CLIMATE CHANGE IMPACTS ON AGRICULTURE AND MITIGATION STRATEGIES

Dr. Tripti Arya*

Open Scholar, Department of Geography, Jind, Haryana, India

***Email ID**: triptiarya.phd@gmail.com*

Accepted: 08.11.2022 **Published**: 01.12.2022

Keywords: Climate Change; Greenhouse Gases; Mitigation Strategies.

Abstract

Climate change makes it harder for people to get enough food and stay healthy around the world. Due to the greenhouse effect, as the amount of greenhouse gases in the air goes up, the temperature also goes up. The average global temperature is going up all the time and is expected to go up by 2°C by 2100, which would hurt the global economy in a big way. The amount of CO2, a major component of greenhouse gases, is rising at an alarming rate. This has caused plants to grow faster and make more food because they can do more photosynthesis, but this effect is cancelled out by higher temperatures, which lead to faster crop respiration and evaporation, more pests, a change in weed flora, and shorter crop duration. The number of microbes in the soil and how their enzymes work are also affected by climate change. This paper looks at the information found in the literature about climate change, its possible causes, what might happen in the near future, how it affects agriculture by affecting the physiological and metabolic processes of plants, as well as its possible and reported effects on plant productivity and growth, pest infestation, mitigation strategies and their economic effects.

Paper Identification

**Corresponding Author*

1. Introduction

One of the most pressing issues of our day is climate change. It is defined as long-term changes in the average values of meteorological factors, like rainfall and temperature, that are big enough to be noticed [1]. Over the past few decades, people have done more things that changed the composition of the atmosphere, which has led to big changes in the global climate [2]. Greenhouse gases like methane (CH4), carbon dioxide (CO2), and nitrous oxide (N2O) have all increased significantly since 1750, by 150%, 40%, and 20%, respectively. Carbon dioxide emissions, the most significant greenhouse gas, increased from 22.15 billion metric tonnes in 1990 to 36.14 billion metric tonnes in 2014. Since 1975, the average global temperature has risen at an average rate of 0.15–0.20 C per decade [3]. By 2021, the average global temperature is expected to rise by 1.4–5.8 C [4]. Greenhouse gas (GHG) emissions, particularly CO2 from the combustion of fossil fuels, as well as other

GHGs other than CO2, such as nitrous oxide, methane, and CFCs, contribute to global warming. Since 1751, the world has put out about 1.5 quadrillion metric tonnes of CO2. But the emissions are different in different places. Europe is the biggest source of CO_2, with about 500 billion metric tonnes of CO2 emissions. North America and Asia are the next biggest contributors, with 457 billion metric tonnes of CO_2 emissions each. USA is the biggest source of CO2 emissions (400 billion metric tonnes), and since 1751, it has been responsible for $1/4^{th}$ of all CO2 emissions ever made. China is the second biggest source of CO2 emissions (200 billion metric tons). The European Union (EU-28) has been responsible for 22% of all CO_2 emissions in history. Due to low CO_2 emissions per person, Africa only contributes 3% of the world's total CO2 emissions. But countries like Brazil and India, whose emissions in the past have been lower, add a lot to the total emissions right now [5]. With more CO2 in the air, crops will need more fertiliser, but less energy will be needed to grow them because of the warming. These are some of the positive outcomes of climate change. On the other hand, water resources are getting worse because of climate change. Most of the effects of climate change in the 20th century were good. Most countries benefited from it until 1980. After that, the trend didn't change for the developed world, but it hurt the Third-World countries. Climate change will become a big problem in the 21st century, and both wealthy and poor countries will be hurt by it [6]. The increase of greenhouse gases has an impact on how the temperature of the atmosphere rises. . Most of the infrared-active gases are ozone (O3), carbon dioxide (CO2) and water vapour (H2O). These gases absorb the heat emitted by the earth's atmosphere and surface, which warms the earth. The greenhouse effect is the name for this effect. Since 1850, the average temperature of the Earth has gone up by between 1 and 1.2 C. Still, changes in land temperature are far more obvious, therefore the global land temperature has risen almost twice as much as the ocean temperature. . The average temperature of land around the world has gone up by 1.32 0.04 C since 1951–1980, while the temperature of the ocean surface has gone up by 0.59 0.06 C. (excluding areas of sea ice). The average temperature in the Northern Hemisphere is also greater than in the Southern Hemisphere. . This is because the Northern Hemisphere has more landmass. Since 1850, the temperature of the Northern Hemisphere has gone up 1.31 °C and the temperature of the Southern Hemisphere has gone up 0.91 °C, with a rise of 1.11 °C on average around the world. The polar regions have seen an extreme rise in temperature, which has bad effects like the melting of glaciers [7]. As the world's temperature goes up, greenhouse gas emissions need to go down to keep the temperature from going up by more than 2 C compared to before industrialization. Since 2005, the developed countries are responsible for about 60–80% of the rise in global temperature, melting of sea ice and the upper ocean warming, while the developing countries are only responsible for 20–40% [8]. According to probabilistic predictions of the IPCC's climate sensitivity range, the average global temperature will rise by 2°C by 2100 and by 4.2°C by 2400. . At the current level of radiative force, though, it doesn't look like the temperature will rise more than 2 C by 2100. But the risk is rising, mostly because radiative forces are becoming more stable above 400 ppm of CO2. Also, if humans stopped making pollution tomorrow, it is very unlikely that the temperature would rise by 2 C . In the near future, climate change is expected to get worse. The minimum and maximum temperatures in Pakistan's Punjab region are projected to climb throughout the Kharif and Rabi seasons. The average high and low temperatures are projected to climb by 1-3.3 C and 2-3 C, respectively, throughout the Kharif season. The average high and low temperatures are anticipated to climb by 2.1-3.5 C and 2-3 C, respectively, throughout the Rabi season (2040-2069). There have also been predictions of

changes in the amount of rain in the area, especially during the Kharif season (25–35%), but the changes aren't very big during the Rabi season [9]. By the middle and end of the 21st century, both the lowest and highest temperatures are expected to rise in Punjab, India. This is according to a study by PRECIS (Providing Regional Climates for Impact Studies). Also, there will be extreme cases of high temperatures (heat waves) from March to June and low temperatures (frost) from December to January [10]. With an extra 0.5 C of warming, it is also expected that the most extreme weather conditions, like minimum temperature, maximum temperature, and rainfall, will happen more often and with more force in China. Also, the weather will be less extreme if global warming stays below 1.5 C [11].

From 1901 to 2015, there was a change of 0.78 inches in the amount of rain around the world [7]. But because of global warming, it is more likely that we will see extremes in temperature and rain in the near future. How much rain or how little rain there is in a certain area depends on its geography. South and East Asia are more likely to have higher average river flows because of heavy rain that lasts for a long time, while southern Africa and South America will have less severe drought. It is expected that the pattern of rainfall in the Indus river basin will change in different places and at different times of the year. The upper Indus basin is expected to get more rain, while the lower basin is expected to get less rain. Also, it is expected that the upper basin will warm up more than the lower basin [12]. In the northeastern United States, there is a chance that there will be more extreme heat, less extreme cold, and more extreme rain in the future. If emissions go up, these changes will get worse [13]. Soil erosion is also affected by how much and how often it rains, and the situation will get worse in northeast China if greenhouse gas emissions go up [14]. Anomalies in how much rain falls hurt agriculture, especially in developing countries. In addition to affecting crop yields, it has a big effect on the areas of cropland. There is evidence that the roughly 9% rate of cropland expansion in the developing world over the last 20 years is due to dry anomalies, as farmers expand the area to make up for yield losses [15]. The world's food security will be in danger because of global warming, but if it stays below 1.5 C, 76% of developing countries will be less at risk than if it goes above 2 C [16]. Climate change makes it difficult to feed the world's population since it has a significant impact on agriculture. From 2005/2007 to 2050, global agricultural production must expand by 60% per year, with increases of 77% in poor countries and 24% in wealthy nations. . This is needed to meet the food and nutrition needs of the population [17]. Climate change is known to hurt agricultural production, and it is expected that maize and wheat production will drop by 3.8% and 5.5%, respectively, around the world [18]. Plants have to deal with abiotic stresses like saltiness, drought, heat stress, cold stress, etc. because of the weather. Climate change has a lot of bad effects, but the most important ones are less water, less fertile soil, and pests in crops [19]. This study attempts to compile research on how climate change may effect agriculture output, weed infestations, and the economy from 1998 to 2020. . Also, mitigation and adaptation strategies to fight climate change are talked about so that everyone can understand what they might mean.

2. Materials and Methods

PRISMA (Preferred Reporting Items for Systematic Meta-Analysis), was used to do a systematic review of the literature. We used keywords like "climate and agriculture," "climate change and mitigation," "climate change and economics," and "climate change and mitigation" to find studies that fit with our research goals. Also, the search was done for the period from 1998 to 2020. Out of the 410 documents that were

looked over, only 200 were found to be useful. In the end, research papers that had been published in journals with a "impact factor" were chosen, and their results are given here.

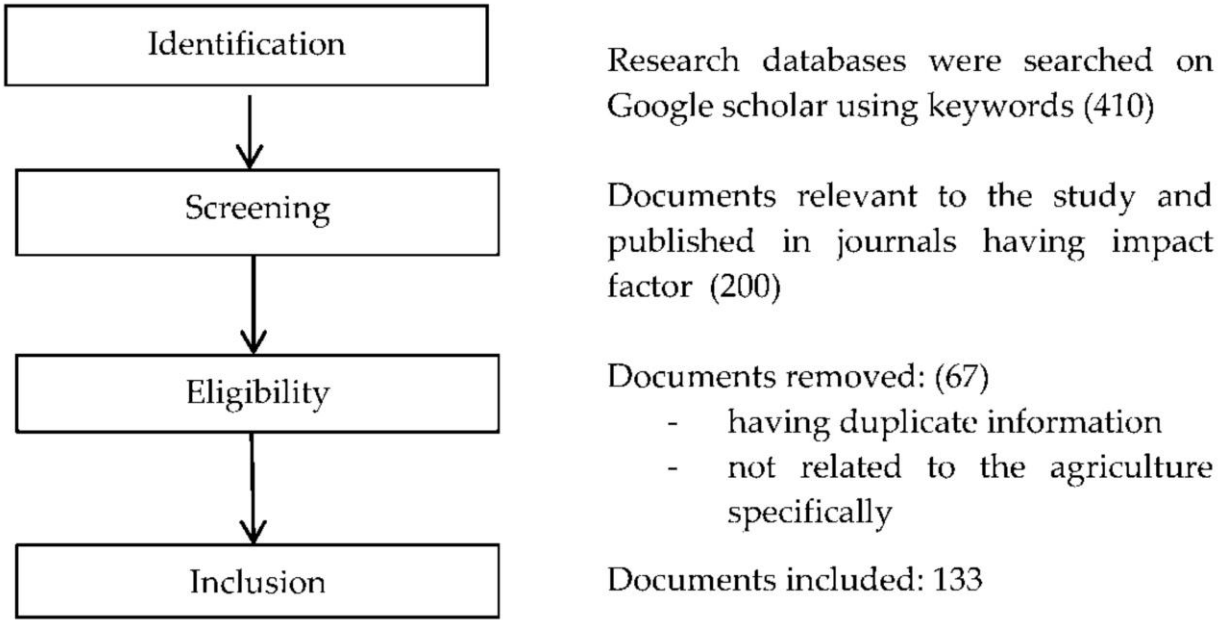

Fig: Method for selection of research papers for review and analysis.

3. Causes of Climate Change

Changes in temperature are caused by natural events and human actions on Earth, which in turn lead to the buildup of GHGs. Human actions cause the release of greenhouse gases like CO2, methane, and nitrous oxide, as well as other chemicals that deplete the ozone layer in the atmosphere. Increased CO2 in the atmosphere can change how microorganisms work in the soil and how much water is in the soil. As a result, increased atmospheric CO2 (463–780 ppm) can cause more nitrous oxide and methane to be released from upland soil and wetlands, which cancels out the 16.6% reduction in climate change predicted by increasing terrestrial carbon sink [20]. 15% of all emissions, mostly methane and nitrous oxide, come from the agriculture sector. If people keep eating the same way and using the same amount of energy from food as they did in 1995, it is expected that non-agricultural greenhouse gas emissions will rise until 2055. But because people are becoming more interested in high-value foods like milk and meat, the emissions are expected to rise even faster.

Either technology can be used to cut down on the emissions, or people can eat less meat, or both [21]. The livestock industry is the main source of greenhouse gas emissions. The IPCC says that it is responsible for 8–10.8% of emissions, but a lifecycle analysis shows that it can be responsible for up to 18% of GHG emissions [22]. The main ways that livestock contribute to greenhouse gas emissions are through enteric fermentation, N2O emissions, liming, fossil fuels, organic farming, and making fertiliser. Greenhouse gases are also made when nitrogen-based chemical fertilisers are used . N fertiliser use can be cut by 38% if crop production is better planned. Better crop management also increases yields by 33% and uses 11% less energy to grow the crops. This cuts greenhouse gas emissions by 20% [23].

4. Climate Change and Agriculture

Agriculture is the most affected by climate change because of how big it is and how sensitive it is to weather conditions. This has huge economic effects. Changes in weather events like temperature and rainfall have a big effect on how much crops grow. The effects of rising temperatures, changes in rainfall, and CO_2 fertilisation depend on the crop, where it is, and how much the parameters change. It has been found that a rise in temperature lowers the crop yield, but a rise in rainfall is likely to cancel out or lessen the effect of a rise in temperature [24]. As seen in Iran, climate variables affect crop production, which depends on the crop's ability to adapt, the climate scenario, and the effect of CO2 fertilisation [25]. In Cameroon, it has been found that when it rains less or gets warmer, farmers' net income goes down by a lot. Because of this and bad policymaking, Cameroon's agricultural exports are not in high demand, which makes the country's income go up and down [26]. Statistics show that the temperature affects the amount of coffee that can be grown in Veracruz, Mexico. It was also found that the producers may not be able to make money from coffee production in the coming years, as there are signs that production will drop by 34% [27]. How climate change affects crop yields depends on where the crops are grown and how much water they get. By expanding irrigated areas, crop yields can be raised, but this can be bad for the environment . By making crops grow faster, a rise in temperature is likely to lower the yield of many crops. If both temperate and tropical regions warm up by 2 C, the total amount of wheat, rice, and maize that can be grown is expected to go down [28]. In general, climate change has a bigger effect on tropical areas because crops there stay closer to their high-temperature optimals and suffer more from high-temperature stress when the temperature goes up. Also, insect pests and diseases are more common in places that are humid and warm [29]. Along with temperature and rainfall, other factors like humidity and wind speed also affect crop yields. Without these factors, there was a chance that the cost of climate change would be overestimated. Also, it was found that climate change is likely to reduce the yields of wheat, corn, and rice in China by 18.2612.13, 45.1011.55, and 36.2510.75% until 2100 [30]. Since the 1900s, there have been more and more extreme weather events in the Netherlands, which has had a big effect on the amount of wheat grown there. How much a wheat crop dropped because of bad weather depended on what week it happened [31]. Most parts of the world are expected to have more droughts in the near future because of climate change. By 2100, the area affected by drought is expected to grow from 15.4% to 44.0%. Africa is said to be the most dangerous place. It is expected that the yield of major crops in areas with drought will drop by more than 50 percent by 2050 and by almost 90 percent by 2100 [32].

When crop yields go down, food prices can go up, and this can have a crazy effect on agriculture around the world, leading to a 0.3% annual loss of GDP by 2100. But [33] found that climate change doesn't have much of an effect on the world's food supply, but it will have a big effect on the developing countries. In India, the temperature is expected to rise between 2.33°C and 4.78°C, CO2 levels are expected to double, and heat waves are expected to last longer. This could hurt the agriculture industry [34]. In the dry area of Rawalpindi, Pakistan, farmers will lose INR 4,180 per acre every year by 2100 if the temperature goes up by 1°C, but their net income will go up by INR 377.4, and by INR 649.21 if the amount of rain goes up by 8% or 14% [54]. With a 1 C rise in the average surface temperature around the world, rice, maize, and wheat are expected to lose 10–25% of their yields [55]. Climate change is expected to lower the average crop yield in sub-Saharan Africa by 6–24% [35]. Solomon Island is also expected to need more fish than it can produce in 2050, which will have a big effect on food

security because the amount of fish each person eats will go down.

The relationships between plants and water are very sensitive to changes in temperature and precipitation, and extreme changes in these parameters are more likely to cause physiological changes than changes in the average climate [58]. How plants react to climate change depends on what kind of plant it is and what stage of growth it is in. Different species of plants have different thresholds, and their responses, like growing longer roots, changing the angle at which roots grow, and lowering their yield, vary [59]. With more CO2 in the air, plants were found to have less transpiration, which caused the air temperature to rise by 0.42 0.02 K. The warming of land surfaces can be increased by 3.33 0.03 K because of this direct physiological effect of higher CO2 and a direct radiative effect [36]. As the amount of CO2 in the air goes up, the amount of crops that can be harvested should go up, and the way plants grow depends on the type of crop. Even though C3 crops are expected to produce more, both C3 and C4 crops are expected to need less water when there are no stressful conditions. But these good effects of more CO2 are likely to be cancelled out by warmer temperatures and different rain patterns [37]. But in some places, the effects of climate change on agriculture production are also positive. But these regional changes, whether they are increases or decreases, won't have a huge effect, and they will only be more noticeable in some low latitudes. But if the temperature goes up more than what would happen if CO2 doubled, this can lead to big economic losses. The effects of climate change will be very bad in tropical areas of developing countries, but how bad they are will depend a lot on the region's climate. In terms of agriculture, the north and east of Sri Lanka, which are drier, will lose a lot more than the cooler central highlands, where production is expected to stay the same or even go up as temperatures rise [38]. The speed of climate change affects its effects, which in turn affects how much it costs to adapt. This means that environmental policies must be dynamic and put into place in a way that allows for adaptation and flexibility. A sensitivity analysis using CERES (crop estimation through resources and environmental synthesis) has also shown that wheat and rice yields in northwest India could increase by 28% and 15%, respectively, at double the levels of CO2. However, the higher temperatures caused by high CO2 levels almost cancel out the positive effects. Also, the yields of both rice and wheat will go up by 21% and 4%, respectively, if the same irrigation schedule is used even though CO2 levels will be higher and temperatures will be higher. But if there is a severe lack of water and a lot of heat stress, the yield of rice and wheat is likely to go down in the future, even if CO2 levels go up [39]. The increase in CO2 could make up for the decrease in crop yields caused by higher temperatures and less water in the soil. The increased CO2 concentration reduces global yield losses by a lot, mostly by cutting the amount of water used in agriculture by 4–17%. Also, the differences in crop yields between regions are mostly caused by how different crops grow . When the level of CO2 is high, non-leguminous C3 crops have less of the nutrients (N, Fe, Zn, and S) that are mostly found in proteins [40]. At an ambient air temperature of 29°C, rice crops grow faster and produce more seeds when the CO2 level goes up. However, when the temperature goes up, the number of seeds set goes down. When CO2 levels are high, the amount of zinc and iron in C3 grain crops and legumes goes down, which is bad for human health. The amount of protein in C3 plants and legumes also seems to go down when the CO2 level goes up, but C4 plants don't seem to be affected [41]. Changes in climate also affect the kinds of microorganisms that live in the soil and how their enzymes work. The number of microorganisms was found to be much higher in a temperature gradient tunnel with a temperature that was 4–5 C higher than in the field.

Populations of nitrogen-fixing and P-solubilizing bacteria and fungi, as well as enzymatic activities, were significantly higher at a wide range of temperatures, but the highest parameters were found at or near the optimum temperature. On the other hand, the growth of endophytic fungus and bacteria that help plants grow can be good, bad, or have no effect, depending on the temperature range. Table 1 shows what different models say about the effect of climate change on the yield of different crops.

Table 1: Impact of climate change on crop productivity.

Crops	Yield Variation	Cause	Model Used	Location	Source
Corn, soybean, cotton	Yield increase up to 29–32 ◦C −30–46% by 2100 −63–82% by 2100	Slowest warming scenario Rapid warming scenario	Hadley III model	United States of America	[42]
Cotton, sunflower, wheat	−2–9% by 2050	Medium-high and low GHG emissions	DAYCENT	California's Central Valley	[43]
Maize	−5–13% if occurred later in season	Increased frequencies of extreme weather events and warming	SALUS crop model	Northern Midwest USA	[44]
Wheat	-5–17% and −2–18% if occurred early in season				
Sorghum	−2.2%	Increasing temperature	County-specific multiple linear regression model	Great Plains of USA	[45]
Soybean	-0.5%				
Maize	+1.6%				

Most likely, pathogens will be affected by changes in the climate that are expected to happen [46]. Changes in a place's climate or weather pattern are likely to make crops more vulnerable to pests, diseases, and weeds. Yields are expected to go up in countries with high and mid-latitudes, but to go down in countries with lower latitudes . With a one-degree temperature rise, however, it is thought that insect pest infestations will cause 10–25% more damage [47]. Climate change could lead to an increase in the number of pests and their ability to move around. This could hurt agricultural yields and even make farming impossible, since pest populations are mostly affected by things like humidity and temperature. In Brazil, coffee nematodes and leaf miners are likely to become more of a problem because there will be more generations in a month than there were from 1961 to 1990 [48]. Because of this, pest control has cost a lot of money in pesticides. Statistics show that as rain and temperature went up, the cost of pesticides for crops like corn, potatoes, and soybeans went up, but the cost of

pesticides for wheat went down in the USA [49]. For the second generation, the amount of arable land affected by the European corn borer and the Colorado potato beetle is expected to rise by 43% and 48%, respectively, in the HadCM3-high 2050 scenario. Uninhabited areas at high altitudes are also vulnerable to these pests in a warmer Central Europe [86] scenario. In the current global warming scenario, the area where the wheat aphid (Schizaphis graminum) can live is expected to grow to higher latitudes in the northern hemisphere by 2030, but it is expected to shrink in the southern hemisphere [50]. It is also likely that 30 types of pest insects will show up more often. As the temperature rises in Sweden, it is likely to affect new areas and hurt the country's forestry industry [51]. When GIS modelling was used to predict the future of the potato tuber moth (Phthorimaea operculella), it was found that the pest could do more damage in tropical and subtropical warmer regions, where it already lives. It is also expected to grow in temperate and mountainous areas, where it could do a little more damage [52]. The life cycle of pathogens like Puccinia striiformis f.sp. tritici is expected to be slowed down by rising temperatures, while Fusarium pseudograminearum is expected to benefit from a rise in the amount of CO2 in the air [53]. Climate change affects how people live and where they live, as well as how fast they grow and how many generations they have. Changes in climate can make pests live longer and change how crops and pests grow at the same time. It can also make migrant pests more likely to come into an area. Climate change may also make it less effective to protect plants with things like host plant resistance, natural enemies, transgenic plants, synthetic chemicals, or biopesticides [54]. Climate change and globalisation could make it hard to predict how cropping systems, weather, and pests will work together. Changes in climate are likely to affect how fast insects grow and how fast they burn energy, especially in temperate regions . Climate change is also making it easier for pests to live in more places. The habitats of Africa's three most common insect species, Tuta absoluta, Ceratitis cosyra, and Bactrocera invadens, are getting better all over the continent, especially in places close to where they live best [55]. Also, the rising CO2 level and temperature are making it more likely that late blight of potatoes, blast, and sheath blight of rice will happen, which could be very bad for the food security of the world [56]. Climate change also affects the number of weeds that grow in crops. When the amount of CO2 in the air goes up, C3 weeds respond more strongly by growing more leaves and more biomass. C3 weeds are a big problem for C4 plants, but C4 weeds don't do as well on C3 plants . Weeds and crops compete for water and nutrients because weeds need more nutrients than crop plants . Changes in climate also affect how crops and weeds compete with each other. Changes in climate also have a big effect on how well herbicides work because they change the way they kill weeds. Weeds in wheat crops, which are very important to the world's food security, are likely to benefit from climate change. Weeds are spreading to new areas because of climate change, and these new areas can only be managed if new management practises are planned with climate change in mind. Climate change is expected to make pest infestations of different crops worse, since warmer and more humid conditions are better for pest growth. But it will depend on where you live and how well the pests can adapt to climate change.

Climate change: how to stop it and how to deal with it

The most important thing that drives farmers to take action on their own is how they see the threat and severity of climate change. But the change depends on what kind of information is available [57]. With mitigation strategies, the number of people who are exposed to water stress will go down, but the people who are still exposed will need adaptation strategies because they will be under more stress [58]. Traditional management systems and agroecological

management systems, such as biodiversification, soil management, and water harvesting, can help farmers adopt climate-resilient technologies . These management practises make sure there is more carbon sequestration, better soil health, better soil quality, and less soil erosion. This leads to resilient soils and cropping systems, which in turn makes sure there is enough food during climate change . The most effective ways to teach people about climate change for ecological development are these ones, which focus on local, tangible, and doable things and can be measured by how people act . Farmers were mostly in favour of adaptations, but only a few were in favour of reducing GHGs. This shows that we need to focus on interventions that have both adaptation and mitigation features [59]. The main ways to adapt to and reduce the effects of climate change can be roughly put into three groups: technologies for conserving resources, technologies for improving cropping systems, and social, economic, or policy interventions . Small and marginal farmers can't deal with climate change because they don't know enough about it. This makes them more likely to lose money . Farmers in African countries are also very vulnerable to climate change because it will cost them money and they don't have any good ways to deal with it . There have been ways to lessen the effects of climate change, such as moving the dates when crops are planted. The best time to plant wheat in Punjab, India, is between October 22 and 28 in the northeast, between October 24 and 30 in the centre, and between October 21 and 27 in the southwest [60]. Farmers in sub-Saharan Africa lose the least crop yield when they use sequential cropping systems and change when they plant seeds based on the weather . The agroforestry sector can help reduce the amount of GHGs in the air, which will help small farmers in Kenya adapt to climate change. There are some easy ways to reduce GHG emissions, such as changing the way rice dries, draining the soil in the middle of the growing season, giving livestock a better diet, making it easier to use nitrogen, and adding carbon to the soil. Simple ways to adapt, like changing when and what you plant, could make the effects of climate change less severe . The spread of technology is a very important factor in how farmers deal with climate change. Integration of the market, support for public research, and building up of capacities are the most important things. Conservation agriculture has the potential to fix the damage that conventional tillage has done over the years. This is because it leads to less soil disturbance, a wider range of crops, and keeping the soil covered. Conservation agriculture also leads to less greenhouse gas (GHG) emissions, less fertiliser use, and more carbon being stored in the soil . Conservation agriculture is based on the ideas that the soil should be disturbed as little as possible, crops should be rotated, and the soil should be covered. These ideas are the foundation of sustainable farming methods. Farmers in south Asia are growing wheat with no tilling because it saves them 15–16% on the cost of growing wheat. Also, wheat and maize yields are higher and less variable when there is no tilling [61]. People also said that no-till practises could be used instead of conventional tillage, which reduces the effects of climate change by storing carbon. However, the effect of no-till cultivation on climate change is overstated, because it only adds a small amount of organic carbon to the soil . Conservation agriculture (CA) has spread because of a number of things, including people's perceptions of its benefits, the use of functional market exchange techniques to get the necessary resources for CA implementation, economic incentives for farmers, the creation of farmer organisations to encourage local adaptation, and alliances between farmer organisations and institutions to create a good environment [62].

Climate-smart technologies that provide nutrients, water, or support soil structure are the most effective. Some technologies, like half-moons, stone bunds, zai, and nutrient application, were found to work well in

semiarid West Africa to keep food production going and protect smallholder farmers . Climate-smart farming techniques were studied in Punjab, Pakistan, and it was found that cotton yields were higher and resources were used more efficiently . The Indo-Gangetic plain is very susceptible to climate change, which hurts the area's rice and wheat crops. Farmers have said that they are willing to use climate-smart agriculture technologies that can make traditional farming methods more productive. In the eastern Indo-Gangetic Plains (IGP), the most popular CSA technologies are laser land levelling (LLL), weather advisory services, and crop insurance. In the western IGP, the most popular CSA technologies are direct seeding, LLL, zero tillage, crop insurance, and scheduling irrigation [63]. These adaptation and mitigation strategies have a lot of potential for adaptation and mitigation. But they depend on how well a technology fits the region, how people see it, how well it works economically, and how hard it is to use. Also, these strategies work best when a number of different interventions are used together to help each other.

5. Economic Impact of Climate Change and Climate-Smart Agriculture Technologies

Some of the first effects of climate change were good, but the inevitable warming of the environment is a bad externality. If the temperature goes up more than 3 C, the net effect is bad, and if it goes up more than 7 C, the total welfare can go down. In 2015, the social cost of carbon emissions is expected to be USD 29/tC (tonnes of carbon) and to rise by 2% per year . If strategies to slow down climate change are put into place, Solomon Island's fishing industry would make a lot of money. Climate change will also have a big effect on agricultural markets, which will cause a 0.26 percent drop in the global GDP [135]. If the weather predicted for the 2080s happened today, it would cost households between 0.2 and 1% of their annual income [64]. With a 1 C rise in the average global temperature, both market and non-market damages are expected to cost 1.2% of the global GDP [65]. If future strategies for reducing the effects of climate change are based on how past strategies were changed, the world's income is expected to drop by 23% by 2100, and the gap between rich and poor will get bigger [66]. The growth of the world economy is expected to slow by 0.28% per year [67]. Table 2 shows how different climate-smart agriculture technologies can help farmers make more money. Some of the first effects of climate change were good, but the inevitable warming of the environment is a bad externality. If the temperature goes up more than 3 C, the net effect is bad, and if it goes up more than 7 C, the total welfare can go down. In 2015, the social cost of carbon emissions is expected to be USD 29/tC (tonnes of carbon) and to rise by 2% per year [6]. If strategies to slow down climate change are put into place, Solomon Island's fishing industry would make a lot of money. Climate change will also have a big effect on agricultural markets, which will cause a 0.26 percent drop in the global GDP [135]. If the weather predicted for the 2080s happened today, it would cost households between 0.2 and 1% of their annual income [64]. With a 1 C rise in the average global temperature, both market and non-market damages are expected to cost 1.2% of the global GDP [65]. If future strategies for reducing the effects of climate change are based on how past strategies were changed, the world's income is expected to drop by 23% by 2100, and the gap between rich and poor will get bigger [66]. The growth of the world economy is expected to slow by 0.28% per year [67]. Table 2 shows how different climate-smart agriculture technologies can help farmers make more money.

Table 2. Incremental benefits of climate-smart agriculture technologies

Location	Crop	Climate-Smart Technology	Enhanced Efficiency	Incremental Economic Benefit	References
Nyando basin of Kenya	Multiple crops and livestock	Stress-tolerant crop varieties	Increased household income leading to household asset accumulation and investment	Increased HH income by 83%	[68]
Vietnam	Rice	Site-specific nutrient management	Increased partial factor productivity of nitrogen	34 US$/ha	[69]
Sindh, Pakistan	Wheat	Laser land leveling	Saving of 21% irrigation water and reduced irrigation time	INR 23,250/ acre	[70]
Upper Gangetic plains	Wheat	Site-specific nutrient management	Increased yield by 29% over farmers fertilizer practice	INR 68,980/ ha over FFP	[71]
			s (FFP)		
Semi-arid tropics of India	Groundnut	Drought-tolerant varieties	Increase in yield by 23%, lower variability in yield, increased share of risk benefits in total benefits	17% reduction in variable cost	[72]
India	Eggplant	Drip irrigation	Reduced water, electricity and fertilizer use, and increased returns	54% higher net returns	[73]

6. Conclusions and Prospects

A growing population has put a lot of pressure on agriculture to make sure that everyone has enough food and nutrition. Climate change is making things even worse. Even though we don't know exactly what the future climate will be like or how it will affect us, different studies show that climate change will make farming less productive in the coming years. The most important parts of climate, like temperature, rainfall, and greenhouse gases, have had a big effect on pests, soil fertility, irrigation resources, physiology, and the way plants use energy. Agricultural sustainability has been hurt by climate change, but a number of mitigation and adaptation strategies have been made to make up for this. Some of these technologies are water-smart (laser land leveling, rainwater harvesting, micro-irrigation, crop diversification, raised-bed planting, direct-seeded rice), nutrient-smart (precision

nutrient application, leaf colour charts, crop residue management), weather-smart (stress-tolerant varieties, ICT-based agrometeorological services), carbon-smart (zero tillage, legumes, crop residue management), and These technologies reduce the negative effects of climate change on crops and make them better suited to the climate by reducing the effects that aren't good. On both the small and large scales, climate change is expected to cause huge economic losses, which can be lessened with these steps. But these interventions will work better if they are set up at the regional or local level. The goal of mitigation and adaptation strategies is to raise farmers' incomes without hurting the long-term viability of agricultural production. The future of climate change and its effects is very hard to predict, which makes it hard to plan for how to stop or adapt to it. This makes it important to come up with climate-resilient technologies that take into account different fields, depending on the area. Along with planned agronomic management and crop pest control, the right kinds of plants that can adapt to different climates need to be created. Farmers need to be taught about different climate-smart technologies and given training on how to use them in the field.

References

[1] W. M. Organization, "International Meteorological Vocabulary, 2nd ed.; WMO: Geneva, Switzerland," vol. 1992.

[2] I. C. change, *Impacts, adaptation and vulnerability*. In Working Group II Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change; Cambridge University Press: Cambridge, UK, 2007, 2007.

[3] N. E. Observatory, "Goddard Space Flight Centre United States," *Available online: www.earthobservatory.nasa.gov (accessed on*, vol. 15, May 2020.

[4] N. Earth, "System Research Laboratory (NOAA). 2020," *Available online: www.esrl.noaa.gov (accessed on*, vol. 15, Dec. 2020.

[5] C. Carbon, "Dioxide Information Analysis Center. 2020," *Available online: www.cdiac.ess-dive.lbl.gov (accessed on*, vol. 13, Nov. 2020.

[6] R. S. J. Tol, "On the uncertainty about the total economic impact of climate change," *Environ. Res*, vol. 53, pp. 97–116, 2012.

[7] H. Richie and M. Roser, "Our World in Data," *CO*, vol. 2, Nov. 2020, [Online]. Available: https://ourworldindata.org/

[8] T. Wei *et al.*, "Developed and developing world responsibilities for historical climate change and CO2 mitigation," in *Proc. Natl*, 2012, pp. 12911–12915.

[9] S. A. A. Bokhari, G. Rasul, A. C. Ruane, G. Hoogenboom, and A. Ahmad, "The Past and Future Changes in Climate of the Rice-Wheat Cropping Zone in Punjab, Pakistan," *Pakistan J. Meteorol.*, vol. 13, no. 26, pp. 9–23, 2017.

[10] N. Kaur and P. Kaur, *Projected climate change under different scenarios in central region of Punjab, India*. J. Agrometeorol, 2016.

[11] H. Chen and J. Sun, "Projected changes in climate extremes in China in a 1.5 °C warmer world," *Int. J. Climatol.*, vol. 38, no. 9, pp. 3607–3617, 2018, doi: 10.1002/joc.5521.

[12] R. Rajbhandari, A. B. Shrestha, A. Kulkarni, S. K. Patwardhan, and S. R. Bajracharya, "Projected changes in climate over the Indus river basin using a high resolution regional climate model (PRECIS)," *Clim. Dyn*, vol. 44, pp. 339–357, 2015.

[13] L. Ning, E. E. Riddle, and R. S. Bradley, *Projected changes in climate extremes over the Northeastern United States*. J. Climate, 2015.

[14] Y. G. Zhang, M. A. Nearing, X. C. Zhang, Y. Xie, and H. Wei, "Projected rainfall erosivity

changes under climate change from multimodel and multiscenario projections in Northeast China," *J. Hydrol*, vol. 384, pp. 97–106, 2010.

[15] E. Zaveri, J. Russ, and R. Damania, "Rainfall anomalies are a significant driver of cropland expansion," in *Proc. Natl*, 2020.

[16] R. A. Betts *et al.*, "Changes in climate extremes, fresh water availability and vulnerability to food insecurity projected at 1.5°C and 2°C global warming with a higher-resolution global climate model," *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.*, vol. 376, no. 2119, p. 20160, 2018, doi: 10.1098/rsta.2016.0452.

[17] N. Alexandratos and J. W. A. Bruinsma, "Towards 2030/2050; ESA," 2012.

[18] D. B. Lobell, W. Schlenker, and J. C. trends Costa-Roberts, "and global crop production since 1980," *Science (80-.).*, vol. 333, pp. 616–620, 2011.

[19] T. K. Baul and M. McDonald, *Integration of indigenous knowledge in addressing climate change*, vol. 14, no. 1. Indian J. Tradit. Knowl, 2015.

[20] K. J. V Groenigen, C. W. Osenberg, and B. A. Hungate, "Increased soil emissions of potent greenhouse gases under increased atmospheric CO2," *Nature*, vol. 475, pp. 214–216, 2011.

[21] A. Popp, H. Lotze-Campen, and B. F. consumption Bodirsky, "diet shifts and associated non-CO2 greenhouse gases from agricultural production," *Glob*, vol. 20, pp. 451–462, 2010.

[22] F. P. O'Mara, "The significance of livestock as a contributor to global greenhouse gas emissions today and in the near future," *Anim. Feed Sci*, vol. 166, pp. 7–15, 2011.

[23] A. Soltani, M. H. Rajabi, E. Zeinali, and E. E. inputs Soltani, "and greenhouse gases emissions in wheat production in Gorgan, Iran," *Energy*, vol. 50, pp. 54–61, 2013.

[24] R. M. Adams, B. H. Hurd, S. Lenhart, and N. Leary, "Effects of global climate change on agriculture: An interpretative review," *Clim. Res.*, vol. 11, no. 1, pp. 19–30, 1999, doi: 10.3354/cr011019.

[25] V. Karimi, E. Karimi, and M. C. change Keshavarz, *and agriculture: Impacts and adaptive responses in Iran*. J. Integr. Agric.

[26] E. L. Molua and C. M. Lambi, "The Economic Impact of Climate Change on Agriculture in Cameroon; Policy Research," 2007.

[27] C. Gay, F. Estrada, C. Conde, H. Eakin, and L. Villers, "Potential impacts of climate change on agriculture: A case of study of coffee production in Veracruz, Mexico," *Clim. Change*, vol. 79, no. 3–4, pp. 259–288, 2006, doi: 10.1007/s10584-006-9066-x.

[28] A. J. Challinor, J. Watson, D. B. Lobell, S. M. Howden, D. R. Smith, and N. Chhetri, "A meta-analysis of crop yield under climate change and adaptation," *Nat. Clim. Chang.*, vol. 4, no. 4, pp. 287–291, 2014, doi: 10.1038/nclimate2153.

[29] C. Rosenzweig and D. Liverman, "Predicted effects of climate change on agriculture: A comparison of temperate and tropical regions," in *Global Climate Change: Implications*, ; PA The Pennsylvania Academy of Sciences: Grove City, PA, USA, 1992, pp. 342–361.

[30] P. Zhang, J. Zhang, and M. Chen, "Economic impacts of climate change on agriculture: The importance of additional climatic variables other than temperature and precipitation," *J. Environ. Econ*, vol. 83, pp. 8–31, 2017.

[31] J. P. Powell and S. Reinhard, "Measuring the effects of extreme weather events on yields," *Weather Clim. Extrem*, vol. 12, pp. 69–79, 2016.

[32] Y. Li, W. Ye, M. Wang, and X. C. change Yan, “and drought: A risk assessment of crop-yield impacts,” *Clim. Res*, vol. 39, pp. 31–46, 2009.

[33] F. Bosello and J. Zhang, “Assessing Climate Change Impacts: Agriculture,” 2011. doi: 10.2139/ssrn.771245.

[34] R. Kumar and H. R. C. change Gautam, *and its impact on agricultural productivity in India*. J. Climatol. Weather Forecast, 2014.

[35] K. Waha *et al.*, “Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa,” *Glob*, vol. 23, pp. 130–143, 2013.

[36] L. Cao, G. Bala, K. Caldeira, R. Nemani, and G. Ban-Weiss, “Importance of carbon dioxide physiological forcing to future climate change,” in *Proceedings of the National Academy of Sciences of the United States of America*, 2010, vol. 107, no. 21, pp. 9513–9518. doi: 10.1073/pnas.0913000107.

[37] A. Wicaksana, *済無No Title No Title No Title*. Impacts of climate changes on crop physiology and food quality, 2016. [Online]. Available: https://medium.com/@arifwicaksanaa/pengertian-use-case-a7e576e1b6bf

[38] S. N. Seo, R. Mendelsohn, and M. C. change Munasinghe, “and agriculture in Sri Lanka: A Ricardian valuation,” *Environ. Dev. Econ*, vol. 10, pp. 581–596, 2005.

[39] M. Lal, K. K. Singh, L. S. Rathore, G. Srinivasan, and S. A. Saseendram, “Vulnerability of rice and wheat yields in NW India to future changes in climate,” *Agric. For*, vol. 89, pp. 101–114, 1998.

[40] J. Uddling, M. C. Broberg, Z. Feng, and H. Pleijel, *Crop quality under rising atmospheric CO2*. Curr. Opin. Plant Biol, 2018.

[41] S. S. Myers *et al.*, “Increasing CO2 threatens human nutrition,” *Nature*, vol. 510, pp. 139–142, 2014.

[42] W. Schlenker and M. J. Roberts, *Nonlinear temperature effects indicate severe damages to U*. S. crop yields under climate change.

[43] J. Lee, S. D. Gryze, and J. Six, *Effect of climate change on field crop production in California’s central valley*. Clim. Chang, 2011.

[44] L. Liu and B. Basso, *No Title*. Impacts of climate variability and adaptation strategies on crop yields and soil organic carbon in US Midwest.

[45] M. S. Kukal and S. Irmak, “Climate-driven crop yield and yield variability and climate change impacts on the U,” *S. Gt. plains Agric. Prod.*, vol. 8, pp. 1–18, 2018.

[46] Y. Elad and I. Pertot, “Climate change impact on plant pathogens and plant diseases,” *Combat. Clim. Chang. An Agric. Perspect.*, vol. 28, pp. 183–211, 2013, doi: 10.1201/b14056.

[47] S. Shrestha, “Effects of climate change in Agricultural Insect Pest,” *Acta Sci. Agric*, vol. 3, pp. 74–80, 2019.

[48] R. Ghini, E. Hamada, M. J. P. Junior, J. A. Marengo, and R. R. V Goncalves, “Risk analysis of climate change on coffee nematodes and leaf miner in Brazil,” *Pesqui. Agropecu. Braileira*, vol. 43, pp. 187–194, 2008.

[49] C. C. Chen and B. A. McCarl, *Erratum: An Investigation of the Relationship between Pesticide Usage and Climate Change (Climatic Change (2001) 50 (475-487))*, vol. 61, no. 1–2. Clim. Chang, 2003. doi: 10.1023/A:1026357825687.

[50] R. Aljaryian and L. Kumar, *Changing global risk of invading greenbug Schizaphis graminum under climate change*. Crop Prot, 2016.

[51] A. R. Hof and A. Svahlin, "The potential effect of climate change on insect pest species' geographical distribution in the Swedish boreal forest," *Scand. J.*, vol. 31, pp. 1–15, 2015.

[52] J. Kroschel *et al.*, "Predicting climate-change-caused changes in global temperature on potato tuber moth Phthorimaea operculella (Zeller) distribution and abundance using phenology modeling and GIS mapping," *Agric. For*, vol. 170, pp. 228–241, 2013.

[53] H. R. Gautam, M. L. Bhardwaj, and R. Kumar, "Climate change and its impact on plant diseases," *Curr. Sci.*, vol. 105, no. 12, pp. 1685–1691, 2013.

[54] P. P. Reddy, "Impact of climate change on insect pests, pathogens and nematodes," *Pest Manag. Hortic. Ecosyst*, vol. 19, pp. 225–233, 2013.

[55] L. Biber-Freudenberger, J. Ziemacki, H. E. Z. Tonnang, and C. Borgemeister, "Future risks of pest species under changing climatic conditions," *PLoS One*, vol. 11, no. 4, 2016, doi: 10.1371/journal.pone.0153237.

[56] N. E. Korres *et al.*, "Cultivars to face climate change on crops and weeds: A review," *Agron. Sustain Dev*, vol. 36, pp. 12–22, 2016.

[57] J. C. Semenza, G. B. Ploubidis, and L. A. C. change George, "and climate variability: Personal motivation for adaptation and mitigation," *Environ. Heal.*, vol. 10, pp. 1–12, 2011.

[58] D. P. V Vuuren *et al.*, "The use of scenarios as the basis for combined assessment of climate change mitigation and mitigation," *Glob*, vol. 21, pp. 575–591, 2010.

[59] J. G. Arbuckle, L. W. Morton, and J. Hobbs, "Understanding Farmer Perspectives on Climate Change Adaptation and Mitigation: The Roles of Trust in Sources of Climate Information, Climate Change Beliefs, and Perceived Risk," *Environ. Behav.*, vol. 47, no. 2, pp. 205–234, 2015, doi: 10.1177/0013916513503832.

[60] S. S. Sandhu, P. Kaur, K. K. Gill, and B. B. Vashisth, "The effect of recent climate shifts on optimal sowing windows for wheat in Punjab, India," *J. Water Clim. Chang*, vol. 11, pp. 1177–1190, 2019.

[61] O. Erenstein, K. Sayre, P. Wall, J. Hellin, and J. Dixon, "Conservation Agriculture in Maize- and Wheat-Based Systems in the (Sub)tropics: Lessons from Adaptation Initiatives in South Asia, Mexico, and Southern Africa," *J. Sustain. Agric.*, vol. 36, no. 2, pp. 180–206, 2012, doi: 10.1080/10440046.2011.620230.

[62] B. Brown, R. Llewellyn, and I. Nuberg, "Global learnings to inform the local adaptation of conservation agriculture in Eastern and Southern Africa," *Glob. Food Sec.*, vol. 17, pp. 213–220, 2018, doi: 10.1016/j.gfs.2017.10.002.

[63] G. Taneja, B. D. Pal, P. K. Joshi, P. K. Aggarwal, and N. K. Tyagi, "Farmers' preferences for climate-smart agriculture-an assessment in the Indo-Gangetic plain," in *Climate Smart Agriculture in South Asia; Pal*, K. B., J. A., and T. P., Eds. ; Springer: Singapore [CrossRef, 2019.

[64] J. C. Ciscar *et al.*, "Physical and economic consequences of climate change in Europe," in *Proceedings of the National Academy of Sciences of the United States of America*, 2011, vol. 108, no. 7, pp. 2678–2683. doi: 10.1073/pnas.1011612108.

[65] S. Hsiang *et al.*, "Estimating economic damage from climate change in the United States," *Science (80-.).*, vol. 356, pp. 1362–1369, 2017.

[66] M. Burke, S. M. Hsiang, and E. Miguel, "Global non-linear effect of temperature on

economic production," *Nature*, vol. 527, no. 7577, pp. 235–239, 2015, doi: 10.1038/nature15725.

[67] T. A. Carleton and S. M. Hsiang, "Social and economic impacts of climate," *Science (80-.).*, vol. 353, no. 6304, p. 9837, 2016, doi: 10.1126/science.aad9837.

[68] M. J. Ogada, E. J. O. Rao, M. Radeny, J. W. Recha, and D. C. agriculture Solomon, *household income and asset accumulation among smallholder farmers in Nyando basin of Kenya*. World Dev. Perspect [CrossRef], 2020.

[69] M. F. Pampolino *et al.*, "and economic benfits of site-specific nutrient management (SSNM) in irrigated rice systems," *Agric. Syst*, vol. 93, pp. 1–24, 2007.

[70] S. A. Wagan, Q. U. A. Memon, T. A. Wagan, I. H. Memon, and A. Wagan, "Economic analysis of laser land leveling technology water use efficiency and crop productivity of wheat crop in Sindh, Pakistan," *J. Environ. Earth Sci*, vol. 5, pp. 21–25, 2015.

[71] V. K. Singh *et al.*, "Effect of site-specific nutrient management on yield, profit and apparent nutrient balance under pre-dominant cropping systems of Upper Gangetic Plains," *Indian J. Agric. Sci*, vol. 85, pp. 335–343, 2015.

[72] P. S. Birthal, S. N. Nigam, A. V Narayanan, and K. A. Kareem, "Potential Economic Benefits from Adoption of Improved Drought-tolerant Groundnut in India.," *Agric. Econ. Res. Rev.*, vol. 25, no. 1, pp. 1–14, 2012.

[73] A. Narayanamoorthy, M. Bhattarai, and P. Joshi, "An assessment of the economic impact of drip irrigation in vegetable production in India," *Agric. Econ*, vol. 31, pp. 105–112, 2018.