National Conference on Behavioural Economics and Intelligent Decision Systems for Climate Change and Sustainable Development
Journal of Advanced Research in Alternative Energy, Environment and Ecology
Volume 13, Issue 1&2 - 2026

Research Article

The Double-Edged Sword: Climate Change's Impact on Global Agriculture and Pathways to a Resilient Future

Jaideep Singh[1], Parmjeet Kaur[2], Gurnoor Kaur[3]

Department of Computer Applications, CKD Institute of Management and Technology, Amritsar, India
Department of Computer Science & Engineering Khalsa College of Engineering & Technology, India
Department of Computer Science, Army Public School, Khasa, Amritsar, India
DOI: https://doi.org/10.24321/2455.3093.202609

I N F O

Corresponding Author:
Jaideep Singh, Department of Computer Applications, CKD Institute of Management and Technology, Amritsar, India
E-mail Id:
advaysingh56@gmail.com
How to cite this article:
Singh J, Kaur P, Kaur G. The Double-Edged Sword: Climate Change's Impact on Global Agriculture and Pathways to a Resilient Future. *J Adv Res Alt Energ Env Eco* 2026; 13(1&2): 309-315.

Date of Submission: 2025-11-19
Date of Acceptance: 2025-11-26

A B S T R A C T

The global agricultural sector stands at a critical nexus in the climate crisis, functioning as both a significant contributor to greenhouse gas emissions and a primary victim of their climatic consequences. This paper synthesises the current scientific consensus on the multifaceted relationship between climate change and agriculture. It first establishes the dual role of agriculture, detailing its contributions to anthropogenic emissions through livestock, fertiliser use, and land-use change. It then provides a comprehensive review of the severe impacts of climate change on agricultural systems, including reduced crop yields, increased water stress, proliferation of pests and diseases, and threats to livestock and fisheries, all of which undermine global food security. Subsequently, the paper explores a suite of adaptation strategies designed to build resilience, from on-farm practices like crop diversification and precision agriculture to systemic changes in water and soil management. It also examines mitigation pathways to reduce the sector's climate footprint, focusing on sustainable land management, emissions reduction from livestock and fertilisers, and demand-side measures such as reducing food waste. Finally, the paper analyses the crucial role of policy, governance, and investment in facilitating this transition, highlighting the importance of international frameworks like the Paris Agreement and the urgent need to bridge the significant financing gap with both public and private capital. The paper concludes that a rapid, systemic transformation of global agri-food systems, integrating both adaptation and mitigation, is not only essential for ensuring future food security but is also a non-negotiable component of the global solution to climate change.

Keywords: Climate Change, Global Agriculture, Agricultural Resilience, Food Security, Sustainable Agriculture

Introduction

The Agricultural Dilemma: Contributor and Victim

Climate change and agriculture are deeply interconnected in a complex and increasingly precarious feedback loop. The sector is uniquely positioned as both a major driver of climate change and one of the most vulnerable sectors to its impacts. This dual role creates a profound dilemma: the very practices that have enabled unprecedented growth in food production to support a rising global population are now contributing to the climatic instability that threatens the future of that production.

The entire food production system, from farm to fork—including land clearing, cultivation, transportation, and packaging—accounts for as much as 37% of total anthropogenic greenhouse gas (GHG) emissions. The agricultural sector and associated deforestation are directly responsible for approximately 23% of these emissions. These emissions originate from three primary sources:

- **Methane (CH):** Livestock, particularly cattle, are a major source of methane—a greenhouse gas with a warming potential more than 25 times that of CO over 100 years—through their digestive processes. The flooding of land for rice production is another significant source of agricultural methane.
- **Nitrous Oxide (NO):** The use of nitrogen-based synthetic fertilisers in modern agriculture is the primary source of nitrous oxide emissions. NO is a long-lived and potent GHG with a global warming potential 265 times that of carbon dioxide.
- **Carbon Dioxide (CO):** Land-use change, primarily the conversion of carbon-rich forests and grasslands to cropland and pasture, releases vast stores of carbon into the atmosphere. Deforestation, driven largely by agricultural expansion, is a major contributor to rising CO levels and a significant threat to global biodiversity.

Table 1.

Greenhouse Gas	Primary Agricultural Sources	Key Mitigation Strategies
Methane (CH_4)	Livestock digestion (enteric fermentation), Rice cultivation, Manure storage	Improved livestock feeding practices, Manure management (e.g., biogas capture), Water-efficient rice cultivation
Nitrous Oxide (N_2O)	Application of synthetic nitrogen fertilisers, Manure application	Efficient and precise fertiliser application (e.g., precision agriculture), Improved manure management
Carbon Dioxide (CO_2)	Deforestation and land conversion for agriculture, Soil degradation	Stopping deforestation, Reforestation and afforestation, Soil carbon sequestration (e.g., cover crops, conservation tillage)

Simultaneously, this contributing sector is on the front lines of climate impacts. Agricultural production is fundamentally dependent on stable temperature and precipitation patterns, which are being progressively disrupted by global warming. The increasing frequency and intensity of extreme weather events, such as droughts, floods, and heat waves, pose a direct threat to crops, livestock, and the livelihoods of millions of smallholder farmers. These smallholders, who comprise a large portion of the 75% of the world's poor living in rural areas, are disproportionately affected due to their reliance on rain-fed agriculture and limited capacity to adapt.[1]

Climate Change Impacts on Agricultural Systems and Food Security

The effects of climate change on agricultural production are no longer a future projection but a present-day reality, with negative impacts becoming more common than positive ones across the globe. These impacts are not isolated; they create cascading and compounding effects that threaten all four pillars of food security: availability, access, utilisation, and stability.

Crop Yields and Quality

Observed climate change has already negatively affected the yields of staple crops like maize and wheat in many lower-latitude regions. The Intergovernmental Panel on Climate Change (IPCC) warns that without significant adaptation, yield decreases of 10–25% may be widespread by 2050. A local temperature increase of 2°C is projected to further reduce production for most major crops. While elevated atmospheric CO can have a fertilising effect on some plants, this benefit is often offset by the negative impacts of heat and water stress and does not compensate for yield losses from extreme weather.[2] Furthermore, this CO_2 effect comes with a hidden cost: crops like wheat grown under elevated CO levels show decreased nutritional value, with significant reductions in protein (5.9–12.7%), zinc (3.7–6.5%), and iron (5.2–7.5%). This threatens not just the quantity but the quality of the global food supply.

Water Scarcity and Extreme Weather

Climate change is intensifying the global water cycle, exacerbating water scarcity in many key agricultural regions. Each degree of global warming is expected to decrease renewable water resources by at least 20% for an additional 7% of the world's population. Drought is the single greatest cause of agricultural production loss in developing countries, responsible for 34% of all crop and livestock losses and costing the sector over $37 billion between 2008 and 2018. Conversely, the increased frequency of heavy precipitation events leads to destructive flooding, waterlogged fields, and accelerated soil erosion, which depletes vital nutrients and degrades the land's productive capacity.[3]

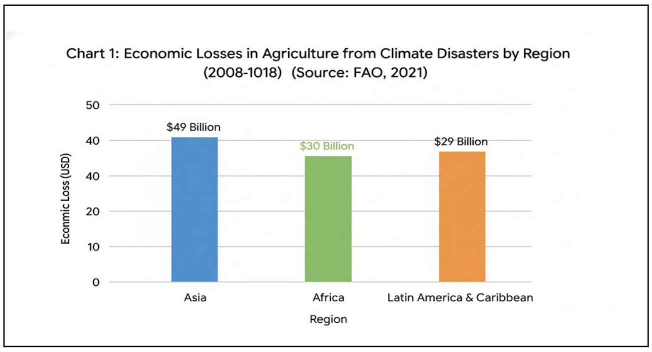

Figure 1.

Pests, Diseases, and Pollinators

Warmer temperatures are expanding the geographical range of many agricultural pests and diseases, exposing crops to new and intensified threats for which they have little resistance. Climate change undermines the natural regulation of pests, leading to more frequent and severe outbreaks that damage crops and reduce yields. At the same time, climate change is a major threat to vital pollinators, such as bees, which are essential for the production of over 100 different crops in the United States alone.[4] Warmer temperatures can create mismatches in the timing of when plants flower and when their pollinators emerge, leading to decreased pollination, lower crop yields, and threats to ecosystem stability.

Livestock and Fisheries

Livestock are highly vulnerable to heat stress, which can reduce appetite, impair reproductive function, and decrease milk and meat production, with high-yield breeds being particularly at risk. Climate change also affects the availability and quality of feed and forage and expands the range of livestock pathogens and diseases. In aquatic systems, the build-up of greenhouse gases is causing rising water temperatures and ocean acidification. These changes severely compromise the ability of both wild-capture fisheries and aquaculture to provide food, threatening the livelihoods of millions in coastal communities who depend on them.[5]

Table 2.

Category	Strategy	Description
On-Farm Practices	Crop & Livestock Diversification	Planting varied crops or raising different livestock to spread risk and buffer against the failure of a single commodity.[1]
	Climate-Resilient Varieties	Developing and using crop varieties tolerant to drought, heat, and salinity.[2]
	Sustainable Water Management	Adopting efficient methods like drip irrigation and rainwater harvesting to manage water scarcity.[1]
	Soil Health Improvement	Using practices like conservation tillage and cover crops to enhance water retention and soil carbon.[3]
Systemic & Institutional Support	Precision Ag & Technology	Using drones, GPS, and sensors for optimized resource use and data-driven decisions.[1]
	Financial Instruments	Providing access to credit schemes and crop insurance to manage climate-related financial risks.[2]
	Knowledge & Training	Disseminating best practices and new technologies through extension

ISSN: 2455-3093
DOI: https://doi.org/ 10.24321/2455.3093.202609

Adaptation: Building Resilience in the Face of Change

Given that many climate impacts are already locked in due to past and present emissions, adaptation is not optional but essential for the survival and sustainability of global agriculture.[6] Adaptation strategies aim to reduce the vulnerability of agricultural systems to climate change by increasing their resilience and coping capacity. These strategies range from technological solutions and on-farm management changes to broader policy and institutional adjustments.

On-Farm Adaptation Practices

Farmers are on the front lines of adaptation, and a range of practices can enhance resilience at the farm level:

- **Crop and Livestock Diversification:** Planting a variety of crops, integrating livestock, or practicing agroforestry spreads risk and provides a buffer against the failure of a single commodity due to specific climate events. Intercropping, which involves growing multiple crops together, can increase yields, improve soil health, and reduce pathogen pressure.[7]
- **Climate-Resilient Varieties:** Developing and planting crop varieties that are more tolerant to drought, heat, and salinity is a critical adaptation measure. This includes leveraging the genetic diversity of traditional landraces, which often possess traits for resilience to extreme conditions and can be used in modern breeding programs.
- **Sustainable Water Management:** As water becomes more unpredictable, adopting efficient irrigation techniques like drip irrigation is crucial.[8]These methods, coupled with rainwater harvesting and better on-farm water storage, help farmers manage increasing water scarcity and make the most of available resources.
- **Soil Health Improvement:** Healthy soils are more resilient soils. Practices such as conservation tillage, planting cover crops, and agroforestry improve soil structure, enhance water retention, and increase soil organic carbon. This makes farms more resilient to both drought and heavy rainfall while also contributing to carbon sequestration.[9]

Systemic and Institutional Adaptation

Individual farm-level actions must be supported by broader systemic changes:

- **Technology and Information Services:** The use of modern technology, including GPS-guided tractors, drones for monitoring crop health, and soil moisture sensors, allows for the optimized use of resources. Crucially, this must be paired with improved access to accurate weather forecasting and early warning systems to help farmers make timely, data-driven decisions.[10]
- **Financial Instruments:** To manage the increasing risks, farmers need access to financial tools. This includes affordable credit schemes to finance adaptation investments and appropriately designed crop insurance programs that protect against climate-related disasters.
- **Knowledge and Training:** Continuous learning is essential. Farmer training, knowledge transfer through extension services and peer-to-peer learning networks are vital for disseminating the latest climate-smart practices and technologies.[11]

Mitigation: Reducing Agriculture's Climate Footprint

Alongside adaptation, the agricultural sector holds significant and largely untapped potential to mitigate climate change by reducing its GHG emissions and enhancing carbon sequestration in soils and biomass. Many mitigation strategies offer powerful co-benefits for adaptation and productivity, a concept often referred to as "climate-smart agriculture".

Table 3.

Category	Strategy	Description & Impact
Supply-Side (Production)	Sustainable Livestock Management	Improving feed and manure management can reduce methane emissions by up to 30%.
	Efficient Fertilizer Use	Precise application of nitrogen fertilizers significantly reduces nitrous oxide emissions.
	Soil Carbon Sequestration	Practices like agroforestry and cover crops can turn soils into a major carbon sink.
Demand-Side (Consumption)	Reducing Food Loss & Waste	Cutting food waste, which accounts for ~8% of annual GHG emissions, is a critical lever.
	Shifting Diets	Moving toward less meat-intensive diets can free up land and significantly cut emissions.

ISSN: 2455-3093
DOI: https://doi.org/10.24321/2455.3093.202609

Supply-Side Mitigation

Sustainable Livestock Management: Improving feeding practices, better manure management, and using technologies like biogas generators can significantly reduce methane emissions from livestock, with some estimates suggesting a reduction potential of up to 30%

Efficient Fertilizer Use: More precise and efficient application of nitrogen fertilisers, guided by soil testing and precision agriculture technologies, can substantially reduce nitrous oxide emissions while maintaining crop yields and lowering input costs for farmers.[12]

Soil Carbon Sequestration: Agricultural soils can be transformed from a carbon source into a major carbon sink.[13] ractices that build soil organic carbon—such as stopping deforestation, using cover crops, practising conservation tillage, and implementing agroforestry-are essential for drawing down atmospheric CO_2. The rehabilitation of degraded agricultural soils alone could remove up to 51 billion tonnes of carbon from the atmosphere.

Demands-Side Mitigation

Changes in consumption patterns can have a profound impact on the climate footprint of the food system:

- **Reducing Food Loss and Waste:** Approximately one-third of all food produced globally is lost or wasted, accounting for about 8% of total annual GHG emissions.14 Reducing this waste at every stage—from farm to consumer—is one of the most effective climate mitigation strategies available.
- **Shifting Diets:** Diets rich in plant-based foods have a much lower GHG footprint than diets heavy in red meat. Shifting toward less GHG-intensive foods could free up hundreds of millions of acres of land currently used for livestock grazing and feed production, allowing for reforestation and further carbon sequestration.

The Role of Policy, Governance, and Investment

Transitioning to a climate-resilient and low-emission agricultural sector is a monumental task that cannot be achieved by farmers alone. It requires a supportive and enabling ecosystem of effective policies, strong governance, and a massive mobilisation of investment from both public and private sources.[15]

International Governance: The Paris Agreement

The Paris Agreement provides the overarching international framework for global climate action. Its central aim is to hold the increase in global average temperature to well below 2°C above pre-industrial levels while pursuing efforts to limit it to 1.5°C. While the agreement does not explicitly detail the role of agriculture in its main text, its preamble recognises “the fundamental priority of safeguarding food security and ending hunger, and the particular vulnerabilities of food production systems”.[16] Agriculture is a priority sector for both adaptation and mitigation in the Nationally Determined Contributions (NDCs) of over 85% of developing countries, demonstrating its centrality to achieving the agreement’s goals. Furthermore, the Koronivia Joint Work on Agriculture (KJWA), established under the UNFCCC, provides a formal process for parties to advance discussions on agriculture’s role in climate action, focusing on issues like soil health, water management, and assessing adaptation.

National Policies and Programs

At the national level, governments must translate international commitments into concrete action. This requires developing policies that incentivise the adoption of climate-smart practices. Key instruments include National Adaptation Plans (NAPs), which serve to guide countries’ efforts to reduce vulnerability and build adaptive capacity. Governments can provide crucial financial and technical assistance through programmes like the USDA’s Climate Hubs and reform subsidies that currently encourage unsustainable practices. Public support for research and development is also critical for innovating new climate-resilient crop varieties and farming methods.[17]

Bridging the Investment Gap

A massive financing gap remains a primary barrier to transformation. Estimates suggest that the climate transition in agriculture requires between $200 billion and $1.2 trillion per year, yet current climate funding to agrifood systems is only around $28.5 billion annually. Bridging this gap is impossible without mobilising the private sector, which manages over $210 trillion in assets.

However, private investment is impeded by barriers such as high upfront costs, long payback periods, a lack of enabling policy frameworks, and the perception of small-scale agriculture as high-risk. Public finance and international institutions like the World Bank and the Green Climate Fund (GCF) have a critical role to play in de-risking private investment through concessional loans, guarantees, and blended finance models. Public-private partnerships, such as the SCALA programme, are essential for creating viable business models for climate-resilient agriculture and developing innovative financial products, like bundling credit with crop insurance and technical assistance, to reach the most vulnerable smallholder farmers.[18]

ISSN: 2455-3093
DOI: https://doi.org/ 10.24321/2455.3093.202609

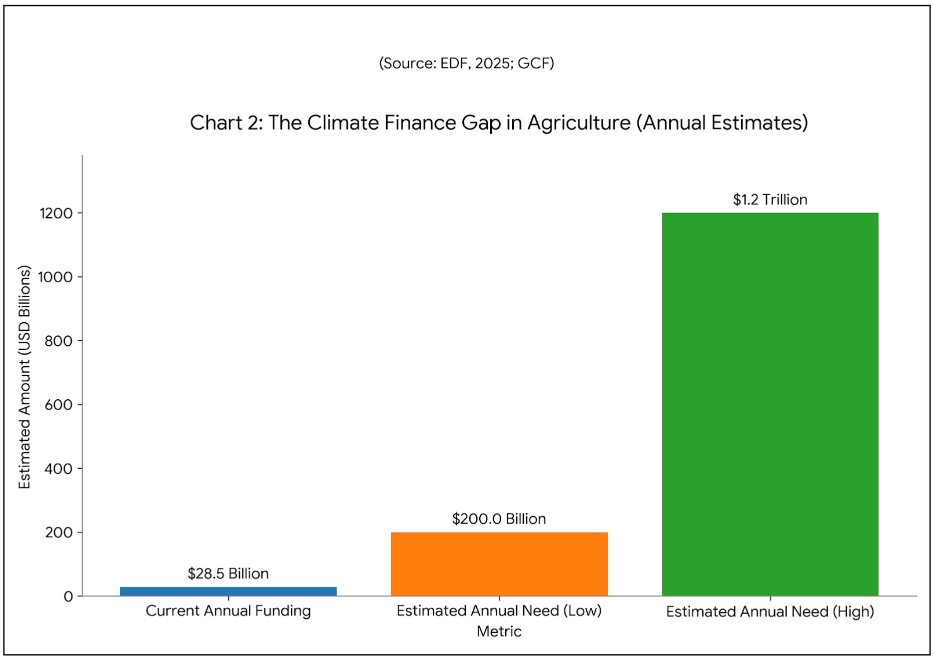

Figure 2.

Conclusion

The relationship between climate change and agriculture is one of the most critical and complex challenges of the 21st century. The global food system is a major engine of climate change, yet it is also profoundly vulnerable to the disruptions that climate change creates. The scientific evidence is unequivocal: business-as-usual is no longer an option. Continuing on the current trajectory will lead to widespread crop failures, increased food insecurity, heightened social and political instability, and devastating impacts on the livelihoods of hundreds of millions of people.

The path forward requires a dual strategy of ambitious adaptation and aggressive mitigation, implemented simultaneously and at a global scale. Farmers are already innovating on the front lines, but they need systemic support. A wholesale transformation of our agri-food systems is necessary—a fundamental shift towards practices that are resilient, regenerative, and low-emission. This transformation depends on a concerted and coordinated effort from all stakeholders: policymakers must create enabling environments and reform harmful subsidies; scientists must continue to innovate and share knowledge; the private sector must mobilise investment and reorient supply chains; and consumers must be empowered to make more sustainable choices. Addressing the agricultural dilemma is not just a sectoral issue; it is fundamental to achieving the goals of the Paris Agreement and ensuring a food-secure, equitable, and sustainable future for all.

References

1. Diamond, S. E., & Martin, R. A. (2020). Evolution is a double-edged sword, not a silver bullet, to confront global change. Annals of the new York Academy of Sciences, 1469(1), 38-51.
2. Ahmed, Abdalrahman, Brian Rotich, and Kornel Czimber. "Climate Change as a Double-Edged Sword: Exploring the Potential of Environmental Recovery to Foster Stability in Darfur, Sudan." Climate 13, no. 3 (2025): 63.
3. Shukla, Kavita, Vishnu Mishra, Jawahar Singh, Vishal Varshney, Rajnandini Verma, and Sudhakar Srivastava. "Nanotechnology in sustainable agriculture: A double-edged sword." Journal of the Science of Food and Agriculture 104, no. 10 (2024): 5675-5688.
4. Lenzerini, Federico, and Erika Piergentili. "A double-edged sword: Climate change, biodiversity and human rights." In Climate Change and Human Rights, pp. 159-172. Routledge, 2015.
5. Moyer, Jonathan D. "A double-edged sword into a plowshare: Analyzing geopolitical implications of alternative socioeconomic development pathways." One Earth 7, no. 2 (2024): 336-347.
6. Su, Y., J. Hammond, G. B. Villamor, R. E. Grumbine, J. Xu, K. Hyde, T. Pagella, N. M. Sujakhu, and X. Ma. "Tourism leads to wealth but increased vulnerability: a double-edged sword in Lijiang, South-West China." Water international 41, no. 5 (2016): 682-697.
7. Ahakwa, Isaac, and Evelyn Agba Tackie. "Natural resources as a double-edged sword towards ecological quality: Can environmental regulations and green human capital rectify the adverse impacts?." Journal of Cleaner Production 457 (2024): 142436.
8. Marcu, Daniel, Shannen Keyser, Leslie Petrik, Samuel Fuhrimann, and Liana Maree. "Contaminants of

emerging concern (CECs) and male reproductive health: challenging the future with a double-edged sword." Toxics 11, no. 4 (2023): 330.
9. Dijkstra, Feike A., Biao Zhu, and Weixin Cheng. "Root effects on soil organic carbon: a double-edged sword." New Phytologist 230, no. 1 (2021): 60-65.
10. Teng, Hsiu-Yu, Ming-Way Li, and Chien-Yu Chen. "Does smart technology, artificial intelligence, robotics, and algorithm (STARA) awareness have a double-edged-sword influence on proactive customer service performance? Effects of work engagement and employee resilience." Journal of Hospitality Marketing & Management 34, no. 3 (2025): 443-466.
11. Woldehanna, Tassew, Yisak Tafere, and Manex B. Yonis. "Social capital as a double-edged sword for sustained poverty escapes in Ethiopia." World development 158 (2022): 105969.
12. Cheng, Hao, Yanxing Xu, Abdelrahman Ibrahim, Yanzheng Gao, Hefei Wang, Ahmed A. Mosa, and Wanting Ling. "Plant enrichment effects of quantum dots in agroecosystems: a double-edged sword." Environmental Science: Nano (2025).
13. Sanchez-Lucas, Rosa, and Estrella Luna. "Elevated CO_2: a double-edged sword for plant defence against pathogens." The New Phytologist 246, no. 6 (2025): 2380.
14. Creamer, Emily. "The double-edged sword of grant funding: a study of community-led climate change initiatives in remote rural Scotland." Local Environment 20, no. 9 (2015): 981-999.
15. Adhikari, Dipan, Parvin Khatun, Satyajit Koley, Moutushi Sen, and Sudip Kumar Ghosh. "Nanotechnology: A double-edged sword for future smart agriculture and phytopathological management in plants." Agriculture and Food Sciences Research 11, no. 2 (2024): 203-221.
16. Parween, Sabiha, Joanne J. Anonuevo, Vito M. Butardo Jr, Gopal Misra, Roslen Anacleto, Cindy Llorente, Ondrej Kosik et al. "Balancing the double-edged sword effect of increased resistant starch content and its impact on rice texture: its genetics and molecular physiological mechanisms." Plant Biotechnology Journal 18, no. 8 (2020): 1763-1777.
17. Salehi, Bahare, Abhay Prakash Mishra, Manisha Nigam, Bilge Sener, Mehtap Kilic, Mehdi Sharifi-Rad, Patrick Valere Tsouh Fokou, Natália Martins, and Javad Sharifi-Rad. "Resveratrol: A double-edged sword in health benefits." Biomedicines 6, no. 3 (2018): 91.
18. Rane, Nitin Liladhar, Abhijeet Tawde, Saurabh P. Choudhary, and Jayesh Rane. "Contribution and performance of ChatGPT and other Large Language Models (LLM) for scientific and research advancements: a double-edged sword." International Research Journal of Modernization in Engineering Technology and Science 5, no. 10 (2023): 875-899.

ISSN: 2455-3093
DOI: https://doi.org/ 10.24321/2455.3093.202609