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Review Article

Modelling the Effect of Climate Change on Agriculture: Crop yield Productivity and Food Security

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A B S T R A C T

Climate change is a reality and the major challenge in global agricultural systems; it has a substantial impact on food security and crop output efficiency. The intricate relationships between shifting climatic factors such as rising temperatures, modified precipitation patterns, and an increase in the frequency of extreme weather events and agricultural output are observed. This paper presents an integrative review of the existing state of literature for the impacts of climate change on crop yields, with particular attention to utilising climate, hydrology, and crop yield models. Soils with high water-holding capacity could potentially aid in mitigating the adverse effects of drought and make it feasible to maintain crop output in future projections when water supply is decreasing. Water availability and total agricultural output, however, would likely diminish when temperature is increasing and precipitation is becoming more streamlined. While adding more irrigated croplands could potentially raise total crop yield, this could present adverse impacts on the quality of food and the sustainability of the environment. Conditions are fluctuating due to increasing temperature, shifting precipitation regimes, an increase in extreme weather, and rising atmospheric CO_2 concentrations, which are threatening food insecurity and lowering crop productivity, particularly in low-income, agriculturally orientated regions. Together with yields, the health of the soil, water availability, and occurrence of pests and diseases all suffer due to this climate change. Long growing periods or fertilisation due to CO_2 may offer temporary advantages in certain regions, yet broad effects would likely be adverse.

Keywords: Climate Change, Co_2, Global Agriculture System, Crop Yields, Food System, Soil Health, Water Availability

Introduction

Changes in climate are affecting the environmental factors that support agricultural productivity. Agriculture is both a cause and a victim of climate change, accounting for about 25% of global greenhouse gas emissions. Global hunger and malnutrition are made worse by climate hazards, which disproportionately affect low-income groups, as

the IPCC (AR6) and FAO have often noted. The frequency and severity of heat waves, droughts, erratic rainfall, pest and disease outbreaks, etc. are all growing due to climate change, endangering farmers' livelihoods, food security, and agricultural production. The intricate and nonlinear interactions between soil, weather, water, pests, and remotely sensed factors are difficult to capture by traditional crop-yield models, whether they are statistical or mechanistic. The ability to learn intricate spatiotemporal correlations and integrate heterogeneous data (such as sensors, weather forecasts, satellite imaging, and soil data) is provided by deep learning. When rainfall, temperature, wind, or snow patterns vary significantly over an extended period of time, it is referred to as climate change.[1] The degree of climate change is thought to be severely accelerated by global warming and greenhouse gas (GHG) emissions.[2] Because of the ongoing rise in human activity, the average global temperature has risen by 0.9°C since the 19th century and is predicted to rise by 1.5°C by 2050.[3] Due to significant and irreversible losses, multiple and ongoing increases in GHG emissions are having a significant negative impact on freshwater, marine, and terrestrial ecosystems.[4] These GHGs trap heat, much like in a "greenhouse", by preventing the transmission of infrared radiation that tries to escape from the atmosphere.[5] The main causes of greenhouse gas emissions are land conversions, burning fossil fuels, applying nitrogen fertilisers, managing soil, and flooding rice fields. In the long run, the usage of fertilisers made from chemicals has done more harm than benefit. Therefore, in order to improve crop output and lessen the effects of climate change, the modern agricultural sector needs more clean and green techniques. Biochar, biostimulants, and biofertilisers are some of the terminology and tactics that have emerged to combat the usage of agrochemicals and aid in enhancing agriculture. Recent studies have demonstrated that these tactics have the ability to significantly reduce greenhouse gas emissions while also improving crop output and soil characteristics. These tactics all reduce the negative consequences of climate change and serve as an alternative to agrochemicals. These tactics further highlighted the usage of natural products to replace synthetic ones and their necessity. The greenhouse effect may have three potential implications for agriculture. First, crop plants' and weeds' rates of growth may be directly influenced by elevated atmospheric CO_2 concentrations. Second, climatic change brought on by CO_2 may modify the amount of sunshine, rainfall, and temperature, which can affect the production of plants and animals. Finally, because of flooding and rising groundwater salinity in coastal regions, sea level rise might result in the loss of farming land.

Literature Review

The existing literature on these economic and physical implications is reviewed in this study, which then interprets the research in terms of recurring themes or conclusions. Findings about how humans are adapting to climate change, potential regional effects on agricultural systems, and prospective shifts in food production patterns are of particular interest. Crop productivity, food security, and rural livelihoods are all impacted by climate change, which is one of the biggest risks to the global agricultural system. The main factor influencing agricultural productivity is the climate. Over the past ten years, a significant amount of study has been driven by worries about the possible impacts of long-term climate change on agriculture. This corpus of study also discusses the potential economic ramifications of agricultural and livestock yield variations as well as the physical effects of climate change on agriculture. The literature covers the following topics in general: (i) the effects on agricultural yields and livestock productivity; (ii) farmers' perceptions and adaptations; (iii) the regional variability of impacts; (iv) indirect effects through soil, pests, and water; and (v) mitigation and policy approaches.

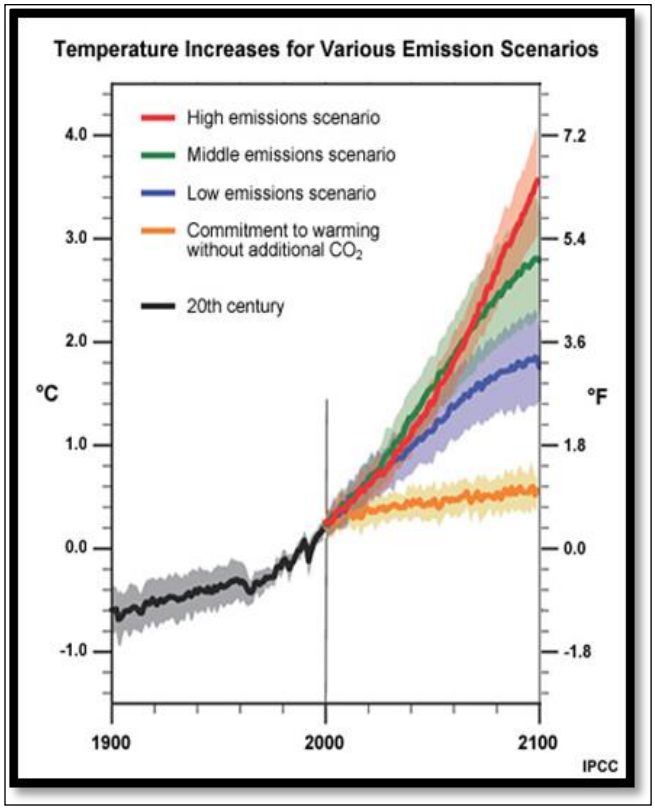

Figure 1.Projected scenarios of global warming

Global Scenario of Climate Change

The temperature is trending upward, contrary to all climate models. Rainfall over South and Southeast Asia has reduced, affecting the precipitation pattern. Since the 1970s, there have been longer and more severe droughts. In terms of

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both area and depth, perpetual snow cover has decreased. It is predicted that by the end of the century, the average sea level will have risen by 0.18 to 0.59 metres. Southeast Asia is home to six of the top ten nations most at risk from climate change. The top five countries are Bangladesh, India, Nepal, the Philippines, Afghanistan, and Myanmar. A 1.5 m sea level rise, for instance, is predicted to result in the loss of agriculture in Bangladesh, displacing around one-fifth of the country's population.

Climate Change Scenario in India

In the northern regions of India, the warming can be more noticeable. Under a changing climate, extremes in maximum and lowest temperatures are predicted to rise; some locations may stay dry while others are predicted to receive more rainfall. With the exception of Tamil Nadu in the south and Punjab and Rajasthan in the northwest, which exhibit a minor decline, a 20% increase in summer monsoon rainfall is anticipated in all Indian states. While there may be fewer rainy days (like in MP), much of India (as in the Northeast) should see an increase in the severity of those days. Water availability in India will drop from 1820 m^3/ year in 2001 to as low as 1140 m^3 per person in 2050. More than half of India's forests are probably going to undergo a change in type, which would have a negative effect on the biodiversity that is linked to them, the dynamics of the local climate, and the livelihoods that depend on the forest products. In under 50 years, the majority of India's forest biomass appears to be extremely sensitive to the anticipated changes in climate. According to projections, there will likely be a shift in the types of forests in 77% and 68% of India's wooded grids by 2085.

Crop Adaptation to Forecast Climate Change Aspects

Higher temperatures, altered precipitation patterns, and increased atmospheric CO_2 concentrations are all examples of climate change scenarios that may have an impact on growth rates, photosynthesis and transpiration rates, yield (both quality and quantity), moisture availability, and water use (irrigation) as well as agricultural inputs like fertilisers, herbicides, and insecticides. Agricultural production may also be impacted by environmental factors such as soil erosion, crop diversity loss, soil drainage frequency and intensity (which causes nitrogen leaching), and land availability. Extremely high temperatures are especially crucial for rice throughout the three flowering stages, which typically span two to three weeks. A few hours of exposure to high temperatures can significantly lower pollen viability, which will result in a loss of production. Temperatures above 35°C significantly increase spikelet sterility, and elevated CO_2 levels may make this issue worse, perhaps as a result of decreased transpiration AL cooling (Matsui et al., 1997a). The first indication of potential genotypic variation in resistance to high night temperatures was found in a recent climate chamber study. Crop development rates are likely to be impacted by high CO_2 levels and/or temperatures. Climate change has anticipated consequences on agriculture over the next fifty years. Biochar, biostimulants, and biofertilisers are some of the terminology and tactics that have emerged to combat the usage of agrochemicals and aid in enhancing agriculture. These tactics have the potential to significantly reduce greenhouse gas emissions while also improving agricultural output and soil quality, according to recent research findings. Agrochemicals are replaced by all of these methods, which also reduce the negative effects of climate change. These tactics further highlighted the usage of natural products to reduce the necessity for and consumption of synthetic ones.[6]

Data and Methodology

The panel data approach proposed by Deschenes and Greenstone (2007) was used to empirically establish the association between meteorological factors and crop yields. The effects of time-invariant factors (such as soil properties, elevation, etc.) and farmers' self-adaptations (such as varying planting dates or varieties, input usage, etc.) in response to annual variations in meteorological factors are captured by this method. The location-specific time variation determinants of crop yields that might be connected with meteorological factors are absorbed by the spatial fixed effects in panel data. The India Meteorological Department, Government of India, provided the 1×1 degree high-resolution daily gridded data from which the district-specific rainfall and temperature data were taken. The daily rainfall has been added up to show the total amount of rainfall for the crop-growing time, and the daily temperature, incorporating minimum and maximum, was converted to the average temperature for the crop-growing period. Crop yields, harvested area, and production amounts for main food crops are among the annual agricultural production statistics presented by the Crop Yield Dataset. It provides a thorough understanding of the connection between crop performance and environmental factors by incorporating

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Table 1.Representing the effects of climate change on agriculture system

Area of crop region	Gathered(ha)	Production in tons/ ha of yield	Average temperature (°C)	Rainfall in millimeter	Irrigated (%)
Punjab	3500000	4.5	23.1	512	98
Punjab	3480000	4.5	23.4	490	97
Rajasthan	3460000	4.4	24.0	470	96
Punjab	3450000	4.35	24.5	465	96
Punjab	3400000	4.18	25.5	430	94
Punjab	3420000	4.24	25.1	450	95

Source: SEDAC (Socio economic Data and Applications Center "updated 5 years ago")

pertinent climate variables like average temperature and rainfall throughout the growing season.

Global warming is thought to increase with population development and industrialisation, and its effects will eventually be distributed throughout the Earth's ecosystems rather than being limited to a specific area. Global food security may be jeopardised by the adverse effects of climate change on agricultural production. Climate change and global food insecurity are therefore considered to be two of the most urgent problems of the twenty-first century.[7]

Climate Change's Effect on Crop Yield

Climate change is negatively impacting soil systems in addition to directly affecting plants. Variations in atmospheric carbon dioxide concentrations, rate, pattern,

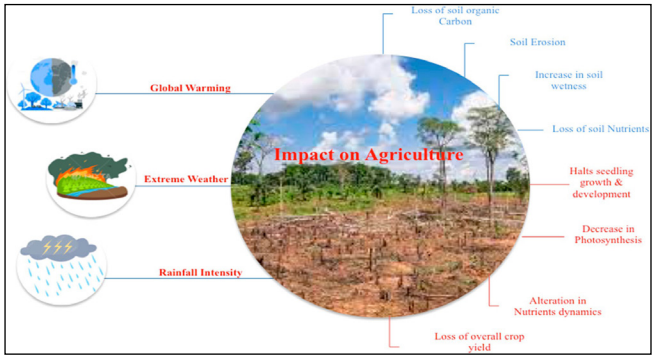

Figure 2.Effects of climate change on crops, soil, and agriculture

and precipitation amounts, along with rising temperatures, are altering the soil-plant system by affecting soil organic carbon levels and the rate of decomposition.[8]

According to a recent study, the process by which minerals are converted into soil compounds is determined by the combined effects of temperature and moisture. By altering the soil water regime, seasonal temperature, precipitation frequency, and fluctuation also have an impact on the hydro-physical characteristics of soil. The hydrological features are greatly influenced by the physical characteristics of the soil, including bulk density, porosity, size distribution of pores, mechanical composition or texture, and structure, including shape and stability. Rice, groundnuts, wheat, and rapeseed-mustard all exhibited high irrigation coefficients with the predicted indications, indicating that irrigation is of paramount importance to counteract the adverse impacts of climate change on these crops. But the results did not come to statistical significance in other crops. The yields of most crops, however, are significantly increased by an increase in the minimum temperature. Temperature seems to have a non-linear effect on farm yields, as evident from the opposing effects of increasing minimum and maximum temperatures. The yield of chickpeas is strongly decreased when both minimum and maximum temperatures increase. From experiment results, productivity of cool-season crops declines negatively when daytime or nocturnal temperatures exceed their optimum value.

Results of simulations illustrating potential future crop yields

The figure shows 2020, 2050, and 2080, which are represented by Hadley climate model results. According to the maps, rising temperatures will result in a decrease in food production in several regions of Africa. In some cases, irrigation may be able to counteract Australia's falling rainfall, which could lead to decreased agricultural yields.[9]

Food production may benefit from North America's moderate temperature increase and increased rainfall. The world's poorer nations are set to bear a disproportionate amount of the burden of climate change. We must keep in mind while interpreting the maps that the outcomes are contingent upon the climate, the impact of CO_2

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Table 2.Shows the expected changes in agriculture system in upcoming years

An Aspect of climate	Anticipated changes by 2050's	Forecast confidence	Agricultural-associated effects
Rainfall	Seasonal fluctuations of ± 10%	Low	Effects of drought risk on transpiration, water logging irrigation supply, and soil workability
Rise in sea level	Increase by 10 to 15 cm boosted in the south and counterbalanced in the north by natural subsistence and recovery	Very high	Land loss, erosion along the shore, flooding, and groundwater salinization
CO_2	rise from 360 ppm to 450–600 ppm (now at 379 ppm from 2005 levels)	Very high	Benefits for crops include higher photosynthesis and lower water consumption.
Adaptability	Rises in the majority of climate variables. Hazardous predictions	Very low	Changing the potential of harmful occurrences that affect crops and the timing of farm operations, such as heat waves, frost, droughts, and floods
Storminess	Higher wind speeds, particularly in the north. Occurrences with heavier rainfall.	Very low	Lodging, soil erosion, and reduced water infiltration

Source: Agriculture and Climate Change, MAFF (2000)

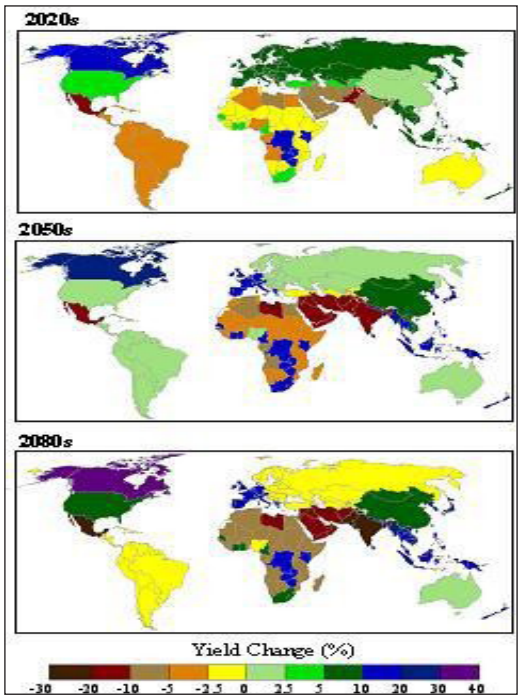

Figure 3.Showing the possible crop yields of future

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levels on agricultural growth, and shifts in socioeconomic circumstances. For instance, irrigation can be used to compensate for decreasing rainfall levels in wealthy nations, while less developed nations may not be able to implement similar technological advancements.[10]

Conclusion

The uncertain climate situation adversely affects agriculture and is a major reason for concern in the context of international food security. The mitigation measures to compensate for the climate-driven adverse effect on farm productivity, like biochar and biostimulants, have the potential to significantly reduce the negative effect while not affecting environmental sustainability. Additional planning and implementation of these mitigation strategies in an interdisciplinary way can salvage the fate of agro-ecosystems and can be implemented as biological tools to counter the unforeseen effects of climate change on agriculture. Specifically, policymaking for large-scale production and health risks caused by the emission of black carbon particles in the air. Agriculture is negatively impacted by the uncertain climate situation, which also presents serious questions regarding the security of the global food supply. Examples of mitigation strategies which mitigate the adverse effects of climate change on agricultural productivity include biochar and biostimulants.

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