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Review Article

Climate Change and Crop Productivity: A Global Review of Impacts, Adaptation, and Future Challenges

Imran Aslam[1], Muhammad Bilal[2], Farhan Tariq[3], Rana Muhammad Faheem Saeed[4], Syeda Arooj Fatima[5], Muhammad Rizwan[6], Muhammad Ahmad[7*], Muhammad Bilal[8]

[1,2,3,4]Department of Entomology, University of Agriculture Faisalabad 38040, Pakistan

[5]Institute of molecular biology and biotechnology, Bahauddin Zakariya University 60090, Pakistan

[6,8]Institute of soil and environmental science, University of Agriculture Faisalabad 38040, Pakistan

[7]Department of Agronomy, University of Agriculture Faisalabad 38040, Pakistan

*Corresponding Author E-mail: ahmad391ch@gmail.com

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ABSTRACT

Climate change is a challenge in agriculture throughout the world and knocking on the door in terms of production through changed temperatures, rain distribution and frequency of calamities. This review reviews the global history of climate change, how climate change affects agriculture and impacts different cereals, fruits and vegetables, pulses, oilseeds as well as special crops. In this context, it is possible to analyses regional differences of these impacts with the division of developed and developing regions, and tropical and temperate climate zones. The review also looks at how farmers adjust to adverse changes in Climate such as in terms of technology, farming practices, and public policies on changes in climate that reduces yield on crops. Projections for the future of the field are made while pondering upon the fact that most of the climate change effects on agriculture are still complex to model. Based on the findings of the review the following are suggested for further research and policy actions towards food security in view of climate change.

Keywords: *Climate change, farming methods, food production, environmental temperature changes, crop yields, sustainable agriculture.*

INTRODUCTION

Global warming is globally accepted as one of the biggest challenges the world is faced with in the twenty-first century, bearing an impact on all sectors of the global climate, the earth's economy and society. (Burroughs, 2003) As the economy's base since – and an industry dependent on environmental factors it seems that agriculture remains to be the most vulnerable to climate change. (Fischer et al., 2002) The global population increases every year and to meet the food demand the agricultural systems are already exerting pressure due to the effects of climate change (McMichael, 2001).

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This increasing demand therefore generates real problems of the need for higher agricultural productivity where environment stability is decreasing. And if there exists one issue that cannot be disassociated from agriculture, the issue is climate change. (Pretty, 2008). Meteorological factors are a set or complicated factors that affect farming in relation to weather conditions including temperature, humidity, rainfall, and atmospheric CO2 levels. Fluctuations in these aspects are able to bring about major changes in plant growth and productivity, which feeds straight into one of the key concerns of mankind: food production. (Kabir et al., 2023) As extreme weather condition remains a constant feature with its severity increasing, it is highly necessary that such subject as agriculture reacts to the mentioned facts and remains sensitive towards the dynamic changes. (McCown, 2002).

The effect of climate change on crop yield is profound for several reason which include the following. First, it interferes with food security which is of most concern in areas where agriculture is the main source of income. (Newton et al., 2011) This is especially the case in many developing countries where a large number of people engage in subsistence farming hence a slight variation in climate greatly affects food productivity hence enormously deepening poverty and malnutrition. (Praveen & Sharma, 2019) Secondly, the losses are economic because it is one of the most crucial sectors even in the contemporary world, as it still contributes greatly to the gross domestic product of many countries, most especially the developing ones. (Kolahchi et al., 2021) Agricultural productivity is closely associated with changes in food prices, export earnings and hence growth and development of different economies. (Dorward, 2013).

Crop yields are not constant, and when there's a decrease, societies are affected as noted below. (Fischer, 2015) Lack of food causes social problems, as people fight over the limited resources; people also try to move to other regions in a search for improved living conditions. This may cause instabilities, skirmishes and in a broader perspective, conflict between and within the countries involved. (Barraclough, 1991) Thus, climate change and agriculture are not only the environmental problem but the phenomenon connected with economic, social, and political spheres. (Fischer et al., 2005) Due to the sensitivity and contentiousness of this topic, it is necessary to produce a systematic analysis of the current knowledge on how climate change affects crop output in a global context. (White et al., 2011) This review will provide a comprehensive dissection of climate change and its impacts in; historical climatic changes and changes on the agriculture sector, particularly crops, and different regions with special focus on the measures being taken towards adaptation. (Pathak et al., 2012) The purpose of this current review is to provide a detailed insight of prior works done on the effects of climate change on crop yields and the general requirements for improved yield in the light of the challenges posed by climate change. (Rezaei et al., 2023) Thus, while filling gaps in existing studies based on integration of recent findings and empirical data, the present review aims at offering a balanced view on the relationship between climate aspects and agricultural output. (Adams, 1989) The review covers a broad range of topics, including the findings point out that previous climate changes have affected agriculture and crop production practices, a knowledge that can be used to predict future changes. In this section the issue of climate change over the years and how climate has affected agriculture historically will be discussed in this paper. (Karki et al., 2020) This review will explore the changes in physiology as well as in environment introduced by climate change as a phenomenon that affects alterations in temperature, precipitation, CO2 environment and more frequently, extreme climate changes. (Trenberth, 2011) These mechanisms will be discussed separately for the purpose of showing how they affect crop performance either singularly or in combination with another. Various crops as have been observed by various researchers and biologists as having varied sensitivity towards climatic conditions due to their inherent biological makeup as well as the specific regional settings which they are grown in. (Challinor et al., 2009) This section will consider effects on ate crops, and starch crops that are essential food security staple crops, and also assess effects on export crops, or specialty crops key to some economies. (Nanbol & Namo, 2019) The impacts of climate change are not similar anywhere in the world since they differ according to location, climate, and development standards. (Chinowsky et al., 2011) This section will address the global aspects of the problem and will illustrate how the tropical, temperate and developed as well as developing countries are affected and how they respond to the problem with reference to crop yields. Climate change has various adverse impacts, and consequently different adaptation approaches and mitigation measures are in the process of elaboration. (Abbass et al., 2022).

Climate Change and Agriculture

It is however important to note that climate change is not a recent thing; it has been in existence for millions of years. However, the rates of changes that have been witnessed in the last few hundred years and most especially in the industrial age, are unbelievable. (Thompson, 2010) Americans have participated in the universal surge in greenhouse gases emissions particularly CO2 resulting from burning of hydrocarbons, deforestation, and industrial processes that have caused a proportional rise in global temperatures. (Filonchyk et al., 2024) Global temperatures have increased by roughly one degree centigrade over the course of the hundred years. Almost all the regions of the world experience warming, which is by 2°C and even higher. (Lindsey & Dahlman, 2020) This warming has also been observed to come with changes in precipitation pattern with some regions experiencing higher frequent and intense rainfall and other experiencing long durations of drought. (Dore, 2005) In the duration the frequency and intensity of such calamities as hurricanes, heat waves, and floods have improved. The employments of these changes are diverse and stupendous. (Summers et al., 2022) Ecological systems are shifting, and quite a number of animals and plants are finding it extremely difficult to cope with the new climatic changes, hence changing the flow of species distribution and contributing to a new round of extinction. (Parmesan, 2006) Atlantic temperatures are increasing and ocean acidification is also becoming a problem from which coral bleaching which is poisonous to all sea life is surfacing from its depths this marine source of food directly impacts the world food chain. (Pörtner, 2008).

The calving and melting of polar ice caps and glaciers have increased and therefore increased sea level that is dangerous to coastal regions and ecosystems. (Barua et al., 2022) In particular, in agricultural contexts, climate changes have become a crucial issue, because they disrupt traditional growing seasons and, thus, create new difficulties for farmers as far as climate predictability is concerned. (Altieri & Koohafkan, 2008) Due to increase in pest and diseases attacks which has been attributed to increase in temperatures, vulnerability of crops is worsened. (Skendžić et al., 2021)These environmental changes plead their causes with socio-economic difficulties which primarily affect vulnerable groups of the population, especially in the developing countries where the agricultural sector is dominant. (Warner et al., 2010) At some point, resources are limited and conditions are not friendly, which increases the chances of conflict and displacement: climate change is not only an environmental problem, but a major source of social and economic insecurity. (Barnett, 2006) Considering such shifts, the need to address the consequences of climate change has become rather critical and should be done internationally. These are for instance; averting the emission of greenhouse gases and encouraging the use of clean sources of energy, sustainable use of land. (Schipper & Pelling, 2006) What has quietly dawned is the fact that stakeholders must begin setting aside resources towards finding ways on how vulnerable populations can cope with the climatic changes that are already upon us. Climate change science has thus moved more and more to the forefront of policy consideration as countries continue to search for ways to both sustain their present standards of living and at the same time preserve the earth for the future population. (Council et al., 1999).

Relationship between Climate Variables and Agriculture

Climate change affects agricultural output to a large extent owing to it being very much influenced by climatic factors. The key climate variables that affect crop's growth and production include temperature, rainfall, and CO2. (Lobell & Gourdji, 2012) All these variables have significant impacts on the life cycle of plants right from germination to the mature stage and thus their change because of climate change has a multiplier effect on agricultural production. (Bhadouria et al., 2019).

Temperature: The temperature too poses a significant influence in the growth of most of the crops since they embrace their most suitable temperature bands. Any extremes to such ranges through heat affects the development of the plant or through severe cold leads to low yield. (Bhadouria et al., 2019) For example, in the phase of flowers, early heat can harm pollination, that is why yields reduce to fruits or grains. (Jagadish, 2020) On the other hand, flash freezes harm young seedlings badly or give frost injury to plants in the process of development, slowing them down completely. (Sakai & Larcher, 2012) Long-term exposure to under-optimal conditions can also affect the process of effective photosynthesis the plants undergoing – an imperative process in energy generation. (Hussain et al., 2024) If growth is retarded this way the biomass production is also reduced and consequently there is loss in crop productivity. (Bugbee & Monje, 1992) Furthermore, fluctuations in the temperatures will lead to changes in the microbial activity of the soils impacting on the availability of the nutrients and thus stressing the plants even more. (Schimel et al., 2007).

At times it could lead to faster crop maturity which is not so good for yield quality and quantity because of reduced time for grain fill. (Yang & Zhang, 2006) On the one hand, the temperature below the optimal level of plant growth leads to longer time for crop maturity and in turn plants may be pruned by early frosts or just provide fewer days to harvest in a season. (Ritchie & Nesmith, 1991) Water deficits affect plant temperature fluctuations as well which are conditions of water stress. With rise in temperature, rates of evapotranspiration rises meaning that water will be lost in bigger amounts from the soil as well as the physical plant. (Tardieu, 2013) This will only exacerbate the problem of drought in areas where fresh water is a scarce resource as it is. (Postel, 2000) On the other hand, low temperatures affect water uptake efficiency in the plants and which could be worsen if root growth is affected by cold temperatures of the soils. (Kuiper, 1964) In conclusion, the temperature management of crops is one of the greatest significance for increasing yields as well as for stabilizing and improving the quality of the crops grown. (Waraich et al., 2012) Since climate change has proceeded to some extent in its capacity to raise temperatures beyond former historic averages, the assessment as well as control of temperatures vary will demand heightened focus if the food security is to be enhanced globally. (Salinger, 2005).

Precipitation Crop growth requires enough and on time rainfall. Three sources of risks that affect the yields include; unfavorable climatic conditions, and especially either lack of enough rainfall or too much rain. (Hatfield et al., 2011) Water stress is occasioned by pre-harvest rains while post-harvest rains results in soil erosion, nutrient leaching and water logging, which are negative when it comes to crop yield. (El-Ramady, 2013) Under conditions where it is dry, crops can undergo risky situations whereby they fail to get adequate water hence undergo a process known as water stress that hampers growth, lowers the processes undergone in photosynthesis, lead to wilting and crop failure (Farooq et al., 2009). By the process of translocation water play a major role in the transportation of nutrients to inside the plant but when the moisture level is low then all the above process gets affected. (Alam, 1999) Drought stress can also adversely affect the amount of available moisture and this in conjunction can lead to the hard setting of the soil which will be detrimental to root growth and inhibits the plant's ability to access deep water sources. (Seleiman et al., 2021) There are negative impacts which include crop failure whereby crops such as cereal crops are most likely to be affected as well as food insecure arid areas which have relied on rain fed agriculture. (Devereux, 2007).

On the other hand they are equally misleading; if it rains heavily it becomes disastrous. Rain Splash and this is another misfortune; torrential rains lead to soil erosion and thus remove the most productive top soil layer that has most nutrients. (Ellison, 1950) It is a loss of nutrient wealth and strength of the ground reducing its capacity to produce and also have long term detrimental impacts on some specific agricultural plots. (Lal, 2009) Excessive precipitation also results to leaching that affects nutrient that are essential to plant growth such as nitrogen, potassium and phosphorus. (Rashmi et al., 2017) This not only reduces the strength of the crops, but also makes the plants require more fertilizing; this comes with its own disadvantages since it is expensive and can contribute greatly to the spoiling of the environment. (Zeppel et al., 2014).

Torrential and continuous rainfall results to water logging; a state which the ground is full of water the way it is full of air. (Akhtar & Nazir, 2013) Stagnant or water saturated soil prevents the delivery of oxygen to the roots of the plants which needs it for respiration and absorption of nutrients. (Bhattarai et al., 2011) This leads to root rot, and low nutrient uptake and finally results in plant death other factors such as over-watering and water logging, effect nutrients and water absorption by the plants. This is especially so because waterlogged conditions affect the crops that are easily affected by moist conditions and which leads to even higher yield losses. (Gareeb, 2007) These direct impacts of erratic rainfall mean that farmers can be affected through changes of the time frame of planting or harvesting. Irrational distribution of rainfall may lead to postponement of planting and hence reduce on the period of growth reducing on yields. (Simelton et al., 2013) Similarly, stringent foods during the period of harvesting compromise the yields, and post-harvest losses augment since most foods are likely to be spoiled by such weather conditions (Prusky, 2011). These, and other similar changes in the climate mean that in most parts of the world, the climate has become unpredictable, with alternating dry weather and storm events. (Seneviratne et al., 2021) This variability makes the risk and the level of unpredictability faced by farmers higher and the conditions they have to reach for sustenance Yields harder to achieve. Hence, comprehension of the effects of precipitation in farming is of great importance in food security concerns and adaptability to changed climate in agriculture. (Berhane, 2018).

CO2 Levels: Higher levels of atmospheric CO2 stimulate plant photosynthesis, potentially increasing crop yields, but it is a double edge sword because other climatic changes such as higher temperatures, and changes in precipitation are likely to have negative effects on crop yields. (Kimball & Idso, 1983) Moreover, CO2 fertilization effect, which is the process of enhancement of plant growth through increase of CO2 concentration is low and differs from crop to crop and is also maximum when other mandatory resources like water and nutrients are available. (Erda et al., 2005) For example, C3 plants like wheat, rice, and soybean stimulate their growth by increased CO2 levels owing to their photosynthetic process; however, these effects can be hampered or counterproductive due to heat stress because of high temperatures. (von Caemmerer & Evans, 2010) Optimum temperature increases the rate of respiration, utilization of stored carbohydrates, and shortens the period for growth thus resulting in poor grain filing and low yields. (Jain et al., 2007) At its worse, heat stress can reduce the crop yield by affecting crops at sensitive phonological stages, including flowering, which will negate any positive effects of increasing levels of CO2. This is due to the interrelationship of CO2 levels and the nature of precipitation in relation crops productivity. (Prasad et al., 2008) If climate change results in either increased frequency of droughts or irregular distribution of rainfall in the regions, favorable impacts of elevated CO2 on crop productivity may be substantially reduced by water deficits. (Calanca, 2007) Stomata of plants also close during drought conditions meaning that the plant will not be in a position to take and intake a lot of CO2 and thus causes minimal photosynthesis and growth. (van Meeteren & Aliniaeifard, 2016) On the other hand, where rainfall is high or there are frequent floods, the CO2 uptake may be accompanied by water logging and soil erosion which reduces root growth and nutrient uptake. (Mchunu & Chaplot, 2012).

In fact, as we analyses the consequence of CO2 fertilization, it can be seen that though it improves the yield in a sense of biomass it ultimately affects the quality of the crop. (Liliane & Charles, 2020) Higher levels of CO2 cutting have been found to lower concentration of proteins, vitamins and minerals in crops including those of wheat, rice and potatoes. This deterioration of nutritional value is a major problem for the world food security especially in the third world countries where people depend on staple foods as their main source of food. (Taub et al., 2008) Higher level of atmospheric CO2 can also affect plant metabolism to the extent that crops become susceptible to pests and diseases. (Fuhrer, 2003) Higher levels of CO2 also alter the relative composition of tissues within plants in some way and this makes the plant tissues more palatable to herbivorous insects. (Whittaker, 2013) This in turn may cause greater density of pests, which could mean the need to apply more strenuous pest control methods thus adding to challenges of farming in a given climate. (Altieri, 1993) In total, therefore, while the message contained within the concept that the process of photosynthesis could be stimulated by CO2 to guarantee the constant sustenance of agricultural yields carries a certain potentiality of truth, it is far from the whole truth; for more often than not, these seeming advantages are offset by the much greater global impacts of climate change. (Bassham, 1977) Interaction of these factors, namely, increased levels of CO2, temperature, alteration in precipitation and other climatic factors show that combining effect of these changes pose significant challenges for agriculture; and hence requirements for effective adaptation measures that cannot solely depend on the aspect of CO2 fertilization. (Malhi et al., 2021).

Mechanisms through Climate Change affects Crop Yields

It is destructive to crops to have climate change. The most ostensible consequences are due to changes in the temperatures and favorable conditions that change the morphology of plant in one or the other way. (Aslam et al., 2022) For example, warmer temperatures exert an influence of early maturity, the time available for managing the grain filling stage is limited hence low yields. (Arshad et al., 2017) With this, things like the amount of moisture on the ground which is very essential for plant growth is determined by precipitating factors. In addition to these changes, climate change has the following other effects on yields of crops through remote impacts. (Hilgard, 2025) These include: Temperatures and altered rainfall patterns alter the conditions surrounding the crops and provide a favorable ground for pest and diseases thus reducing the yield of crops. (Newton et al., 2011) These changes in climate may render risky the balance of plant, its pests and diseases and lead to a rise of the effect of the latter two. This they are able to do because warmer temperatures enhance their growth and breeding; they therefore reproduce and increase their numbers more than other organisms. (Goudriaan & Zadoks, 1995) For instance, insect pests such as aphids and caterpillars may reproduce at a younger age and at multiple times, in a single growing season, so as to attain a number that has the potential of causing massive damage to crops. (Kumar & Rathor, 2020) Beside, through raising temperature many pests can expand the coverage area, and they can infest the area, which they could not survive before. (Hill, 1987) It can also make crops that are grown in these new regions easily attacked by 'new' pests which the farmer has nearly no resistance against. Influence also to pests and diseases because of change in rainfall and/or irrigation, the population structure of pests and diseases change that is associated with that crop. (Gould, 1991) Excess humidity and excess of duration gives chances of development of diseases like rust, blight and mildews etc. These diseases hit crop not sparing those grown in areas of high humidity and they are very aggressive because they lead to high crop losses, in case they are not well attended to. (Lucas et al., 1992) On the other hand drought conditions have a negative effect of the plant making them to dull and become prone to pests and diseases. (Farooq et al., 2009) These threats are even more adverse to stressed plant since through a weakened ability by the plants to mitigate or contain such damages and hence increased vulnerability and yield losses. (Pandey et al., 2017).

Pollination: While with increasing concentrations of atmospheric CO2 planting yields in certain crops may increase because of enhanced photosynthesis, climatic change such as increase in temperature and changes in the cycles of rainfall drawback from the advantage. (Polley, 2002) Also, carbon dioxide fertilization – the idea that plant grow better with high levels of CO2 spices it up by the fact that it vary by crop and in most instances, they will only get the plus if other vital inputs such as water and fertilizers are available. (Sharangi et al., 2023).

For example C3 crops such as wheat, rice and soybean that have Avmp of 0. 15 to 0. 36 have positive response to elevated CO2 being part of their photosynthetic pathway However, any such benefit could be offset or nullified by heat stress due to high temperate. (Pathak et al., 2010) Stress resulting from drought could augment the metabolic rates, use up carbohydrates faster, reduce the plant growth and development period and thereby reduced grain filling and yield. (Farooq et al., 2009) This is because while enhancing the rate of plant photosynthesis through high levels of CO2 has been realized to have an effect on irrigation water use but not on rain, since the plant s use water more efficiently when there is high amounts of CO2. (MacAlister, 2020) Indeed, where climate change leads to more frequent drought or less reliable rain, then the advantages on the increased CO2 can be far overtaken by water depression. It reduces the capacity of stomata to open for the plants so that they are in a position to access CO2 this also retards photosynthesis and growth due to drought (Oliver et al., 2009). In the other hand in areas where there is high rainfall or flooding the benefit of CO2 may be overwhelmed by the negative effect of water logging and soil erosion thus damaging the root system and nutrient leaching. Thus, raising yield in terms of biomass as a result of CO2 fertilization, the overall nutritional quality of the plants diminishes (Kaur et al., 2020). Higher levels of CO2 known to depress the nutritional value of crops such as wheat, rice and potato reducing their protein, vitamin and mineral content. This loss of nutritional value is a critical problem to world food security especially for the third world populations where these starchy foods form the food staple (Zhu et al., 2018). Extreme weather events, such as heavy rainfall and droughts, can degrade soil health, reducing its fertility and ability to support crop growth. These events disrupt the delicate balance of soil structure, composition, and microbial activity, which are crucial for maintaining productive agricultural systems.

There will also be threats of soil erosion in which a large portion of surface soil with high nutrients and organic material will be washed by the rain water. This topsoil is very important since most of nutrient and organic matter of the soil is usually concentrated in it and is important in growth of crop plants (Rhodes, 2014). It also affects soil fertility, besides this, with erosion of the topsoil, the water retention capacity of the soil is also hampered and the area is vulnerable to further droughts. It was also establish that erosion results into depositing of sediments within water bodies hence resulting into other adverse impacts on the environment and water quality. This is called water logged and this occurs when there is lot of water in the soil, this limits the supply of oxygen to the root of plants. Roots need oxygen for respiration; if this supply is cut off, roots die and plants or crops will not survive at best, will yield poor result at worst (Armstrong & Drew, 2002). Too much of water also interferes with the process of decomposition of organic matter by soil microorganisms which are involved in the process of cycling nutrients. Such disruption can result to accumulation of destructive elements like hydrogen sulfide, which is detrimental to plant root and crop yields. Droughts on the other hand lead to desertification of the soils through other processes including compaction and salinization of the soil. During periods of drought the soil may compress and this in the case where the soil is poor in organic matter. The pore space is reduced in compacted soil and this hinders the growth of the roots and the water holding capacity of the soil is also limited. There are general effects which include reduced seed germination, reduced plant growth and therefore reduced crop yield (Le Houérou, 1996). However, drought in arid and semi-arid regions whereby conditions significantly increase salinity whereby salts deposit as water sublimates. Salinity affects plant water and nutrient uptake reducing the yield or even prove lethal to the crop in high concentrations. Eutrophication is likely to be more pronounced in the irrigated areas since poor irrigation techniques perpetuate the problem of salt buildup in the soil (Majeed & Muhammad, 2019).

Impact on Different Crop Types

Salinity affects plant water and nutrient uptake reducing the yield or even prove lethal to the crop in high concentrations. Eutrophication is likely to be more pronounced in the irrigated areas since poor irrigation techniques perpetuate the problem of salt buildup in the soil. (Majeed & Muhammad, 2019) Cereals as wheat, rice, and maize is a staple food for more than half of the world's population and hence any danger that might compromise the yield age of these grains is worrisome to the global food security.

Wheat: Temperature is a very influencing factor affecting wheat production in a given region or country. High temperatures, especially when the loci of most genetic feedbacks for yield are most sensitive, which is during flowering and carrying of grains, negatively influences yield. High temperatures during the flowering stage lead to stress which in turn leads to what is called "heat sterility" where pollen shrivel, or fail, so that more grains cannot be set (Fischer, 2011). Likewise, during grain-filling period, higher temperatures increases the rate of crops developmental process and thereby shortens the grain filling period and decreases the size and weight of grains which are the main contributions for yield and quality. Wherever there is Communities where wheat is produced under rain fed systems, fluctuations in precipitation base will further compound these effects. Partial supply moisture deficit or temporal distribution in the course of planting season means that except when water is applied through irrigation, water stress in combination with high temperature greatly constrains yield formation in wheat. It affects plant growth by causing poor plant vigor, fewer tillers, and stunted grain head development, all of which leads to poor production (Ali, 2008). However, either too much water early in development as well as waterlogged conditions favor root pathogens such as Fusarium that contributes to poor growth and yield.

Rice: Rice is cultivated where there is high temperatures and humidity which is why most of it is grown in Asia where 96% of the world's rice production is realized. However, one of the factors that threaten rice yields is in the extreme natural disasters like floods and droughts. They are happening far more often and on a more severe scale as a result of climate change, which threatens the world's rice production and, therefore, the world's food security. Rice paddies suffer the problem of flooding more commonly in areas where monsoon is the prominent source of precipitation (Fahad et al., 2019). Despite rice being a semi aquatic plant that does well in flooded conditions, there are adverse effects of flooding either intense and for significant period of time. Severe floods can submerge rice plants completely, depriving them of oxygen and sunlight, which are essential for photosynthesis. Submergence beyond a few days can lead to plant death and total crop loss. Moreover, floods can cause soil erosion, nutrient runoff, and the deposition of harmful sediments, which degrade soil quality and reduce the productivity of subsequent crops (Upadhyay, 2016).

Maize: Maize is generally known to be sensitive to both temperature and water letting factors. Heat stress during the flowering phase may have poor pollination and reduced grain set which an issue is given maize as a food and feed staple for the globe. At the flowering stage of development, the male flower, called tassel emerges and the female flower, known as the silk, must be pollinated by the tassel in a process referred to as tasseling and silking (Hama & Mohammed, 2019). If the temperatures go high during the period which is conducive for pollination it creates a thermal stress that affects the viability of the pollen grain and the ability of silks to capture pollen. This can lead to a situation that is referred to as silk delay by which pollen shedding and silk emergence are not well coordinated hence poor pollination, fewer kernels per cob, and poor grain yield. To temperature stress, alteration in rainfall is another challenge that affects maize production more so in areas that rely on rain in its production hence taking a large share in the global production (Anderson et al., 2004). Irregular rainfall or continuous drought reduces the water supply and it becomes very difficult to secure the water requirements during periods of rapid growth, for example, during germination tasseling or grain filing periods. Stress at these developmental stages results to water deficit and thus reduces plant growth rate, smaller leaf area, less photosynthesis and therefore low yields when there is drought. During very dry years germination can be deeply affected and often, even before the grain has reached full maturity, the plant dries up and dies, resulting in huge production losses or even crop failure (Rockström, 2003).

Fruits and Vegetables

Fruits and vegetables are generally more sensitive to temperature changes than cereal crops. These crops require specific temperature ranges for optimal growth, and deviations from these ranges can lead to reduced yields and lower quality produce (Moretti et al., 2010).

Temperature Sensitivity: Many fruits and vegetables are highly sensitive to temperature changes, making them particularly vulnerable to the effects of climate variability and extremes. For example, high temperatures can cause heat stress in crops like tomatoes and lettuce, leading to reduced yields and poor quality (Thornton et al., 2014). **Tomatoes** exposed to excessive heat may experience blossom drop, where flowers fail to set fruit, significantly reducing the number of harvestable tomatoes. Additionally, heat stress can cause **uneven ripening** and the development of sunscald, which leads to discoloration and lesions on the fruit, making them less marketable. In **lettuce**, high temperatures can trigger bolting, where the plant prematurely flowers and sets seed, resulting in bitter-tasting leaves and a drastic reduction in the crop's commercial value (Levy et al., 1978). Similarly, low temperatures can lead to frost damage in crops like **citrus** and **grapes**, which are particularly susceptible to cold snaps. **Citrus trees**, when exposed to freezing temperatures, can suffer from **fruit drop** and **damage to the tree's vascular system,** which can lead to dieback or even the death of the tree if the frost is severe and prolonged. Frost can also cause the skin of citrus fruits to become pitted and discolored, significantly reducing their quality and marketability. Climate change can alter the length and timing of growing seasons, affecting the availability and yield of fruits and vegetables. For example, earlier spring temperatures can lead to premature flowering, increasing the risk of frost damage. When fruit trees and vegetable crops bloom ahead of their typical schedule due to unseasonably warm temperatures, they become more susceptible to late-season frosts that can kill or damage the blossoms, significantly reducing potential yields (Ayyogari et al., 2014). This is particularly concerning for crops like **apples, peaches**, and **strawberries**, where frost can lead to partial or complete crop loss, directly impacting both farmers' livelihoods and market availability.

Legumes and Oilseeds

Pulses and seeds are the vital foods for food security in the world and hold significant places for the supply of protein and oil. These crops are also affected by climatic change in one way or the other since the climate change can affect their growth rates, development and productivity (Medendorp et al., 2022).

Flowering Times: A change in temperature can therefore influence the time it takes for the legumes and oil seeds to flower and this is very important for the yields. For the instance, high temperature stresses during flowering stage would lead to less pod set and reduced grain filling in the case of soybeans (Sita et al., 2017). The time of flowering is very important because it is influenced by the availability of pollen and the reactivity of the stigma which needs to intermingle in order to ensure proper fowling. Flowering may be affected by heat stress, which makes flowers to abort and may also affects grain filling of the flowers, leading to small heavy grains. Besides, temperature changes affect the co-ordination between flowering and other phases with regard to development and yield (Arshad et al., 2017). Such impacts on flowering times in areas where climate change is expected to cause temperature rises may result into more frequent and serious yield losses thus threatening food security as well as agricultural based livelihoods.

Pest and Disease Prevalence: Fluctuation in temperatures and relative humidity levels may lead to the development of pests and diseases that exert a very terrible effect on the yield of the legumes and oil seeds (Sharma et al., 2010). For instance, higher temperatures contribute to the increase in aphid population, a tendency that poses as a major calamity in legumes. While feeding on plant sap which slowly starves the plant, aphids also spread viruses which could detrimental to crops. Rusts and blights are fungal diseases that are enhanced by high humidity; these diseases cause severe yield losses in legume and oilseed crops if their management is not well enhanced. Also, climate change results in the creation of new pests and diseases in areas where they are not a menace because prevailing climatic factors in such areas become more favorable for invasive species (Gebeyehu, 2004). Such pressure can demand application of more effective pest and disease control measures more frequently often using more chemicals such as pesticides and fungicides for pest and diseases control this may form part of higher production costs and came with adverse environmental impacts (Gill & Garg, 2014).

Niche Products (for instance Coffee, Tea, Cocoa etc.)

Coffee, tea, and cocoa are among those crops that are extremely vulnerable to unfavorable climate change because they are grown in certain areas only within a restricted climatic range. Many of these crops are important for the world economy and smallholders involved in farming as a central means of subsistence (Schroth et al., 2016)**.**

Vulnerability to Climate Shifts: All these crops are produced in coastal areas where small fluctuations in climate factors such as temperature and rainfall can cause large effects. For instance, coffee is very much affected by temperature, with very advantageous temperatures for growth ranging from 18 °C and 24 °C (Gopalakrishnan et al., 2019). This influences the quality of the beans and reduces the yield in the event that the temperatures rise. This causes an early maturation of the cherries and as a result, unripe fruits are picked and the quality of the beans are thereby, compromised which in turn reduces the taste of the coffee and thus, the market value of the coffee (Hameed et al., 2020). Also, higher temperatures affect coffee plants and their susceptibility to pests like the coffee berry borer, a significant problem that thrives in warmer environment and therefore, cause large loses. As with tea and cocoa, the plants associated with these products are very sensitive to the geographical climate; fluctuations in rainfall several times may result in drought or excessive precipitation and, as a consequence, changes in the quality and amount of crops produced (Ahmed et al., 2019).

Regional Dependence: Specialty crops are usually the major economic earner in regions where farming is practiced. Climate change can affect the income of these farmers by slicing yields and the odds for crop failure. In many occasions, these crops are produced in the developing countries, where the producers have constrained and restricted access to tools and technologies that they can use to tackle the ever-evolving climatic conditions (Bowman & Zilberman, 2013). For instance, coffee growing areas in East Africa are calamitous to climate change because most of the growers are smallholders who are using traditional production practices and have little access to climate-smart agronomic varieties of crops (Lemma & Megersa, 2021).

Regional Variations in Impact

Influence of climate change on yields of the crops varies from one developed region to another and the developing regions. The differences are realized depending on technology factors, the adaptation capability and the economic vulnerability of the learner (Hertel & Lobell, 2014).

Developed Regions: First world countries have many resources to use in farming including precision farming, and climate resistance crops. These technologies could assist to reduce effects of climate change on production of crops. Precision farming for instance, incorporate GPS, Remote sensing, farm machinery to manage farming, planting, and yielding, fertilizing, and irrigating the crops in the right time and correct quantity (Pande & Moharir, 2023). It in addition increases productivity but minimizes the possibilities of crop failure as a result of variation in climate. Climate-smart plant varieties, developed for cultivation in harsh weather conditions like droughts, heat and floods offer a hedge against what climate change has in store for food production when the predictable negative effects of climate change hit the fields. Also, there are physical infrastructure like well–developed transport network, efficient physical facilities for storage, sufficient energy base for supporting the agriculture and to control post–harvest losses in developed countries (Kaur & Watson, 2024).

Developing Regions: On the other hand, the climatic change impacts affect the developing nations more severely because they can ill afford the expensive technologies or any resource to invest on them. The two regions rely greatly on rain agriculture which makes them be very sensitive to changes in the climatic patterns such as drought, flood, or any other that is unfavorable to agriculture, all of which are disastrous to human life (Nath & Behera, 2011). Technology requirements for implementing crop health and any matter related to it is not feasible in such areas as it is in the developed countries; and therefore, the farmer has been barred from many tools that make farming less precarious and more fruitful. Moreover, such nations lack the resources for financing of new development in, for example, irrigation, flood protection and climate smart storage that will be useful for adjustment to the new climatic conditions (Alavian et al., 2009).

Tropical vs. Temperate Zones

Effects of climate change on yields of the crops also differ between the tropics and the temperate regions predominantly due to difference in climate sensitivity (Challinor & Wheeler, 2008).

Tropical Zones: High impact of climate change is often observed in the tropical areas of the world since they are either hot to commence with, or they are entirely depending on a certain amount of rainfall in a given period (Deb et al., 2018). In these areas, fluctuations of even a couple of degrees in temperature or a few millimeters of difference in rainfall can markedly affect yields. For instance, the agriculture in tropical regions is well-adapted to the current climate, and this is the reason why crops are often very close to the upper limit of temperature for their growth. Thus, the further elevation in temperatures may not take these crops too long before attaining areas that are highly toxic to their growth, photosynthesis, and, in effect, their overall yields are reduced. Besides, because the regions depend on recurrent rainfall patterns, any change in precipitation proves especially unfavorable (Pepin & Lundquist, 2008).

Temperate Zones: There may be some gains and losses in temperature regions as well in connection with the climate change. That is, in some regions of the temperate climate zone, an increase in temperature and longer growing seasons might lead to increased yields and these crops as wheat, barley, and maize (Hitz & Smith, 2004). It may lead to multiple cropping or growing of crops that could not be produced earlier because of long winters thereby increasing food production and the fortunes of the farmers. Yet, courtesy of climate change, the aforementioned benefits may be offset by escalating incidences of very hot temperatures, shortages of water and harsh storms. Adaptation Strategies and Mitigation Measures (Singh et al., 2010).

Technological Innovations: Possibly the biggest and still unfulfilled adaptation opportunity to climate change is the cultivation of crop varieties that are resilient to climate change reality. These varieties are developed for resistance to drought, heat or flood stress and other environmental adversities but with high yields. Due to biotechnology and plant breeding the management has been able to develop crops that can grow in unfavorable conditions and therefore the issue of crop failure is minimized (Reddy & Reddy, 2015). For example, there are low-e vigor maize cultivars which can withstand dry conditions in an attempt to minimize yield declines in the dry areas. In the same manner, new scuba or flood-tolerant rice varieties can withstand flooding for a lengthy period and safeguard their earnings when floods ensue. These innovations are especially important due to the effects of climate change which is increasing the risks of severe weather conditions, and harm that still traditional plant varieties that now cannot adapt to these conditions. Precision farming is the application of technology including the Global Positioning System, sensors, and analysis of data to farm. With the info given to the farmers on their fields specificity of planting, irrigation and fertilizer use, precision agriculture can increase on efficiency in farming and adapt to climate variability (Singh, 2010). For instance, soil moisture sensors can be used to control irrigation time and this helps in supplying water to crops at the right time, and this can help in avoiding use of excess water and at the same time avoiding drought stress. Use of guided mechanical tools such as tractors and planters enable proper arrangement of crop planting and eradication of wastage (Cardenas-Lailhacar & Dukes, 2010).

Agronomic Practices

This is for the reason that altering planting dates is considered as one of the simplest plants management practices that farmers can employ with a view to mitigating the altered growing seasons by climate change. He relays information to farmers that they should plant their crops at that particular time of the year; in so doing they are locked out from harsh conditions a particular time of the year offers (Altieri & Nicholls, 2017). That is, if heat stress is appearing more frequently on an area, planting can be done in an earlier time of the year as a means to preventing high heat to influence yield. On the other hand in areas of fluctuating rainfall calendar, planting may be carried out after the rainy season so that the crops have to look for water after they have been planted. Crop rotation, the act of growing different crops on the same piece of land throughout different seasons, can be employed so as to increase the health of the soil and to minimize the risk which is posed by pests and diseases (Shah et al., 2021). This practice can also increase the farming systems adaptive capacity of emerging climate change by promoting the fertility and structure of the soil that greatly determines the crops yields under different climatic conditions. Cycling crops with varying nutrient and root configurations lessen the effects of soil depletion and erosion thus making the land produce throughout modern disasters like flooding or drought prone regions (Rhodes, 2014).

Policy Interventions

Policy making favoring farmers and aiding them in the process of adapting to climate change is a department governments should prioritize. For instance climate friendly cheap seeds or policies such as insurance for losses occasioned by negative outcomes of climate change are some of the policies or incentives that can be adopted in order to combat impacts of climate change (Singh et al., 2016). Further, one towards research on new agricultural technologies and structures of farming that can sustain the destructive weathers, availability of irrigation and proper usage of water can also enhance the farming villages. The policy design approach indicates that with policy support and control, the farmers will key into this new solution space that ensures food security in view of climate change. Environmental protection particularly the challenge of global warming is a universal problem hence demands international cooperation (Brooks & Loevinsohn, 2011). This paper is on the current intentions in place with some of the key current global intention being the Paris Agreement which focuses on limiting global warming and encouraging adaptation efforts in sectors like agriculture. These frameworks obliges countries to participate in emissions reductions and to exchange knowledge, technologies and experience on the effects of climate change on agriculture. The Global Alliance for Climate-Smart Agriculture: solidarity between governments, research institutions and the private sector for the promotion of climate-smart agriculture across the world. In addition, such international financial sources, such as the Green Climate Fund assistance developing countries with financial resources to help execute measures for adaptation and create more sustainable structures in the agricultural sector (Alexander, 2019).

Future Projections and Challenges

Global climate models are therefore very useful hypergolic models when it comes to projecting the future effects of climate changes on crop yields. These are models which simulate numbers of climate circumstances according to increasing levels of greenhouse gases and what is expected to occur climatically under these circumstances (Jägermeyr et al., 2021). Though, ‘weathering’ or mimicking the effects of climatic change on farming is challenging because of numerous factors arising from the relationship between the climate factors, the crop and the farming practices. Furthermore, the unproductive nature of disasters such as droughts and floods, and the dynamic farming approaches which is seen in coping strategies make it even difficult to predict future productivity{Azadi, 2018 #5}.

CONCLUSION

There is sometimes an implication that climate change might affect agriculture around the world, and hence food security. This review has urged various impacts on crop yields as a result of warming climate including changes in the temperatures and rainfall, the rise and spread of pests and diseases. The climatic change impact on agriculture therefore opens mixed responses complicating them by implications of space, crop type, and SES. While climate change affects crop yields through various ways, cropping technologies, improvement of cropping practices and policies have to be adopted. Although, there are apparently certain limitations still to come, and first of all, these relate to the definition of the corresponding contingencies in the future climate change and the means for its further evolution. The future work in this field should be directed at enhancing the accuracy of the climate changes model, and revealing the relations between climate indices and physiology of plant crops, as well as on developing more effective measures of climate change adaptation. Policy makers also have the responsibility of ensuring that farmers should be baked especially those in the ‘‘harshest’’ environments by putting more efforts into coming up with policies that would help feed the world despite the changing climate.

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