IMPACT OF CLIMATE VARIABILITY AND EXTREMES ON 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. This has increased plant productivity and growth because of increased photosynthesis; however, higher temperatures also increase crop respiration rate and evapotranspiration, cause pest infestation, change the flora of weeds, and shorten crop duration. This paper reviews the causes of climate change, the climate variables affecting crop production, the climate change related stressors in plants, the effect of climate change on plant processes and the mitigation and adaptation strategies against climate change.

INTRODUCTION

There's mounting evidence that the earth's temperature has increased during the past century, leading to unprecedented and unpredictable variations in the climate and negative effects on people's lives everywhere. (IPCC (Intergovernmental Panel on climate change, 2022). Due to agriculture's heavy reliance on weather, climate change has slowed down agricultural growth globally and is predicted to have 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).

The rise in global air temperature brought on by higher greenhouse gas concentrations 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 number is predicted to rise to 9.7 billion, and by 2100, it will reach 11.2 billion (UN, 2015). By 2100, food production will need to increase several times over current levels in order to ensure food security for the world's rapidly growing population. Both the Indian and South Asian regions are heavily populated, have poor economies, and rely heavily on agriculture—which is susceptible to the effects of climate change. India's population could reach 1.66 billion 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 seriously 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 particularly sensitive (Knox et al. 2012). The impacts of climate change on agriculture 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-filling period, which shorten crop cycles and lower yield per unit area (Chattopadhyay, 2011). High temperatures during the day and at night are expected to 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 relative increase being smaller in the rabi (winter) season than in the kharif (monsoon) season (Lal et al. 2001).

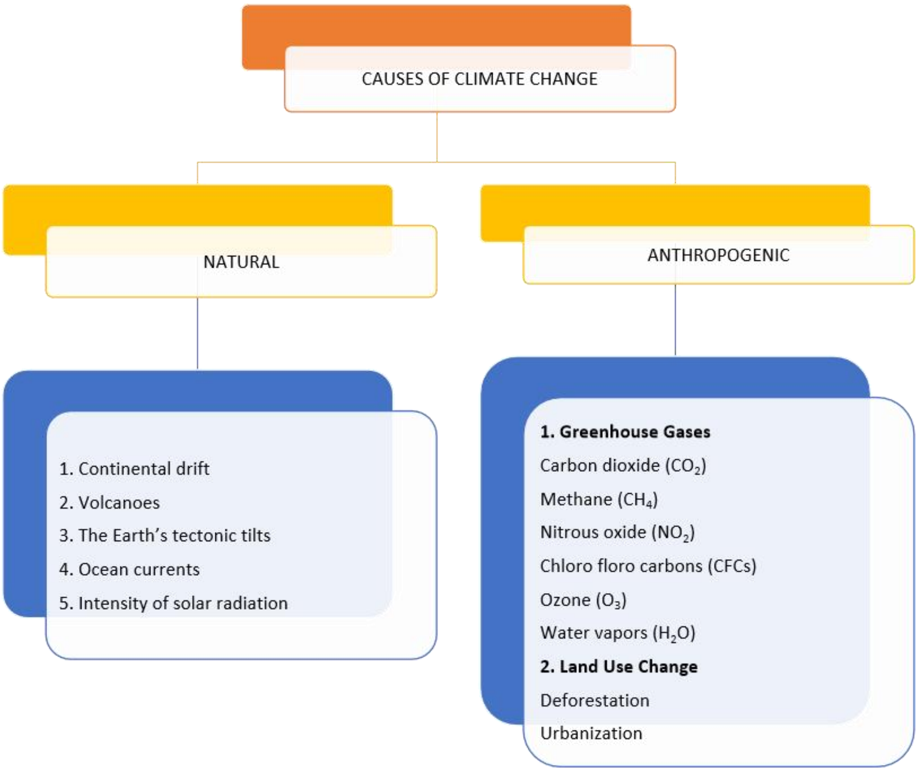
Rainfall is expected to increase in the kharif season by 2050, despite a tendency to decline in the rabi season (Lal et al. 2001; Prabhakar et al. 2008; Randhawa et al. 2014). Consequently, it is anticipated that rising temperatures and erratic rainfall will have a variety of effects on agriculture in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

The unpredictability of the climate and its causes

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 variability is rising as a result of rising temperatures. In many 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).

Chart 1. Causes of climate change



Ahmad Khan, 2012

The relationship between agriculture and climate change

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 all affect the effects of rising temperatures, fluctuating precipitation, and CO2 fertilization. It has been discovered that rising temperatures lower yields, while rising precipitation is likely to neutralize or lessen the effects of rising temperatures (Adams et al. 1998). Crop productivity is dependent on crop type, climate scenario, CO2 fertilization effect, and adaptability skills when it comes to climate variables as observed in Iran (Karimi et al. 2018).

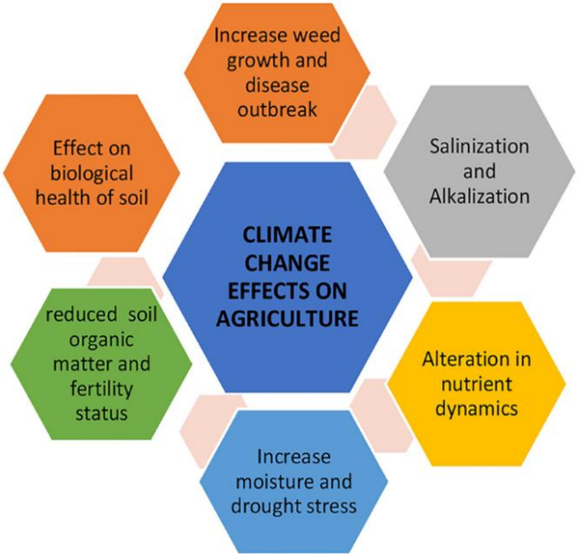


fig 1 : Impact of climate change on agriculture. (Ullah et al. 2021)

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 both the temperate and tropical regions undergo a warming of 2^{O}C, the total production of wheat, rice, and maize is anticipated to decline (Challinor et al. 2014). Because tropical crops stay closer to their high-temperature optima and so face 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 (Rosenzweig and Liverman, 1992). 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 crop yields 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 industry in India may suffer as a result of expected temperature increases of 2.33 to 4.78^{O}C, a doubling of CO_2 concentration, 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 development angle, or producing less of a crop (Grey and Brady, 2016). Plant transpiration was shown to be reduced with increased CO_2 level 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 effect of increased CO_2 (Cao et al. 2010). Harvestable crop yields are predicted to rise in response to rising atmospheric CO_2 levels, 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).

On the other hand, some regions also show that climate change has a favourable effect 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), environmental policies need to be dynamic and executed with adaptability and flexibility, as the pace of climate change influences its impact and, in turn, the cost of adjustment.

Climatic variables versus crop production

Research unequivocally 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 (Patterson and Flint, 1990); as a result, heterogeneity within or between species can be expected when atmospheric CO_2 levels 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 cropping zones have been and will continue to be the most pervasive aspect of climate 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 20th century 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 when temperature 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 (Hendrick and Pregitzer, 1993; Redmond, 1995). 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 improving root uptake kinetics, as seen by improved plant nutritional status when root development and morphological traits are severely affected (BassiriRad, 2000). High temperatures impair the processes that allow light to be absorbed and transformed into 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 also frequently exacerbate the stress on water resources, which are crucial for crop growth. Since the air's capacity to store water increases nonlinearly 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 moisture extremes. If the yearly variability of the climate were to rise, extremes might 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 productivity are significantly impacted by radiation (Gholipoor and Shahsavani, 2008). Crop development and production are derived from photosynthesis and are reliant on the receipt and absorption of solar energy, as demonstrated by Loomis and Amthor's (1996) documentation. According to Richards (2006), seasonal fluctuations in solar radiation have a significant impact on yield. This notable crop response trend to solar radiation could be the result of a change in photosynthesis' duration. Due to the unequal partitioning of 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 may also result in good seed establishment and yield. On the other side, owing of cloud cover's reduction of solar radiation, growth and development would turn negative. Solar radiation is a significant environmental element that modifies light partitioning and leaf architecture, promoting favourable alterations in crop growth. Any decrease in solar radiation will significantly lower agricultural productivity because it is closely linked to crop growth. The concomitant rise in minimum temperatures causes the crops to require more respiration, which lowers net growth and productivity (Aggarwal, 2003). Additional research points to a declining trend in solar radiation. Recently, it has been shown that gases and particulate matter (aerosols) released into the atmosphere by human activity have disrupted the earth's surface's ability to intercept solar radiation (Yamasoe et al. 2006).

Precipitation and crop Production: Thirty percent of the world's population lives in areas of the globe that are water stressed (McCarthy, 2001). With global warming, the hydrological regimes in which crops flourish will undoubtedly alter. The availability of water is a significant factor in agricultural output fluctuation in various situations (Ritchie, 1983). 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 result in increased convective rainfall, especially in the tropics. Over the course of the 20th century, 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 by 3% 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 (Adams et al. 1990).

CO_2 increase and crop production: Since carbon dioxide is a fundamental resource for plant growth, the continuous rise in its concentration would enable breeders to start choosing the best cultivars from the existing crop lines. It is the belief of breeders and agronomists that empirical selection for the fastest-growing, highest-yielding cultivars under current environmental conditions will lead to CO_2 responsiveness; these conditions will eventually reflect changes in the background concentration of CO_2 (Lawlor and Mitchell, 2000).

According to projections made by the Intergovernmental Panel on Climate Change (IPCC, 2001), atmospheric CO_2 concentrations 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 5.8^0C between 2000 and 2100 as a result of greenhouse gas accumulation in the atmosphere. These worldwide trends will be supported by significant regional variances (White et al. 2004). Higher CO_2 concentrations 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 combined with increased photosynthesis, frequently results in improved WUE (Haskett et al., 2000).

As a result, higher CO_2 concentrations can boost productivity while lowering water consumption. Under conditions of doubled CO_2, these C3 crops can experience growth rates of up to 50% (Kobiljski and Dencic, 2001). Compared to tropical crops, temperate crops might gain more from higher CO_2. It has been demonstrated that CO_2 enrichment 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 as a whole. Because C4 crops fix CO_2 into 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_2 levels. C4 crops are particularly characteristic of tropical and warm arid regions (e.g., maize, sorghum, and millet). Experimental studies indicate that C4 plants are less susceptible to CO_2 enrichment because of this CO_2-concentrating and photorespiration-avoiding mechanism (Acock and Allen, 1985).

Climate change-related stressors and their effects on crop 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 impact on 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 summertime weather 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).

list 1 :

Plant Growth Affected by Various Stresses Caused by Climate Change

Stress	Induced Secondary Stresses	Effects in Plant	References
Chilling/freezing stress	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. • Reduced development and efficiency	Esim and Atici, 2014; Megha et al. 2018
Drought	Osmotic, heavy metal, and oxidative stress	• Increased ROS production and ion leakage; induced dehydration and turgor loss. • Decrease in absorption and translocation of mineral nutrients. • Protein denaturation, loss of enzyme activities, reduced photosynthetic activity due to abridged chlorophyll content and CO2 assimilation. • Elevated leaf temperature, necrosis, early abscission, and slowed plant development.	Ansari and Lin, 2010; Iqbal et al. 2020
Flooding/ waterlogging	Water and nutrient deficiency stress, oxidative stress	• Reduced absorption and translocation of mineral nutrients; increased generation of reactive oxygen species (ROS) and ion leakage; induced dehydration and turgor loss. • Denaturation of proteins, loss of enzyme activity, and decreased photosynthetic activity as a result of lower CO2 absorption and chlorophyll concentration. • Stunted plant development,	Bailey-Serres and Voesenek 2008; Ashraf, 2012

		early abscission, necrosis, and elevated leaf temperatures.	
Heat stress	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, disturbance of PS I and PS II, and disrupted ion transport.	Nievola et al. 2017; Sarkar et al. 2018; Demirel et al. 2020
Light/radiation stress	Oxidative stress	• 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	Oxidative stress	• Reduced antioxidants leading to a buildup of reactive oxygen species (ROS); increased ion and 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	Bisht et al. 2019; Saleem et al. 2020
Ozone (O3) stress	Oxidative stress	• 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 et al. 2012; Ueda et al. 2013
Salinity	Water scarcity, ionic imbalance, nutrient, osmotic and oxidative stress	• The generation of ROS results in oxidative damage, decreased K+, Ca2+, and Mg2+ content, restricted water and mineral	Kumar et al. 2017; Rahman et al. 2016;

		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	Jalil et al. 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 temperature range. According to Tkemaladze and Makhashvili (2016), plants can only 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_2 concentration brought by 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 energy content in photosynthetic organisms. Rubisco activase removes metabolites to maintain Rubisco active within typical temperature ranges. Rubisco deactivates at 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 activate Rubisco. Temperature elevation has been shown to cause a very quick drop in 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 (Sage et al. 2008). Plants that produce too much reactive oxygen species (ROS) pose a threat to proteins, lipids, and DNA, ultimately causing cellular damage and death (You and Chan 2015).

Climate Change Mitigation and Adaptation

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). 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, enhanced carbon sequestration, and resilient agricultural systems that will ultimately 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 supported adaptations, but only a small percentage supported reducing greenhouse gas emissions. 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 that is alternately dried and drained in the middle of the season, better animal nutrition, 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 of factors, 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 results in enormous economic losses, of which over 80% are attributable to nutrient mismanagement (Lu et al. 2015). Soil restoration, nitrogen management, cover crops, manuring, no-till farming, and agroforestry can all promote carbon sequestration, or an increase in soil organic carbon (SOC). One irrigation method that is being promoted to lessen groundwater overdraft 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, farmers are employing drip irrigation in their intensive farming practices, which is producing more groundwater over extraction and the Jevons dilemma (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. Reduced N 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 potential for both adaptation and mitigation. But they also rely on factors like people'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

The world's most serious issue right now is climate change. Climate has a 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 reduce agricultural productivity in the coming years, according to a number of studies, 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. Agronomic choices, tactics, and interventions that result in climate-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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