

# *Climate-Smart Agriculture: Pathways to Resilient Farming Systems*

**Abdul Tahir Khan<sup>1</sup> and Diptanu Banik<sup>2\*</sup>**

<sup>1</sup>Swami Vivekananda University, Sagar, MP

<sup>2</sup>Lovely Professional University, Kapurthala, Jalandhar, Punjab

**Corresponding Author**

Diptanu Banik

Email: [dipbanik4me@gmail.com](mailto:dipbanik4me@gmail.com)



## **Keywords**

Climate-Smart Agriculture, Policies, Practices

*How to cite this article:*

Khan, A. T. and Banik, D. 2025. Climate-Smart Agriculture: Pathways to Resilient Farming Systems. *Vigyan Varta* 6(7): 261-267.

## **ABSTRACT**

Climate-smart agriculture (CSA) has emerged as a comprehensive response to the intersecting challenges of food security and climate change. It aims to sustainably increase agricultural productivity, adapt to and build resilience against climate change, and reduce or mitigate greenhouse gas emissions where possible. As climate change intensifies, with increasing temperatures, shifting precipitation patterns, and more frequent extreme weather events, the agricultural sector faces unprecedented risks. However, CSA not only addresses these risks but also opens opportunities to transform food systems toward sustainability. This paper examines the dual nature of climate change's impacts on agriculture, highlighting both the potential advantages, such as longer growing seasons and the rise of green energy markets, and the detrimental consequences, including biodiversity loss, food insecurity, and economic disparities. Through an examination of CSA practices like agroforestry, conservation agriculture, and precision farming, the paper outlines a pathway toward resilient farming systems. It also delves into the role of indigenous knowledge, technology, international policies like the Paris Agreement, and the ethical imperative of climate justice. The study seeks to provide an academically rigorous foundation for advocating climate-smart agricultural policies and practices. The conclusion underscores the urgency for global, collective action supported by innovation and inclusivity, presenting a

vision of agriculture that is both productive and sustainable.

## INTRODUCTION

Climate-smart agriculture (CSA) is an integrated approach designed to transform agricultural development in the face of climate change by pursuing three core objectives: sustainably increasing agricultural productivity and incomes, adapting and building resilience to climate change, and reducing or removing greenhouse gas (GHG) emissions where possible (FAO, 2013; Lipper *et al.*, 2014). This approach encompasses diverse practices such as conservation agriculture, climate-resilient crop varieties, agroforestry, improved water-use efficiency, and integrated pest management, emphasizing synergy between environmental sustainability and economic viability tailored to various agroecological zones and farming systems.

### Historical Context and Drivers of CSA

The concept of CSA was formally introduced by the Food and Agriculture Organization (FAO) in 2010 during the Hague Conference on Agriculture, Food Security, and Climate Change, although its roots trace back to earlier agroecological and sustainable agriculture movements (Altieri, 2009). The approach gained urgency following global food crises and climate-related agricultural disruptions, such as the 2007–08 food price crisis and severe droughts in East Africa and South Asia, which highlighted the limitations of traditional agricultural paradigms like the Green Revolution. CSA emerged as a response to increasing climate-induced stresses—droughts, floods, heatwaves, erratic rainfall, and shifting agroecological zones—alongside challenges like declining soil fertility and biodiversity loss (Thornton *et al.*, 2011). Technological innovations such as real-time weather forecasting, precision agriculture, drone

surveillance, and mobile extension services have enabled CSA's implementation by improving adaptive capacity and resource efficiency.

### Relevance to Food Security and Livelihoods

Agriculture supports over 2.5 billion people globally, making CSA critical for addressing food insecurity, malnutrition, and poverty (IPCC, 2022). By promoting diversification, conservation agriculture, and improved value chains, CSA strengthens local and national food systems. The World Bank estimates that by 2050, CSA could reduce food insecurity risks for more than 500 million smallholder farmers, especially in Sub-Saharan Africa and South Asia. It empowers vulnerable groups—including women, youth, and indigenous communities—by improving access to adaptive tools, extension services, financial credit, and social safety nets. CSA also supports improved nutrition through diversified diets and resilience-building mechanisms such as insurance and safety nets, reducing seasonal hunger in climate-sensitive regions.

### International Agreements and Policy Frameworks

CSA aligns with key international agreements, notably the Paris Agreement (2015), which focuses on limiting global temperature rise and enhancing adaptive capacity. The Koronivia Joint Work on Agriculture under the UNFCCC recognizes agriculture's role in climate action. CSA is integral to the United Nations Sustainable Development Goals (SDGs), particularly SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action),

and SDG 15 (Life on Land). Regional frameworks such as the African Union's Comprehensive Africa Agriculture Development Programme (CAADP) and India's National Action Plan on Climate Change (NAPCC) have incorporated CSA principles into national strategies, highlighting its policy relevance.

### Technological and Scientific Foundations

Scientific advancements underpin CSA's effectiveness. Remote sensing, climate forecasting, and genomics facilitate development and deployment of climate-resilient crop varieties like drought-tolerant maize and flood-resistant rice. Decision support tools such as crop simulation models (e.g., DSSAT), geographic information systems (GIS), and mobile advisory platforms enable better planning and risk management. Digital platforms like India's eNAM, Kenya's M-Farm, and the USA's Climate Field View enhance data-driven decision-making. Renewable energy innovations, including solar irrigation and biomass-fueled cold storage, exemplify CSA's integrative potential to boost productivity while reducing emissions.

### Institutional and Stakeholder Landscape

CSA's success relies on multi-level coordination among governments, research institutions, private sector actors, and civil society. Organizations such as CGIAR, FAO, the World Bank, and the Global Alliance for Climate-Smart Agriculture (GACSA) play key roles in policy development, capacity building, and monitoring. At the grassroots level, farmer-producer organizations, cooperatives, and NGOs facilitate knowledge dissemination and community mobilization. Public-private partnerships and inclusive governance mechanisms ensure equitable, participatory, and context-specific CSA transitions.

## Principles, Practices, and Policies of Climate-Smart Agriculture

### Core Principles and Pillars

CSA is founded on three interlinked pillars: (1) increasing agricultural productivity and incomes, (2) enhancing resilience and adaptation to climate change, and (3) reducing or removing GHG emissions (FAO, 2013). These pillars reflect CSA's multi-dimensional goals, distinguishing it from conventional agricultural strategies. The productivity pillar addresses the need to increase food production by 60% by 2050 to meet global demand (Alexandratos & Bruinsma, 2012), emphasizing resource-efficient and input-sensitive models like conservation agriculture and crop-livestock integration. For example, conservation tillage can increase yields by 15–25% in rainfed Sub-Saharan Africa (Giller *et al.*, 2015). The adaptation pillar focuses on reducing vulnerability to climate shocks through diversified cropping, drought-resilient seeds, early warning systems, and social safety nets. In Kenya, climate-smart villages practicing mulching, intercropping, and solar irrigation improved household food security by 30% within three years (CIAT, 2018). The mitigation pillar targets emission reductions through agroforestry, improved livestock feed, anaerobic digesters, and efficient fertilizer use; biochar application in Southeast Asia reduced N<sub>2</sub>O emissions by up to 50% while enhancing soil fertility (Lehmann & Joseph, 2015).

CSA operates under five guiding principles: context-specific design, evidence-based planning, multi-stakeholder engagement, long-term impact orientation, and equity-focused implementation. It integrates indigenous knowledge with modern science and emphasizes system integration, considering crops, livestock, water, biodiversity, and energy as interconnected. Silvopastoral systems in Latin America have reduced emissions intensity and increased milk yields

by over 40% (FAO, 2020). Climate risk assessment tools like the Climate-Smart Agriculture Prioritization Framework (CSAPF) assist policymakers in selecting appropriate interventions based on local vulnerabilities.

### **Climate-Smart Crop Production Techniques**

Climate-smart crop production enhances productivity and sustainability while reducing vulnerability to climate variability. Conservation agriculture (CA)—involving minimal soil disturbance, permanent soil cover, and diversified rotations—is widely adopted, covering over 180 million hectares globally and contributing to sustainable intensification in Sub-Saharan Africa and South America (Kassam *et al.*, 2019). Climate-resilient crop varieties, such as drought-tolerant maize (DTMA initiative) and flood-tolerant Sub-1 rice in India, have significantly improved yields under stress conditions (CIMMYT, 2016). Integrated crop management (ICM) promotes site-specific nutrient management, integrated pest management (IPM), and bio-fertilizers, reducing pesticide use by up to 50% while maintaining yields (ICAR). Agroforestry integrates trees with crops and livestock, enhancing productivity, carbon sequestration, and ecosystem services. The Farmer-Managed Natural Regeneration (FMNR) technique in the Sahel restored over 5 million hectares, boosting cereal yields and incomes (Reij & Winterbottom, 2015). Water-smart practices like drip irrigation and alternate wetting and drying (AWD) reduce water use and methane emissions in rice cultivation (Lampayan *et al.*, 2015). Precision agriculture and digital advisory platforms improve input efficiency and decision-making, exemplified by reduced nitrogen fertilizer use in the U.S. and China and mobile apps like “Kisan Suvidha” and “Esoko” improving farmer profitability and resilience.

### **Livestock and Agroforestry Systems**

Livestock and agroforestry are vital CSA components, enhancing ecosystem services, diversifying income, and improving resilience. Climate change challenges such as heat stress and feed quality decline are addressed through heat-tolerant breeds (e.g., Red Maasai sheep, Sahiwal cattle) and improved nutrition (Thornton & Herrero, 2015). Improved forages like *Brachiaria* reduce enteric methane emissions by up to 30% (Rao *et al.*, 2016). Manure management via biogas digesters and composting recycles nutrients and reduces emissions, with biogas units in Nepal and East Africa providing clean energy and reducing deforestation (SNV, 2018). Agroforestry systems improve soil fertility, microclimate regulation, and carbon sequestration; *Faidherbia albida* parklands in West Africa increased millet yields by 30% (Garrity, 2012). Silvopastoral systems in Colombia improved milk yields by 25–40% while sequestering carbon (FAO, 2020). These systems diversify income and nutrition, enhancing food security. Scaling requires enabling policies, capacity building, credit access, and gender-sensitive approaches recognizing women’s roles in livestock and agroforestry management.

### **Soil Health, Water Management, and Resource Efficiency**

Soil and water management underpin CSA’s productivity, resilience, and sustainability. Over 33% of global soils are degraded due to erosion, nutrient depletion, acidification, and salinization (FAO, 2015). CSA promotes conservation agriculture, organic amendments, minimal tillage, cover cropping, crop rotation, and compost application to restore soil organic carbon and microbial diversity. Improving soil organic matter by 0.1% annually could sequester 1.2 gigatons of CO<sub>2</sub> globally (Lal, 2020). Soil conservation measures like contour farming and terracing reduce erosion and runoff, exemplified by watershed management

in Ethiopia's Tigray region, which halved soil loss and doubled yields (Gebreselassie *et al.*, 2016). Water-smart techniques such as drip irrigation, AWD, and rainwater harvesting improve water-use efficiency and stabilize availability, with micro-irrigation in Andhra Pradesh increasing water productivity by 50–70% (World Bank, 2020). Precision irrigation and nutrient scheduling utilize soil moisture sensors and remote sensing. Integrated Nutrient Management (INM) combines organic and inorganic inputs to enhance fertilizer efficiency and reduce runoff, as demonstrated by urea deep placement in Bangladesh, which cut fertilizer use by 30% and increased yields by 20% (IFDC, 2017). Resource circularity through composting and waste recycling closes nutrient loops, benefiting smallholders with limited input access.

### Socio-Economic and Gender Dimensions

CSA addresses socio-economic and gender challenges critical for sustainable adoption. Smallholder farming, accounting for over 70% of global food production, is dominated by vulnerable groups including women, who constitute 43% of the agricultural labor force but face disparities in land, inputs, credit, and training access (FAO, 2011; IFAD, 2021). Gender-sensitive participatory extension programs have increased CSA adoption in Kenya, Bangladesh, and Ethiopia (World Bank, 2022). Inclusion extends to youth, indigenous peoples, and landless laborers, with programs like India's National Rural Employment Guarantee Scheme integrating CSA activities to provide income and resilience. Financial inclusion tools—microfinance, credit-linked subsidies, weather-indexed insurance, and savings groups—overcome initial cost barriers. In Malawi, combining CSA advisory services with credit access increased maize yields and incomes by 38% (CIMMYT, 2019). Value chain

integration strengthens market access and income stability, particularly for women-led enterprises. Education and capacity building correlate with CSA success; in Uganda, training female farmers improved yields by 50% and dietary diversity by 25% (CARE International, 2020). Institutional support includes gender-sensitive research, inclusive policies, and disaggregated data to guide interventions, supported by tools like the Gender Climate-Smart Agriculture Toolkit (G-C-SAT).

### Risk Management and Insurance Mechanisms

Risk management is essential to CSA, helping farmers cope with climate variability, market fluctuations, and extreme events. CSA integrates early warning systems, diversified cropping, livelihood diversification, and agricultural insurance. Weather-indexed crop insurance, which triggers payouts based on measurable parameters like rainfall, reduces administrative costs and expedites compensation. India's Pradhan Mantri Fasal Bima Yojana (PMFBY) covers over 50 million farmers using satellite and weather data, though effectiveness varies regionally (Ravikumar *et al.*, 2021). The R4 Rural Resilience Initiative in Sub-Saharan Africa combines risk reduction, insurance, credit, and savings, leading to higher investment and food security (WFP, 2019). Crop diversification reduces income variability and enhances resilience. Digital climate advisory platforms improve decision-making and reduce losses, as seen in Kenya (TechnoServe, 2021). Social protection programs like Ethiopia's Productive Safety Net Programme build resilience while providing income during lean seasons. Challenges to uptake include affordability, trust, and infrastructure gaps, requiring inclusive insurance models, subsidized premiums, bundled services, and public-private partnerships for scaling.

## CONCLUSION

Climate-smart agriculture offers a comprehensive framework addressing productivity, adaptation, and mitigation simultaneously. Empirical evidence from countries such as India, Kenya, Ethiopia, and Colombia demonstrates CSA's potential to enhance food security, resource efficiency, and community resilience across diverse agricultural systems. The escalating impacts of climate change and rising global food demands necessitate urgent, coordinated action involving governments, civil society, international organizations, private sectors, and farming communities. Digital innovations, biotechnology, remote sensing, AI-based forecasting, and precision agriculture can accelerate CSA adoption, especially if scaled affordably and inclusively among smallholders. Public investment in research and rural digital infrastructure is critical. CSA must be grounded in fairness, justice, and inclusivity—acknowledging historical responsibilities and ensuring vulnerable groups, including Indigenous peoples, women, and youth, have voice and access. Integrating indigenous knowledge with modern science fosters context-appropriate, culturally sensitive strategies. Participatory approaches empower communities as co-creators of solutions.

Ultimately, CSA envisions a transformation toward resilient, equitable, regenerative, and climate-neutral food systems. This requires rethinking supply chains, promoting circular economies, and embedding CSA into national development agendas. With bold leadership, inclusive governance, and sustained investment, climate-smart agriculture can lead the way to a future where farming thrives, nature is preserved, and communities prosper.

## REFERENCES

- African CSA Alliance. (2021). *Annual progress report 2020–2021*. <https://africacsaalliance.org>
- CARE International. (2020). *Enhancing gender equality through climate-smart agriculture: A learning brief*. <https://careclimatechange.org>
- CGIAR. (2023). *Climate-smart agriculture and food systems*. <https://www.cgiar.org>
- CIAT. (2021). *CSA country profiles: Evidence-based planning and implementation*. <https://ccafs.cgiar.org>
- CIMMYT. (2016). *Drought Tolerant Maize for Africa (DTMA): Improving food security in sub-Saharan Africa*. <https://www.cimmyt.org>
- CIMMYT. (2019). *Climate-smart villages: Improving resilience in Malawi*. <https://www.cimmyt.org>
- FAO. (2011). *The role of women in agriculture* (ESA Working Paper No. 11-02). <https://www.fao.org>
- FAO. (2015). *Status of the world's soil resources*. <https://www.fao.org/soils-portal>
- FAO. (2020). *Silvopastoral systems and their contribution to sustainable livestock production*. <https://www.fao.org>
- FAO. (2023). *Climate-smart agriculture sourcebook* (2nd ed.). <https://www.fao.org>
- GACSA. (2020). *Climate-smart agriculture overview*. <https://www.fao.org/gacsa>
- Garrity, D. P. (2012). Agroforestry and the future of global land use. In N. Lamers & M. Baumgärtner (Eds.), *Land Use—Challenges and Solutions* (pp. 35–50). Springer.
- Gebreselassie, S., & Kirub, A. (2016). Impact of community-based watershed management on farmers' livelihood in northern Ethiopia. *Environmental Systems Research*, 5(1), 8.

- IFAD. (2021). *Smallholders and climate-smart agriculture*. <https://www.ifad.org>
- IFDC. (2017). *Urea deep placement technology improves rice yields in Bangladesh*. <https://ifdc.org>
- India Meteorological Department. (2022). *Agro-Meteorological Bulletin Series*. <https://mausam.imd.gov.in>
- IPCC. (2022). *Sixth Assessment Report: Climate change 2022*. <https://www.ipcc.ch>
- Kassam, A., Friedrich, T., Derpsch, R., & Kienzle, J. (2019). Overview of the worldwide spread of conservation agriculture. *Field Actions Science Reports*, (12), 1–10.
- Lal, R. (2020). Regenerative agriculture for food and climate. *Journal of Soil and Water Conservation*, 75(5), 123A–124A. <https://doi.org/10.2489/jswc.2020.0620A>
- Lampayan, R. M., Reyes, R. M., Singleton, G. R., & Bouman, B. A. (2015). *Adoption and economics of alternate wetting and drying water management for irrigated lowland rice*. IRRI.
- Ministry of Agriculture & Farmers Welfare. (2021). *Annual report 2020–21*. Government of India. <https://agricoop.nic.in>
- National Innovations in Climate Resilient Agriculture [NICRA]. (2020). *Annual progress report*. <https://www.nicra-icar.in>
- Rao, I. M., Peters, M., Castro, A., Schultze-Kraft, R., White, D., Fisher, M., & Miles, J. W. (2016). LivestockPlus: The sustainable intensification of forage-based agricultural systems. *Tropical Grasslands–Forrajes Tropicales*, 4(3), 163–177.
- Ravikumar, T., Kumar, A., & Joshi, P. K. (2021). Agricultural insurance in India: Challenges and prospects. *Agricultural Economics Research Review*, 34(2), 123–134.
- Reij, C., & Winterbottom, R. (2015). *Scaling up regreening: Six steps to success*. World Resources Institute.
- SNV. (2018). *Biogas support programme in Nepal: Lessons and achievements*. <https://snv.org>
- TechnoServe. (2021). *Smart agriculture for smart farmers: Digital platforms in Kenya*. <https://technoserve.org>
- Thornton, P. K., & Herrero, M. (2015). Adapting to climate change in the mixed crop and livestock farming systems in Sub-Saharan Africa. *Nature Climate Change*, 5(9), 830–836. <https://doi.org/10.1038/nclimate2754>
- UNFCCC. (2022). *Koronivia Joint Work on Agriculture*. <https://unfccc.int>
- United Nations. (2021). *Food systems summit: Action tracks summary*. <https://www.un.org>
- WFP. (2019). *R4 Rural Resilience Initiative: Annual Report 2018*. <https://www.wfp.org>
- World Bank. (2020). *Transforming India's irrigation sector*. <https://www.worldbank.org>
- World Bank. (2022). *Closing the gender gap in agriculture*. <https://www.worldbank.org>
- World Resources Institute. (2021). *Creating a sustainable food future*. <https://www.wri.org>