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Mini Review

Maladies and Remedies of Climate Change in Agriculture: Searching for a Path to Resilience and Sustainability

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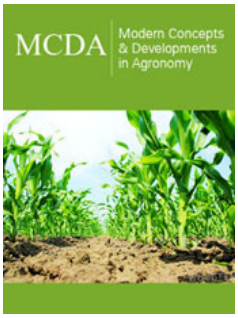
ISSN: 2637-7659



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Submission: March 18, 2025
Published: May 08, 2025

Volume 15 - Issue 2

How to cite this article: MA Ansari*. Maladies and Remedies of Climate Change in Agriculture: Searching for a Path to Resilience and Sustainability. Mod Concep Dev Agrono. 15(2). MCDA. 000856. 2025. DOI: 10.31031/MCDA.2025.15.000856

Abstract

Climate change poses unprecedented and unforeseen challenges to global agriculture, threatening food security, livelihoods and ecosystems. Increasing trends of global temperatures, shifting precipitation patterns, increased intensity & frequency of extreme weather events and the rising atmospheric carbon dioxide (CO_2) levels are profoundly altering agro-ecosystems worldwide. The maladies of climate change in agriculture include reduced crop yields, increased pest and disease manifestation, water scarcity, soil degradation, livestock stress, biodiversity loss and extreme weather events. These climate change induced impacts are exacerbated by economic and social vulnerabilities, particularly among smallholder farmers in developing countries. Additionally, agriculture also contributes to climate change through greenhouse gas emissions, creating a feedback loop that intensifies the problem. Addressing these challenges requires a multifaceted approach that integrates adaptation, mitigation, and sustainable development strategies. The potential remedies for climate change in agriculture encompass a range of strategies aimed at building resilience and reducing environmental impacts. Key solutions include the adoption of climate-resilient crop varieties, sustainable water management practices, conservation agriculture and integrated pest management. Agroforestry, improved livestock management and renewable energy use further enhance sustainability. At policy level, national governments must invest in research and development in agriculture, strengthen early warning climate systems and support smallholder farmers through financial and technical assistance. This review highlights the interconnectedness of climate change challenges and the need for coordinated action at both national and global levels. By implementing these remedies, the agricultural sector can enhance resilience, ensure food security and contribute to global climate goals.

Keywords: Climate change; Agriculture resilience; Food security; Climate-smart agriculture; Sustainable agriculture; Climate policy interventions; Conservation agriculture

Introduction

Climate change has emerged as one of the most pressing global challenges of the 21st century, posing significant threats to agricultural productivity, food security and rural livelihoods. In fact, climate change has become an inherent and indispensable component of global development and deliberations on food security and sustainable farm livelihoods [1]. The Intergovernmental Panel on Climate Change (IPCC) has consistently warned that rising temperatures, shifting precipitation patterns, increased frequency of extreme weather events, and rising atmospheric carbon dioxide (CO_2) levels are profoundly altering agro-ecosystems worldwide [2]. Agriculture is not only a victim of climate change but also a significant contributor to it, accounting for approximately 14% of Global Greenhouse Gas (GHG) emissions [3]. The vulnerability of agriculture to climate change is threatening to compromise food security, rural livelihoods and economic stability of millions of farmers, particularly in developing nations like India. Perceptions not only shape knowledge, but knowledge also shapes perceptions about an object, event or phenomena. Farmers' perceptions about climate change, therefore, strongly affects how they understand and deal with climate-induced risks

and uncertainties and undertake specific measures to mitigate the adverse impact of climate change on agriculture [4]. This review explores the major challenges (maladies) induced by climate change in agriculture, examines the potential solutions (remedial strategies) and highlights key policy and technological interventions required to mitigate its impacts and enhance agricultural resilience.

Maladies of Climate Change in Agriculture

Maladies of Climate Change in Agriculture refers to the adverse effects and challenges that climate change imposes on agricultural systems, including crops, livestock, soil, water resources and farming communities. However, with targeted interventions and specific responses to these remedies, the agricultural sector can build resilience, mitigate these challenges, and ensure sustainable food production. These key maladies of climate change in agriculture are as follows:

Rising temperatures and heat stress

Global average temperatures have increased by approximately 1.1 °C since pre-industrial levels and further warming of 1.5 °C to 2.0 °C is expected by the end of the century [2]. Increased temperatures shorten the growing season, accelerate crop maturation and reduce biomass accumulation, leading to lower crop yields. For instance, wheat yields are projected to decline by 6% for each 1 °C increase in temperature [5]. Heat stress also negatively impacts livestock productivity by reducing feed intake, milk production, and reproductive performance [6].

Shifts in precipitation patterns and water scarcity

Erratic rainfall patterns and shifting monsoon behavior have led to increased drought and flooding risks. In India, over 60% of agricultural land is rain-fed, making it highly vulnerable to precipitation variability [7]. Prolonged droughts due to water scarcity reduce soil moisture, restrict nutrient uptake and increase plant stress. Conversely, excessive rainfall leads to water logging, soil erosion and nutrient leaching, compromising soil fertility and crop yields [8]. Groundwater depletion due to over-reliance on irrigation further exacerbates water scarcity.

Pest and disease proliferation

Warmer temperatures during the last decade and increased humidity create favorable conditions for pests and pathogens. For instance, the geographic range of major crop pests like the fall armyworm (*Spodoptera frugiperda*) has expanded due to changing climate patterns, threatening staple crops like maize and sorghum [9]. Increased pest and disease pressure further reduces crop yields and increases reliance on chemical pesticides, leading to environmental degradation and concerns on human health.

Soil degradation and loss of soil fertility

Climate change has exacerbated soil erosion, salinization and desertification, thereby reducing soil fertility and organic matter content [10]. Higher temperatures accelerate soil organic carbon loss, reducing soil health and productivity. In India, over 30% of the land area is already affected by soil degradation, further reducing agricultural potential [7].

Impact on livelihoods and food security

Smallholder farmers, who constitute most of the global agricultural workforce, are disproportionately affected by climate change. Reduced crop yields and livestock productivity directly threaten farm household income and food availability. The World Bank (2018) estimated that climate change could push over 100 million people into poverty by 2030, with rural farming communities being the most vulnerable.

Biodiversity loss

Climate change disrupts ecosystems, threatening the survival of pollinators, beneficial insects and other organisms. For example, the decline in bee populations, loss of native plant species and habitat destruction can lead to reduced pollination, lower crop yields, and loss of genetic diversity in crops and livestock.

Remedies to Mitigate Climate Change Impact Strategies

Remedies refer to the targeted interventions that can take care of maladies of climate change and consequently reduce the severity of climate change and its impact on agriculture. With these targeted remedial interventions, the agricultural sector can also build resilience, mitigate these challenges and ensure sustainable food production. Some of the key remedies that can be addressed are as follows.

Development of climate-resilient crop varieties

Developing and promoting crops that are tolerant of heat, drought, floods and salinity can ensure stable yields under changing climatic conditions. The focus on breeding and genetically engineering climate-resilient crop varieties that can tolerate heat, drought, and salinity is therefore essential for climate change mitigation and adaptation. For example, the development of drought-tolerant rice and heat-resistant wheat varieties has shown promise in enhancing agricultural resilience [11]. Promoting crop diversification and introducing resilient minor millets and legumes can further enhance resilience.

Sustainable water management

Practices like drip irrigation, rainwater harvesting and water-efficient cropping systems optimize water use efficiency and conserve resources, mitigating the impacts of water scarcity [12]. Restoration of natural drainage systems and soil moisture conservation can enhance groundwater recharge and reduce water stress.

Climate-Smart Agriculture (CSA)

CSA, a holistic approach that integrates climate adaptation, mitigation and productivity, includes practices like diversified cropping systems and precision farming. Agro forestry along with crop-livestock integration can also help mitigate the climate

induced uncertainties, besides providing multiple benefits for farmers and ecosystems. Renewed focus on integrating trees and shrubs into agricultural landscapes can provide shade, reduce soil erosion and enhance carbon sequestration [13]. Further, livestock production systems have always been a popular choice in agriculture diversification. Therefore, diversifying farm production systems can enhance the resilience of Agri-food systems and reduce vulnerability to climate shocks.

Renewable energy in agriculture

Using solar-powered irrigation, biogas, and wind energy can greatly help reduce the greenhouse gas emissions and lowers dependency on fossil fuel.

Conservation agriculture

Techniques such as minimum tillage, crop rotation and cover cropping improve soil health, reduce erosion and enhance water retention, ensuring long-term soil fertility.

Integrated Pest Management (IPM)

The emergence of pests and pathogens has become a recurring problem in agriculture. Combining biological, cultural and chemical methods to control pests reduces reliance on pesticides and minimizes environmental harm.

Early warning systems and climate information services

Weather forecasting has proved crucial in reducing the production losses to farmers. Providing farmers with specific locations and timely weather forecasts and climate data helps them make informed decisions, reducing losses from extreme weather events.

Besides the above stated remedies, Policy and Financial Support by the governments and institutions in the form of incentives, subsidies and research funding helps to encourage the adoption of climate-resilient practices. Enhancing the investments in research and innovation to develop and implement specific climate mitigation and adaptation strategies will go a long way in ensuring that solutions are context-specific and culturally appropriate for different categories of farmers.

Conclusion

Climate change presents complex challenges to global and Indian agriculture, threatening food security, rural livelihoods and environmental stability. The maladies of climate change-such as reduced crop yields, water scarcity, soil degradation, and biodiversity loss-demand urgent and coordinated action. However, the remedies outlined above, including climate-resilient practices, sustainable water management, agroforestry and policy support, offer a pathway to resilience and sustainability. By adopting these strategies, the agricultural sector can mitigate the impacts of climate change, enhance productivity and contribute to global climate goals.

Looking ahead, the future strategic interventions must focus on:

a) Long-Term Mitigation: Governments and industries should commit to net-zero targets by mid-century through a combination of renewable energy expansion, energy efficiency improvements, and nature-based solutions like reforestation and soil carbon sequestration.

b) Integrated Climate and Development Policies: Embedding climate resilience into national development strategies, with a focus on poverty reduction, gender equality and sustainable rural development.

c) Scaling Innovations in Agriculture: Accelerate the development and dissemination of climate-resilient technologies, such as drought-tolerant crops and precision agriculture tools, through increased investment in research and development.

d) Strengthening Global Collaborations: Strengthening multilateral agreements, enhancing climate diplomacy, and fostering collaborative research initiatives to tackle transboundary climate challenges. Besides, focus on international partnerships to share knowledge, resources and technologies, ensuring that developing countries are not left behind.

e) Empowering Farmers: Provide smallholder farmers with access to finance, insurance and climate information services to enhance their adaptive capacity.

f) Promoting Circular Agriculture: Encourage practices that minimize waste, recycle nutrients and reduce emissions, such as integrated crop-livestock systems and organic farming.

g) Mainstreaming Climate change Policies: Integrate climate adaptation and mitigation into national and global agricultural policies, ensuring coherence and long-term commitment.

h) Leveraging Digital Tools: Expand the use of digital technologies, such as remote sensing and blockchain, to improve supply chain efficiency and climate monitoring.

i) Innovative Financing Models: Establishing green bonds, carbon markets, and international climate funds to support large-scale adaptation and mitigation projects, especially in developing and vulnerable regions.

By adopting these strategies, the agriculture sector can transform into a resilient, sustainable and climate-smart agriculture sector, ensuring food security for future generations while safeguarding the planet. Strengthening institutional support, expanding financial safety nets and promoting knowledge transfer through extension services are essential for sustaining agricultural productivity in a changing climate scenario. A comprehensive, multi-stakeholder approach that integrates scientific research, policy reforms, and grassroots participation is crucial for building a climate-resilient agricultural sector. The time to act now, with collaboration, innovation and inclusiveness at the heart of all efforts.

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