greenhouse gas emissions must be reduced. From 2005 to the present, developed countries have contributed 60–80% of the rise in global temperatures, the melting of sea ice, and the warming of the upper ocean, while developing countries have contributed only 20–40% (Maqbool et al., 2020). North America and Asia have reported cumulative CO_2 emissions of 457 billion metric tons and 414 billion metric tons, respectively, making Europe the largest contributor to CO_2 emissions. Among all countries in the world United States accounting highest emission (399 billion metric tons) followed by China (200 billion metric tons recorded since 1751(Lachaud et al., 2022). Recent years have seen a major contribution to overall emissions from nations with lower historical emissions, such as Brazil and India (Eftekhari, 2022). Methane emission from agricultural soils alongwith NO_x is a major threat for our environment (Maqbool et al., 2020).When it comes to climate change, soil management, land conversion, and biomass change, agriculture is a significant source of greenhouse emissions, especially when it comes to nitrogen fertilizers and the flooded rice industry. The production of animals and the resulting changes in manure contribute to climate change in the agriculture sector, which will also be influenced by changing management techniques (Lachaud et al., 2022). Certain crops may yield more in certain locations when the temperature and carbon dioxide (CO_2) increased gradually. However, certain requirements, including adequate water supply, soil moisture, and nutrient levels, must also be satisfied to experience these benefits (Song et al., 2022). Variations in the frequency and intensity of floods and droughts may endanger food safety and enhance difficulties for farmers and ranchers. All things considered, crops, livestock, and fishing may become more challenging to do in the same locations and methods as in the past due to climate change. Along with other changing elements that impact agricultural productivity, like adjustments to farming techniques and technological advancements, the effects of climate change also need to be considered (Anh et al., 2023). The present study highlights the causes and effects of climate change on agriculture.

Causes of Climate Change

i) Global temperature riseis a resultant of both natural and human events, which eventually start due to increase in the concentration of greenhouse gases. The atmospheric ozone layer is being depleted as a result of anthropogenic activities through which greenhouse gases such as CO_2, methane, and nitrous oxiderelease(Kulanthaivelu et al., 2022). Figure 1. depicted the contribution of different gases which are the primary causes of climatic change and global warming.

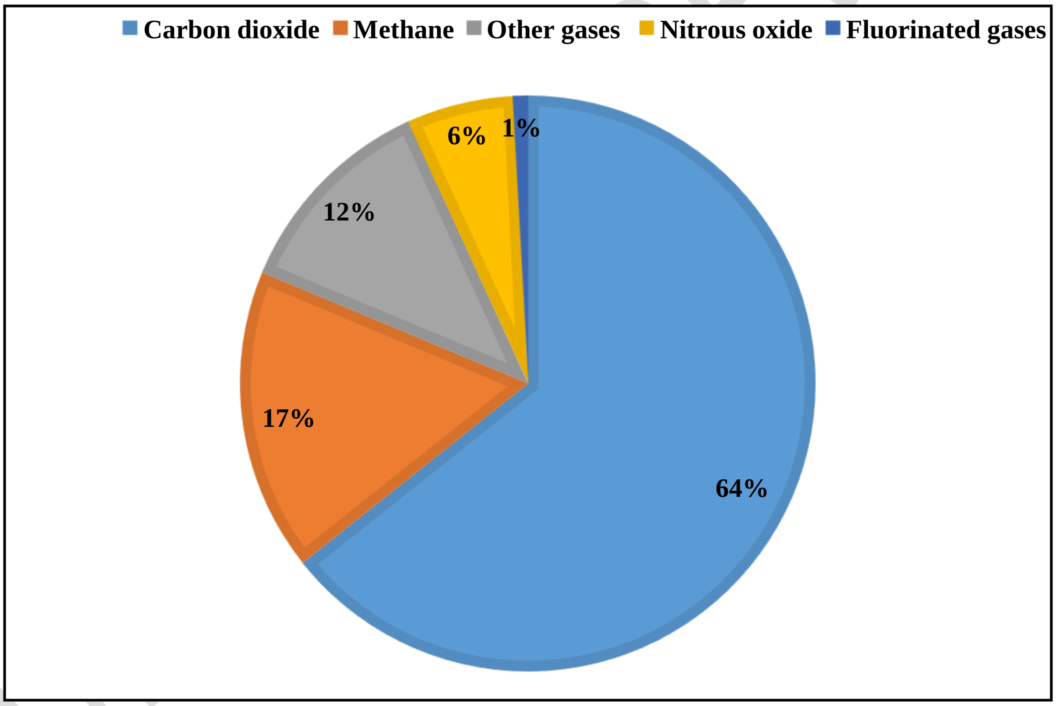

Figure 1. Different gases contributed to the causes of climatic changes (Bhupenchandra et al., 2022).

ii) An increase in atmospheric CO_2 concentration (463–780 ppm) can therefore stimulate nitrous oxide and methane emission from upland soil and wetlands, respectively, negating the 16.6% predicted mitigation effect of climate change by increasing the sustainability retrial carbon sink. Increased atmospheric CO_2 concentration can also have an impact on microbial activities in the soil and water content (Bhupenchandra et al., 2022).

iii) The agriculture sector accounts for 15% of overall emissions, mostly methane and nitrous oxide. If dietary habits and food energy consumption remain unchanged from 1995 levels, global non-agricultural greenhouse gas emissions are expected to rise until 2055. However, as people's preferences shift toward high-value items like milk and meat, emissions are expected to climb even faster (Guo et al., 2022).

iv) According to (Kulanthaivelu et al., 2022) emissions can be decreased by technology mitigation and reduced meat consumption. According to the IPCC (Intergovernmental Panel on Climate Change), the cattle industry is the largest contributor to greenhouse gas emissions, accounting for 8-10.8% of total emissions; however, based on lifecycle analysis, it can account for up to 18%

v)The manufacturing of fertilizer, liming, fossil fuels, enteric fermentation, N_2O emissions, and organic farming are the primary causes of greenhouse gas emissions from the cattle industry. Greenhouse gas emissions are also a result of the use of nitrogenous chemical fertilizers (Kumari et al., 2022).

vi) It is possible to reduce the consumption of nitrogen fertilizer by 38% by improving crop production management. Improved crop management also results in 33% higher yields at an 11% lower input energy usage, which cuts greenhouse gas emissions by 20% (Guo et al., 2022).

Impact of climate change on Global and Indian scenario

i) Global scenario

Climate change is predicted to have a direct impact on world food production. Many crops' growing seasons can be shortened by an increase in the average seasonal temperature, which will ultimately reduce agricultural yields. In areas where temperatures are already approaching the physiological maximum for agriculture, warming will have an immediate impact on agricultural productivity (EkaSuranny et al., 2022). Global warming will cause a significant drop in world agriculture this century. In the 2080s, agricultural productivity is expected to drop by an average of 10 to 25% in developing nations, many of which already have average temperatures that are close to or above crop tolerance levels (Murken and Gornott, 2022). Rich nations, whose average temperatures are generally lower, will see a considerably milder or even positive average effect, with productivity potentially rising by 8% or declining by 6%. Even greater decreases are expected in individual developing nations.

For instance, India might experience a 30–40% decline (Okolie et al., 2022). Australia's decreasing rainfall will result in lower agriculture yields, while irrigation may be able to partially offset this reduction. In North America, a mild rise in temperature along with an increase in rainfall could be advantageous for food production (Abbass et al., 2022).

Different sectors are affected by climatic changes on world scenario and are represented in Figure 2. Mainly agriculture (13%), industrial (19%) and forestry (18%) is affected. The world's poorest nations are probably going to bear a disproportionate amount of the burden caused by climate change. For instance, irrigation can be used in wealthier nations to compensate for decreasing rainfall levels, while less developed nations may not be able to use similar technological solutions (Shrestha, 2019).

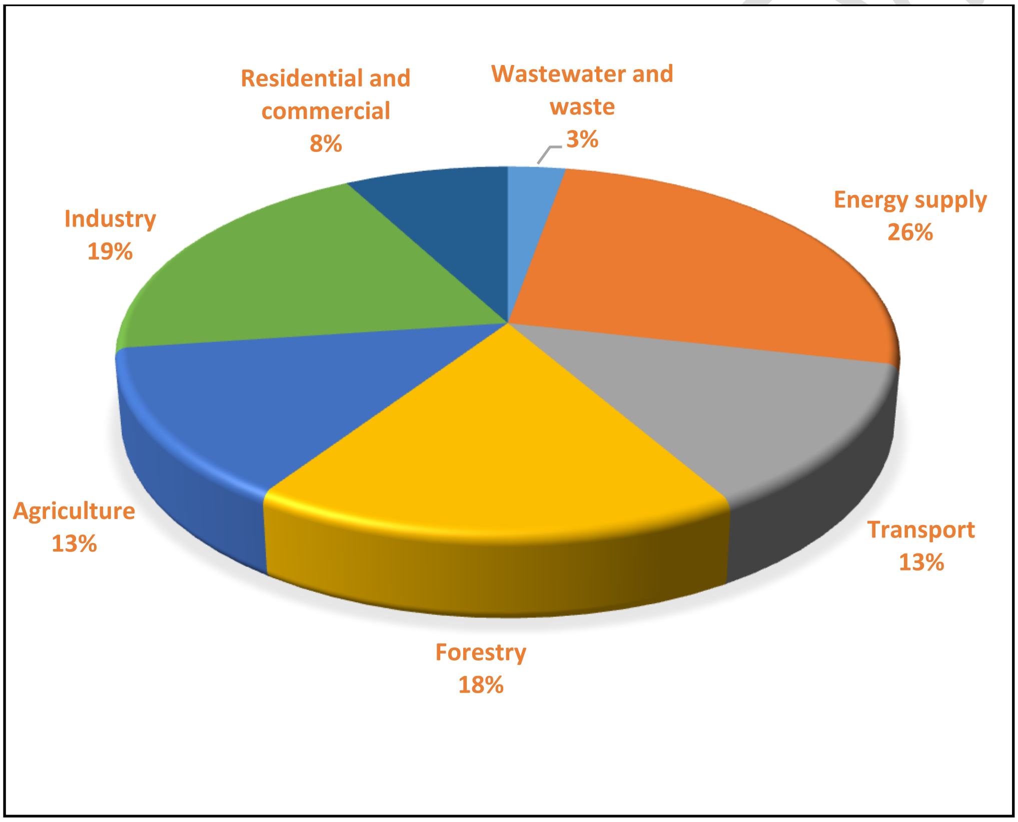

Figure 2. Impact of climatic changes in World (Shrestha, 2019).

ii) Indian scenario

In India's northern regions, the warming can be more noticeable. As a result of the changing climate, it is anticipated that there will be greater extremes in both maximum and lowest temperatures. Some locations may experience heavier rainfall than others (Dandotiya and

Sharma, 2022). In contrast, a 20% increase in summer monsoon rainfall is anticipated in all states in India, except for Punjab, Rajasthan, and Tamil Nadu, which exhibit a little reduction on average. While the number of rainy days may decrease in some regions of India (like Madhya Pradesh), most regions of the country (like the Northeast) are predicted to see an increase in intensity (Fujimori et al., 2022).

a)Agriculture

In India agriculture and land use sectors are mainly affected due to climatic changes and are depicted in Figure 3. India's gross per capita water availability is projected to drop from 1820 m^3/year in 2001 to as low as 1140 m^3/year in 2050. In the coming summer, corals in the Indian Ocean will be subjected to temperatures over the thermal thresholds recorded during the previous two decades (EkaSuranny et al., 2022). Starting in 2050, annual coral bleaching will very certainly occur. The areas in India most susceptible to the effects of cyclones becoming stronger and occurring more frequently are now the districts of Jagatsinghpur and Kendrapara in Odisha; Nellore and Nagapattinam in Tamilnadu; and Junagadh and Porbandar in Gujarat. A 100-year trend of approximately 1.0 mm/year rise in mean sea level has been seen in the past along the Indian coast (EkaSuranny et al., 2022). However, according to the latest research, the sea level is rising around the Indian coastline by 2.5 mm annually. The sea surface temperature near India is expected to rise by 1.5-2.0°C by the middle of this century and 2.5-3.5°C by the end of the century. A one-meter rise in sea level is expected to displace around 7.1 million people in India, as well as 5764 $km^2$of land and 4200 km^2 of highways (Dandotiya and Sharma, 2022; Fujimori et al., 2022).

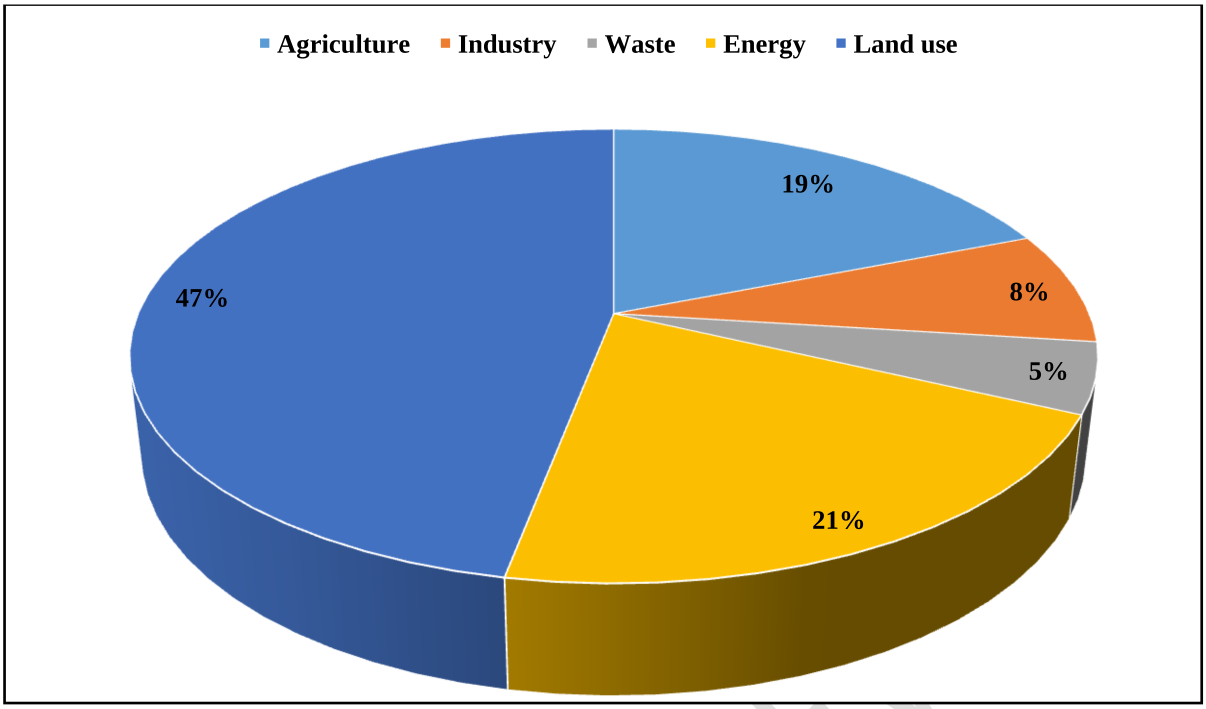

Figure 3. Impact of climatic changes in India (EkaSuranny et al., 2022).

b)Forest

More than half of India's forests are anticipated to change kinds, threatening associated biodiversity, regional climate dynamics, and forest-based livelihoods. The majority of the forest biomass in India appears to be quite vulnerable to the expected change in climate, even in the relatively short period of roughly 50 years. Furthermore, it is predicted that the types of forests in 77% and 68% of India's wooded grids will probably change by 2085 (Bhupenchandra et al., 2022).

How climate change affects agriculture

Agriculture has a complicated structure and connections with several components, making it unpredictable in a future climate that poses a severe risk to regional food security. As a result, it is critical to identify the detrimental effects of climate change on agricultural productivity and devise adaptive ways to resist it (Agovino et al., 2019). Primary techniques are also available for estimating the negative effects of climate change on crop yield, which is critical for food availability and access. There are several ways in which farmers' livelihoods and well-being are directly threatened by extreme weather and changing seasons (Reddy and Reddy, 2015). Some of them are explained below:

i) Variations in agricultural productivity

Agriculture affects so many people and has such a large economic impact on climate conditions, it is the sector most sensitive to climate change. Crop productivity is significantly impacted by fluctuations in temperature and rainfall (Kumar and Sharma, 2022). The crop, the location, and the magnitude of the parameter change all affect the effects of rising temperatures, variations in precipitation, and CO_2 fertilization differently. Raising temperatures are said to reduce yield, although increased precipitation is supposed to offset or mitigate the effects of rising temperatures (Praveen and Sharma, 2020). Crop productivity is influenced by a number of factors, including crop type, climate scenario, CO_2 fertilization effect, and degree of flexibility to Iranian climate conditions. Different areas and irrigation techniques have different effects on food yields as a result of climate change. Aggravating irrigated areas can result in higher crop yields, but at the expense of environmental sustainability (Ahmed et al., 2023). Temperature rise is projected to reduce the yield of numerous crops because of their shorter lifespan. Total wheat, rice, and maize yields are expected to decrease with every 2 °C increase in temperature in both the temperate and tropical zones. In general, tropical regions are more affected by climate change because tropical crops remain closer to their high-temperature optima and hence experience high-temperature stress as temperatures rise (Ahmed et al., 2023; Sharma, 2022). Crop yield declines have the potential to drive up food prices and have a significant impact on agricultural wellbeing worldwide, with a 0.3% annual loss of future global GDP by 2100. The global food supply is shown to be less affected by climate change, but developing nations would still suffer greatly as a result (Praveen and Sharma, 2020). Different models are also utilized to check the crop productivity and to know the yield losses to specific crops. The data related to impact of climatic change on crop productivity was represented in Table 1. Climate change may make agricultural cultivation easier or harder in particular places. For example, growing seasons that are longer are caused by differences in temperature, precipitation, and days without frost in almost all states. According to Praveen and Sharma (2019), longer growing seasons can both help and impair food production. A longer, hotter growing season may require more irrigation for certain farmers, while others may be able to sow more crop cycles or crops with longer maturation durations. Furthermore, air pollution can injure crops, trees, and plants. High ground-level ozone, for instance, causes plants to absorb less photosynthesis, grow more slowly, and become more disease-prone (Bibi and Rahman, 2023). The risk of wildfires may increase as a result of climate change. Wildfires pose a serious threat to rangelands, meadows, and farmlands. The range and frequency of insects, weeds, and diseases will likely increase in response to changes in temperature and precipitation. Pest and weed control may become more necessary as a result (Mendelsohn, 2014). Pollination is necessary for over a hundred crops grown in the United States. Variations in precipitation and temperature can affect when plants bloom and when pollinators such as bees and butterflies come. If pollinators emerge at different times from when plants blossom, pollination may drop (Carter et al., 2018).

Table 1. Impact of climatic changes on different crops and their productivity

Crops	Variation in yield	Causes	Model used	References
Maize Wheat	-5-13% -5-17%	Increased extreme weather and warming Emission of gases	SALUS crop model	Liu and Basso, 2020
Maize	-0.5%	Increasing temperature Decrease in productivity	Linear regression mode	Shrestha, 2019
Rice, wheat	-3.7%	Increase in mean growing season temperature Low and medium gases emission	Regression, Kendall-tau statistic, Pearson correlation	Kukal and Irmak, 2018
Rice, Wheat	-6%	Low productivity Low greenhouses gases emission	Global grid-based, local point-based, statistical regression and field warming experiments	Zhao et al., 2017
Soybean	+1.6%	Increasing temperature and greenhouses gases	Linear regression mode	Hof and Svahlin, 2016
Wheat, sunflower, maize, cotton	−63–82% by 2100 −2–9% by 2050	Medium and low greenhouse gases emissions Impact the yield	DAYCENT	Lee et al., 2011
Barley, Wheat	-9.1%	Increasing annual temperature Low emission of gases and productivity	Probability-based approach	Cai et al., 2009
Cotton, soybean, maize	-30-46% by 2100	Causes rapid warming Impact the yield production and overall scenario of crops	Hadley III model	Schlenker and Roberts, 2009

ii) Effect on soil and water resources

In the United States, heavy precipitation is predicted to occur more frequently due to climate change. This could be harmful to crops because it could erode the soil and reduce the amount of nutrients present. Heavy rains can also increase agricultural runoff into lakes, streams, and oceans. This runoff could impair the cleanliness of the water (von Braun, 2020). Low oxygen levels in water bodies can be caused by runoff when paired with climate change-induced increases in water temperature. The term hypoxia refers to this. Fish and shellfish might perish due to hypoxia. The coastal communities and economies that depend on those ecosystems may suffer as a result, as it may also make it more difficult for them to find food and a suitable habitat (Hristov et al., 2020). Coastal farming communities are put at risk by storms and rising sea levels. Invasion of seawater, which can contaminate water supplies, erosion, and loss of agricultural land are some of these issues. These hazards should get worse due to climate change (Pais et al., 2020).

iii) Impact of climate change on livestock

The livestock industry in arid to semi-arid regions is particularly vulnerable to rising temperatures and falling precipitation. For domestic livestock, a temperature range of 10–30°C is pleasant, and for each degree that the temperature rises, the animals will consume 3–5% less feed (Hertel et al., 2016; Taylor et al., 2016). Likewise, a drop in temperature would result in a 59% increase in required feed. Furthermore, in scenarios of climate change, animal output would be severely impacted by heat stress and drought. Variability in the climate influences the development and spread of several diseases in animals. For example, Rift Valley Fever (RVF) brought on by increased precipitation and tick-borne illnesses (TBDs) brought on by rising temperatures have spread like wildfire among sheep, goats, cattle, buffalo, and camels (Hertel et al., 2016). Animal breeds vary in how they react to rising temperatures and water scarcity. Thermal stress negatively affects animal reproduction features in India, which leads to low growth and high rates of poultry mortality. Severe feed scarcity would result from excessive rainfall variability combined with drought stress in arid regions of Asia (Tobin, 2017). High CO_2 concentrations have been shown to degrade fodder quality by lowering its protein, iron, zinc, and vitamins B1, B2, B5, and B9. The quality and quantity of feedstuffs, pastures, grasslands, and biodiversity would all be significantly impacted by future climatic scenarios. Future climatic scenarios affecting livestock productivity could have an impact on rangelands' ability to support and buffer ecosystems, control grazing, change the type of grain that is fed to animals, and emit greenhouse gases (Jacobs et al., 2019).

iv) Impact of climate change on forest

Variations in productive features, carbon dynamics, and vegetation change, in addition to the depletion of soil resources and the associated drought and heat stress in South Asian countries, are only a few of the detrimental effects that climate variability has had on forests (Falco et al., 2019). Forests in Bangladesh are susceptible to climate fluctuations because of heightened fire hazards, rising sea levels, storm surges, coastal erosion, landslides, and eventually shrinking forest areas. Forests are considered major facilities because they maintain biodiversity, sequester carbon, supply food and fiber, improve water quality, and produce medical goods (Carter et al., 2018). In contrast, trait-climate connections and environmental conditions have had a significant impact on structure, distribution, and forest ecology. High temperatures and frequent dry spells have caused higher rates of tree death and die-off in forest trees. For example, drought, habitat modification, and ongoing forest clearing brought on by climate change have put Sal, pine, and garjan trees in danger in South Asian nations (Hertel et al., 2016; Taylor et al., 2016). In North China, the infestation of insect pests on forest trees has grown due to rising temperatures and increased CO_2 fertilization. Insect pests are growing quickly due to rising temperatures, increased carbon dioxide (CO_2), and erratic precipitation patterns. Eventually, more of these pests will damage forest trees. Therefore, adaption strategies for forest restoration must be devised in order to meet Asia's expanding demand for food, fiber, and pharmaceuticals (Hristov et al., 2020).

v) Impact of climate change on aquaculture and fisheries

Considering that terrestrial agriculture has much more control over the production environment, aquaculture will react to climate change scenarios very differently than terrestrial agriculture. Aquaculture in South Asia has been adversely impacted by climatically driven extremes such as drought, flood, cyclones, global warming, ocean acidification, salinity, and sea level rise (Toor et al., 2020)). As the ocean's acidity and temperature rise, several species in Asia, including hilsa and algae, have lost their habitat. Coral reefs are now in danger due to rising sea temperatures and the acidity of terrestrial agriculture; in India and other parts of Asia, coral reef bleaching can occur after four weeks of consecutive 1°C increases in average temperature. The marine fisheries of China have suffered significant harm due to ocean warming (Jacobs et al., 2019). Due to increased salty water invasion near the Indus Delta, strong cyclonic activity, rising sea levels, and temperature fluctuations, Pakistan's aquaculture and fisheries have lost habitat quality, particularly fish breeding grounds. It is shown that various Asian countries are vulnerable to the detrimental impacts of climatic fluctuation on freshwater and brackish aquaculture. Additionally, it is determined that India's aquaculture and wetlands are profoundly impacted by extreme climate variability (Agovino, et al., 2019; Praveen and Sharma, 2019).

vi) Impact of climate change on reduced yield

Farmers are reporting losses that are breaking records. It is projected that by 2050, global food yields might decline by as much as 30% if farmers do not adapt to the effects of climate change (Ortiz-Bobea, 2021). Climate change affects the agriculture industry as a whole, resulting in increased food prices and less food available globally. These disruptions are not limited to farmers (Kumar et al., 2018).

vii) Impact of climate change on land degradation and water scarcity

The land needed to cultivate crops and pasture is significantly impacted by climate change. Agriculture is negatively impacted by and frequently irrevocably damaged by changes in rainfall patterns, deforestation, and overgrazing (Agovino, et al., 2019). With drier and harsher weather, farmers are finding it difficult to maintain the health of their animals. Soil is drying up to dust, and crops are having a tougher time growing due to a lack of water and rising temperatures (Praveen and Sharma, 2019). As farmers compete for arable land and access to clean water, land productivity declines and becomes more vulnerable to future shocks such as droughts. The competition and fighting over resources are also increasing (Mendelsohn, 2014).

viii) Impact of climate change on increased poverty

Farmers' livelihoods are directly impacted by climate change. Income is lost with cattle and crops. Farmers in the most susceptible areas of the world frequently already exist on the verge of destitution, and as climate change picks up speed, the risk increases (Taylor et al., 2016). If grain yields keep falling, an estimated 43 million people in Africa alone may become impoverished by 2030 (Anderson et al., 2020).

ix) Impact of climate change on reduced soil health

Fertile soil is mineral-rich, has a balanced moisture level, and is teeming with microbes, fungi, bacteria, and other organisms that aid in the growth of nutrient-dense crops. However, climate change can decrease soil quality, particularly in locations with high temperatures and unpredictable precipitation. These consequences are exacerbated where soil and crops are less adaptable to environmental changes as a result of industrial, chemical-dependent monoculture farming (Skendžić et al., 2021).

x) Impact of climate change on food shortages

The world's food supply is ultimately directly threatened by changes to our agricultural systems. Climate change will also not equally affect everyone in terms of food shortages and price increases (Nhemachena et al., 2020). Richer people will still have greater access to food options, but there's a chance that billions more people could fall into food insecurity, joining the billions who already struggle moderately or severely to obtain enough food (Corwin, 2021).

Technological adaptation to mitigation climate change

A) Farmers role

i) The primary driving force behind voluntary mitigation of climate change is farmers' assessments of its severity and hazard. The adaption is contingent upon the accessibility of pertinent data, though. Additionally, the number of individuals exposed to water stress will decrease with mitigation techniques; yet, the remaining individuals will require adaption strategies because of their elevated stress levels (Wang et al., 2023).

ii) Farmers can support climate-resilient technologies by utilizing agro-ecological and traditional management practices, including soil management, water harvesting, and biodiversification. These management strategies generate resilient agricultural systems and soils, which guarantee food security in the face of climate change, by improving soil health, soil sequestration, soil quality, and soil erosion (Raihan, 2023).

iii) The most effective educational interventions for climate change education for ecological development are those that center on local, palpable, and achievable issues that can be tracked by individual behaviour. The majority of farmers supported adaptations, but only a small percentage supported reducing greenhouse gas emissions (Wang et al., 2023; Grafakos et al., 2020). This indicates the need to concentrate on programs that include mitigation and adaptation elements. The primary techniques for adaptation and mitigation fall into three categories: technology for cropping systems, technologies for resource conservation, and socioeconomic or policy interventions (Sharifi, 2021). Because they are less aware of the effects of climate change, small and marginal farmers are more vulnerable to losses and are unable to adapt. The financial ramifications and deficiency of management measures for climate change make African farmers particularly vulnerable. Several agronomic strategies can be used to mitigate the effects of climate change, including changing the date of sowing (Sharifi, 2021; Maiella et al., 2020).It has been determined that the best times to plant wheat in Punjab, India are October 22–28 in the northeast, October 24–30 in the center, and October 21–27 in the southwest. (Hurlimann et al., 2021).

B. Role of agriculture

i) There are a few easy ways to reduce greenhouse gas emissions, like rice that is dried alternately, mid-season drainage, better animal nutrition, higher N-use efficiency, and soil carbon. It may be possible to lessen the effects of climate change by implementing straightforward adaptation techniques such as altering planting dates and cultivars (Borras and Franco, 2020). The way farmers react to climate change is greatly influenced by the diffusion of technology. The primary areas of focus are capacity building, support for public research, and market integration.Because it promotes minimal soil disturbance, crop diversity, and soil cover management, conservation agriculture can undo the damage caused by conventional plowing over time (Roberts et al., 2020).

ii) Additionally, less fertilizer is used, less greenhouse gas emissions are produced, and more terrestrial carbon is sequestered. Conservation agriculture's guiding principles, which open the way for sustainable agricultural practices, include minimum soil disturbance, crop rotation, and soil cover. A 15–16% decrease in cultivation costs is the main reason why farmers in South Asia are switching to zero tillage for wheat farming (Maiella et al., 2020; Locatelli et al., 2015).

iii) Furthermore, zero tillage produces maize and wheat yields that are greater and less variable. It was also argued that no-till farming was a better option than traditional tillage, which reduces global warming by sequestering carbon. This argument, however, is overblown because no-till farming adds relatively little new organic carbon to the atmosphere (Roberts et al., 2020). The perception of personal benefits, practical market exchange strategies to provide the necessary resources for CA in sustainability implementation, financial incentives for farmers, the establishment of farmer organizations to support local adaptation, and the formation of appropriate environments by coalitions of farmer organizations and institutions are some of the factors that have contributed to the adoption of conservation agriculture (CA) (Roberts et al., 2020; Demski et al., 2017).

iv) Modified farming techniques provide the primary means of adapting to climate change, and they are heavily impacted by social, political, and economic factors as well as policy decisions that take into account climatic extremes and unpredictability. Nutrient management is a critical component of conventional agricultural intensification, as it accounts for about 80% of the significant economic losses associated with this practice (Rojas-Downing et al., 2017).

v) No-till farming, cover crops, manuring, nutrient management, agroforestry, and soil restoration can all promote carbon sequestration or an increase in soil organic carbon (SOC).Furthermore, globally, carbon sequestration can cut emissions from fossil fuels by 5–15%. Comparing transplanted rice to direct-seeded rice (DSR), less greenhouse gas emissions are produced (Osberghaus, 2017). Compared to transplanted rice, the potential for global warming in dry DSR and wet DSR is 76.2% and 60.4% lower, respectively. Additionally, the yield from wet DSR was 10.8% higher than that from transplanted rice. Because aerobic rice uses 73% less irrigation water during the preparation of the land and 56% less water throughout the crop-growing season, it also offers a great deal of potential to mitigate future climate change (Seidl et al., 2017).

vi) One viable strategy for sustainably producing rice is to use micro-irrigation technologies to cultivate aerobic rice.It also aids in lowering rice fields' methane emissions. In the western United States, China, and south, west, and central Asia, there may not be enough fresh water for irrigation (Demski et al., 2017; Seidl et al., 2017). This could result in the conversion of 20–60 million hectares of irrigated land to rainfed land, which would reduce food output by 600–2900 pcal. One irrigation method that is being promoted to lessen groundwater overdrafts and shocks brought on by climate change is drip irrigation. It lessens the need for groundwater for irrigation and has the potential to be climate change resilient.However, intensive farming practices such as drip irrigation are being used by farmers, which is further depleting groundwater and creating the Jevons dilemma (Reyes- García et al., 2016; Locatelli et al., 2015).

C. Irrigation approaches

i) In addition to providing long-term economic benefits, water-saving irrigation methods like drip irrigation and sprinkler irrigation can help mitigate and adapt to climate change. However, due to water pressure needs that may increase GHG emissions, sprinkler irrigation is said to have the largest incremental cost of mitigation, ranging from USD 476.03 to USD 691.64/t. Reducing nitrogen application without sacrificing profitability can be achieved by agricultural strategies based on site-specific knowledge (Yohannes, 2016).

ii) Therefore, it is thought that precision agriculture is more profitable than field management. decreased nitrogen utilization efficiency in northwest India is a result of farmers' ineffective fertilizer management practices. Improved fertilizer rate and duration were discovered to be highly suited for a leaf color chart (LCC). The resulting rice yield was comparable to the suggested blanket dose of 120 kg N/ha after fertilizer application when the LCC exhibited less than 4 shades (Chen et al., 2016).

iii) Crop yields and farmer revenue have grown as a result of the use of laser land leveling (LLL). According to reports, LLL increased the production of paddy crops by 0.5 metric tons/ha in the Raichur district of Karnataka. This might increase the net agricultural income of INR 5000 per year. Additionally, it has lowered agricultural expenses and limited losses brought on by climate fluctuation (Jat et al., 2016). One strategy for adjusting to environmental challenges in plants is to breed them to create new types. To test a variety's fitness for the intended habitat, multilocation experiments, breeding cycle shortening, and germplasm selection will all be necessary.It is crucial to create stress-tolerant cultivars as a mitigating measure because it is anticipated that climate change will increase the frequency and severity of abiotic stress (Wang et al., 2023; Grafakos et al., 2020). The integration of the SUB1A gene into several high-yield varieties of rice that have been released in South Asian countries has been made easier by the cloning of the gene in rice plants. After being submerged for eighteen days, these submergence-tolerant cultivars yield more than the original types (Borras and Franco, 2020). By accumulating data, boosting the efficacy of local institutions, advocating for climate-smart agricultural practices, and connecting agricultural financing to climate, climate-smart agriculture increases resilience to climate change (Bhattacharya, 2019). The most effective climate-smart devices either promote soil structure or supply water or nutrients. Table 2. represented the different smart climatic technologies and its beneficial effects. Certain technologies such as half-moons, stone bunds and zai, and nutrient application were proven to be effective in sustaining food production and protecting smallholder farmers in semiarid West Africa (Jayaraman and Murari, 2014). In Punjab, Pakistan, climate-smart agricultural technology was investigated, and it was found that cotton yield increased with higher returns and more resource efficiency.The rice and wheat crops of the Indo-Gangetic plain are negatively impacted by climate change, which makes the region extremely vulnerable. Farmers have shown a readiness to embrace climate-smart agriculture technology, which has the potential to convert traditional farming methods into more efficient ones (Moore et al., 2017). The most popular CSA technologies in the eastern indo-gangetic plains (IGP) are laser land leveling (LLL), weather-advisory services, and crop insurance; in the western IGP, farmers primarily favor direct sowing, LLL, zero tillage, crop insurance, and irrigation scheduling.There is enormous potential for both adaptation and mitigation with these measures (Yadav et al., 2015). They are contingent on several factors, including the technological complexity, people's perceptions, economic viability, and the technology's fit for the area. Furthermore, a variety of interventions employed in tandem and in solidarity with one another yield better results with these tactics (Bhattacharya, 2019).

Table 2. Different smart climatic technologies and its beneficial effects

Smart climatic technologies	Crops	Regions	Importance	References
Direct seeded rice	Wheat, Rice	Punjab, India	Saves irrigation water Improve labour requirement	Bhullar et al., 2018
Drip irrigation	Eggplant, Okra	Tamil Nadu, India	Reduced irrigation Saves irrigation water Reduced cultivation cost	Narayanamoorthy and Devika, 2018
Laser land leveling	Rice, Wheat	Northwestern Indo-Gangetic plains, India	Enhanced production Reduced irrigation time Improved yield	Khatri-Chhetri et al., 2016
Zero tillage	Rice-Wheat	Pakistan, Punjab	Improved water productivity Saves irrigation water Improve nitrogen use efficiency	Latif et al., 2013
Zero tillage	Wheat, Rice	Karnal, Haryana, Northern western India,	Enhanced production Lower cultivation cost Reduced irrigation time Improved yield	Tripathi et al., 2013
Drought tolerant varieties	Groundnut	Semi-arid areas of India	Increase in yield Increased total benefits in crops	Birthal et al., 2012
Site-specific nutrient management	Rice	Vietnam,Philippines, India, Kenya	Increased productivity of nitrogen	Pampolino et al., 2007

Future Problems associated of Climate Change

The World Health Organization estimates that between 2030 and 2050, the effects of climate change will result in an extra 250,000 deaths year from diseases spread by insects, heat stress, and malnutrition (Arora, 2019). More than 140 million people would have been displaced by climate change in Sub-Saharan Africa, South Asia, and Latin America by 2050, according to World Bank estimates. Climate mitigation, or our ability to stop climate change and reverse its widespread effects, will depend on the effective implementation of policies that significantly reduce carbon pollution, end our reliance on dangerous fossil fuels and the deadly air pollution they produce, and prioritize the people and ecosystems at the front lines (Van Meijl et al., 2018). And to guarantee a healthier today and tomorrow, these steps need to be done right away. The IPCC (Intergovernmental Panel on Climate Change) released a study that included its most optimistic emissions scenario, according to which global warming will only momentarily exceed 1.5 °C before sequestration efforts force it to return to below 1.5 °C by the year 2100 (Zhang et al., 2017). Coping with the repercussions of climate change, or "climate adaptation," is now essential and not optional, especially for the world's most vulnerable communities. Following the IPCC's urgent warnings and limiting warming may allow us to avoid crossing some of the important thresholds that, once passed, can result in possibly permanent, catastrophic consequences for the world, including further warming (Masud et al., 2017). These thresholds, known as climate tipping points, occur when a natural system "tips" into another state. Arctic permafrost, for example, stores carbon like a freezer: as temperatures rise, the permafrost melts and releases carbon dioxide into the sky. Firstly, taking action on climate change is not a simple pass/fail assessment. Reducing even a small amount of global warming can lessen human suffering and mortality while preserving a greater proportion of the planet's natural systems (Fanzo et al., 2018; Zhang et al., 2017). Fortunately, there is a wealth of available options to drastically cut emissions, moderate global warming, and safeguard people most vulnerable to the effects of climate change. Ancestral and Indigenous knowledge of the natural world, which dates back thousands of years, is the foundation of many of these remedies (Arora, 2019). Certain solutions necessitate large expenditures for sustainable technologies and clean, renewable energy. In addition to addressing the core causes and consequences of the climate catastrophe, effective climate solutions must also address related issues including gender inequality, racism, and poverty (Van Meijl et al., 2018).

Conclusion

Climate change enhances the global food crisis and weaken nutritional security. A rising global population exerted extra pressure on agriculture to meet sufficient food for all. Even though the future changes of the climate are unknown, a number of studies indicate that climate change will cause agricultural productivity to drop in the upcoming years. A pest infestation, soil fertility, irrigation supplies, plant physiology, and metabolic processes were all severely impeded by the main climate factors temperature, precipitation, and greenhouse gases.Many mitigation strategies have been developed to offset the negative impacts of climate change on agriculture's sustainability. These technologies include carbon-smart (zero tillage, legumes, crop residue management), knowledge-smart (agricultural extensions to boost capacity-building), and weather-smart (stress-tolerant cultivars, ICT-based agrometeorological services) technologies. Water (direct-seeded rice, raised beds, micro-irrigation, rainwater gathering, laser land levelling, and crop diversification) and nutrient (precise nutrient application, leaf colour charts, and crop residue management) efficient methods are also included for the same purpose. By reducing the adverse consequences, modernagricultural technologies can improve environmental condition in this era of severe climate change.

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