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Effect of Climate Change on Agricultural Food Commodities- A Review

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Abstract

Climate change is posing increasing threats to ecosystems and biodiversity, although direct human actions such as habitat loss and overharvesting have had a larger impact so far. Climate change has led to significant decreases in crop yields in western and southern Europe, ranging from 6.3% to 21.2% for dominant crops. This review article examines the impacts of global climate change on food commodities, focusing on how changing climate patterns affect agricultural production and food availability. The article explores the key drivers of climate change, including rising temperatures, altered precipitation, and extreme weather events, and their direct influence on staple crops, livestock, fisheries, and aquaculture. It discusses the consequences of climate change on food systems, such as crop failures, reduced yields, and diminished quality, as well as the indirect effects on pests, diseases, soil fertility, water availability, and food distribution networks. The article emphasizes the need for urgent adaptation and mitigation strategies, sustainable agricultural practices, technological innovations, and international collaborations to address the challenges posed by climate change on global food security.

Keywords: Climate change, Agriculture, Crop yields, food security, Agricultural commodities, Adaptation, Sustainability, Market volatility

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1. Introduction

Ecosystems are the interconnected systems of living organisms and the physical environment that they inhabit. They provide a wide range of essential services to humans, including food, water, and other resources. Unfortunately, climate change is having a significant impact on ecosystems, which can in turn affect the availability and quality of these services (1). This review explores these interactions, providing a comprehensive understanding of how climatic factors influence crop productivity and market stability. One example of how climate change is affecting ecosystems is through changes in temperature and precipitation patterns (1,4). As temperatures rise, certain plant and animal species may be unable to survive in their current habitats, leading to declines in biodiversity (1, 2). Changes in precipitation patterns can also lead to droughts or floods, which can have serious consequences for food and water supplies (3). Climate change is posing increasing threats to ecosystems and biodiversity, although direct human actions such as habitat loss and overharvesting have had a larger impact so far. On land, climate change is causing more extreme weather events and increasing stress on ecosystems. In the ocean, rising temperatures and acidification are causing physiological stress on organisms. These impacts are amplified by other human stressors like deforestation and overfishing (2). It is harder to make a prophecy about the effects of climate change on complex ecosystems and biodiversity loss (1). Another way that climate change is affecting ecosystems is through ocean acidification, when the ocean absorbs carbon dioxide emitted by human activities, it leads to a decrease in the water's pH level, resulting in increased acidity (2). The increased acidity caused by this process can severely affect marine life, especially species that depend on calcium carbonate for the formation of their shells or skeletons. This can have devastating consequences for their survival and well- being (4). The intensity of ocean acidification varies in different locations and is influenced by many factors. Some marine ecosystems may have less intense impacts from ocean acidification, called ocean acidification refugia (OAR). Sea grass meadows, dense algal beds, and algal boundary layers are some examples of proposed OAR. The differences in CO_2 chemistry found in various marine ecosystems result in unique variations, implying that different populations will experience diverse future trajectories based on their specific locations and habitats. This variability adds an additional layer of complexity to the potential impacts of CO_2 on marine ecosystems (4).

Rising temperature and arctic ecosystem

Arctic ecosystem is declining rapidly, with a record low in 2019 just because of climate change. This could lead to an ice-free Arctic Ocean before the middle of the century. In the Southern Hemisphere, krill populations are linked to the extent of sea ice. Rising ocean temperatures and melting land based ice are being caused sea levels to rise up, putting coastal ecosystems and communities at risk (1). Climate change and time of ecosystem process can also affect the intervals of key ecosystem processes, such as the timing of plant flowering or the migration patterns of birds. If these processes occur at the wrong time, it can have serious consequences for the availability of food and other resources. Climate change is causing plant species to shift their distributions, changing the characteristics of ecosystems. Forests are growing in areas that used to be tundra, and the rate of change is increasing. These shifts are affecting the productivity of ecosystems, with some areas experiencing increased growth and others facing drought stress (1, 2). Micro plastics (tiny particles of plastic, generally smaller than 5 millimeters in diameter, which are the result of the breakdown of larger plastic items or are intentionally manufactured for specific purposes. These particles are often found in the environment, especially in oceans, rivers, and soil. Micro plastics can originate from sources like plastic bottles, bags, synthetic fibers from clothing, cosmetics, and industrial processes) that are becoming an increasingly significant pollutant, with far- reaching impacts on the environment. These tiny particles have a pervasive presence and can interact with biotic and abiotic factors in ways that have yet to be fully understood. One major concern is the influence of micro plastics on aquatic ecosystems, which play a crucial role in providing a healthy food source and maintaining a balanced food chain. Aquatic ecosystems are also closely linked to terrestrial and atmospheric ecosystems, facilitating important substance exchanges (2, 5). Food-web structure in a high-latitude marine ecosystem changes along environmental gradient. This means that the way different species interact with each other and depend on each other for food varies depending on factors such as water temperature and nutrient availability. Understanding these changes is important for predicting how the ecosystem might respond to environmental changes in the future (6). Climate change has complex and far-reaching effects on ecosystems, with significant implications for human well-being. It is essential that they take action to address climate change in order to preserve the essential services that ecosystems provide (2, 6). Global climate change is affecting the human food supply by changing the growing conditions for crops and other plants that they rely on for food. For example, changes in temperature, rainfall patterns, and weather extremes can lead to reduced crop yields, lower nutritional quality, and increased pest and disease problems (2). This can make it more difficult and expensive to produce enough food to meet the needs of a growing population (7). Climate change significantly influences agriculture, especially temperature-sensitive crops such as rice, highlighting another example of its impact on food production. Pakistan, which has a significant amount of agricultural land devoted to rice cultivation, has experienced adverse effects due to climate change, resulting in a decline in rice production. Previous studies have shown that climate change has led to a decrease in rice yield, particularly due to changes in radiation, temperature, and rainfall. Other factors affecting rice production in Pakistan include land degradation and limited adaptation to climate change at the farm level (8). Certain regions in the United States have experienced an increase in stream discharge, due to changing precipitation patterns and land-use changes, while it has decreased in other regions and is expected to decrease in arid areas. These changes in stream discharge are leading to the transport of more nutrients and base cations, which can cause eutrophication and affect water ph. Extreme events such as hurricanes can expedite the transportation of sediment and particles to coastal zones this can lead to flooding and damage to homes and farmland (5, 6).

Variability, temperature, carbon dioxide on atmosphere

The Carbon dioxide (CO_2) is an important greenhouse gas that has a substantial impact on the Earth's climate system. It absorbs heat radiation emitted by the Earth's surface and atmosphere, trapping it in the lower atmosphere. This process contributes to the warming of the planet. Since the industrial revolution, human activities such as burning fossil fuels and deforestation have led to a significant increase in the concentration of CO_2 in the atmosphere (9, 10). The increase in atmospheric CO_2 levels has led to a rise in global temperatures, which has a wide range of effects on the Earth's climate system. Elevated temperatures can result in the melting of glaciers and ice caps, causing sea levels to rise and an escalation in coastal flooding. It can also alter weather patterns, causing more extreme weather events such as droughts, heat waves, and hurricanes (9-11).

Temperature variables such as ocean temperature, atmospheric temperature, and land temperature can all impact the Earth's climate in different ways. Ocean temperatures, for example, can affect the formation of hurricanes and the distribution of marine life. Atmospheric temperatures can impact the rate of evaporation and precipitation, which can lead to changes in regional climate patterns. Land temperatures can affect vegetation growth, soil moisture, and wildfire risk (9). Overall, the effects of temperature variables on the Earth's climate are complex and interrelated. Understanding how changes in temperature and greenhouse gas concentrations impact the climate is essential for predicting and mitigating the potential consequences of global warming (9, 11).

Internal Variability Drives Antarctic Sea Ice Expansion amid Rising CO_2 Levels

Antarctic sea ice has been expanding despite the expectation of retreat due to rising CO_2 levels. Various hypotheses have been proposed, but none seem viable. An alternative explanation suggests that internal variability within the Earth system could be driving the observed expansion. While some climate models support this idea, historical runs show rare instances of multidecadal expansion. More research is required to interpret the paradoxical phenomenon of Antarctic sea ice expansion (12). Human-driven causes of climate change can be attributed to various activities and factors that contribute to the alteration of Earth's climate patterns. The main source of greenhouse gases (GHGs) in the atmosphere is primarily attributed to human activities. These activities include the burning of fossil fuels, deforestation, industrial processes, and agricultural practices. These actions release significant amounts of GHGs, contributing to the overall greenhouse effect and subsequent climate change (13). The Burning fossil fuels, including coal, oil, and natural gas, for energy production and transportation, plays a significant role in climate change. These activities release substantial quantities of carbon dioxide (CO_2) into the atmosphere, which is the most abundant greenhouse gas. The rising levels of CO_2 in the atmosphere contribute to the greenhouse effect, trapping heat and resulting in global warming (14). Deforestation (large-scale removal or clearing of forests or trees, often to make way for agricultural activities, urban development, mining, or infrastructure projects. This process leads to the loss of biodiversity, disruption of ecosystems, and significant environmental and social consequences) in the Amazon, especially in Brazil, harms plants, animals, and people's health. It contributes to climate change, extreme weather patterns, and the spread of infectious diseases. This review focuses on the impact of deforestation on public health in Brazil and offers potential solutions. It emphasizes the need to protect the Amazon, promote sustainability, and ensure a healthy future for all (15). Deforestation also causes climate change. Forests sink CO_2 and absorb CO_2 through photosynthesis and storing it in trees and vegetation. However, widespread deforestation particularly in tropical regions lowering planet's capacity to absorb CO_2. Additionally, when trees are cut down and burned, the stored carbon is released back into the atmosphere as CO_2, further contributing to the greenhouse effect (16). Deforestation in tropical regions is causing a significant loss of carbon storage in trees. These forests play a crucial role in stabilizing the Earth's climate. The expansion of agriculture in these areas has led to widespread forest loss. Climate change worsens the problem by making it harder for forests to retain carbon (14). Industrial processes, including cement, steel, and chemical production, release greenhouse gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These emissions stem from fossil fuel combustion, manufacturing reactions, and the release of byproducts and waste gases (17). Amazon’s rainforest are the biggest rainforest on Earth, covering around (5.7) million square kilometers. That is home for approximately 13% of all trees globally and holds great biodiversity. However, deforestation and human-driven climate change pose significant threats to the Amazon's tree species (18). Deforestation has already caused a loss of about 11% of the Amazon's area, putting 27% of tree species at risk of extinction. Future projections indicate that deforestation could further increase forest reduction up to (21-40%) by the year of 2050, with the number of endangered species rising to 40-64%. While deforestation remains a major threat, mounting evidence suggests that the impact of climate change is projected to intensify in the coming decades (18, 19).

Climate change is altering the suitability of the Amazon's climate for tree species. The distance between current and future suitable climates may increase by hundreds of kilometers, making it difficult for species to adapt or migrate (20). This is particularly concerning the upcoming climate change is predicted to occur at a faster pace than in the past, limiting the ability of tree species to track suitable conditions and potentially leading to extinction in unsuitable areas (19, 20). They examined the mixed effects of deforestation and climate change on 10,071 Amazonian trees. They used species distribution models to estimate the original area of occupancy for each species and assessed losses caused by historical deforestation, as they'll projected scenarios for 2050. They also evaluated the role of protected areas in mitigating habitat loss and species decline (21, 22). Although deforestation rates have slowed down in recent years, many tropical forests are still losing carbon due to factors like forest degradation and increased fires. The carbon emissions from deforestation over the centuries are comparable to the current carbon stored in trees (22).

Deforestation not only releases carbon but also changes the environment. It reduces evaporation, increases surface heat, and alters rainfall patterns. These changes affect the local climate and can make it more difficult for remaining forests to grow (23, 24).

Understanding the impact of deforestation on carbon storage is essential for climate solutions. Studies show deforestation affects carbon storage in tropical forests on different continents. By analyzing changes in rainfall and temperature, they assessed the additional carbon loss caused by deforestation-driven climate change (19, 22). The importance of preserving tropical forests and implementing strategies to reduce deforestation. By protecting forests, they can mitigate climate change and preserve carbon storage (17, 24).

Agricultural practices also contribute to climate change through the release of GHGs. Livestock production, particularly cattle and sheep generates significant amounts of methane through enteric fermentation and manure management. Furthermore, the cultivation of rice and the application of synthetic fertilizers contribute to the emission of methane and nitrous oxide, respectively (14, 25). It is important to note that these human-driven causes of climate change are interconnected, and their combined effect amplifies the impact on the Earth's climate system. The increasing concentrations of GHGs in the atmosphere lead to changes in temperature, precipitation patterns, sea level rise, and other climate-related phenomena (13, 14, 25). Effectively addressing the human-driven causes of climate change necessitates global collaboration and collective efforts to reduce greenhouse gas emissions and transition towards sustainable and low-carbon energy sources. This involves promoting renewable energy, enhancing energy efficiency, implementing initiatives for forest conservation and reforestation, adopting sustainable agricultural practices, and fostering international cooperation to mitigate the impacts of climate change (13, 17).

2. Effects of climate change on tropical storms

A Tropical cyclones known as hurricanes or typhoons, occurs when the ocean surface is warm enough and other atmospheric conditions are favorable. Climate models predict that as the earth warms, the ocean surface will become warmer, which could lead to new regions where tropical cyclones could form. However, there are other factors that also influence the formation of tropical cyclones, such as changes in the atmosphere that could make it harder for them to form (26). Scientists are still unsure how global warming will affect the number of tropical cyclones, but they are studying how these different factors could change in the future. Scientists have been studying whether global warming will cause more tropical cyclones in the future. They have used computer models to make predictions, but their results have been uncertain. Some studies suggest that the number of cyclones may increase, while others suggest it may decrease. The effects of global warming on the Earth's atmosphere are complex and not fully understood, and there are many factors that could affect the number of cyclones, such as changes in ocean temperatures and wind patterns (26, 27). One effect from climate change on tropical storms is the ability for increased storm intensity. As the Earth's oceans warm, they provide more energy for storms to develop and strengthen. Warmer sea surface temperatures can lead to the formation of stronger hurricanes and typhoons, with the potential for higher wind speeds and more intense rainfall. This increased intensity can pose greater risks to coastal areas and communities in the path of these storms (26, 24). Tropical cyclone intensity is influenced by sea surface temperature (SST). Warmer SST provides the energy needed for cyclone development and intensification. Climate models predict that SSTs will slowly increase in greenhouse conditions, which may lead to a normal increase in the amount of cyclone intensity. However, past data shows short and little dependence of maximum possible intensity (MPI) on SST, except for some intense storms in the North Atlantic. Higher SSTs may also increase the longevity of storms in higher latitudes and extend the regions of occurrence pole ward (28). Another impact of climate change is the potential for changes in storm frequency and distribution. While the total number of tropical storms may not necessarily increase, studies suggest that there may be a shift in their distribution. Some regions may experience a decrease in the number of storms, while others may see an increase (25). This variability makes it challenging to predict the exact changes in storm patterns, but it highlights the importance of monitoring and adapting to the evolving risks (26).

Factors affecting tropical cyclones

The height of the tropopause (top layer of the atmosphere) can affect how strong tropical cyclones become. Climate models suggest that the height of the tropical tropopause may decrease, which could make tropical cyclones less intense. Additionally, the models suggest that the atmosphere in the tropics will become more stable, which may also limit the strength of tropical cyclones. However, some studies have found that increased moisture in the atmosphere could actually decrease stability and potentially increase cyclone intensity under certain conditions (16, 29). Additionally, climate change can contribute to increased rainfall associated with tropical storms. Warmer air holds more moisture, leading to the potential for heavier downpours during storms. This poses risks of flooding, particularly in areas with poor drainage or inadequate infrastructure. The combination of storm surge, intense rainfall, and sea-level rise can exacerbate the impacts of tropical storms on coastal regions, increasing the potential for damage and displacement (27). A warmer world, average precipitation is projected to increase due to the enhanced water- holding capacity of the atmosphere. Climate models indicate that rainfall events will become more intense, resulting in more frequent and higher intensity heavy rain occurrences. This has implications for infrastructure projects like flood control systems and settlement planning. Research utilizing climate models has found that under 2xCO_2 conditions, the return periods for heavy rain events decrease, indicating an increase in the maximum expected rainfall within a specific timeframe (29). There are different climate models that offer insights into global climate changes resulting from greenhouse gas emissions, but their accuracy in predicting regional changes and short-term weather events, like tropical cyclones, is limited. While there is evidence suggesting a potential increase in extreme rainfall events in tropical areas, the specific impact of climate change on tropical cyclone frequency, locations, and intensities remains uncertain. This uncertainty introduces both positive and negative consequences for vulnerable regions, including heightened risks of storm surge damage and flooding. Advancements in climate models are necessary to enhance our understanding of these potential impacts and improve predictions (26, 29).

3. Climate change affects capture fisheries and the developments

Climate change affects the ocean in various ways, including warming waters, ocean acidification, and rising sea levels. These changes have significant consequences for marine ecosystems, resources, and the people who depend on them. In this article, they examine how climate change impacts fisheries and the institutions responsible for managing them, leading to an increased risk of conflicts. Fisheries conflicts, which have become more common, can occur at local, national, and international levels (30, 31). They propose policy solutions such as adaptive institutions, multinational response teams, maritime law reforms, and marine protected areas to address these challenges. Inadequacies in current fisheries governance systems hinder effective management of the escalating risk of conflicts (3). Climate change exacerbates existing drivers of fisheries disputes, such as diminishing catches, illegal fishing, food insecurity, and contested maritime boundaries. However, the correlation between climate change and marine security concerns has received insufficient research attention, leaving it understudied. They explore the linkages between climate change and known conflict drivers, highlighting the need for new approaches to governance and regimes to address these emerging challenges (3, 31, 32).

Climate change has complex effects on fisheries, impacting fish populations, fishing activities, and the institutions managing them. The key phenomena are warming waters, ocean acidification, and sea level rise. These changes disrupt fish habitats and alter the distribution and productivity of fish stocks (30, 32). Warming and acidification affect primary productivity, growth, and behavior of fish, leading to changes in food webs and reduced yields. Coral reefs, important for fish populations, are damaged by warming and acidification, causing coral bleaching and impeding reproduction. Sea level rise affects coastlines, altering territorial boundaries and coastal infrastructure, and disrupting the habitats of juvenile fish. These changes Increase the risk of conflicts among fishers, fishing communities, sectors, and states. Additionally, climate change exacerbates the already growing reliance on fishing for livelihoods. Overall, these impacts create new challenges for fisheries governance, including managing scarcity, shifting populations, changing boundaries, and intensifying fishing practices, all contributing to increased risk of fisheries conflict (3, 32). Climate change is expected to increase the number of fishers and their reliance on fishing as a source of income. As temperatures rise on land, agricultural losses may push people towards coastal fishing communities. This migration to fishing areas is driven by the need for alternative livelihoods (3, 31). The relationship between agricultural problems and increased dependence on fisheries is observed in many coastal and deltaic countries. Changing water security and temperature patterns also contribute to human migration. Recurring crop losses due to climate change act as "push" factors, while fishing and aquaculture opportunities act as "pull" factors for migrants. The growing dependence on fishing livelihoods and migration to fishing economies may lead to increased fishing pressure and tensions in fishing communities. Rapid in-migration can escalate fishing pressure and become a source of conflict, especially in fisheries with declining catches. However migration out of stressed fisheries may reduce fishing pressure and conflict, but it can harm local economies and demographics. The sustainability of fisheries and the vulnerability of coastal communities to future climate change remain uncertain in the face of these changes (30, 32, 33).

4. Climate change effects on livestock production in multiple ways

Implications: Livestock farming has a significant impact on climate change due to the production of greenhouse gases, particularly methane and nitrous oxide. Methane is released through enteric fermentation in the digestive systems of animals and during the storage of manure. It has a warming effect 28 times greater than carbon dioxide (34). Nitrous oxide is emitted from manure storage and the use of fertilizers, with a warming potential 265 times higher than carbon dioxide. These greenhouse gas emissions are measured in carbon dioxide equivalents to account for their impact on global warming (35, 36). Feed production for livestock is another major contributor to greenhouse gas emissions (34). This includes the cultivation of crops for animal feed, which leads to carbon dioxide and nitrous oxide emissions from soil dynamics, the manufacturing of synthetic fertilizers, and the use of fossil fuels in agricultural operations. Nitrous oxide is also released when fertilizers are applied to the soil (35, 36). According to estimates, feed production and processing contribute approximately 45% of greenhouse gas emissions from the livestock sector (34). Enteric fermentation accounts for around 39% of emissions, while manure storage contributes about 10%. The processing and transportation of animal products make up the remaining 6% of emissions (35, 36). The livestock sector significantly contributes to climate change through greenhouse gas emissions from enteric fermentation, manure storage, and feed production (34). Efforts to reduce these emissions are crucial in mitigating the impact of livestock farming on the environment (35, 36). Livestock farming significantly contributes to climate change through the emission of greenhouse gases, including methane and nitrous oxide. Methane is produced during the digestion process of animals and from the storage of their manure. It has a warming effect on the planet that is 28 times more potent than carbon dioxide. Nitrous oxide is released from the storage of manure and the application of fertilizers, and it has a warming potential 265 times greater than carbon dioxide. To assess their impact on global warming, these emissions are converted into carbon dioxide equivalents (34-36). Livestock farming contributes to global warming through methane and nitrous oxide emissions (34). To address this, effective strategies are needed to reduce emissions while increasing animal productivity. These strategies should be considered within the entire livestock production system, taking into account factors like animal health and welfare. Optimizing productivity can have a significant mitigating impact, but its effectiveness depends on factors such as genetics and technology adoption (34-36).

5. Causes of Climate Change: Natural Factors; Causes of climate change over the historical record; several reasons of climate change

Much of the research on climate change has focused on the second half of the 20th century. Recent studies show that human activities, particularly greenhouse gas emissions, have significantly contributed to global warming (10). While analyzing recent data has advantages, studying a longer time period provides a better understanding of climate response to forcing and internal variability (37). Historical records and proxy data offer valuable information, although more research is needed to integrate findings into a comprehensive framework. This paper discusses the causes of climate change, climate variability, and extreme events, emphasizing the need to consider longer time horizons for a complete understanding (38, 39). The Sun is the primary source of energy for our planet. However, the amount of energy it emits can vary over time. This variation occurs in cycles, with periods of increased or decreased solar activity. These cycles can last for years or even decades (10). When the Sun is extreme active, it releases more energy, which can takes to a slight warming effect on the Earth's surface. Conversely, during periods of decreased solar activity, less energy reaches the Earth, resulting in a cooling effect (38, 39). Volcanic eruptions release large amounts of gases, such as sulfur dioxide, into the atmosphere. These gases can react with water vapor and form tiny particles called aerosols (37). These aerosols can remain in the atmosphere for months or even years, scattering and reflecting sunlight back into space. As a result, less sunlight reaches the Earth's surface, leading to a temporary cooling effect (10). However, the impact of volcanic eruptions on climate is relatively short-lived compared to other factors (37-39). The Earth's climate is regulated by the oceans, which have a crucial role in maintaining global climate patterns. Ocean currents are responsible for transporting heat across different regions, thereby influencing climate variations. One notable example is the El Niño-Southern Oscillation (ENSO), a natural climate pattern occurring in the tropical Pacific Ocean (37). During El Niño events, warm waters shift eastward, affecting weather patterns worldwide (10). This can lead to changes in rainfall distribution, temperature, and even storm patterns in various regions (38, 39). Greenhouse gases are essential for maintaining a habitable temperature on Earth. Certain natural processes in the presence of greenhouse gases in the atmosphere (37). For instance, the decay of organic matter in forests and wetlands releases methane, a potent greenhouse gas. Additionally, natural sources, such as volcanic emissions and biological activity in the oceans, also release small amounts of greenhouse gases (39). While these natural emissions are part of the Earth's natural carbon cycle, human activities have significantly increased greenhouse gas concentrations since the Industrial Revolution (38, 39).

6. How does climate change impact human rights?

Climate change has a profound impact on human rights, affecting various aspects of individuals' lives and well-being (39). Here are some key ways in which climate change impacts human rights. Climate change poses significant threats to human health and well- being. It leads to increased frequency and intensity of extreme weather events such as hurricanes, heat waves, floods, and droughts, which can result in loss of life, injuries, and displacement (40). Climate change also affects access to clean air, water, and food, leading to the spread of diseases, malnutrition, and water scarcity, thereby jeopardizing the right to life and health (41). Climate change alters precipitation patterns, leading to changes in water availability and quality. Rising temperatures and changing rainfall patterns can cause droughts or floods, affecting access to safe drinking water and sanitation facilities. (42) Vulnerable communities, particularly in developing countries, often face water scarcity, which hinders their ability to fulfill their basic needs and infringes upon their right to water and sanitation. (43, 44). Climate change-induced events such as storms, floods, and sea- level rise can result in the destruction of homes and infrastructure, leading to mass displacement and homelessness (45). Vulnerable populations, including marginalized communities and indigenous peoples, are disproportionately affected. The loss of adequate housing infringes upon the right to a safe and secure place to live (46). Climate change impacts agricultural productivity, disrupting food production systems. Extreme weather events, changing rainfall patterns, and rising temperatures can reduce crop yields, affect livestock, and damage fishing communities (47). These changes undermine food security and the ability of individuals to access sufficient and nutritious food, violating the right to food and the right to a sustainable livelihood (48, 49). Climate change exacerbates existing inequalities and hinders development efforts, particularly in vulnerable and low-income countries (50). The adverse impacts of climate change, including economic losses, environmental degradation, and displacement, hinder the realization of sustainable development goals. It impedes the ability of individuals and communities to enjoy their right to development (51).

Right to Culture and Indigenous Rights: Climate change impacts ecosystems and biodiversity, leading to the loss of cultural heritage, traditional practices, and indigenous knowledge (52). Indigenous communities, whose livelihoods are deeply connected to their lands and resources, face unique challenges from climate change, including loss of territory, forced displacement, and disruption of traditional ways of life. This threatens their right to culture, self-determination, and participation (53, 54). Addressing climate change and its impacts is crucial for upholding and protecting human rights. It requires international cooperation; Efforts to combat climate change involve mitigation to reduce greenhouse gas emissions, adaptation for building resilience, and support for vulnerable communities. (55) Integrating a human rights perspective into climate action can help ensure that the rights and needs of individuals and communities are at the forefront of climate change responses. (56, 57)

7. Microorganisms and climate change

In our current era, known as the Anthropocene, climate change is affecting life on Earth. Microorganisms are crucial for the existence of all other forms of life. To understand how humans and other organisms can survive the effects of human- caused climate change, we must consider the role of microorganisms. (58) It's important to learn how microorganisms contribute to climate change (such as by producing or consuming greenhouse gases) and how they will be impacted by climate change and human activities. This statement emphasizes the significant role of microorganisms in climate change biology and highlights that the success of our efforts to address climate change depends on their responses. We need to prioritize the understanding and preservation of microorganisms to achieve an environmentally sustainable future (59, 60, 61). Human activities are causing species extinctions and biodiversity loss, but we often overlook the impact on microorganisms. However, microorganisms are essential for a healthy ecosystem and play key roles in climate regulation, nutrient cycling, and overall organism health. (62) Despite their significance, microorganisms are rarely studied in relation to climate change and are not considered in policy decisions. Neglecting them limits our understanding of the biosphere and hinders efforts to create a sustainable future (63). The marine biome covers about 70% of the Earth's surface and includes diverse habitats like estuaries, coral reefs, and open oceans. (64) Sunlight fuels the top 200 meters, where photosynthetic microorganisms thrive, while deeper zones rely on different energy sources. Temperature, water density, stratification, and nutrient. Transports are influenced by rising temperatures, precipitation, salinity, and winds. Microorganisms play a crucial role in marine ecosystems, with their sheer numbers and biomass dominating the water column. (65) They drive carbon and nutrient cycles, support ocean food webs, and sequester carbon through organic matter deposition in marine sediments. Climate change affects the balance between carbon regeneration and burial, and it also leads to ocean acidification. The changing conditions impact marine life, with potential consequences for productivity, food webs, carbon export, and burial. Understanding and addressing these effects are essential for the health of marine ecosystems. (66, 67)

8. Climate Change Impacts on major crop yields and Agriculture

Climate change poses significant challenges to agriculture in South Asia, impacting food production and farmers' income. Variability in climate, such as temperature changes and water scarcity, affects crop yields and growing seasons. (68) Rising temperatures and heat stress reduce biomass production and harm crop health. Natural resources like land and water are also affected, with groundwater depletion and unsuitable conditions for agriculture projected in some regions. These challenges exacerbate food insecurity, poverty, and economic losses. Farmers employ various resources and strategies to adapt, but access and institutional support remain limited. Adaptation measures tailored to local contexts are crucial. This study explores smallholder farming systems in South Asia and the barriers to effective adaptation, emphasizing the need for policies that address climate risks and support sustainable agriculture. (69, 70, 71). Climate change has a significant impact on agriculture in South Asia. The region is expected to experience rising temperatures and changes in precipitation patterns, which can affect cropping seasons and crop yields. (72) For example, spring maize-growing periods in Pakistan have shifted earlier, and autumn maize sowing has been delayed, leading to lower yields. These Changes have a negative impact on farmers' livelihoods, especially those with limited capacity to adapt to climate change. (73). The Impact of Climate Change on Crop Production and Food Security in South Asia: Evidence suggests that changing temperatures and precipitation patterns are expected to have increasingly negative effects on crop yields and food security in the region. Crop health and productivity may be compromised due to water and heat stresses during critical growth stages. (74) The effects of climate change on agriculture vary depending on crops, locations, and adaptive capacities. Vulnerable regions like the Hindu Kush Himalayas, encompassing parts of Pakistan, India, and Nepal, face higher risks due to their heavy reliance on agriculture and limited access to resources and markets. (75, 76). Recent studies have shown that major food crops such as rice, wheat, and maize are significantly influenced by temperature and precipitation changes in South Asia. Crop yields are projected to decrease by 2.5-10% in the 2020s and 5-30% in the 2050s. (77) By the end of the century, cereal production in the region could decline by 4-10% if temperatures increase by 3 °C. These changes will have a substantial impact on food production and could lead to decreased yields and increased pest incidence (78). Farmers in South Asia, particularly smallholders, face challenges such as lack of access to crop insurance and loans, which can contribute to economic difficulties and even suicides. (79) Some areas, like mountainous regions of Nepal, may experience positive impacts on wheat yields, but rice and maize yields could decline. Other countries like Bhutan, Bangladesh, Pakistan, and Sri Lanka also report yield reductions due to climate change impacts. (80) The relationship between rainfall variability and crop productivity is less explored, but studies indicate that rainfall variability negatively affects crop production. (81) More research is required to understand the magnitude of this effect. Given these challenges, it is crucial to adapt Agriculture to climate change, focusing on rising temperatures, heat stress, waterlogging, and other climate-related risks. (82)

The Impact of Climate Change on Global Food Production: Evidence of Current Effects

Crop Yields Decline in Western and Southern Europe Due to Climate Change, ranging from 6.3% to 21.2% for dominant crops. This has contributed to the stagnation of yields in Europe. Regions like European Russia and Western Siberia have experienced reduced yields in crops like wheat, barley, maize, and rapeseed. (83) Ukraine has also seen negative effects on barley, maize, and sorghum productivity. While there are some exceptions, overall, there are widespread yield losses in eastern and northern Europe for maize, barley, and wheat. (84) These yield losses have resulted in substantial reductions in consumable food calorie production in countries like France, Germany, Spain, and Italy. Eastern and Northern European countries such as Hungary, Romania, and Ireland have also been affected, experiencing significant decreases in consumable food calories from these crop Climate change has led to significant decreases in crop yields in western and southern Europe, ranging from 6.3% to 21.2% for dominant crops. This has contributed to the stagnation of yields in Europe. Regions like European Russia and Western Siberia have experienced reduced yields in crops like wheat, barley, maize, and rapeseed. (85) Ukraine has also seen negative effects on barley, maize, and sorghum productivity. While there are some exceptions, overall, there are widespread yield losses in eastern and northern Europe for maize, barley, and wheat. These yield losses have resulted in substantial reductions in consumable food calorie production in countries like France, Germany, Spain, and Italy. (86)Eastern and Northern European countries such as Hungary, Romania, and Ireland have also been affected, experiencing significant decreases in consumable food calories from these crops. (87) Maize is a vital crop in sub-Saharan Africa, playing a key role in providing food calories. It is closely followed by sorghum, cassava, and sugarcane. Climate change has had a noticeable impact on these crops in recent times. Maize and sugarcane yields have experienced reductions of 5.8% and 3.9% respectively. However, crops like sorghum and cassava, which are more tolerant to heat and drought, have seen slight increases in yields, with sorghum up by 0.7% and Cassava by 1.7%. (88) South Africa has seen the highest maize yield losses, particularly in the provinces of The Free State and North West. Overall, maize yields have declined in sub-Saharan Africa, but cassava yields have increased in some areas while decreasing in others. Eastern Africa has generally experienced reductions in cassava yields, except for certain districts in Tanzania where yields have benefited from climate changes. (89) In Western Africa, the response of crop yields to climate change shows variation, with some regions experiencing decreases while others witness improvements. The impact on consumable food calorie production differs across countries, with notable reductions observed in South Africa, Ghana, and Zimbabwe, while Tanzania has experienced an increase. On average, climate change has led to an annual reduction of around 1.4% in food calories derived from these ten crops in sub-Saharan Africa. This corresponds to an overall decrease of approximately 0.8% in food calories consumed from these crops. (90, 91)

In the Oceania region, climate change has had a significant impact on crop yields. Australian wheat yields have experienced a reduction of approximately 9%, which aligns with previous studies. (92) In addition to barley, maize, sorghum, and soybean, other crops such as rapeseed, rice, and sugarcane have also experienced decreases in yields due to climate change. However, there have been overall increases in rapeseed, rice, and sugarcane yields. As a result, climate change has contributed to a decrease of approximately 6% in consumable crop calorie production annually in Australia for these ten crops. This corresponds to a reduction of around 3% in overall calorie production. (93, 94)

Climate change has generally had a positive effect on crop yields in North and South America, particularly in crops such as maize, oil palm, soybean, and sugarcane. However, regional variations exist, with some areas experiencing yield losses. Parts of the United States and northern South America have observed decreases in crop yields due to the impacts of climate change. (95) In the United States, climate change has led to decreased yields in crops such as barley, rice, and wheat, while crops like maize, sorghum, soybean, and sugarcane have experienced increases in yields. The impact on consumable food calories varies across countries in the region. Some countries, including Canada, Panama, Honduras, and Belize, have observed decreases in food calories, while others like the United States, Mexico, Brazil, Argentina, Paraguay, and Cuba have seen increases. Significant losses in consumable food Calories have been observed in the Dominican Republic, Ecuador, Bolivia, Uruguay, and Venezuela due to the effects of climate change. (96, 97) Climate change has had diverse effects on crop yields and consumable calories in Asia. In China, the overall impact of climate change has been favorable, leading to increased crop yields and higher food calorie production. However, there are exceptions to this trend, with certain regions experiencing decreases in rice and wheat yields. Notably, specific areas in China have seen benefits in wheat and maize yields as a result of climate change.(98) The impact of climate change on consumable food calories has been negative across various Asian countries, affecting both food secure nations like Iran and Israel, as well as food insecure countries like Bangladesh, Nepal, and India. When analyzing the effects of temperature and precipitation changes on crop yields, it is evident that temperature has a stronger influence in regions such as Europe and East Asia, while precipitation plays a significant role in sub-Saharan Africa, South Asia, and Australia. (100)

Control measures

Climate change can affect food safety through various pathways such as temperature and precipitation changes, more frequent extreme weather events, ocean warming and acidification, and alterations in the transport of complex contaminants. Different ways to prevent food from climate change which can create positive impact. Promoting sustainable farming techniques can help minimize the effects of climate change on food production. These practices include efficient water management, soil conservation, and the use of organic fertilizers. They can enhance the resilience of crops and reduce their vulnerability to extreme weather events. Encouraging farmers to diversify their crop varieties can help mitigate the risks associated with climate change. Growing a range of crops with different characteristics can improve resilience to changing environmental conditions and reduce dependence on a single crop, thereby safeguarding food supplies. Implementing efficient irrigation systems, such as drip irrigation or precision irrigation, can conserve water resources and ensure that crops receive adequate moisture. This reduces water wastage and helps farmers adapt to changing precipitation patterns caused by climate change. Enhancing weather forecasting capabilities and early warning systems can help farmers prepare for and respond to extreme weather events. Timely information about approaching storms, floods, or droughts enables farmers to take preventive measures and protect their crops. Promoting the adoption of climate-smart technologies, such as drought-tolerant crop varieties, precision agriculture tools, and renewable energy solutions, can help farmers adapt to climate change. These technologies are designed to optimize resource use, reduce emissions, and enhance productivity in a changing climate. Developing robust storage and distribution systems can help minimize post-harvest losses caused by extreme weather events. Proper storage facilities and efficient transportation networks ensure that food commodities reach consumers without spoilage or contamination. Providing farmers with access to knowledge and training on climate-resilient farming practices is essential. This empowers them to make informed decisions and adopt sustainable techniques that can mitigate the impact of climate change on food commodities (101).

Conclusion

Climate change is having a big impact on our food supply. It's causing problems like extreme weather, changing temperatures, and unpredictable rainfall patterns. These changes are hurting our ability to grow enough food and affecting its quality. It's a serious problem because it means there's less food available, and it's harder for some people to access the food they need. To address this issue, we need to take action. We can use sustainable farming methods, develop new technologies, and work together globally. It's also important to help farmers adapt to these changes and make sure everyone has equal access to food. By doing these things, we can protect our food supply and ensure that everyone has enough to eat, even as the climate continues to change.

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