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Impact of Climate Change on Agriculture and Countermeasures

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Abstract. The impact of climate change globally, particularly on the agriculture sector, is becoming harder to ignore. Changes to the means of food production due to climate change may risk the wellbeing of crops and livestock, jeopardize the sustainability of certain farming practices, and threaten food production in Sub-Saharan Africa and South Asia. While some of the literature documents these challenges, the unique contribution of this essay is to document the diverse and multifactor challenges posed by climate change on food production. Such an analysis, based on peer-reviewed literature, must consider the crop and livestock responses to climate change, the challenges posed by declining the quality of water and soil, and the socioeconomic impacts on farmers. Such an analysis must also address the proposed and implemented adaptive and mitigative measures on climate change, including crop diversification and the adoption of water and soil conservation practices of agroecology, and the advocated policy measures. By addressing these issues, this essay hopes to demonstrate the complementary role of scientific research and local practices, policy, and climate agriculture. Knowing the relationship between climate and agriculture is necessary to achieve the goals of food sustainability, development, and environmental resilience.

Keywords: climate change, agriculture, food security, adaptation, mitigation

1. Introduction

As a primary means of climate change adaptation, agriculture has a climate related influence on every food system. Climate determines agricultural productivity, including where and how crops and livestock flourish. For approx. 75 million years, the climate system has encouraged the development of agrarian civilization. This was, however, the climate system. What is of immediate concern is the change driven by historical and contemporary anthropogenic greenhouse gas (GHG) emissions. The consequences of a >1.1 °C increase on the global mean surface temperature is already a reality, as is the predicted temperature increase from every Intergovernmental Panel on Climate Change (IPCC) emissions scenario with the exception of a plausible mitigation scenario [1].

Agriculture both influences and is influenced by this warming. It contributes about 23 % of total anthropogenic GHG emissions through methane (CH_4) from ruminants and rice paddies, nitrous oxide (N_2O) from fertilizers, and carbon dioxide (CO_2) from land-use change [2]. The dual role of

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agriculture as both a source of emissions and a sector acutely vulnerable to climate change creates a complex feedback loop that challenges policymakers and producers alike.

With over 27 percent of the global workforce employed in agriculture, the sector is of exceptional importance around the world, impacting the lives of 2.5 billion individuals, or one third of the global population [2]. However, the FAO's 2023 State of Food Security report documented that in 2022, 735 million people were still living with chronic hunger, much of it impacted by climate shocks and crises in the global economy [2]. The current report cards and statistics are only reminders that climate change is much more than an independent phenomenon. It is a risk multiplier woven together with poverty, war, and inequality.

The phenomena of warming trend differentials do not, however, change the overall global warming picture. Areas of higher latitude, like northern Europe or Canada, will see the warming allowing for a longer growing season; however, it will only be for a short period of time compared to the tropical and sub-tropical climates, where the majority of small holder farmers live and where climate induced heat stress and poorly distributed rainfall will be even more severe [3]. In areas such as South Asia and Sub-Saharan Africa where rain-fed agriculture predominate and tempers are even slightly raised, productivity will drastically decline. The 2022 IPCC Sixth Assessment Report is clear that without adaptation, by mid-century, the world will see a 10 % decline in global crop yields [3].

The global supply chain is designed to the shifts. The Canadian wildfires (2023) and European heat waves (2022) demonstrated the interconnectedness of food systems, specifically showing how fragile export systems are when grain and fertilizer production are disrupted [4]. The risk and vulnerability of agriculture is not confined to the farms, but extends to the trade, finance, and the broader logistics of the business of farming.

The effects on society are also important. Climate-related reductions in crop yields are expected to cause up to 216 million people to migrate by 2050 [5]. This type of migration alters population distribution and puts pressure on silvering cities. On the other hand, there are also practices that could help. Certain regenerative practices such as agroforestry and the use of low-emission technologies can help turn farming practices and soils and become a carbon sink. There is a focus on equity in the COP28 UAE Sustainable Agriculture Declaration (2023) and the Global Alliance for Climate-Smart Agriculture [6].

The global agricultural sector is, in a sense, a crossroads. Agriculture faces challenges to productivity such as warming, extreme events, and water scarcity. Yet, there are positive forces such as innovation, the new governance, and international collaboration, which could help sustain agriculture. This paper analyzes the main climate drivers - temperature, precipitation, extreme events, pests and disease, and soil water saturation - and discusses important strategies for adaptation and mitigation to foster agricultural resilience in a climate-challenged future.

2. Rising temperatures and crop physiology

Temperature influences the processes of photosynthesis and respiration, as well as the reproduction of plants. For certain cool climate areas, the crops may develop faster with slight climate changes; however, overheating will cause the crops to wither and yield less. Global wheat, rice, and maize production are estimated to lose 3 to 7 percent with every degree of climate increase beyond optimum conditions [7]. Higher temperatures cause negative impacts on pollen viability, shorten the grain-finishing, and quicken senescence processes. For the already tropical areas, heat impacts shorten the crop cycle and increase the frequency of irrigation.

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The expectation of higher CO2 on the atmosphere, or the CO2 fertilization effect, will increase photosynthesis and reduce the considerable CO2 effect on the circulation of water in plants. Unfortunately, this offset and negative impacts of higher CO2 will become more apparent with nutrient dilution and higher pest pressure while the heat will reduce the grains and increase the hidden hunger in the low-income countries of the world [8, 9].

High temperatures disturb livestock as well. Prolonged heat stress will reduce milk output by as much as 25 percent by decreasing the feed intake of the crops, fertility of the livestock, and milk yield. Similarly, hens will stop egg production and lose productivity due to the heat. Solar shading, improved circulation, and selection of heat tolerant plants are forms of selection for heat tolerant livestock [10].

Not all of the climate change effects will be negative. Increased productivity may be possible in higher pixelated areas while the lower tropical regions will bear the opposing of increased baseline heat and resource extremities. These climate consequences will be mitigated with robotic precision crop breeding, remote sensing, and improved water surveying.

3. Precipitation and water availability

The availability of water reflects the viability of an agricultural system. It is the alterations of the hydrological cycles under the influence of climate change that increases the frequency and intensity of droughts and floods. In the semi-arid southern regions of Europe and the American West, there is less and less rainfall, but there is greater evaporation. In South and Southeast Asia, the monsoon systems are affected by extreme climate variability, resulting in periods of heavy rainfall and extreme droughts.

The floods that swept across Pakistan in 2022 are an example of extreme hydrological variability. The floods impacted the cropland and food stores, destroying the livelihoods of those who depended on subsistence agriculture. In California and the Horn of Africa, the crisis is the opposite and caused by chronic drought. The loss of pasturelands due to drought forces the culling of livestock. The alterations of hydrological conditions increase volatility in production and the availability of staple crops for trade.

The adoption of more efficient systems for irrigation is an important component of adaptation and the reduction of the water resource crisis. The use of drip systems, the harvesting of rainwater, and the monitoring of soil moisture are ways to increase the efficient use of water. Yet, the depletion of groundwater is alarming as aquifers are being drained faster than they are being recharged and this is the case in India, China, and the U.S. Midwest [11]. The reduction of risk in the system over the long term will be achieved through the management of water resources in an integrated manner and regional cooperation along shared basins like the Nile and the Mekong Rivers.

4. Extreme weather events

One of the consequences of climate change is the increasing intensity of cyclones, floods, heatwaves, and wildfires. All of these disasters have and will continue to result in negative losses in the agricultural sector and destabilize the global economy. The heatwave in Europe in 2003 was particularly devastating, resulting in a 30% loss of maize. In South Asia, Cyclone Amphan in 2020 wiped out 2.4 million hectares of cropland.

Disasters also have consequences that go beyond direct losses. They impact infrastructure, labor, and supply chains as well. The wildfires in Canada in 2023 and droughts in East Africa impacted

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livestock forage, and thereby, food prices increased. After disasters, rural poverty is deepened and exposed because recovery resources are often scant.

To build resilience, there needs to be early warning systems, disaster-resistant infrastructure, and diversified cropping. New mobile data-sharing and satellite forecasting technologies enable rapid response to disasters, which significantly reduces the human toll [3].

5. Pests and disease dynamics

Changes in climate will increasingly facilitate the expansion of the ranges of pests and diseases. Milder winters increase the chances of overwintering survival of pests previously temperate-inhabiting. The fall armyworm is an American native that has spread to sub-Saharan Africa and Asia, where it has been documented to reduce maize yields by as much as 50% [5]. Diseases such as the fungal pathogens, coffee rust and stem rust of wheat, have expanded into regions where they had been previously uncommon and are resurging. Livestock diseases are shifting as well, such as bluetongue and Rift Valley fever, which have been documented to appear further north in Europe. These are evidence of the long-expected impact of climate change on the destabilization of pest–host relationships. - Climate change, to a large extent is responsible for the destabilization of long-expected pest–host relationships. The Integrated Pest Management (IPM) approach combines biological control, the use of resistant varieties, and reduced dependence on pesticides, which provide the needed sustainable solutions. Genomic surveillance, as well as international coordination by the FAO and UNEP, will increasingly provide the needed foresight to contain and predict the spread of diseases.

6. Soil and water quality degradation

Healthy soil is the foundation of agriculture, and yet, an estimated one-third of the world's soil is degraded. Extreme weather events, like heavy rains and deforestation, increases the rates of erosion, while droughts reduce the balance of microbes and the cycling of nutrients. The consequence of over-irrigation in arid zones is the build up of soil salinity which, in turn, leads to a decrease in crop yields. The use of fertilizers and the resulting runoff is the primary cause of eutrophication, which is exemplified by the algal blooms in Lake Erie and coastal Asia [8].

The practices for Sustainable land management such as contour plowing, cover cropping, reduced tillage, and composting help in the restoration of the soil organic matter. Each 1% increase in the soil organic carbon can compensate for 20 tons of carbon per hectare and help in achieving mitigation goals. Some international initiatives that promote "climate-smart soils" aim for the restoration of the soils and the carbon markets, and encourage farmers to use regenerative practices [8].

7. Socioeconomic impacts and equity

The socioeconomic aspects of climate change in this sector are very significant. Smallholders, who produce more than 70% of the food in developing countries, are the most exposed to the negative consequences of climate change due to low savings, inadequate insurance, and weak infrastructure [5]. Climate shocks can decrease household income and increase food prices, leading to exacerbating malnutrition.

The inequitable social structures related to gender are also part of the reasons increasing this vulnerability. Women, who make up 43% of the agricultural workforce, have very little land tenure

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and access to credit. Extension services and climate information targeted to women will increase household resilience [9].

The consequences of climate change can also lead to forced displacement and migration. More than 200 million people will be displaced due to declining agricultural productivity and water scarcity by the year 2050 [5]. Without forced displacement, social protection, microfinance, and education initiatives will help communities to adapt.

8. Adaptation and mitigation strategies

Strategically, sustainable agricultural transformation is rooted in adaptation and mitigation. Implementation and adoption of risk minimizing practices is adaptation. For example, the adoption of drought-resistant crop varieties, shifting planting dates, or changing irrigation practices to be more efficient. On the other hand, mitigation is the reduction of greenhouse gas emissions, which can be accomplished through better fertilizer use, capture of methane, or through agerelated afforestation activities.

CSA, or Climate-Smart Agriculture, consolidates the two objectives, promoting productivity, resilience, and emissions efficiency simultaneously. Sustainable agricultural intensification can be achieved through practices such as agroforestry, intercropping, and the use of digital precision agriculture tools. Technologies such as AI-enabled weather prediction and planning, CRISPR gene editing, and the development of climate friendly fertilizers, will promote agricultural resilience more effectively if developed and deployed collaboratively [4].

Governance and finance will still be key to success. The prioritization of smallholders in carbon credit schemes and other green investments will produce equitable outcomes. Integrated, cross-sector policies will be more effective as they simultaneously address the land, water, and energy ecosystems [11].

9. Conclusion

Adaptation is critically important as, without it, global food production is projected to drop anywhere from 10-20% by 2050, which would jeopardize billions of lives. Nevertheless, agriculture has the unique capability of driving positive change on the climate. It could convert from a primary emissions source to a net carbon sink through regeneration of soils, digital innovations, and renewable energy.

The resilience of the future focuses on four areas: (1) decarbonizing supply chains, (2) restoring degraded ecosystems, (3) empowering smallholders and women, and (4) combining local knowledge and scientific research. There should be global collaboration based on initiatives such as COP28 and the Paris Agreement, where every investment made on adaptation should go to the most vulnerable populations.

Finally, agriculture and climate changes affect each other and should be viewed as a single coupled system. In the near future, the sector will need to adapt to dual roles — as a victim and a solution. To build resilience, the future of food systems must be designed to be sustainable and equitable, relying on collaboration across disciplines. The global agricultural system — and, with it, human civilization — will continue to survive only if a dramatic shift is made.

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