AREVIEWONTHERELATIONSHIPOFCLIMATEVARIABILITYAND EXTREMES WITH CROP PRODUCTION

ABSTRACT

Risks are always present in agriculture for a variety of reasons. Climate-related risks are the most significant among them since they can occur unexpectedly and cannot be avoided. The main climatic factors influencing crop productivity are rising temperatures, altered precipitation patterns, and rising atmospheric CO_2. The average global temperature is expected to rise by 2°C until 2100, which would result in significant global economic losses. The average global temperature is currently rising steadily. The concentration of CO_2, which makes up a large amount of greenhouse gases, is rising alarmingly. Climate change, with rising temperatures and increased greenhouse gas emissions, impacts agriculture significantly, leading to varied crop yields and potentially catastrophic economic consequences. While some regions may experience favorable effects, overall, climate variability poses challenges such as reduced crop productivity, increased pest activity, and elevated food costs,particularly affecting underdeveloped nations. Environmental policies must be adaptable and flexible to mitigate these impacts effectively. Farmers' responses to climatechange,influencedbyperceptionsanddataaccessibility, drivebothmitigation and adaptation efforts. Sustainable agriculture, conservation practices, and technological innovations play key roles in mitigating climate change impacts and enhancing resilience in farming communities, though success depends on multiple factors including local perceptions, technical feasibility, and economic viability. This paper reviews the causes of climate change, the climate variables affecting crop production and the mitigation and adaptation strategies against climate change.

Keywords:ClimateChange,Agriculture,Climatevariability,Mitigation,Adaptation.

INTRODUCTION

There's mounting evidence that the earth's temperature has increased during the past century, leading to unequalled and unpredictable variations in the climate andnegative effects on people's lives everywhere. (IPCC (Intergovernmental Panel on climatechange, 2022). Due toagriculture's heavy reliance on weather, climatechange has slowed down agricultural growth globallyand ispredicted tohave a major impact on crop production. (IPCC, 2022).The numerous documented instances of ongoing crop yield declines worldwide serve as evidence of the severe effects of the global climate on crop production. (Bednar-Friedl et al. 2022, Trisos et al. 2022).

Therise inglobalair temperaturebroughton byhigher greenhousegasconcentrations is an impending change in the climate (Mall et al. 2006). Numerous studies have demonstrated that India has experienced an unparalleled rise in surface temperature over the past century. Compared to the previous century, the average global temperature has risen by 0.8°C (IPCC, 2013). Approximately 7.3 billion people live on Earth today; by 2050,that numberis predicted to riseto9.7 billion,and by 2100, it will reach 11.2 billion (UN, 2015). By 2100, food production will need to increase severaltimesovercurrentlevelsinordertoensurefoodsecurityfortheworld's rapidly growing population. Both the Indian and South Asian regions are heavily populated, have poor economies, and rely heavily on agriculture—which issusceptible to the effects of climate change. India's population could reach 1.66billion by 2050 (UN, 2015).

In South Asia, climate change poses a threat to sustainable development because of the region's high population density, extreme poverty, and lack of resources for adaptation. Thus, climate change is expected to severely harm the region's economy, society, and environment, undermining prospects for growth and initiatives to combat poverty (Ahmed et al. 2014). Because climate change affects crop growth and output, hydrologic balances, input sources, and other management methods, agriculture is particularlysensitive(Knoxetal.2012).Theimpactsofclimatechange onagriculture are numerous and include variations in sea level, pest and disease conditions, average temperatures, rainfall, and weather extremes, among other things (Niang et al. 2014; Porter et al. 2014). Increased temperatures cause early flowering and a shorter grain-fillingperiod,whichshortencropcyclesandloweryieldperunitarea (Chattopadhyay, 2011). High temperatures during the day and at night are expectedto increase in the near future and pose a serious environmental threat to food production and security worldwide (Lobell et al. 2011; Cairns et al. 2012; Hijioka et al. 2014). According to Randhawa et al. (2014), future climatic variability will also result in more frequent extreme weather events, such as unpredictable monsoons and an increase in the frequency and severity of drought and flooding, which will have an impact on both rainfed and irrigated agriculture systems.

With the minimum temperature rising at twice the rate of the maximum temperature, the diurnal temperature range has likewise shrunk throughout India (Roy and Balling, 2005). Over the Indian subcontinent, climate forecasts suggest an annual mean temperature increase between 3.5^{O}C and 5.5^{O}C by the 2080s, with the relativeincrease being smaller in the rabi (winter) season than in the kharif (monsoon) season (Lal et al. 2001).

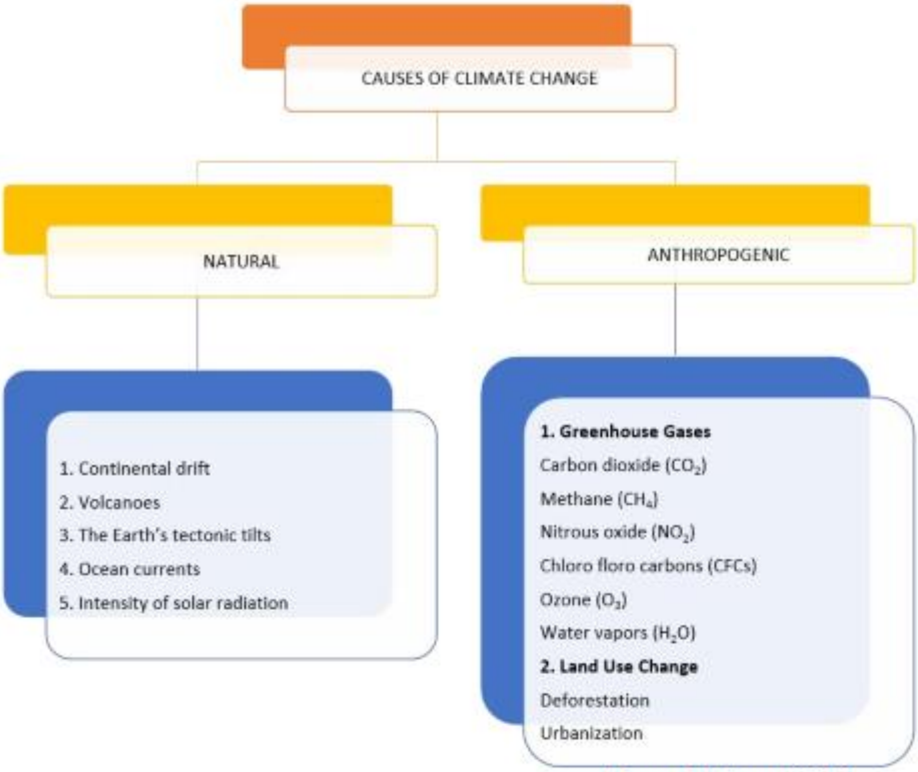
Rainfall is expected to increase in the kharif season by 2050, despite a tendency to decline in the rabi season (Lal et al. 2001; Prabhakar et al. 2008; Randhawa et al. 2014). Consequently, it is anticipated that rising temperatures and erratic rainfall will have a variety of effects on agriculture in India, endangering the food security and means of subsistence for over 700 million rural residents (Chattopadhyay, 2011; Dagar etal.2012).Globalclimatechangehasoccurred, althoughitseffects frequently differ from place to place and even from region to region (Trajkovic, 2009; Hadgu et al., 2014).

Therefore in this paper we discuss the relationship between effect climate variability and extremes on crop production. The relationship is discussed under the following headings; the unpredictability of climate change and its causes, the relationship between agriculture and climate change, climate variability versus crop production, climate change related stressors and their effects on crop adaptation, effect of climate changeonphysiological,metabolicandmorphologicalprocessesinplantsandclimate change mitigation and adaptation. The paper therefore helps to understand the effectof climate change on agriculture and the mitigation strategies as well.

Theunpredictabilityoftheclimateanditscauses

Many studies have been conducted on the significant climate variability (mean computation and variability of linked parameters of variables, such as temperature, rainfall, and wind during certain periods of time). According to estimates, climatic variabilityisrisingasaresultofrisingtemperatures. Inmany respects,the physiology of plants is significantly impacted by climate fluctuation. While most tropical and subtropical regions have seen a drop in precipitation, high latitudes have seen an increase. Animals as well as crop plants are under more stress due to climate variability and extreme weather events (Thornton et al. 2014).

The implications of climate change, especially its biological effects, have become abundantly clear in the last several years. Due to human activity and natural sources, there is an increase in the emission of gases such as carbon dioxide, methane, nitrous oxide, and halocarbons. These gases absorb solar radiation and contribute to the greenhouse effect (Valizadeh et al. 2014). Drought is caused by high temperatures, little precipitation, salt stress, and intense light (Salehi-Lisar and Bakhshayeshan, 2016).



Ahmad Khan, 2012

Fig 1: Causes Of Climate change

Therelationshipbetweenagricultureandclimatechange

Due to its vast scope and extreme weather sensitivity, agriculture is the industry most susceptible to climate change, with potentially catastrophic economic consequences (Mendelsohn, 2009). The amount of crop output is greatly impacted by variations in meteorological events like temperature and rainfall. The crop, location, and degree of parameter change allaffect the effects of rising temperatures, fluctuating precipitation, and CO_2fertilization. It has been discovered that rising temperatures lower yields, while rising precipitation is likely to neutralize or lessen the effects of rising temperatures (Hatfield et al. 2011). Crop productivity is dependent on crop type, climate scenario, CO_2fertilization effect, and adaptability skills when it comes to climate variables as observed in Iran (Karimi et al. 2018).

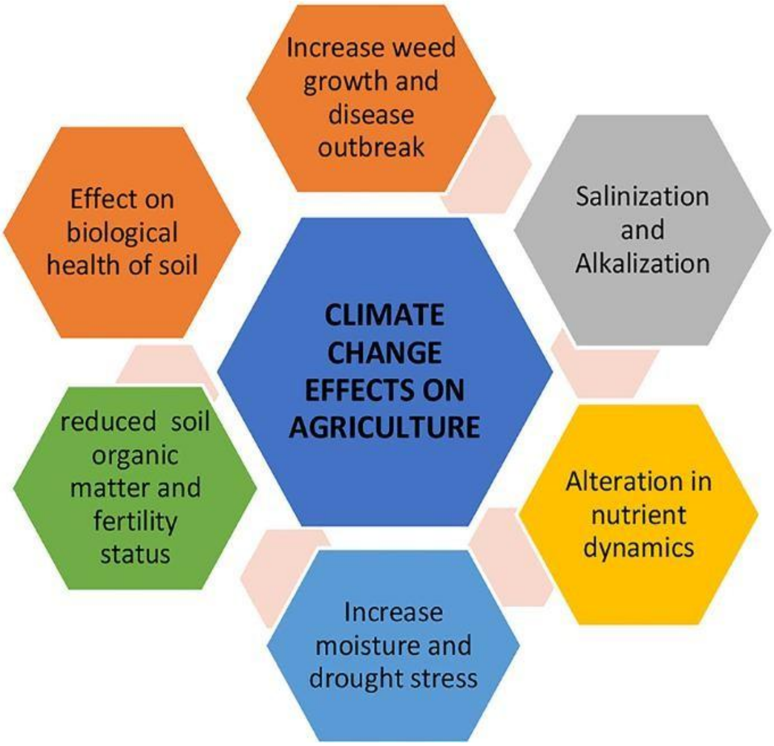


Fig 2: Impact ofclimatechangeonagriculture.(Ullahetal.2021)

Depending on the region and irrigation technique, agricultural yields are affected differently by climate change. Extending irrigated regions can boost crop yields, but doing so may have negative environmental effects (Kang et al. 2009). As a result of their shorter lifetime, several crops are expected to yield less due to temperature rise (Mahato,2014).If boththetemperateandtropicalregionsundergo awarmingof2^{O}C, thetotalproduction of wheat, rice, and maize isanticipated todecline (Challinor etal. 2014). Because tropical crops stay closer to their high-temperature optimaand soface high-temperature stress under rising levels of temperature, climate change generally has a greater impact on tropical regions.

Furthermore, humid and warmer regions tend to have higher rates of disease and insect pests (Malhi et al. 2021). Crop yields are also affected by other factors like humidity, wind speed, temperature, and rainfall; in the absence of these factors, there has been a potential for overestimating the cost of climate change.Reduced cropyields have the potential to drive up food costs and have a disastrous impact on agricultural wellbeing worldwide, with an estimated 0.3% yearly loss of future global GDP by 2100 (Stevanovic et al. 2016).

However, (Bosello and Zhang, 2005) discovered that while climate change has little impact on the world's food supply, underdeveloped nations will suffer greatly as a result.The agriculture industryinIndia maysuffer asa result of expectedtemperature increases of 2.33 to 4.78^{O}C, a doubling of CO_2concentration, and longer heat waves (Kumar and Gautam, 2014).

Temperature and precipitation variations have a significant impact on plant-water relations, and physiological changes are more likely to be affected by abrupt shifts in these variables than by variations in the average climate (Reyer et al. 2013). The way that different plant species and developmental stages react to climate change is evident. Different plant species have different thresholds, and different plant species respond differently—for example, by elongating their roots, altering their root developmentangle,orproducinglessofacrop(GreyandBrady,2016).Plant transpiration was shown to be reduced with increased CO_2level in the environment, resulting in an increase of 0.42 ± 0.02 K in air temperature. Land surfaces can warm by 3.33 ± 0.03 K due to a direct radiative effect and the indirect physiological effectof increased CO_2(Cao et al. 2010). Harvestable crop yields are predicted to rise in response to rising atmospheric CO_2levels, and plant developmental changes vary depending on the kind of crop. While higher yields are anticipated for C3 crops, decreased water requirements are anticipated for both C3 and C4 crops in the absence of stressful situations. However, higher temperatures and changed precipitation are expected to counterbalance these positive effects of increased CO_2(DaMatta et al. 2010).

Ontheotherhand,someregionsalsoshowthatclimatechangehasafavourableeffect on agricultural productivity. However, these regional variations—whether they were increases or decreases—would not cause significant alterations, and they would only become more noticeable in a few low latitudes. On the other hand, significant economic losses may result from temperature increases greater than those caused by doubling CO_2(Aydinalp and Cresser, 2008). The tropical regions of developing countries will bear a heavy burden from climate change, however the exact impact will primarily depend on local climate conditions.According to Zilberman et al. (2012),environmentalpoliciesneedtobedynamicandexecutedwithadaptabilityand flexibility, as the pace of climate change influences its impact and, in turn, the cost of adjustment.

Climaticvariablesversuscropproduction

Research clearly demonstrated that an increase in global temperature would have a negative impact on agriculture in the Indian subcontinent. According to Joshi and Amalkar (2009), temperature fluctuations, precipitation, carbon dioxide fertilization, short-term weather variability, and surface water runoff are the primary climatic elements that could impact agricultural output. Both good and negative effects on agricultural productivity are attributed to these factors. Temperature and precipitation trends in the climate have had, and will continue to have, a major influence on agriculture. Individuals of the same or different species will respond differently to changes in light, nutrients, water, or CO_2(Fernando et al. 2016); as a result, heterogeneity within or between species can be expected when atmospheric CO_2levels rise globally. With the right fertilization, variety selection, and optimal nutrient supply, adverse agro-ecological weather effects can be mitigated.

Temperature and crop production: Higher average temperatures in all major croppingzoneshavebeenandwillcontinuetobethemostpervasiveaspectofclimate change. In most places, the temperature thresholds for crops, such as 35°C or 40°C, will be exceeded on more days due to this increase in average temperatures alone. Global agriculture will typically suffer from temperature increases exceeding 2.5^{O}C (IPCC, 2001). Compared to precipitation, the growing trend towards global warming over the 20thcentury has been remarkably noticeable. Global warming is predicted to cause a 9–21% decrease in total agricultural productivity in developing nations, according to Cline (2007). Increases in temperature in mid- to high-latitude regions lead to higher yields; however, the impacts become less pronounced whentemperature fluctuations above 30^{O}C. Temperature variations may result in air vapour pressure deficits, which may have an effect on how much water is used in agricultural landscapes (Kirschbaum, 2004).

This may result in changes in temperature and water loss, as well as an impact on the rate of transpiration. According to reports, soil warming may have a deleterious impact on the growth, shape, and longevity of roots (McCormack et al. 2014). Numerous studies have shown that variations in soil temperature can affect the way that NH^{4+}, NO_3, P_2O_5, and K^+ are transported by roots, hence having a direct impact on plant nutrient absorption. Soil warming may promote plant nutrient acquisition by improvingroot uptakekinetics, asseen byimproved plantnutritionalstatuswhen root development and morphological traits are severely affected (BassiriRad, 2000). High temperaturesimpairtheprocessesthatallowlighttobeabsorbedandtransformedinto energy, which causes photorespiration to rise.

It is possible for the light-harvesting chlorophyll protein complex to irreversibly split apart from the nucleus of the photochemical reaction centre, and there may also be harm to the oxygen-producing water splitting mechanism. Higher temperatures so typically result in lower yields since they accelerate a plant's growth to maturity earlier, thereby shortening the time available for yield generation. They alsofrequentlyexacerbatethestress onwater resources, whicharecrucialfor cropgrowth. Since the air's capacity to store water increases non linearly with temperature, higher average temperatures will also result in higher rates of evapo-transpiration (ET). Higher ET rates will therefore tend to dry up the soil, increasing the frequency of low moistureextremes.If theyearlyvariabilityof theclimatewere torise,extremesmight also become more frequent in addition to variations in the average temperature. Pests, illnesses, and weeds are also more likely to be present in areas that are warmer and wetter.

Radiation and crop production: The only known source of energy for the universe's ecology, either directly or indirectly, is solar radiation. Photosynthesis and crop productivityaresignificantlyimpactedbyradiation(GholipoorandShahsavani,2008). Crop development and production are derived from photosynthesis and are reliant on the receipt and absorption of solar energy, as demonstrated by Reynolds et al. 2012. According to Richards (2006), seasonal fluctuations in solar radiation have a significant impact on yield. This notable crop response trend to solar radiation couldbe the result of a change in photosynthesis' duration. Due to the unequal partitioningof light, sowing time can be used to introduce variability in solar radiation, which eventually affects the duration of crop growth.

A longer period of time spent exposing a crop to favourable environmental conditions mayalsoresultingoodseedestablishmentandyield.Ontheotherside,owingof cloudcover'sreductionofsolarradiation,growthanddevelopmentwouldturn negative.Solarradiationisasignificantenvironmentalelementthatmodifieslight partitioningandleafarchitecture,promotingfavourablealterationsincropgrowth. Anydecreaseinsolarradiationwillsignificantlyloweragriculturalproductivitybecauseitisclоselylinkedtocropgrowth.Theconcomitantriseinminimum temperatures causes the crops to require more respiration, which lowers net growthand productivity (Aggarwal, 2003). Additional research points to a declining trend in solarradiation. Recently, it has beenshown that gases and particulatematter (aerosols) releasedintotheatmospherebyhumanactivityhavedisruptedtheearth'ssurface's ability to intercept solar radiation (Yamasoe et al. 2006).

Precipitation and crop Production: Thirty percent of the world's population lives in areas ofthe globe that are water stressed (McCarthy, 2001).Withglobal warming,the hydrologicalregimesinwhichcropsflourishwillundoubtedlyalter.Theavailability of water is a significant factor in agricultural output fluctuation in various situations (Keating et al. 2010). Variations in the amount of precipitation throughout the year, within-season patterns, and seasonal variations may also have an impact on the crop water regime. Stronger convection cells and more air moisture are expected to resultin increased convective rainfall, especially in the tropics. Over the course of the 20thcentury, precipitation has most likely grown by 5–10% over the majority of the mid- and high-latitude continents in the northern hemisphere, whereas it has declined by3% on average over the majority of the subtropical land area. Precipitation is widely acknowledged to be a major element influencing crop productivity, particularly for rainfed crops (Izaurralde et al. 2003). While insufficient precipitation can harm crop output, particularly if dry spells happen during crucial developmental stages,excessive precipitation can lead to disease infestation in crops. Changes in the precipitation and seasonal and yearly evapotranspiration regimes will have an impact on the availability and quantity of water held in the soil, which is an essential component of crop growth. The need for irrigation water is projected to increase due to global climate change (Jones et al. 2017).

CO_2increase and crop production: Since carbon dioxide is a fundamental resource for plant growth, the continuous rise in its concentration would enable breeders tostartchoosingthebestcultivarsfromtheexistingcroplines.Itisthebeliefofbreeders and agronomists that empirical selection for the fastest-growing, highest-yielding cultivars under current environmental conditions will lead to CO_2responsiveness; these conditions will eventually reflect changes in the background concentration of CO_2(Bouras et al. 2019).

According to projections made by the Intergovernmental Panel on Climate Change (IPCC, 2001), atmospheric CO_2concentrations will rise from 368 µmol/mol in 2000 to a range of 540 to 970 µmol/mol in 2100. Temperature rises are predicted to coincide with increases in the atmospheric concentration of CO_2. According to IPCC predictions, air temperatures will rise by 1.4 to 5.8^{0}C between 2000 and 2100 as a resultofgreenhousegasaccumulationintheatmosphere.Theseworldwidetrendswill be supported by significant regional variances (White et al. 2004). Higher CO_2concentrations cause plants to develop at faster rates of net photosynthesis and/or smaller stomatal diameters (Kobiljski and Dencic, 2001). Positively, some crops are predicted to benefit from the increased atmospheric concentration of carbon dioxide. Reduced transpiration per unit leaf area caused by partial stomatal closure, when combinedwith increasedphotosynthesis, frequentlyresults inimprovedWUE(Neenu et al. 2013).

As a result, higher CO_2concentrations can boost productivity while lowering water consumption. Under conditions of doubled CO_2, these C3 crops can experiencegrowthratesofupto50%(Dixon.2009).Comparedtotropicalcrops,temperatecrops might gain more from higher CO_2. It has been demonstrated that CO_2enrichment reduces photorespiration, or the quick oxidation of recently generated sugars in the light, in crop species that have the C3 pathway characteristic of non-tropical plants (such as wheat, soybean and cotton). This reduces the efficiency of photosynthesis asa whole. Because C4 crops fix CO_2into malate in their mesophyll cells before transferring it to the RuBP enzyme in the bundle-sheath cells, they are more photosynthetically efficient than C3 plants under current CO_2levels. C4 crops are particularly characteristic of tropical and warm arid regions (e.g., maize, sorghum,andmillet).ExperimentalstudiesindicatethatC4plantsarelesssusceptibletoCO$_2$

enrichment because of this CO$_2$-concentrating and photorespiration-avoiding mechanism (Prior et al. 2011).

Climatechange-relatedstressors andtheireffectsoncrop adaptation

Because of climate fluctuations, the impacts of abiotic pressures on crop adaptability and productivity have been reported (Nowsherwan et al. 2017). Abiotic variables cause abiotic stressors in plants. Extremes in temperature (stress from heat or cold), light, radiation, water (stress from flooding and drought), chemicals (metals and pH), and gaseous pollutants (ozone, sulphur dioxide) are some of these causes. According to Pereira (2016), heat and drought are two common field stressors that significantly affect plant performance and that of their progeny. They can also cause a plant's persistent problems.

Because plants need an ideal range of temperatures for both growth and adaptation, the range of temperatures surrounding any species' plants determines how much of that species' output there is. Temperature changes have an equally important impacton plant phenology (Hatfield and Prueger, 2015). Drought stress negatively impacts plant physiology, morphology, and biology. Heat stress decreases grain production and grain-filling duration. Frost causes sterility and abortion of grains (Barlow et al. 2015).

While climate change may benefit agriculture in certain parts of the world where the temperature is above 55^{O}C, many plants, particularly those that are native to warm environments, are negatively impacted by these changes. Severe summertimeweather events pose major risks to crop adaptability and productivity. For example, a rise in temperature, evaporation, and transpiration causes a wheat plant to shorten its flowering period from planting to emergence. A 1^{O}C temperature increase shortens flowering by 5 days. Temperature increases also affect the grain filling period, which ultimately results in a decrease in biomass (Valizadeh et al. 2014).

Table 1: PlantGrowthAffectedbyVariousStresses CausedbyClimate Change

Stress	Induced Secondary Stresses	EffectsinPlant	References
Chilling/freezingstress	Nutritional imbalance, osmotic and oxidative stress	• Buildup of reactive oxygen species (ROS) and oxidative damage; suppression of enzyme function and imbalance in metabolism. • Reduced photosynthetic activity, senescence, delayed maturity, increased cell starvation and dehydration, and damage to PS II. • Reduceddevelopmentand efficiency	Esim and Atici,2014; Megha et al. 2018
Drought	Osmotic,heavymetal, and oxidative stress	• Increased ROS production and ionleakage;induceddehydration and turgor loss. • Decrease in absorption and translocationofmineral	Ansariand Lin, 2010; Iqbaletal. 2020

		nutrients. • Protein denaturation, loss of enzyme activities, reduced photosynthetic activity due to abridgedchlorophyllcontentand CO2 assimilation. • Elevated leaf temperature, necrosis, early abscission, and slowed plant development.	
Flooding/ waterlogging	Water and nutrient deficiency stress,oxidative stress	• Reduced absorption and translocation of mineral nutrients;increasedgenerationof reactive oxygen species (ROS) and ion leakage; induced dehydration and turgor loss. • Denaturation of proteins, loss of enzyme activity, and decreasedphotosyntheticactivity as a result of lower CO2 absorption and chlorophyll concentration. • Stunted plant development, early abscission, necrosis, and elevated leaf temperatures.	Bailey-Serres and Voesenek 2008; Ashraf, 2012
Heatstress	Water scarcity, osmotic and oxidative stress	• Increased oxidative damage, denaturation, misfolding of proteins, and generation of ROS. • Reduced CO2 fixation, foliar senescence and abscission, growth inhibition, fruit and leaf discolouration,disturbanceofPS I and PS II, and disrupted ion transport.	Nievola et al. 2017; Sarkar et al. 2018; Demirelet al. 2020
Light/radiation stress	Oxidativestress	• Increased oxidative damage and ROS generation, interrupted photosynthesis ETC, and/or increased activity of membrane-bounded NADPH oxidase, degraded chlorophyll, decreased photosynthetic activity, and suppression of epidermal cell growth. • Condensed inflorescence stem with an increased number of flowering stems, decreased rosette diameter, and leaf senescence.	Noshi et al. 2016
Nutrient imbalance	Oxidativestress	• Reducedantioxidantsleading toabuildupofreactiveoxygen species(ROS); increasedionand	Bishtetal. 2019; Saleem et

		solute leakage; decreased metalloenzyme activity; and decreased photosynthesis. • Vulnerability to additional biotic and abiotic factors. • Growth retardation, chlorosis, necrosis, little fruit and flowering, and decreased output	al.2020
Ozone(O3)stress	Oxidativestress	• The generation of ROS results in oxidative damage, reduced stomatal conductance, decreased photosynthesis, slowed enzyme activity, and degradation of chlorophyll and xanthophyll. • Reduced plant biomass and productivity, early senescence, and chlorosis and necrosis of the leaves	Ainsworth etal.2012; Uedaetal. 2013
Salinity	Water scarcity, ionic imbalance, nutrient, osmotic andoxidative stress	• The generation of ROS results in oxidative damage, decreased K+, Ca2+, and Mg2+ content, restricted water and mineral nutrient uptake and translocation leading to Na+ toxicity, and decreased soil water potential. • Reduced photosynthesis, disordered thylakoid ultrastructure and decreased stomatal opening. • Decreased seed germination, premature leaf withering, as well as reduced productivity and growth	Kumar et al. 2017; Rahmanet al. 2016; Jaliletal. 2020

Effects of climate change on physiological, metabolic, and morphological processes in plants

Plants are experiencing unique ecological settings that fall outside of their optimal range for adaptation as a result of the rapid changes in climate conditions. The significant variations in temperature and precipitation patterns may make plant migration an impractical strategy. Despite the fact that plants have modified their physiology for benefit in unique settings, but according to Becklin et al. (2016), climate change might be just as harmful as pushing plants over their tolerance limits. Many plant species' morpho-biochemical processes are significantly impacted by abiotic stressors (Jan et al. 2016). However, according on agricultural physiology responses to anticipated climatic conditions for the next few years, crops will grow more quickly and, depending on the crop variety and specie, may see modest changes in blooming and fruiting (DaMatta et al. 2010). For plants, 10 to 35^{O}C is the ideal temperaturerange.Accordingto Tkemaladzeand Makhashvili (2016), plants canonly create a limited amount of energy as temperatures rise. After that, photosynthesis in the leaves drastically declines and is irreversibly lost.

Plant turgor pressure is lowered during drought, which eventually restricts cell development. Lack of water affects photosynthetic enzyme activity, lowers metabolic process efficiency and ultimately causes failure in the photosynthetic apparatus (Zargar et al. 2017). A rise in CO_2concentration broughtby shifting weather patterns causes a decrease in plant respiration and an increase in temperature. Temperature increases cause crop respiration to rise up to a maximum of 15–40ºC before declining (Amedie, 2013). The enzyme Rubisco is a component of the carbon fixation process, which transforms atmospheric carbon dioxide into molecules with high energycontent in photosynthetic organisms. Rubisco activase removes metabolites to maintainRubiscoactivewithintypicaltemperatureranges. Rubiscodeactivatesat low temperatures because it produces chemicals that are inhibitory (xylulose-1, 5-bisphosphate). Rubisco activase also denatures over the optimal range of species temperature, forming insoluble aggregates that are unable to remove inhibitors and activateRubisco.Temperatureelevationhasbeenshowntocauseavery quickdropin the activation state of Rubisco in cotton (Nasim et al. 2017). Enzymatic and non-enzymatic antioxidant defence mechanisms regulate reactive oxygen species (ROS), which are byproducts of cellular metabolisms and include hydrogen peroxide (H_2O_2), super oxides (O_2), hydroxyl ions (OH), and singlet oxygen (O_2). ROS are predominantly produced by cells and organelles at low concentrations under normal environmental settings, but their concentration rises under stressful circumstances (Sageetal.2008).Plantsthatproducetoomuchreactiveoxygenspecies(ROS)posea threat to proteins, lipids, and DNA, ultimately causing cellular damage and death(You and Chan 2015).

ClimateChangeMitigationandAdaptation

Farmers' perceptions of the severity and threat of climate change are the primary drivers of voluntary mitigation. However, the adaption is contingent upon the accessibility of pertinent data (Semenza et al. 2011).The anticipated rise in extreme weather events, alongside diminishing soil health and biodiversity, may elevate the costoffoodproduction.TheUnitedNationsadvocatesforglobalinterventionthrough 17 sustainable development goals (SDGs), four of which pertain to food production and security. These include tackling biodiversity decline (SDG 15), addressing ecosystem service loss and agroecosystem instability due to heightened stress from intensified food production and climate change (SDG 13), combatting soil health deterioration stemming from agricultural methods (SDGs 2 and 6), and reducing reliance on synthetic fertilizers and pesticides for enhanced productivity (SDG 2). Achieving these SDGs necessitates the agricultural sector's proactive engagement in reversing prevalent negative environmental trends. This entails implementing significant changes in agricultural practices to ensure resilience and adaptation to climate change by 2030 and beyond. (Shahmohamadloo et al. 2022).

Additionally, fewer individuals will be subjected to water stress thanks to mitigation methods; nevertheless, those who remain will still require adaptation strategies because their stress levels will be elevated (van Vuuren et al. 2011). Farmers can embrace climate-resilient technologies with the assistance of agroecological and traditional management techniques, such as biodiversification, soil management, and water collection (Altieri and Nicholls, 2017). According to Lal et al. (2011), these management techniques guarantee improved soil health, reduced soil erosion, enhancedcarbonsequestration,andresilientagriculturalsystemsthatwillultimately guarantee food security in the face of climate change. The most effective educational interventions for promoting climate change awareness for ecological development are those that centre on local, palpable, and doable issues that can be observed through individual behaviour (Anderson, 2012). The majority of farmers supportedadaptations,butonlyasmallpercentagesupportedreducinggreenhousegasemissions. This indicates the need to concentrate on programmes that include mitigation and adaptation elements (Arbuckle et al. 2015). Ventakeswarlu and Shanker (2009) have grouped the primary adaptation strategies of mitigation into three categories:resource-conservation technologies, cropping-system technologies, and socio- economic or policy initiatives. Small and marginal farmers are particularly vulnerable to losses because they lack the awareness necessary to adapt to climate change (Baul and McDonald, 2013). A few easy ways to reduce greenhouse gas emissions are rice thatisalternatelydriedanddrainedinthemiddleoftheseason,betteranimalnutrition, increased N-use efficiency, and soil carbon. It may be possible to lessen the effects of climate change by implementing straightforward adaptation techniques such altering planting dates and types (Aggarwal, 2008). Technology diffusion has a significant impact on how farmers react to climate change. According to Lybbert and Sumner (2012), the primary areas of focus are capacity building, market integration, and support for public research. Because conservation agriculture promotes minimal soil disturbance, crop diversity, and soil cover management, it has the ability to undo the damage caused by conventional ploughing over time. Additionally, conservation agriculture increases terrestrial carbon absorption, decreases fertilizer consumption, and reduces greenhouse gas emissions (Pagnani et al. 2019). Sustainable agriculture approaches are made possible by conservation agriculture, which is based on the fundamental concepts of minimum soil disturbance, crop rotation, and soil cover. Farmers in south Asia are cultivating wheat with zero tillage mainly due to a 15–16% decrease in cultivation costs. Furthermore, according to Erenstein et al. (2012), zero tillage produces higher yields of wheat and maize with less variability. No-till farming was also promoted as a substitute for traditional tillage, which reduces the effects of climate change by sequestering carbon. However, this claim is overstated because no-till farming adds very little additional organic carbon to the soil (Powlson et al. 2014). The adoption of conservation agriculture (CA) can be attributed to a number offactors, including the perception of personal benefits, the development of farmer organizations to support local adaptation, the use of functional market exchange techniques to supply the necessary resources for CA implementation,and the alliances between farmer organizations and institutions to create appropriate environments. (Brown et al. 2018).

Modified farming methods are the primary means of adapting to climate change. These practices are heavily influenced by policy decisions that take into account social, political, and economic factors as well as climate extremes and variability (Smit and Skinner, 2002). Nutrient management is crucial since the conventional intensification of agriculture resultsin enormous economic losses, of which over 80% are attributable to nutrient mismanagement (Lu et al. 2015). Soil restoration, nitrogen management,cover crops, manuring,no-tillfarming, andagroforestry can allpromote carbon sequestration, or an increase in soil organic carbon (SOC). One irrigation methodthatis beingpromoted tolessen groundwater overdraft and shocksbroughton by climate change is drip irrigation. It lessens the need for groundwater for irrigation and has the potential to be climate change resilient. However, farmers are employing drip irrigation in their intensive farming practices, which is producing more groundwateroverextractionandtheJevonsdilemma(Birkenholtz,2017).Sprinkler and drip irrigation are two examples of water-saving irrigation methods that can both reduce and adapt to climate change and offer long-term economic benefits. ReducedN application can be achieved through agricultural practices that take into account site-specific information without compromising profitability. For this reason,precision farming is thought to be more profitable than field management (Bongiovanni and Lowenberg-Deboer, 2004).One strategy for adjusting to environmental challenges in plants is to breed them to create new types. In order to test a variety's appropriateness for the target environment, multilocation experiments, breeding cycle shortening, and germplasm selection will be necessary (Atlin et al. 2017; Chhogyell et al. 2016).

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. By accumulating evidence, boosting the efficacy of local institutions, advocating for climate-smart agricultural policies, and connecting agricultural financing to climate, climate-smart agriculture increases resilience to climate change (Lipper et al. 2014).

The most effective climate-smart technologies are those that either support soil structure or supply water or nutrients. These mitigation techniques offer enormous potentialfor bothadaptationand mitigation.But theyalso relyonfactors likepeople's perceptions, technical complexity, economic viability, and a technology's suitability for the area. Furthermore, these tactics function best when several interventions are applied in tandem and in support of one another.

Conclusion

Theworld's mostserious issueright nowisclimatechange. Climatehasa well-known impact on crop quality and quantity, making it a significant and independent component in agriculture. The burden of maintaining global food and nutritional security due to population growth has placed significant strain on agriculture, a situation that is made worse by climate change. In a typical climate, the weather during the growing season mostly determines crop growth, development, and production. Little variations from the typical weather have a significant negative impact on food output, applied input efficiency, and weather. Climate change will reduceagriculturalproductivityinthecomingyears,accordingtoanumberofstudies, notwithstanding the uncertainty surrounding the future climate scenario and its potential effects. The primary determinants of climate, which are temperature, precipitation, and greenhouse gas emissions, have a substantial negative impact on plant physiology, pest infestation, soil fertility, irrigation resources, and metabolic processes.Agronomicchoices,tactics,andinterventionsthatresultinclimate-resilient farming systems can be guided by an understanding of how the climate is changing and will change locally, as well as the degree of the change and the opportunities and hazards it presents.

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