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Effects of Climate Change on Crop Yield: Is it a Benefit or Menace?

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Abstract

The review explained the detrimental and beneficial effects of climate change on crop yields of major value crops such as corn, wheat, rice, and soybean. The trend in crop yields of these crops among the largest food producers in the world was examined. The study observed the changes that have occurred in crop yields because of climate change over the years. The changes have effects that cause shifts in temperature and precipitation, rising sea levels, and loss of biodiversity which are detrimental to the environment, economy, and health of humans, plants and animals, and the ecosystem in general. The effects of these changes as observed in plants cause high CO_2 levels, increased temperature and precipitation, droughts, floods pests, and diseases. The study emphasized the fact that some phenomena caused by climate change such as CO_2 fertilization and increased temperature because of global warming proved to be beneficial to crop yields in specific crops. Further deliberations on the effects on yields looked into the implications of factors such as weather, crop physiology, soil properties, and the economic aspect of how climate change affected the yield of crops. We then emphasized the fact that adaptation and mitigation strategies should be put in place to reduce the effects of climate change on the yield of crops by taking into consideration the beneficial aspects and non-beneficial aspects of climate change.

Keywords: Climate change, yield, CO2, temperature, adaptation, mitigation

Introduction

Climate change according to United Nations Framework Convention on Climate Change (UNFCCC, 2011), refers to alterations in weather conditions for long periods that are directly or indirectly caused by anthropogenic which modify the structure of the airspace globally. Climate change is defined as shifts or changes in weather patterns that have been observed for long periods which can run from several decades to millions of years with negative effects such as global warming, droughts, flooding, wildfires, etc (IPCC, 2007; Foster et al., 2017; Clark et al., 2022). The changes have effects that cause shifts in temperature and precipitation, rising sea levels, and loss of biodiversity which are detrimental to the environment, economy, and health of humans, plants and animals, and the ecosystem in general. These changes are caused by anthropogenic activities and sometimes natural occurrences like volcanic eruptions.

Climate change has varying effects on society and the ecosystem. This is exemplified by variations in temperature and precipitation, varying rainfall patterns and intensity, increased greenhouse gas emissions, heightened regularity and intensity of natural disasters, quality of human health, changes to forests and other ecosystems, etc (Amenu, 2017). The shifts in temperatures and order of rainfall and their effects on water availability, pests, disease, and unfavorable natural occurrences can affect agricultural production. Some studies such as Cline (2007) and Walthall *et al*. (2012) have predicted the effects of climate worldwide if not properly managed would lead to about a 15.9% decrease in global agricultural productivity by 2080s. This decrease would affect developing counties more with a greater decline in productivity to 19.7%.

Studies on climate change inform that in the short run, global crop production may increase due to global warming but this increase will turn negative in the long run (Bruinsma, 2003: IPCC 2007: Foster *et al*., 2017). It is expected that developing economies and regions with low latitude will be more affected by the impacts of global warming caused by climate change because of their vulnerable topography, high share of agriculture in their economies, and restricted adaptive capacity. High-latitude regions, on the other hand, will benefit from the effects of climate change. This claim indicates that climate change might be beneficial and not all the time detrimental in some cases. This study aims to explore the instances and conditions that propose these claims and how such conditions can be diverted to boost the yield of crops.

Crop Yield of Value Crops Across the Globe

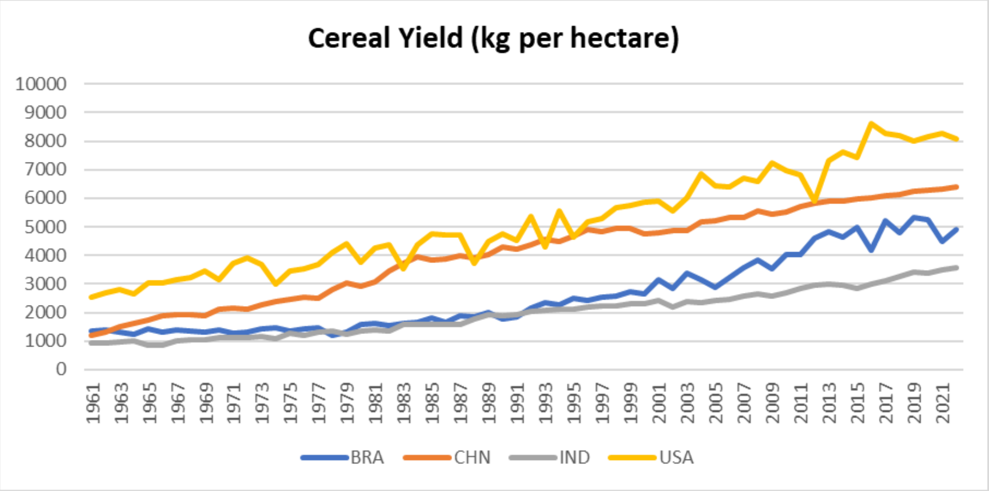

Figure 1: Yield of cereal crops among the largest crop producers in the world
Source: World Bank DataBank (2023)

Cereals are crops found as grasses that are cultivated for their edible grains. These crops are cultivated in large quantities and are great sources of energy. They are regarded as staple crops in most parts of the world because of their easy accessibility which informed their use as a standard diet for most populations of the world. They include rice, wheat, corn, oats, rye, barley. The highest producers of these crops in the world are China, the United States, Brazil, and India. The United States is the largest producer with 8,268 kg per hectare of cereal produced in 2021, China follows with 6,319.8 kg per hectare and Brazil produced 4,478.7 kg per hectare while India had 3,478.8 kg per hectare of cereal (World Bank Data, 2023). These crops are harvested and processed into food for human nutrition, animal feed for poultry and livestock; and in the production of other substances such as adhesives, glucose, alcohol, oils, and even as biofuels for power generation. Figure 1 above shows the yield of cereal crops over the years among the largest crop producers in the world. This trend has been in an upward moving position indicating that there is an increase in the yield across countries as the years roll by. This can be attributed to the adoption of commercial farming by these producers to meet the world food demand. Farmers have had to increase their level of production by increasing their farm size, adopting new technologies to boost production, implementing best agricultural practices to prevent pests and diseases, etc. All these innovations have yielded positive results, but these results have been hampered by agriculture's dependence on weather and climatic factors.

Agriculture at any level is still very dependent on weather though the level of dependency varies. This is because factors such as temperature, humidity, and precipitation affect stages of crop growth. Anthropogenic activities such as the burning of fossil fuels, mining, the release of industrial wastes to water bodies, and excessive and indiscriminate use of pesticides, herbicides, and fertilizers have amplified the effects of climate change. These effects of climate change can be felt on plants and animals and by extension the environment.

Effects of Climate Change on Plants

The effects of climate change on plants can be explained in the following ways:

- **High CO_2 Levels**

As CO_2 increases in the atmosphere, plant productivity improves (Morison and Matthews, 2016). High and heightened amounts of atmospheric CO_2 are expected to improve plant productivity. However, the improvement in plant productivity reduces at higher concentrations of CO_2 and is determined by other factors such as temperature, plant species, and water and nutrient availability. When CO_2 concentrations are high, the rate at which plants use water is reduced and this causes a reduction in productivity due to drier atmospheric conditions. Also, when CO_2 levels are increased, the chemical composition of plants can be altered which affects nitrogen contents and the higher soluble carbohydrates concentration. The resultant effect of all these is the reduced quality of nutrients. When atmospheric CO_2 is higher than the ambient level, increased rates of photosynthesis are observed which would lead to an increase in the yield of crops like legumes and tubers but less in cereals (Parry *et al.*, 2004; Ainsworth & Long, 2020; Alimagham *et al.*, 2024). This occurs because high CO_2 shrinks down the opening of the stomata of plants which causes lowered transpiration per unit area. With enhanced photosynthesis comes water-use efficiency (the ratio of the rate of assimilation of carbon during the process of photosynthesis to the rate of transpiration). From these processes, it is observed that increased CO_2 levels alone help to improve the growth and yield of agricultural crop plants in terms of grain yield, harvest index, and total biomass yield (Tubiello and Ewert, 2003; Castano-Sanchez et al., 2020). Zinyengere *et al.* (2013) examined CO_2 fertilization rates and how they affect crop yield in a study on the reactions of crops to alterations in weather conditions in Southern Africa. The study looked into the importance of increasing CO_2 levels as a determinant of global warming and climate change phenomena and how it affects the crop metabolic processes resulting in low crop yields. However, it was revealed that depending on crop physiology (C3 or C4 pathways) as CO_2 levels go higher, yields of crops can also be impacted positively during the process of CO_2 fertilization as tested in simulation models using corn and alfalfa. (IPCC, 2007; Ainsworth and Long; 2020). CO_2 fertilization caused a counterbalance through the interaction between land surfaces and gas exchanges which then leads to higher yields (Walker and Schilze, 2006; Knox et al., 2010; Zhu et al., 2017. They projected that by 2050 yields in sugarcane production in the area would increase by 15% if CO_2 fertilization rates are doubled. Abraha and Savage (2006) and Clark et al. (2022) confirmed that yields would increase with doubling CO_2 levels. Their studies further revealed that an increase in temperature by 4^0C will offset the positive effect of CO_2 fertilization. Chipanshi et al., (2003) in Botswana and Chemura et al., in South Africa, deduced that increased CO_2 would not cause high crop yields in maize and sorghum and due to the high-altitude level of the countries. Cline (2007) used climate models and made predictions of increased CO_2 concentrations by 2080 accompanied by a rise of 3.3^0C in mean temperature globally. His study revealed that carbon fertilization to a limited extent would affect productivity in agriculture globally. This was proved by the results that showed that the carbon fertilization effect on productivity would lead to a 3% decline in yield whereas with no carbon fertilization effect, the decline would increase to a 16% decrease in yield. Also, the study confirmed a huge percentage of these losses would be concentrated in developing economies. It was observed that the developing economies would experience 9% losses in yield with the effect of carbon fertilization and 21% losses without the carbon fertilization effect. On the other hand, developing countries were expected to have an 8% increase in yield in the effect of carbon fertilization and a 6% loss without carbon fertilization. Therefore, from all these, it is evident that CO_2 increases through carbon fertilization can lead to increases in yield in the short term. Also these positive increases in yield, however, are evident at certain temperatures which when exceeded become counter-effective. This also shows that in the long run, crop yield tends to decrease at a rate that is higher than the earlier reported increases which leads to crop losses.

- **Extreme Temperatures**

Climate change has had its effects on the earth's ecosystem leading to global warming and increased atmospheric temperatures. Over recent decades, warmer average temperatures characterized different agroecological regions which has led to an early onset of spring and delayed winter (Morison and Matthew, 2016). This invariably implies longer growing seasons and higher productivity of crops that require more day length such as pasture, root crops, leafy vegetables, and some fruit crops. Lower yields can sometimes occur because these high temperatures cause crops to develop faster in short periods in some regions of the world than others (Stone, 2001; Beillouin *et al.*, 2020). What is experienced in such scenarios is that crops do not fully develop because of the short durations which causes lower yields. The plant developmental processes affected by these high temperatures are photosynthesis, respiration, and grain-filling. Plants experience an increase or decrease in net photosynthesis when it is warm during the day, while respiration costs are elevated during warming at night with no gain for photosynthesis because of the absence of sunlight (Crafts-Brandner and Sallvucci, 2002; Moore *et al*., 2021). Amenu (2017) studied crop diversity and its effects on climate change adaptation and affirms that the process of photosynthesis is affected in that crops like maize and sugarcane which possess a C4 photosynthetic pathway utilize optimum temperature for photosynthesis than C3 crops such as rice and wheat. He added that this does not always hold because it has been observed that even with high temperatures, some C4 crops have low rates of photosynthesis.

Contrarily, crops such as cereals whose development is not affected by day length, hot temperatures, and frequent heat waves hasten maturity and reduce the lifecycle of the crops thereby affecting the yield and quality negatively. For example, Asseng *et al.* (2015) in their research observed 30 different crop models of wheat by running experiments on the fields with artificial means of heating at high temperatures of between 150 to 32^0C.

The study confirmed that wheat production was greatly affected by extreme temperature and heat waves which reduced crop yield by 6% for each ^{o}C rise in temperature. Ababor and Zakir (2019) observed the influence of water deficit and extreme temperatures on the reproductive phases of plant growth and discovered that processes such as the initiation of flower and inflorescence were affected by stress caused by water in cereals. Also, it was discovered that a 30^oC increase in temperature during floret development causes sterility in cereals. With such temperatures and resulting conditions, crops can not even be produced thereby leading to huge losses in crop yield.

- **Droughts**

Drought with the accompanying effects of high temperatures causes pressure on plants and leads high impact on cereal yields particularly during reproductive growth and seed-filling in lentils (Barnabas *et al.*, 2008; Seghal *et al.*, 2017; Zhu *et al.*, 2022). The process of photosynthesis stops abruptly when the temperature increases from 35^oC because an important enzyme that acts as a catalyst in the process of photosynthesis, Rubisco, is disrupted at levels of temperature higher than that. In rice, drought stress greatly disturbs the process of fertilization and anthesis (Griffin *et al*., 2004; Perdomo *et al*., 2017; Yang *et al*., 2022). Zhao *et al.* (2017) experimented to analyze the climate change impact on major crop yields such as wheat, rice, soybean, and maize in different geographical locations. The study revealed that climate change caused a reduction in the yields of 6%, 3.2%, 3.1%, and 7.4% of the crops, respectively. The study added that the availability of water at the different stages of a plant's life is important for the crop's productivity. The warmer, drier, and longer summers that result from the effects of climate change can reduce plant yields. Morison and Matthews (2017) believed extended periods of drought can have a permanent impact on crops if they occur at specific stages of crop development where the need for adequate water is required. Such periods can be during the vegetative stage which can cause reduced CO_2 uptake and reduce crop canopy expansion. The only remedy to this is to engage in irrigation to cover up for the unavailability of water in the short run but if the frequency and intensity of drought increases in the long run, it will be disastrous.

- **Flooding**

In recent times, the world has experienced an increase in winter rainfall patterns as a result of climate change (Morison and Matthews, 2017). Rainfall is good for plants but excessive rainfall has negative impacts on agricultural production. The effects can be seen in the loss of topsoil and nutrients due to erosion as we experience a higher volume of rainfall. In soils that cannot hold water, growth can be impeded because of the restriction of the flow of oxygen in waterlogged areas. The incidence of soil compaction is a common occurrence during flooding and this can restrict movement of machinery operations on the field. Soil compaction can also intensify the spread of pests and diseases on the farm which can cause damage to plants and soils. However, flooding can be redirected into irrigation use if the infrastructure to store up the excess water in winter for use during the drier summer months is made available. Moreso, Byishimo (2017) believes that based on the intensity of the falls, patterns of rainfall can lead to either an increase or decrease in crop yield. It is estimated that about one-fifth of the population of the world resides in river basins and a slight increase away from the norm in rainfall intensity could heighten the susceptibility of such areas to floods thereby affecting farming activities (IPCC, 2007; Seneviratne et al., 2021). In a bid to cope with the risk of flooding, farmers in developing countries adapt to these changes by switching crops, engaging in crop diversification, and planting trees to break the flow of the floods. (Ziervogel et al., 2006; Antwi-Agyei et al., 2018; Alhassan, 2020).

- **Pests and Diseases**

The loss of crop yield due to the rampancy of pests and diseases is heightened by climate change because of the increased temperature, precipitation levels, rainfall, and soil moisture (Ababor and Zakir, 2019; Morison and Matthews, 2016). These weather conditions have been observed to favor the release and production of spores which aid pathogens in the completion of their life cycles. When an area experiences milder winters and warmer or drier summers, pests and diseases increase. Amenu (2016) asserts that temperature changes can lead to changes in weather patterns that result in adverse situations and thus, for example, overwintering and summer survival which favor the virulent spread of pests and diseases. Atmospheric gases like CO_2 and O_3 can influence the prevalence of plant disease due to the interaction between these gases and pathogen growth (Chakraborty and Newton, 2011). In an attempt to control pests and diseases through the use or overuse of pesticides, biodiversity which is important to crop growth and yield could be lost (Ababor and Zakir, 2019).

The movement of weeds leading to the naturalization of alien species was enhanced by climate change (Bauckland et al., 2008; Sheppard et al., 2016). Several weeds, especially the C3 weeds that are invasive, grow rapidly when CO_2 is high even more than cash crops. This results in their prevalence on farms during periods of high CO2 concentration thereby competing with plants for water, nutrients, and sunlight and sometimes overshadowing plants. There could also be an increase in pest and disease prevalence even while trying to curb it with the use of chemicals because it was recently observed glyphosate loses its efficacy on weeds grown at high concentrations of CO_2 (Martzafi *et al.*, 2019). The early onset of spring and warmer winters that have been experienced in recent times due to climate change cause the multiplication of pathogens and parasites resulting in diseases spread among crops and animals.

Effects of Climate Change on Crop Yields

Some studies compared the different effects of climate change in different regions of the world. The main approaches to these studies were the use of crop models and regression analysis to depict these relationships. Some studies have shown that there was evidence of a reduction in crop productivity in equatorial and tropical regions due to temperature differences; while temperate regions benefited from an increase in crop productivity because of the lower ambient temperature in such places (Vose *et al.*, 2005; Tang *et al.*, 2013; Wang *et al.*, 2021). Schlenker and Roberts (2009) discovered the temperature thresholds for different crops by using panel data of their yields for different counties while incorporating varying temperatures within the days and across the days in the growth period of the crops which resulted in increased yields for temperatures up to 29°C for corn, 30°C for soybeans, and 32°C for cotton. This means that temperatures above these stated thresholds would have adverse effects on the crops. Zhang *et al.* (2017) examined how crucial it is to include other variables apart from temperature and precipitation in the study of the effect of climate change on agricultural production and found that when other factors but humidity are considered, the impacts of climate change on yields on crops are over-speculated. Oehninger *et al* (2017) studied the effects of changes in temperature, precipitation, and humidity on crop choice and agricultural variety using the Tobit regression model showing that factors such as temperature, precipitation, and humidity affect the acreage of crops at varying degrees while depending on the crop, the specification, and/or month. Also, while considering temperature effects Sharma *et al.* (2022) computed the effect of variables such as temperature(daily maximum and minimum) and rainfall on crops such as corn, rice, and wheat using a fixed-effect model. They applied the production function to the data obtained from 1980-2020 from 11 states in South Eastern United States. It was observed that warming at night was higher than that of the day during the growing seasons of the crops. Wheat yield was significantly affected by rainfall with no effect on rice and corn yields. On the other hand, maximum and minimum temperatures did not affect wheat yield but we saw reductions in the yield of corn and rice due to the rise in maximum temperature. This rise was further offset by an increase in minimum temperature to cause an increase in the yield of rice and corn. This hereby concluded that temperature did not affect wheat yield making it a crop that is tolerant to temperature. Temperature serves as one of the most prominent effects of climate change on agricultural production. Hence, Bento *et al.* (2021) developed regression models and regional climate model (RCM) simulations with temperature and precipitation as predictors to show the impacts of climate change on wheat and barley yields. The results showed varying responses of wheat and barley according to the regions. The main determinant of yield in the southern region was spring maximum temperature while early winter maximum temperature served as the determinant for the north. Petersen (2019) used a statistical model to predict US yields to 2100 for corn, soybean, and rice using low and high-emissions future scenarios in the event of greenhouse gas emissions. The model used linear regressions between crop yields and daily weather observations and observed that the yield of corn and soybeans will be reduced by the effect of warming temperatures with no effect on rice. This indicates that cultivation of rice in such areas even in the advent of greenhouse gas emissions would have high productivity as compared to the other crops. In addition to this, Lobell and Field explained that increasing temperature and precipitation resulted in approximately 30% yearly variation in average yields for the six most widely globally grown crops. They reported that there is negative response of yields to increased temperatures in wheat, barley, and maize. Estimations were made based on the uniqueness and studied climatic patterns and they concluded that annual overall losses of the three crops amounted to 40Mt of $ 5 billion yearly because of warming from 1981 to 2002. Though the impacts of temperature on yields may be small as compared to the technical gains from the yield of crops over time, these results indicate that the impacts of climatic patterns on the global yield of crops are negative. The importance of knowing the drivers of yields would help in decision-making by farmers which would inform them.

Other factors apart from temperature and precipitation were examined. For example, Blanc (2012) estimated the impact of climate change on the yields of crops considering additional factors like evapotranspiration. The yields were predicted for 2100 and while comparing them to a case without climate change, yields for cassava hit near zero figures while that of maize ranged from -19% to 6%, millet ranged from -38% to -13%, and of sorghum was within -47% to -7% with climate change effects. This means that climate change still had negative impacts on yield even when considering other factors.

From an agronomical standpoint, Cai *et al* (2009) based their study on the soil water obtained from rainfall and how it is retained in the soil to promote the yield of crops in the event of climate change. The study obtained results from cornfields in Illinois that were majorly dependent on rainfall using models such as regional-scale climate models, crop growth models, and General Circulation Models (GCM) while citing scenarios of emissions to get results. The study predicted if interventions for adaptation were not being considered or put in place currently, there would be a huge decline (23%-34%) in the yield of rainfed corn by 2055. These results are quite alarming and call for quick action to be able to meet the population's demand for food by then. These estimates are like warning signals to the impending loom that awaits the world concerning the level of food insecurity that will be facing the world shortly.

Zhao *et al* (2022) revealed that the frequency and intensity of compound hot-dry-windy events (HDW) have heightened drastically in the U.S. Great Plains from 1982 to 2020 due to the peculiarity of the terrain. The absence of trees and hills in such areas where agricultural activities are practiced makes it prone to natural disasters such as tornadoes, cyclones, and windstorms. The study reported that these events caused great loss in wheat production which was about a 4% reduction for every 10-hour event of HDW affecting the maturity of the crop. Windy events can cause slow development and restricted growth in plants. High winds can cause low fertilization rates leading to lower yields. This can also affect the water and soil loss in plants because as the speed of the wind increases, particles of water and soil are carried off from the plants. Farmers in these areas employ the use of windbreaks to help curtail the menace of soil and wind erosion because of climate change.

Sultan *et al.* (2019) used historical climate simulations to examine the effects of historical climate change on crop production in West Africa. The study simulated yields of sorghum and millet with crop models for the real climate of the crops and with simulations that had human influences on the climatic systems. The study showed that there was a yield reduction of approximately 10%-20% for millet and a decrease of 5%-15% in yield for sorghum. These reductions when valued accounted for a loss of about $2.33-4.02 billion in millet production and $0.73-2.17 billion in sorghum production between 2000-2009 in the region. This stresses the fact that agricultural production remains a risky enterprise to venture into. These losses for a region were huge and could have been salvaged if proper mitigation and adaptation strategies were put in place.

In a study to quantify the long-run adaptation of U.S. corn and soybean yields to changes in temperature and precipitation, Yu *et al* (2021) looked into the effects of droughts on the productivity of corn and soybeans in the U.S. Their studies indicated that the crops' ability to withstand heat and drought increased but their productivity reduced. The ability of the crops to withstand heat and drought caused yield to increase by 33%(corn) and 20%(soybean) but these increases were offset by the 41% and 87% reduction in yield caused by the effects of climate change. This indicated that even with technological advancements like the formulation of new varieties of seeds, there is a need for studies to determine how far-reaching the effects of these technological advances would resolve the menace caused by climate change.

In the same vein, Santini *et al.* (2022) explored a comprehensive evaluation of how the pattern of droughts is related to the negative impacts on crop yield globally. The study stresses the multifaceted nature of drought as characterized by their magnitude, frequency, duration, and timing on the yield of crops like maize, rice, soybean, and wheat over different cropping seasons from 1981 to 2016. The crops that had high susceptibility under complex drought patterns were winter and spring wheat, soybean, and main-season maize while second-season maize and rice were less susceptible. With regards to regions, the most critical regions for the most vulnerable crop (wheat) were Eastern Europe, the Middle East, and Central Asia whereas the Americas, Southern and Eastern Europe, and sub-Saharan Africa possess susceptibility for different crops. It was also concluded that movement from moderate to extreme multiscale droughts worsens yield losses for wheat and soybean. Also, Eze *et al.* (2022) shared the same view on relating the effects of drought on crop yield. They combined data obtained from climatic conditions, field surveys, and remote sensing to analyze the effects of the droughts of 2015 and 2017 on crop yields in Northern Ethiopia. The study utilized correlation and multilinear stepwise regression to determine drought-yield relationships and spot predictors of yield and yield losses during the years. The precipitation deficit was more in 2015 than in 2017 which made the lowland experience entire sorghum losses. Moreover, it was reported that spatiotemporal variations across the two ecological zones caused by drought which occurred during the planting and maturing stages of barley and sorghum made growth slow leading to more yield losses. These losses resulted in a shortage of food and reduced the income of smallholder farmers which affected their level of food security during that period. The study recommended that spate irrigation should be encouraged especially in the lowland regions of Northern Ethiopia. Following the same line of thought, Mohammed *et al.* (2022) studied how the intensity, duration, and severity of droughts in Hungary affect crop yield by using different precipitation index levels. The results showed that the western part of Hungary had a higher susceptibility to agricultural drought than the eastern part. For results on frequency, all other parts except the southern parts of Hungary were high which showed that they experienced drought often in those areas. Severe droughts were experienced during the following years: 1970–1973, 1990–1995, 2000–2003, and 2007 and this affected productivity and yield during those periods. The resiliency of maize and wheat to drought was tested and found to be low, especially in the western and central parts of the country. The results obtained indicate that drought events serve as a threat to achieving the aim of food security in the sense of the availability and accessibility of nutritional food. It is therefore recommended that drought-resistant crop varieties be formulated to serve as an adaptation strategy against the effects of climate change on agriculture. Policies that favor the establishment of proper irrigation systems that are suitable for the terrain should also be enacted to combat the menace caused by drought.

Helman and Bonfil (2022) pride as the first study to prove that warming and drought cancel out the rewards of increased CO_2 in the world over the last 60 years. The study combined the use of census observations of the yield of wheat at the country level, records of CO_2, and gridded climate data in a statistical model to show that an increase in CO_2 will increase yield in the top twelve wheat-producing countries, but on the other hand, warming and water depletion reduced grain yield of wheat. The study showed that the increase in CO_2 does not cancel the effects of warming and drought in countries like Germany and France with recorded net loss in yield of 3.1% and no gain. Therefore, intervention programs specific to these areas have to consider these effects while formulating policies. The study even went further and suggested that improving the understanding of the effects of warmer and drier weather on higher CO_2 would require engaging in more experimental studies in warm and dry areas and running them with statistical and numerical modeling.

From an economic point of view, Chen *et al.* (2014) used linear regression models to determine the effects of weather elements on yield in China while controlling for factors such as socioeconomic and climatic adaptation variables. The study discovered a non-linear and asymmetric dependence between corn and soybean yields and variables of weather. The net economic loss as an effect of climate change amounted to about $200 million for the country's corn and soybean sector. It was also discovered that a net economic loss of about $200 million in China's corn and soybean sector was recorded due to climate change. It was further predicted that a decline of 4-14% and 8-21% in corn and soybean yields by 2100 would be recorded if proper measures for mitigating and adapting to the effects of climate change were not put in place. This stresses the fact that the world should be thinking of appropriate mitigation and adaptation techniques that are suitable for different locations against climate change. Wang *et al.* (2021) followed the same line of thought and assessed the economic impacts of different levels of warming(from 1.5-4°C) on rice and wheat yields in China, India, Brazil, Egypt, Ghana, and Ethiopia. Out of the six countries, only China recorded increased GDP and welfare from the benefits of increased crop yield which lowered domestic consumer rice prices. However, it is important to note that all these patterns change when the temperature is increased above 4°C. The opposite is the case for the remaining five countries with India and Ethiopia being the most affected, but it all followed the same patterns for the different variables. While also addressing the economic impact of climate change on crop yields, Deschênes and Greenstone (2007) estimated the effect of random year-to-year variation in temperature and precipitation on agricultural profits, showing that climate change will increase annual profits by $1.3 billion in 2002 dollars, or 4 percent.

Findings and Conclusions

This study delved into the beneficial and detrimental effects of climate change on the yield of crops. The main point in this discussion is the fact that at some level of temperature (caused by climate change), an increase in yield is observed for some crops but when the temperature increases above such thresholds, yields begin to reduce. This indicates that such points are the allowable thresholds to increase yield. Farmers and crop producers can use this information during production for increased yield. The adaptation strategy to be adopted here would be how to maintain temperatures to remain at those threshold levels. Therefore, the bone of contention here would be how to control the temperature at those threshold levels. In recent times, the discussion on sustainable agricultural practices has introduced techniques in which temperature can be controlled in farming such as the use of high tunnels and hydroponic farming. These practices are being encouraged because of the massive benefits that have been derived from them in terms of cost reduction, increased yield, and being environmentally friendly. This study hereby recommends that such practices be encouraged in intervention programs for the implementation of government policies to boost the yield of farmers.

Also, it was observed that not all crops experienced low yields through the effects of climate change. For example, from the discussion, wheat stood out as a crop that could resist high temperatures in different geographical locations. Therefore, it would be a good adaptation strategy if wheat production is well encouraged for cultivation by farmers in such areas. For other crops that could not cope with such higher temperatures, the strategy suggested is that a new variety of such crops that would be able to withstand such high temperatures should be formulated.

In addition, while discussing the effects of climate change on plants, one beneficial aspect that stood out was the increased yield effects caused by CO_2 fertilization. We understand that rising CO_2 levels serve as the force behind global warming and climate change and some studies have observed benefits from this process. Therefore, adopting sustainable agricultural practices that would improve carbon fertilization while keeping other factors such as crop physiology, temperature, and precipitation in check would be a way of mitigating against loss of crop yield.

The analysis portrayed in Figure 1 shows that over the years there has been an increase in yield of crops in the mentioned countries, but consideration has to be given to the issue of population increase. For countries like China and India with high populations, even with the increase in yield, the high population might indicate that this increase does not lead to an increase in the standard of living of the people especially when considering the aspect of food security. We need to address how well this increase is distributed among the populace to ensure. It is projected that the world population will increase to 10 billion in 2050 (UN, 2017). Even with increased yields, attention has to be given to how agricultural production would be increased to meet the needs of that population.

In conclusion, from this study, it is seen that climate change can be a menace and a beneficial phenomenon to agricultural crop yield. The onus lies on us as humans to learn how to adapt to the phenomenon by implementing the suggested solutions discussed.

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