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Climate change in relation to agriculture: A review

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Abstract

Climate change is among the most crucial concerns of the world. It is a serious threat to the global agriculture and its overall impact on global agriculture is yet not clear. A rise of 2.5-4.5ºC is expected in the global temperature until the end of 21st century. The amount of greenhouse gases particularly CO_2 is increasing at an alarming rate and is enhancing the plant photosynthesis and productivity. However, this increase in productivity is counteract by the more negative effects of climate change on agriculture like increased evapotranspiration, drought, floods, changes in the amount and distribution of rainfall, higher pest infestations and more irrigation demand. Climate change also affects the nutrients availability and efficiency by influencing microbial activities and population in the soil. Therefore, adaptation of agriculture sector to the changing climate is indispensable because of its sensitivity and size. This review is aimed to document the possible impacts of climate change on agriculture, its causes and future projections. Some strategies are also advised to mitigate the emission of greenhouse gases, to reduce the negative impacts of climate change on agriculture and to make new policies keeping in view their broader consequences on agriculture.

Additional key words: greenhouse gases; crop yield; food security; higher temperatures; yield

Abbreviations used: GHG (Greenhouse Gases); IPCC (Intergovernmental Panel on Climate Change); UNFCCC (United Nations Framework Convention on Climate Change).

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Introduction

Climate change alters the local weather conditions of a region thus, greatly influencing the agriculture of that area, both positively and negatively. In the past 100 years or more, the pace of climate change has been increased significantly (Arora, 2019). The change in climate is a serious threat to global food security (Tripathi *et al.*, 2016), water resources and human health (Magadza, 2000) and scientists agree that this issue should be addressed on priority basis (Tripathi *et al.*, 2016). The earth might experience an increase in the average temperature of 2.5 to 4.5ºC by the end of 21st century due to continuous rise in greenhouse gases (GHGs) (Bernstein *et al.*, 2007). Higher temperatures with elevated CO_2 levels compelled scientists to devise new strategies to cope with the less foreseeable challenges (Rosenzweig *et al.*, 2014).

Change in annual or seasonal precipitation distribution pattern along with alterations in temperature will cause the agriculture sector to suffer in terms of productivity, soil water, and crop yield in particular (Elmassah & Omran, 2014). Due to the deficiency of accurate data regarding future climatic conditions (daily temperature, precipitation and radiation), it is difficult to assess the conclusive impacts of climate change on agricultural production (Zhang *et al.*, 2017). Expected climate change and its subsequent effects on crop production are still an uncertainty that require greater attention for projecting the output of climate change on the agriculture sector (Liu *et al.*, 2017). The changes occurred due to climate change are expected to intensify in the 21st century if the emission of GHGs are not reduced (Abdulla *et al.*, 2009). Quantifying the impacts of climate change offers significant insights regarding cost to be spend on mitigation approaches.

Crop growth and yield can be simulated using crop (Yang *et al.*, 2018) and global climatic models (IPCC, 2013). However, the output from these models cannot be used directly to determine the site-specific impacts of

climate change on the crop (Wang *et al.*, 2016). Adaptation of agriculture sector to climate change through development of efficient strategies requires crop scientists, farmers, agribusiness, and policy makers to be aware of the potential threats to the agriculture posed by climate change (Howden *et al.*, 2007). The main goal of this study is to review previous studies regarding climate change and its various effects on the agriculture sector. Furthermore, mitigation strategies to confront climate change are also discoursed for a clear understanding of their potential significance.

Global climate change and its forecast

Global climate change has a key role in the challenges facing the whole world and threatening the future development planning, food security, prosperity, and economics of a country. In the 21st century, the two major problems of the globe are climate change and food insecurity. Globe's environment is continuously changing and one of the major factors responsible for this change is industrialization as it increases temperature by emitting large amounts of GHGs. The intensity of global warming is increasing gradually and has disturbed the global ecosystem (Kanojia & Dijkwel, 2018); however, the degree it will further disturb the global ecosystem is still dependent on human activities. Some impacts of climate change are shown in Fig. 1.

Global climate change in terms of increasing temperature, variations in precipitation, solar radiations, and elevated concentration of CO_2 have considerable effects on crop development and its output in terms of production (Wheeler & Von Braun, 2013). Fig. 2 shows natural and anthropogenic causes of global climate change. After the industrial revolution, an increase of almost 40% has been observed in the CO_2 concentration and it is estimated that it will further increase from its present level of around 400 ppm to 770 ppm in 2100, while it is suggested that a CO_2 level of 450 ppm is the threshold which could cause a rise of 2°C in the global average temperature as compared to values of preindustrial temperature (Challinor *et al.*, 2018). It was anticipated in the fourth IPCC Assessment Report (IPCC, 2007), that the impacts of climate change vary with rising in temperature and latitudinal locations; when the rise in temperature is less than 1°C, natural calamities like floods and water shortage will occur in some areas; with a rise of temperature by 2-3°C, it will affect most areas via natural calamities and about 20-30% of organisms (both plants and animals) will be under threat; if the temperature rises by more than 3°C, severe economic and environmental damages are forecasted like acute water shortages, im-

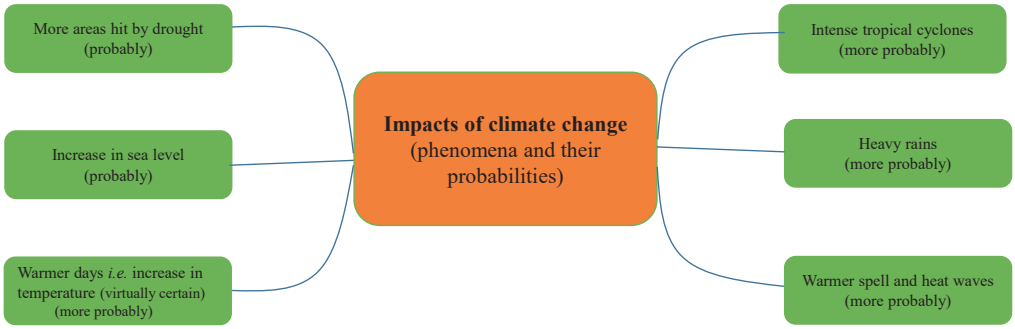


Figure 1. Impacts of climate change and their likelihood (IPCC, 2007)

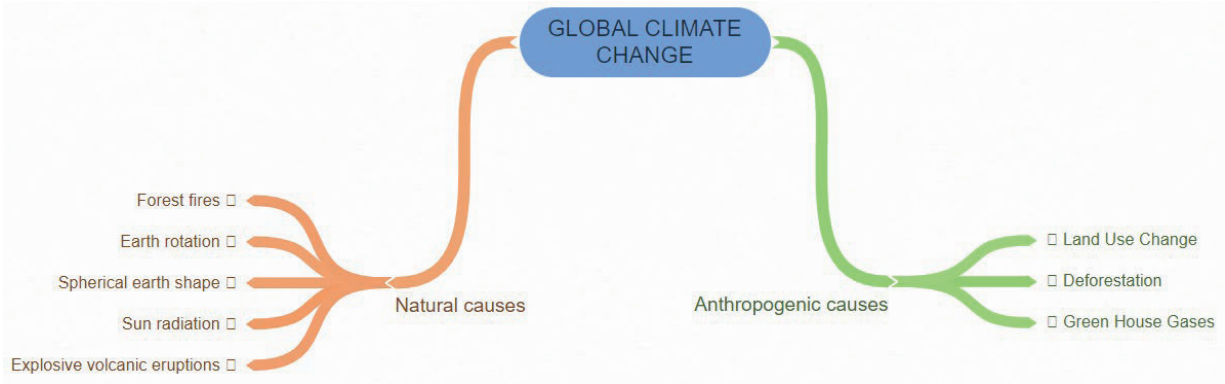


Figure 2. Causes of global climate change (Elmassah & Omran, 2014)

balance in the ecosystem, and decrement in food production with enhanced chances of diseases.

Climate change and agriculture

Agricultural productivity is the outcome of crop genotype and environment. Besides other sectors, agriculture is most vulnerable to climate change because any alteration in temperature and/or precipitation patterns directly influences the agriculture in terms of plant growth and finally the yield. However, this variation in yield varies from region to region. The change in production potential due to climate change will affect the trade flow too, with an estimated increase in the cereals import to developing countries (by 10–40%) by 2080 (Huang *et al.*, 2010). A series of impacts of climate change on the agriculture sector is shown in Fig. 3. The degradation in land is increasing day by day, being considered a major global threat (Arora, 2019) because it results in desertification and nutrient deficient soils. The agriculture sector is one of the major contributors to the emission of GHGs via N fertilization, livestock rearing, rice cultivation, and deforestation, but at the same time agriculture is also a great victim of environmental changes produced due to these emissions. Floods and droughts are not unknown for the world, but their frequency and intensity are expected to increase in this century, a threat to sustainable agriculture and food security. Srex (2012) reported that the near future predictions regarding climate change will have a more drastic effect on overall crop performance, subsequently giving rise to food insecurity mainly in South Asia and Sub-Saharan Africa.

Approximately 815 million people around the globe are affected by malnutrition, which is a major obstacle in achieving the universal goal of eradicating hunger by 2030 (Richardson *et al.*, 2018). With rising in temperature, the reduction in the production of major food crops

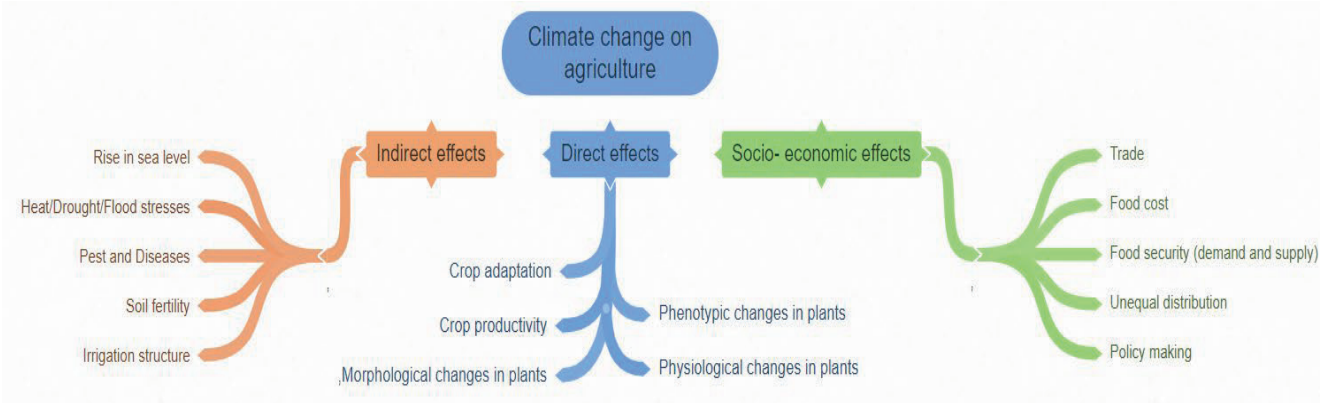


Figure 3. Direct, indirect and socio-economic effects of climate change on agriculture (Raza *et al.,* 2019)

Table 1. Positive and negative impacts of climate change (Raza *et al.*, 2019)

Climate change	
Positive impacts	**Negative impacts**
• Increased productivity due to warmer temperature	• Damages to crop due to extreme heat
• Increase in maturation rate	• Enhanced drought
• Longer and warmer growing seasons	• Increased soil erosion
• Possibility of growing new crops	• Heavy storms and floods
• Decrease of moisture stress in some areas	• Increased crop diseases
• Increased production due to higher CO_2	• Longer growing season
	• Problems in planning due to less reliable forecast
	• Increased weed growth
	• Increased crop diseases
	• Heat stress
	• Lowering in labor efficiency due to high heat
	• Torrential rain
	• Increase in insect outbreaks

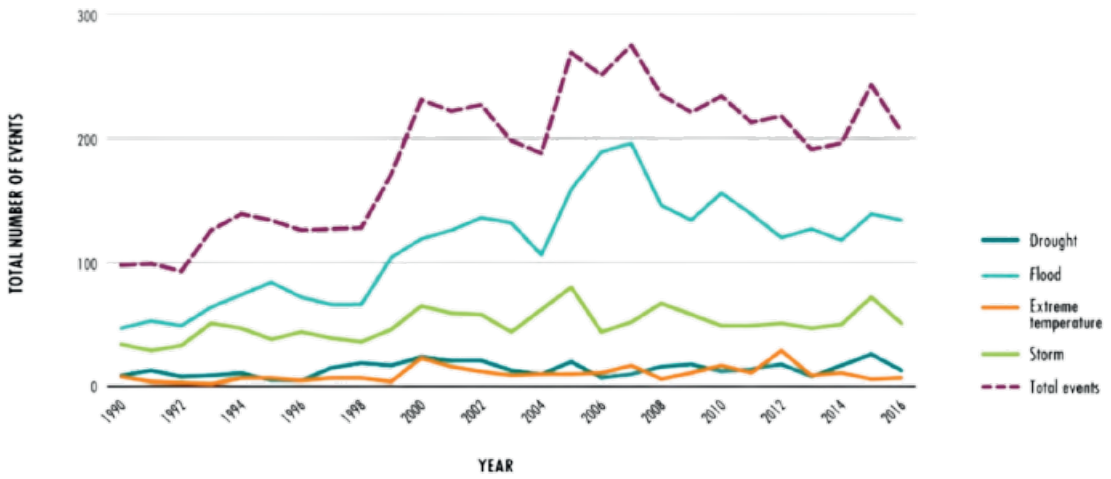


Figure 4. Increasing pace of climate-related phenomena during 1990-2016 (https://www.emdat.be/; FAO et al., 2018).

has been reported across the globe (Ito *et al.*, 2018). Extreme events like drought, flood, and temperature related to climate change increased dramatically during the last years as reported by FAO *et al.* (2018) (Fig. 4). Climate change will positively affect the agriculture in those areas lying within the northern latitudes above 55º (Ewert *et al.*, 2005), while in hot and drier areas, its effect on agriculture will be severe (Gregory *et al.*, 2005). One of the major challenges of the 21st century is to supply sufficient food to the increasing population under agro-environments which are already under severe stresses (Lal, 2005). Moreover, variations in climate are a major factor affecting yearly production even in regions with higher production technologies.

Positive effects of climate change

Various effects of climate change on agriculture are estimated and calculated by researchers. Alteration in annual/seasonal mean temperature, CO_2 concentration, and precipitation could increase the growth and production potential of some crops. However, this effect of climate change depends on several factors like crop genotype and location; *i.e.* wheat is more sensitive and responsive than maize for an increase in CO_2 concentration. Additional heat in northern locations are likely to increase the yield of grain crops (Elmassah & Omran, 2014). The effect of increase in temperature and CO_2 on crop yield is shown in Fig. 5. Higher rainfall in some areas might increase the yield by driving away insects (sensitive to rainfall like onion thrips) from the crops (Reiners & Petzoldt, 2005). It has been predicted that the yield might increase in North-Western Europe due to enhancement of GHGs and abrupt changes in climate (Olesen & Bindi, 2002).

One of the most important benefits of the rise in temperature, particularly in middle and high altitudes like USA, Australia and Europe, might be the improvement in crop growth and development, as growth in these areas is limited due to lower temperatures and shorter growing seasons (Rogelj *et al.*, 1995). Table 1 shows various positive and negative impacts of climate change on agriculture which occur in certain regions but are not common everywhere. Cao *et al.* (2010) reported an annual increase of 30-121 kg ha^{-1} in millet yield as a result of increase in temperature in three cities of China; they suggest more plantation of millet in those regions due to increasing temperature. Singh *et al.* (2017) reported that millet yield increased by 6% with drought stress and 8% with rising in temperature from 27-29ºC. Each crop has its own requirements in terms of climate and environmental conditions for growth, development and better yield. Therefore, va-

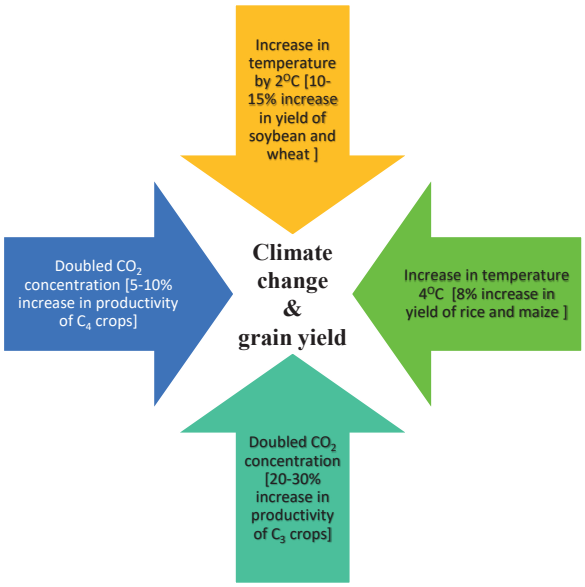


Figure 5. Impact of temperature and CO_2 increase on crop yield (Fisher *et al.*, 2002; Elmassah & Omran, 2014)

riations in these requirements lead to change in the cultivation area of crops. This change in the cultivation areas might be a disadvantage in one but an opportunity in other areas. Thus, this change cannot be classified as either negative or positive impacts of climate change. The warmer temperature and a decrease in moisture can be positive or negative, depending on the local conditions. So, the positive impacts of climate change are potential and located in certain regions.

Negative effects of climate change

Climate change has enormous negative impacts on the overall agriculture sector (Table 1). It includes a reduction in the crop quantity (First Mediterranean Assessment Report – MedECC, 2020) and quality (Fahad *et al.*, 2017) because of reduced crop growth as a result of rising in temperature. Weeds infestation, increase in blights, reduction in soil fertility due to rapid decomposition of stored organic matter in the soil, and increased soil erosion due to more rainfall are the negative consequences of climate change. Extreme drought conditions due to climate change lead to a reduction in crop productivity by causing nutrients immobilization and salt buildup in the soil, affecting negatively soil health and causing soil infertility (Arora, 2019). Such lands become barren and are left by farmers with the passage of time leading to social and economic problems. Moreover, floods and droughts are expected to increase in Sub-Saharan Africa as a result of climate change (Mirza, 2007).

In addition to fluctuations in temperature, variations in rainfall have also affected crop adaptability (Lamers *et al.*, 2011). Changes in environmental factors due to climate change have increased the chances of severe stresses for crops (Wen *et al.*, 2014). In the near future, it is expected that the productivity of major crops will drop due to global warming, water shortage, and other adverse environmental impacts (Zamir *et al.*, 2013). The two major stresses negatively impacting the cereal's yield are drought and high temperature (Hergert & Shaver, 2009). Water deficit during the meiotic phase in wheat and rice could cause a reduction in the grain set by 35-75% (Shang *et al.*, 2011). Furthermore, climate change has a negative impact on food security as various studies show a reduction in productivity of major crops (Thompson *et al.*, 2010). By the end of 2050s, due to reductions in yield caused by global warming, the market price of major food crops will increase, *i.e.* in the case of rice by 11-78% and for corn 42-131% (Conforti, 2011).

Higher temperatures and plant growth

An increase in the ambient temperature to a certain limit will allow the plant to produce more energy, but further increase in the temperature retard the plant growth and the photosynthesis rate drops badly (Tkemaladze & Makhashvili, 2016). Barlow *et al.* (2015) reported that an increase in temperature reduces both grain number and duration of grain filling period in wheat. Hatfield *et al.* (2011) documented that increasing temperature related to climate change will affect plant growth and development in addition to yield. Maize, when exposed to a temperature above 30ºC showed a reduction in cell division and amyloplast replication in seed, thus seed size and yield were reduced (Commuri & Jones, 2001). Plant response to higher temperature is shown in Fig. 6. Root growth improves with an increase in soil temperature because metabolic activities in root cells increases and also higher temperature helps in lateral roots formation (Repo *et al.*, 2004). The growth and development of annual crops mi-

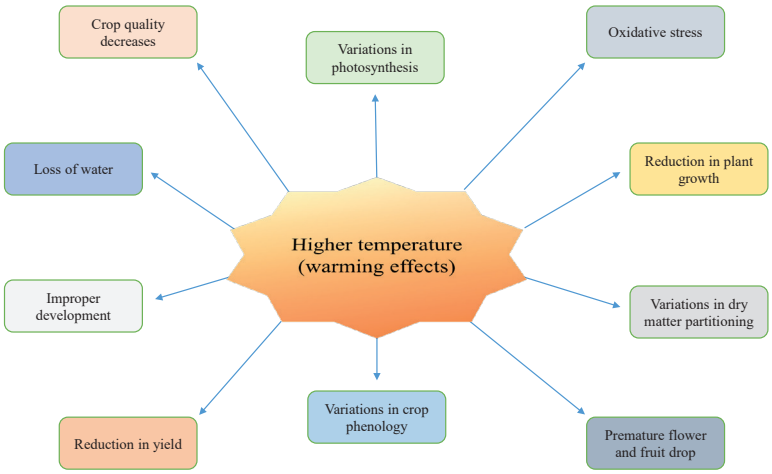


Figure 6. Effects of higher temperatures on plant growth and development (Hasanuzzaman *et al.,* 2013)

ght increase due to higher temperatures in growing seasons particularly in the grain filling phase, thus will result in less grain production (Downing *et al.*, 1996). An increase in the minimum air temperature might have a significant effect on crop growth and phenology (Hatfield *et al.*, 2011), and this increase is more expected under climate change (Knowles *et al.*, 2006). Exposure of apple to temperatures >22ºC during reproduction increases the soluble solids and fruit size but decreases firmness (Warrington *et al.*, 1999). Primary stresses like the production of stress-responsive proteins and associated solutes are induced by salinity and drought, which subsequently induce secondary stresses like osmotic and oxidative stresses (Carvalho & Amâncio, 2018).

Higher temperatures and water availability

The evaporation rate increases with increase in temperature and thus results in faster water cycling (Huang *et al.*, 2010). Global warming is expected to cause an increase in rainfall; however, the overall impact of higher temperatures on water availability is the competition between rainfall and evapotranspiration. This competition is typically won by evapotranspiration (Cline, 2008) but in some regions the opposite is true. It is expected that the demand for irrigation water will increase as more water will be required per area. Likewise, more energy will be required to pump water which will increase the cost of irrigation (Rogelj *et al.*, 1995). The impact of increasing temperature on the water is shown in Fig. 7.

Climate change is also playing a major role in increasing the pressure on the hydrological cycle along with other factors like pollution, population growth, and land-use changes (Aerts & Droogers, 2004). A report by IPCC (2007) informed that climate change might negatively affect water resources in all regions across the world. However, the intensity of the effect could vary from locality to locality. Climate change will increase the frequency of floods and drought spells in the Middle East and North Africa (Parry *et al.*, 2007). The World Bank (2012) evaluated the impact of climate change on water resources in Arab countries and indicated that water resources must be efficiently managed for the coming higher demand of water in the future. The predicted rise in evapotranspiration due to climate change will lead to more irrigation demand. The uncertainty created due to climate change, demands for generating new water resources with efficient use of limited water (Mirza, 2007).

Higher temperatures and soil fertility

Soil fertility could also be affected via climate change mainly through its effect on soil moisture level, increase in CO_2 concentration, and enhancement of soil temperature (Navneet, 2017). Soil moisture and temperature significantly affect nutrient availability and use efficiency because of its impact on root surface area (Brouder & Volenec, 2008). Plants take nutrients in solution form and changes in climate affect soil temperature and moisture, which in turn strongly influence the biological conversion of organic and inorganic forms of nutrients in solution form (Pendall *et al.*, 2004). An increase in soil temperature decreases organic matter content in soil through combustion (Ubeda *et al.*, 2009). This decrease in organic matter and reduction in clay size eventually decreases the cation exchange capacity of the soil (Certini, 2005). An increase in soil temperature increases the availability of water-soluble P because of an increase in the movement of P via diffusion (Yilvainio & Pettovuori, 2012) while

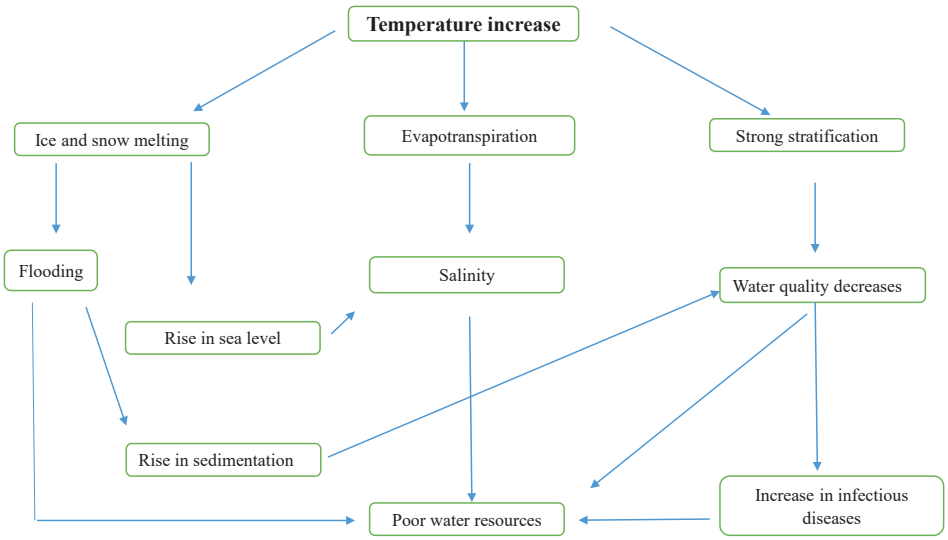


Figure 7. Effect of rise in temperature on water resources (Kazama & Oki, 2006)

decrease in soil temperature the availability of P decreases because lower temperature decreases the availability of P from organic matter (Gahoonia & Nielsen, 2003). Most of the soil microorganisms perform their activities with higher efficiency in 10-35.6ºC temperature (Davidson & Janssens, 2006) while under low soil temperature microbial activities decrease and at the freezing point they stop (Allison, 2005). The CO_2 content in the soil is influenced by soil temperature, as with the increase in temperature microbial activities increase, which leads to more production of CO_2 in the soil (Allison, 2005). Higher temperatures will increase soil evaporation and thus result in a reduction in soil moisture availability (Cline, 2008) and in this way increase the risk of salt accumulation in the soil (Elmassah & Omran, 2014). Global climate change significantly affects soil physicochemical characteristics like temperature, pH, hydrology, and nutrient cycles (Karmakar *et al.*, 2016). Likewise, climate change considerably influences both P (Hou *et al.*, 2018) and N cycles (Conniff, 2017). The effect of change in environmental factors on soil processes is depicted in Fig. 8.

Impact of an increased level of CO_2 on agriculture phenomena

An increase in CO_2 will increase the rate of photosynthesis by permitting plants absorbing more CO_2 and converting it into carbohydrates. However, such a quick response to increase in CO_2 seems to be restricted as stomata closes under long-term exposure to higher CO_2 concentrations (Elmassah & Omran, 2014). Transpiration decreases with increase in CO_2 levels, which results in higher water use efficiency (Rogelj *et al.*, 1995). Impacts of an increased level of CO_2 on various natural phenomena are shown in Fig. 9.

Fisher *et al.* (2002) reported that 20-30% increase in yield is expected in C3 plants (wheat, soybean, rice) at double CO_2 concentration, while this increase might be 5-10% in C4 plants (maize, sorghum). C3 crops are more positively affected by higher CO_2 concentrations than C4 crops (Stern *et al.*, 2006). With increasing CO_2 concentrations, the synthesis of carbohydrates increases, protein decreases, and relative proportions of major macronutrients change in non-leguminous C3 plants that do not fix N (Loladze, 2014). Taub & Wang (2013) reported that with an increase in atmospheric CO_2 concentration, the nutrient contents in edible tissues decrease in most C3 plants like wheat, rice, and potato, and some C4 plants like sugarcane and maize. Stomatal conductance decreases with an increase in CO_2 concentration (Ainsworth & Rogers, 2007). According to IPCC (2007), at elevated CO_2 concentrations (550 ppm) under optimum plant growth conditions, an increase of 10-20% in yield of C3 crops while 0-10% in yield of C4 crops has been recorded. Fig. 10 shows various impacts of increased CO_2 on crops.

Climate change impact on pests and diseases

The interaction between climate change with plant diseases and pests is a complex interaction and is not yet so much clear in terms of its effect on yield. Studies showed that pests like aphids (Newman, 2004) and weevil larvae (Staley & Johnson, 2008) have a positive correlation with the increase in CO_2 concentration. Changing climate in-

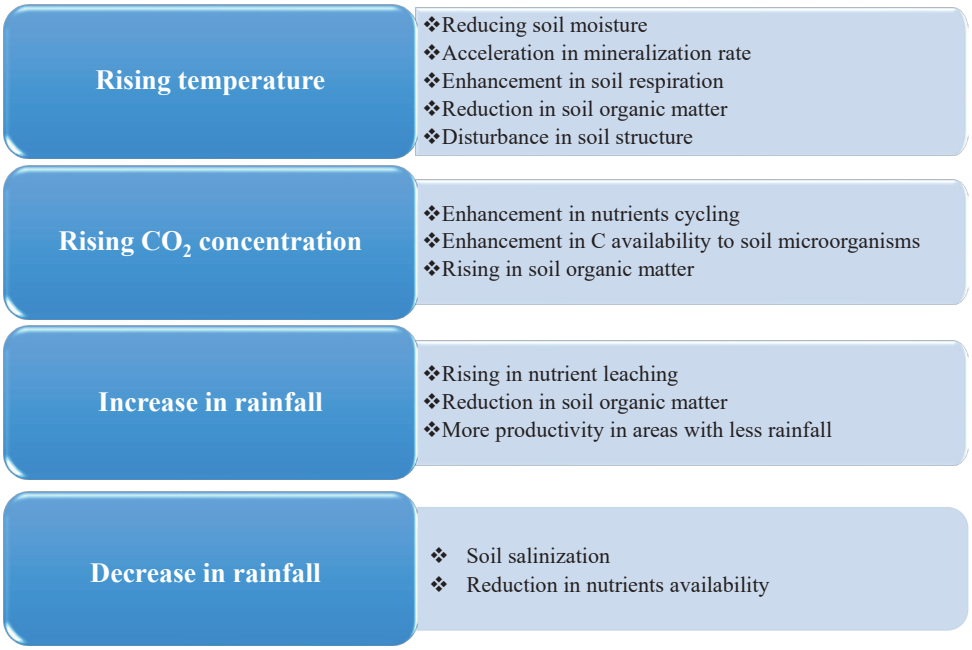


Figure 8. Effect of climate change on soil processes (Pareek, 2017)

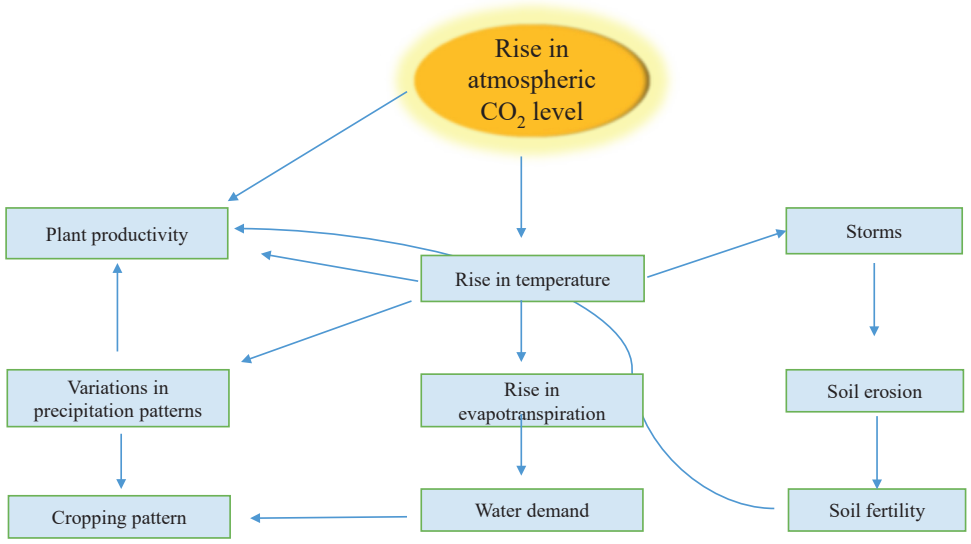


Figure 9. Effect of elevated CO_2 level on some natural processes (Ward *et al.,* 2016)

fluence pathogens and plant diseases. This could be due to the impact of aridity and/or warming on plant resistance to diseases and mutation induced in pathogens due to environmental stresses which increase their pathogenicity (Gregory *et al.*, 2009).

Changes in climate could cause an expansion in disease occurrence as diseases carrying pathogens would migrate from their main origin to other parts for its survival and adaptation (Peace, 2020). Insects living in the soil would survive better than insects living on the surface because soil provides better insulation to temperature than air (Bale *et al.*, 2002). Some insects like *Helicoverpa* spp. are migratory in nature and might be adapted by moving to new areas as a response to climate change (Sharma, 2005). Eastburn *et al.* (2010) reported that a rise in ozone level and CO_2 concentration in the atmosphere influence the type of disease and with rising in temperature the soybean became more susceptible to disease. Climate change can alter the disease triangle *i.e.* plant, pathogen, and environment interaction (Pathak *et al.*, 2018) and this alteration can cause the transmission of pathogens from one location to another and ultimately negatively affect plant population and its production potential (Andersen *et al.*, 2018). The pathogen density, disease transmission, infection mechanism, and host susceptibility (*i.e.* plant and pathogen interaction) is expected to increase as a result of climate change (Abdullah *et al.*, 2017). Similarly, future outbreaks of viral and other diseases are also expected in the future (Jones, 2016).

Climate change and yield

Impact of higher temperatures on plants and subsequently on yield is shown in Fig. 11. Agricultural yield and food security are affected by an adverse climate. The production of major crops has been reduced across the world due to increase in temperature (Ito *et al.*, 2018). Yield of cereals is highly affected by stresses like high temperature and drought (Barnabás *et al.*, 2008). A reduction of 25.7% is expected in agriculture production by 2080 due to a change in climate (Hellin *et al.*, 2014). Zhao *et al.* (2017) reported a reduction of 6%, 7.4%, 3.2%, and 3.1% in wheat, rice, maize and soybean, respectively, due to climate change. Baroowa & Gogoi (2014) documented that drought during the flowering stage reduced the yield of Mash bean by 31-57%, while this reduction was 26% during the reproductive phase. Drought stress during the

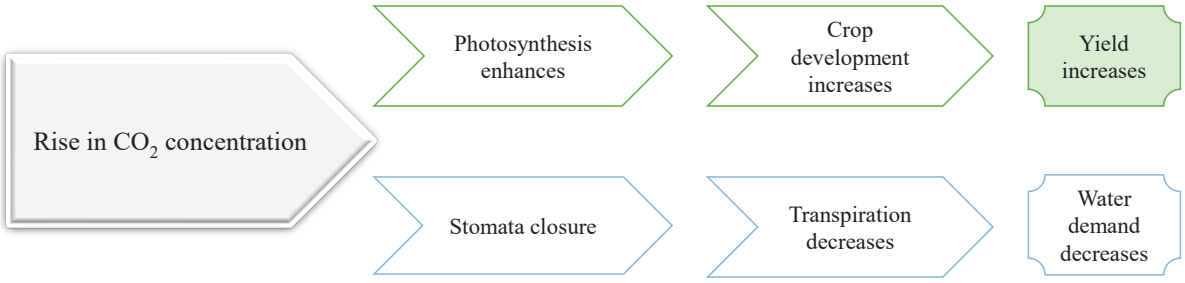


Figure 10. Effect of elevated CO_2 on crop´s phenomena (Elmassah & Omran, 2014)

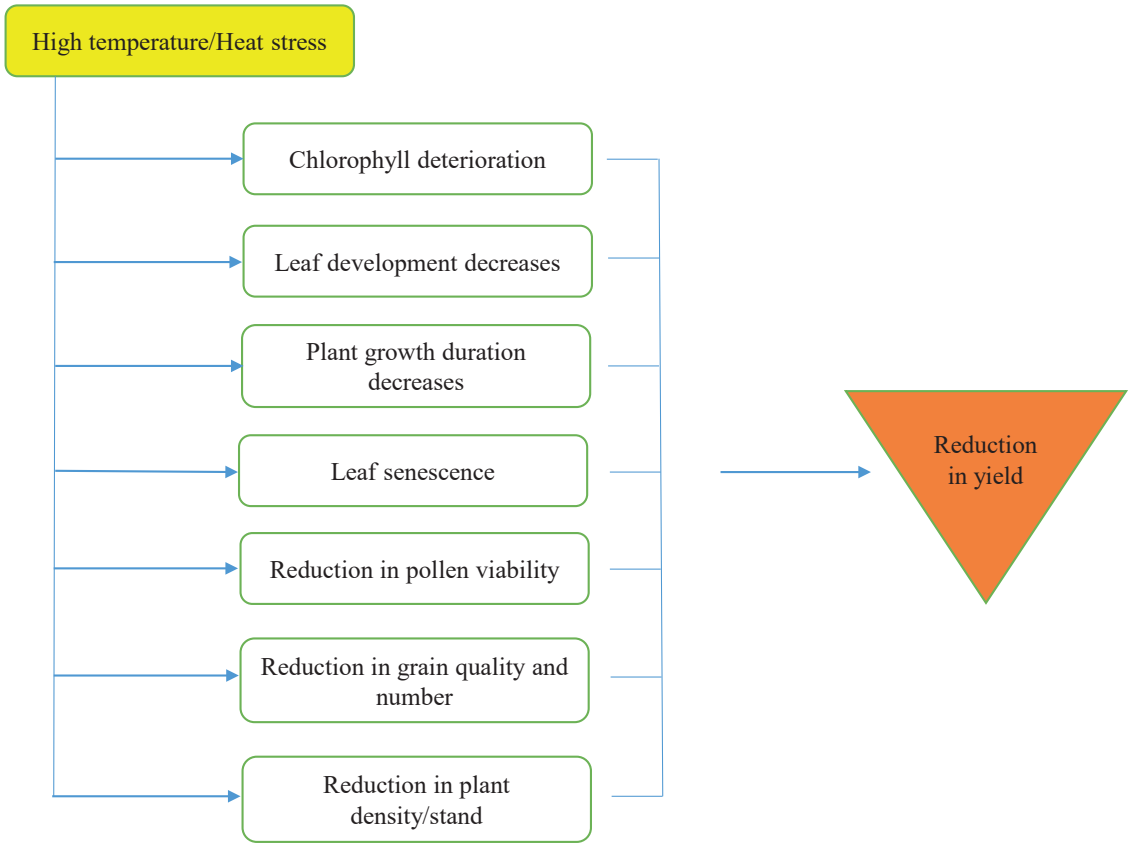


Figure 11. Effect of high temperature on plant and yield (Akter & Islam, 2017)

grain filling stage reduced the yield of soybean by 42% (Maleki *et al.*, 2013). Increase in the atmospheric concentration of CO_2 and the predicted changes in environmental factors due to global warming could drastically disturb the agriculture yield in the future due to alteration in plant development and transpiration factor.

Schlenker & Roberts (2009) reported that an increase in temperature above optimum hindered maize yield. Maize yield negatively affected for every 1ºC rise in temperature from the optimum growth temperature and it resulted in a reduction of maize yield by 10% (Lobell *et al.*, 2011) and the same increase in temperature reduced the wheat yield by 10% (Brown, 2008), rice yield by 2.6% (Easterling *et al.*, 2007) and sorghum yield by 7.8% (Kjellstrom *et al.*, 2018). A rise in temperature above the optimum level up to 30ºC increased the yield in soybean but further increase in temperature abruptly reduced the yield (Schlenker & Roberts, 2009). Respiration increased with an increase in temperature which subsequently increased C metabolism and finally reduces the yield of paddy (Hansen *et al.*, 2010). The number of research studies regarding the impacts of biotic and abiotic stresses on crops has increased in the last 30 years (Fig. 12). According to Skøt *et al.* (2016), if the current pace of GHGs emissions and climate change sustains, then considerable yield reduction of 5-50% in wheat, 20-45% in maize, and 20-30% in rice could occur. It means that the production of major cereal crops could decline to a serious level. One of the reasons for the fluctuation in the food prices is the decline in the crop yield and if this decline in yield continues, it is expected to be the main reason for the rise in food prices in the future.

Strategies for mitigating global warming

The GHGs include CO_2, N_2O, CH_4, HFCs (hydrofluorocarbons), SF6 (sulphur hexafluoride), and PFCs (perfluorocarbons) (UNFCCC, 2008). According to Stern´s (2007) report, an estimated cost of 1% of the global GDP is required for mitigating the effects of climate change and this cost would be 5-20 times higher in the future if nothing is done. The objectives of the global warming mitigation strategies are to limit the emission of GHGs. Various technologies and approaches have been suggested by researchers to reduce the emission of GHGs. Some of them are discussed below.

1. Biochar. The biochar is an organic material generated by heating organic substances like crop residues, woods, and leaves at moderate temperature (300-500ºC) in the complete or partial absence of oxygen (Antal & Gronli, 2003), a process called pyrolysis. Biochar is

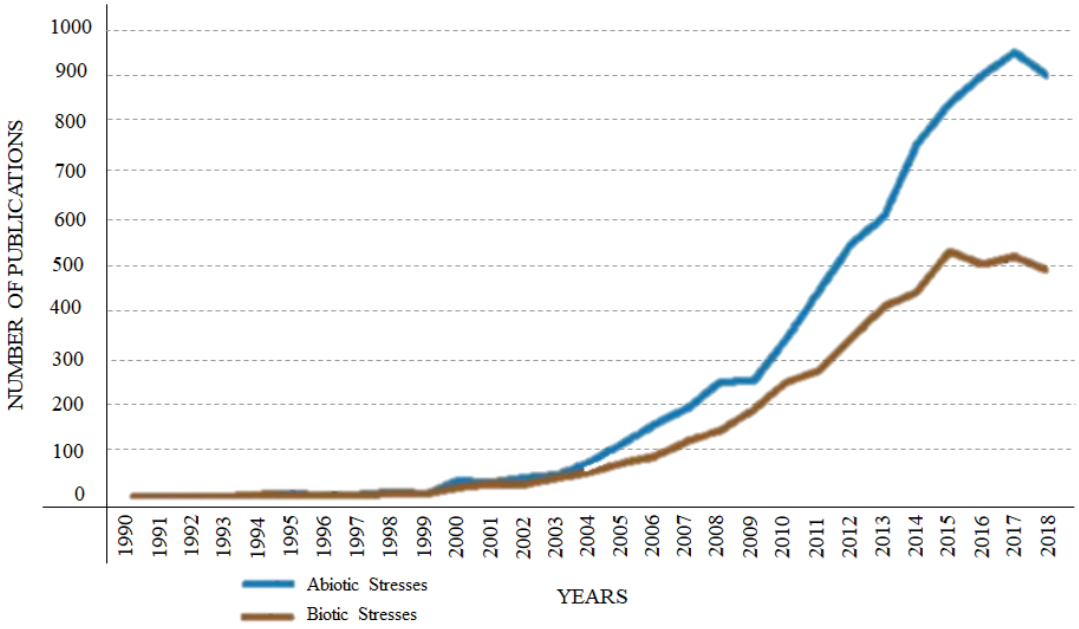


Figure 12. Publications per year (PubMed, 1990-2018) concerning biotic and abiotic stresses (Raza *et al.,* 2019)

highly enriched in organic carbon *i.e.* 70-80% and can be retained in the soil for longer period of time (Lehmann & Joseph, 2009). The resistance of biochar against microbial decomposition is very high because of its strong carbon bonds which do not break easily, thus reducing GHGs emissions from the soil. It is incorporated in the soil for carbon sequestration and improves long-term soil fertility (Kumar & Pooja, 2020). According to Lenton & Vaughan (2009), atmospheric C can be reduced up to 22 GT by 2050 using biochar. Biochar is an eco-friendly technology as it converts organic wastes into organic fertilizers, and can be used for generation of energy too (Lehmann & Joseph, 2009).

2. Renewable energy sources. Most of the energy is produced through fossil fuels which are non-renewable and emit a large quantity of GHGs contributing to global warming. It is necessary to shift to new renewable energy sources like wind, hydro, geothermal, ocean wave, and solar energies which are more efficient for the global environment (Uihlein & Magagna, 2016). Their capacity to emit GHGs is minimum as compared to conventional energy sources. No doubt, the cost of renewable energy sources is higher but as compared to the damages caused by conventional sources of energy is and will be much more in the coming future. The objectives of the approaches adopted to mitigate the effect of global warming is not only to develop a sustainable environment, but also to create a sustainable economy via renewable energy resources (Lackner *et al.*, 2015).

3. Mulching. Mulching is covering the bare soil surface with natural (crop residues) or synthetic (plastic) materials. Instead of burning crop residues which produces a huge amount of GHGs, the incorporation of mulch in the soil can help to reduce the emission of GHGs and also improves the soil fertility (Busari *et al.*, 2015). Mulching reduces evaporation, safeguards soil surface, and regulates the temperature of the soil as it retains soil moisture and decreases soil compaction (Chen *et al.*, 2007).

4. Converting soil carbon into a more stable form via soil micro-organisms. The micro-organisms convert soil organic carbon into various stable compounds like glomalin and humus that can last for hundreds of years (Ingham, 2003). Thus, the production of stable C-compounds like humus by using microbes is a better strategy to mitigate the emission of GHGs and subsequently global warming.

5. Agroforestry. One of the systems with more potential to mitigate the effect of global warming is the forest system, which acts as a huge sink of carbon (Schlamadinger *et al.*, 2007). The GHGs can be managed more efficiently by shifting agricultural landscapes and grasslands to forest-based C-rich systems (Bouman, 2001). Carbon can be efficiently captured from the atmosphere and shifted towards soil or vegetation in the systems of agroforestry (Albrecht & Kandji, 2003). According to Verchot *et al.* (2007), the system providing the highest potential for atmospheric C sequestration is considered agroforestry.

6. Other mitigation strategies. Smith *et al.* (2007) documented some strategies to mitigate the emission of GHGs and subsequently global warming: (a) Reduction in methane emission through integrated livestock and rice system which is traditionally practiced in West Africa, Vietnam, Indonesia, and India. (b) Integrating natural (animal) manures in waste management systems, inclu-

ding capturing of biogas and its utilization which helps in reducing the amount of N_2O and CH_4 and also leads to increase the demand for animal manures and acts as a good source of income for the people engaged with animal husbandry. (c) Land restoration via controlled grazing can enhance soil carbon sequestration.

Karmakar *et al.* (2016) indicated the following practices to mitigate the effect of global warming by reducing the emission of GHGs in the environment: decrease the application of N; reduction in the application of fungicides, herbicides, and pesticides; adoption of tillage methods with less loss of carbon; efficient control of weeds without soil damaging; control erosion; avoid burning of crop residues; avoid bare soil, and encourage soil coverage.

Future perspectives

The global warming produced due to GHGs and other gases has already affected and will affect more water sources, food supply, ecosystems, and infrastructures related to animal, plant, and human health. Different strategies viz forestation, covering bare soils, use of biochar, minimum or zero tillage operations, renewable energy, carbon sequestration, CO_2 capturing and removal, mitigating methane emission from rice field are some of the approaches recommended to reduce the emission of GHGs. An interdisciplinary approach should be adopted to mitigate the effects of global warming, *i.e.*, agronomists, soil scientists, plant physiologists, plant breeders, meteorologists, and water experts need to work in harmony to find an integrated approach to combat global warming. Also, policymakers have to provide financial support to individuals practicing eco-friendly agriculture (climate-smart agriculture). They should be aware of the current status of global warming to make sound and healthy decisions. Furthermore, government and non-government organizations, universities, and other research institutions have to play a key role by helping and convincing farmers to shift towards climate-smart/eco-friendly agriculture to reduce the deleterious impacts of global warming. Otherwise, the current cost for these mitigation strategies will increase many folds if nothing is done in the present.

Conclusions

The devastating change in climate is a bitter truth and need suitable timely actions. It is a major threat to agriculture as disclosed by increasing trend in CO_2 concentration and rise in temperature with variations in other epigenetic factors worldwide. The major yield and productivity losses assigned due to variation in climate particularly are of drought and heat stress in several areas around the globe (with negative effects relatively higher than positive ones in developing countries). It is, therefore, established that climate change has a direct effect on agriculture by changing precipitation, CO_2 concentration, and temperature-critical factors for plant growth and development. The distressing impact in agriculture caused by climate change is very hard to overcome. There is still lack of information and uncertainty in tackling the problem of climate change. In inference, the overall impact of climate change *i.e.* positive and negative impacts can be classified as opportunities and costs. Positive impacts might create better opportunities in some areas while the negative impacts might increase the cost to compensate for these changes in agriculture. It is therefore need of the hour to formulate such strategies that can help in maximizing the opportunities and minimizing the cost to fulfill the needs for sustainable development of agriculture.

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