Review

Scaling Climate-Smart Agriculture for Resilient Farming

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Abstract

Climate change poses a major threat to global agriculture and food security due to rising temperatures, erratic rainfall, droughts, floods and increased pest pressure, particularly affecting the farming systems of smallholder farmers. The global population is projected to reach 9.7 billion by 2050. Sustainable methods are needed to increase food production while conserving natural resources. Climate-Smart Agriculture (CSA) integrates three objectives: increasing agricultural productivity, enhancing resilience and adaptability to climate change, and reducing greenhouse gas emissions. This review examines the key factors influencing the adoption of CSA, including household characteristics, farm size, land ownership, and access to extension services, credit, markets and farmer organizations. It also compiles evidence regarding the impact of CSA on crop yields, farm income, climate resilience and environmental sustainability. Furthermore, the review emphasizes policy strategies for scaling up CSA through improved extension systems, climate finance, digital advisory services, and context-specific institutional support for sustainable agricultural development.

Keywords: Climate-Smart Agriculture (CSA), environmental sustainability, Temperature, Rainfall and Farming System.

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Introduction

Agriculture is deeply linked to weather and climate, accounting for approximately 20% of global greenhouse gas emissions (Rana, *et.al.,* 2017; Kang *et al.,* 2019). Rising temperatures, erratic rainfall, and extreme weather events are reducing crop yields, pest infestation and destabilizing supply chains (Lobell et al., 2014). By 2050, 70% more food will be required to feed a population of 9.7 billion (United Nations, 2021). Since increasing production through conventional methods risks resource depletion, there is a need for climate-resilient practices.

Climate-Smart Agriculture (CSA) offers one such pathway. According to the FAO, it entails transforming agri-food systems to enhance productivity, improve resilience, and reduce emissions (FAO 2013). CSA is not a single technique but a suite of practices, including drought-tolerant crop varieties, water-saving irrigation, conservation agriculture, agroforestry, and improved livestock management (Vermeulen *et al.* 2012).

Despite policy interest, its adoption remains limited. Understanding its determinants and impacts is essential for effective scaling up. This review synthesizes evidence to identify the barriers to and opportunities for the adoption of CSA among smallholder farmers.

Determinants of CSA Adoption

Adoption is a multi-stage decision influenced by household, farm, and institutional factors.

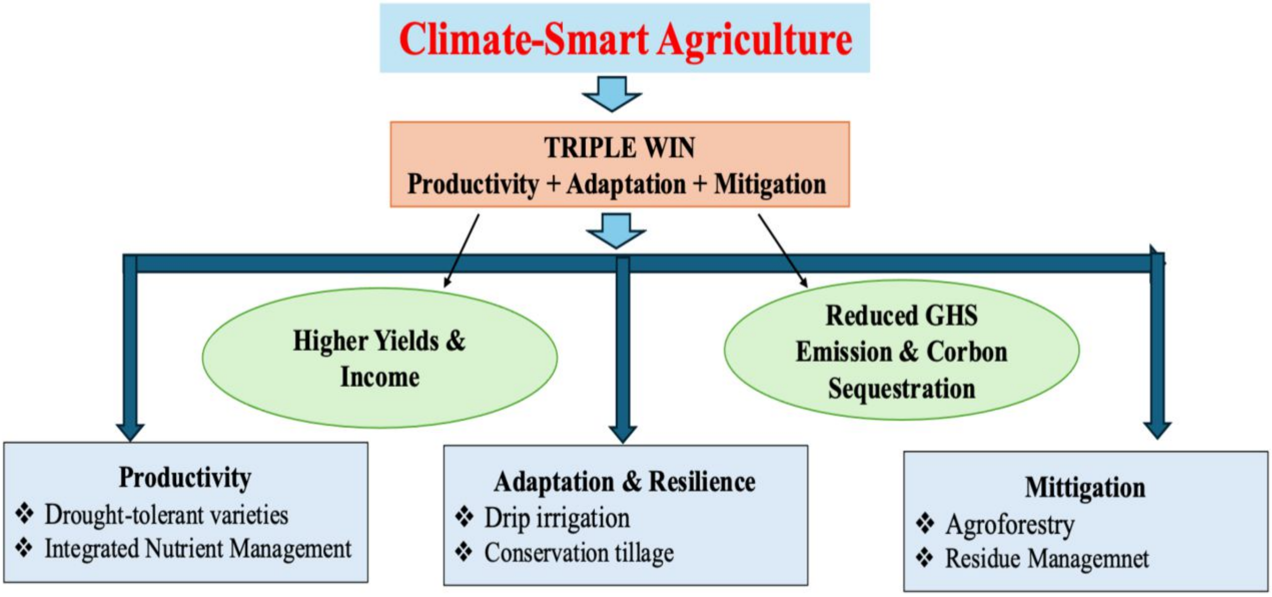

Figure 1: The three pillars of climate-smart agriculture and their overlap for achieving triple wins

Household and farmer characteristics

Age, education, gender, and risk preference influence the adoption of CSA. Older farmers tend to plan for shorter time horizons, resulting in lower adoption rates. Education enhances the capacity to understand climate-related risks and technical information (Li *et. al.* 2024). Women farmers face greater challenges in accessing land, credit, and extension services; consequently, despite being more vulnerable to climate impacts, they are less able to adopt these practices (Porter *et al.* 2014). Farmers who are risk-averse tend to avoid adopting technologies that entail high initial costs and uncertain returns, such as improved seeds or drip irrigation.

While income from non-farm sources provides the capacity to invest, it can also divert labor away from farming activities, potentially leading to reduced adoption of labor-intensive practices—such as crop residue management.

Farm and biophysical conditions: Farm size, fragmentation, and land tenure security influence investment incentives. Small landholdings limit economies of scale for mechanized agricultural practices, such as laser land leveling. Secure land tenure encourages long-term investment in soil conservation and agroforestry, whereas insecure tenure discourages such investments (Thornton *et al.* 2014).

Stress-tolerant varieties are adopted due to agro-ecological stress, but severe resource constraints can hinder their use. Soil degradation and water scarcity act as both 'push' and 'pull' factors (Howden et al., 2007).

Institutional and market access: Extension services help bridge the information gap regarding climate risks and CSA options. However, their reach is limited, and the advice provided is often generic. Access to credit for purchasing inputs and equipment is crucial. Informal credit is expensive and discourages investment (Khatri-Chhetri et al., 2017).

Membership in cooperatives and farmer groups reduces costs associated with inputs, marketing, and information sharing. Social networks and the examples set by peers significantly influence adoption decisions (Ma & Rahut 2024).

Table 1. Key Factors Affecting Climate-Smart Agriculture (CSA) Adoption by Smallholder Farmers

Category	Factors	Impact on CSA Adoption
Household Characteristics	Age, education, gender, risk preference	Higher education promotes adoption, whereas older and risk-averse farmers tend to adopt fewer CSA practices
Farm Characteristics	Farm size, land tenure security, soil quality, water availability	Secure land tenure and larger farms encourage long-term investment in CSA technologies
Institutional Access	Extension services, credit availability, market access, climate information	Better access to information, finance and markets significantly increases adoption
Social Factors	Farmer organizations, cooperatives, peer networks and social learning	Membership in groups and farmer-to-farmer knowledge exchange enhances CSA uptake

Biophysical and Socioeconomic Impacts of CSA

CSA delivers benefits across productivity, resilience, and mitigation pillars.

Productivity and income: Conservation agriculture and integrated soil fertility management improve soil moisture and nutrient use efficiency, thereby increasing yields. In South Asia, adopting crop rotations that include pulse crops reduced input costs and increased both paddy yields and net profits. In sub-Saharan Africa, drought-tolerant maize varieties maintained stable yields despite erratic rainfall (Burney *et al.* 2010). Yield benefits depend on complementary inputs. Without adequate nutrients and water, stress-tolerant seeds show limited gains (Lobell *et al.* 2014).

Adaptation and resilience: Water-saving techniques such as drip irrigation and raised beds reduce water stress in crops during droughts (Porter et al., 2014). Conservation agriculture improves soil structure, thereby increasing water absorption capacity and providing protection against both drought and heavy rainfall. For livestock, feeding with fodder trees in a climate-smart manner and improving fodder storage helps maintain nutritional levels even during periods of feed scarcity (Thornton *et al.* 2014). Integrating intercropping (growing multiple crops simultaneously) with mixed crop-livestock farming spreads risk and stabilizes income despite climate-related shocks (Vermeulen *et al.* 2012).

Mitigation co-benefits: CSA reduces emissions per unit of production. Conservation agriculture, which retains crop residues in the field, builds up organic carbon in the soil over time. Precision nutrient management reduces the excessive use of nitrogen, thereby lowering N_2O emissions (Burney *et al.* 2010).

Agroforestry sequesters carbon in biomass while also providing microclimate-related benefits. However, the carbon mitigation benefit is often viewed as an additional advantage; farmers prioritize productivity and risk reduction (FAO 2013).

Table 2. Major Impacts of Climate-Smart Agriculture Practices

CSA Pillar	Examples of Practices	Major Benefits/Impacts
Productivity	Drought-tolerant varieties, integrated nutrient management, improved crop management	Higher and more stable crop yields, improved farm income and resource-use efficiency
Adaptation and Resilience	Drip irrigation, conservation agriculture, crop diversification, water harvesting	Reduced drought and flood risks, improved soil health and greater climate resilience
Mitigation	Agroforestry, residue retention, precision nutrient management, soil carbon management	Carbon sequestration, reduced greenhouse gas emissions and improved environmental sustainability

Policy Pathways for Scaling CSA

Evidence points to four priority areas for policy (Ma & Rahut 2024).

Extension and advisory services: Extension services should disseminate information related to weather and CSA (Climate-Smart Agriculture) using local languages and methods. Digital platforms, mobile apps, and ICT-based advisories enable reaching a larger audience at a low cost (Li *et al.* 2024). Integrating these with farmer field schools and demonstration plots is essential to build trust and enhance skills.

Training extension agents on climate science and CSA is essential. Climate modules should be integrated into agricultural education.

Finance and input access: There is a need for specially designed financial products, such as credit for CSA investments, index-based insurance, and targeted subsidies for the transition period (Khatri-Chhetri et al., 2017). Public-private partnerships can strengthen supply chains for drought-tolerant seeds and improved irrigation equipmen.

Farmer organizations and social learning: Cooperative societies aggregate the demand for inputs, negotiate prices, and facilitate collective learning (Porter *et al.* 2014). Policy should support the formation of groups and the enhancement of their capacities, particularly for women and marginalized farmers (Ma and Rahut 2024).

Context-specific integration: No single CSA package is suitable for all situations. Policies must be tailored to agro-ecology, market access, and farmers' resources (Howden et al., 2007). Aligning with social protection, nutrition programs, and rural infrastructure improves adoption rates and impact.

Research Gaps and Future Directions

There have been few studies to date on the long-term impacts of CSA on soil health, farm income, and landscape-level outcomes (Lobell et al., 2014). Cost-benefit analyses across diverse climatic conditions are needed (Burney et al., 2010).

Decision-support tools tailored to local conditions can assist farmers in selecting the optimal combination of CSA practices (Vermeulen et al., 2012). Innovations in financing, such as carbon credits for soil carbon sequestration, require testing.

International collaboration and technology transfer are crucial for equitable CSA diffusion, especially in low-income countries facing severe climate risk (FAO 2013).

Conclusion

Climate change poses a serious threat to agriculture, but 'Climate-Smart Agriculture' (CSA) offers a practical way forward. CSA can boost yields, protect farmers from climate-related shocks, and reduce emissions. However, its adoption depends on farmer education, land security, extension support, credit, and strong farmer groups. Policies need to be region-specific and farmer-centric. By combining modern technology with traditional knowledge and ensuring institutional collaboration, CSA can help achieve food security, climate resilience, and sustainable development for future generations.

References

1. Burney, J.A., Davis, S.J., & Lobell, D.B. 2010. *Greenhouse gas mitigation by agricultural intensification. Proceedings of the National Academy of Sciences*, 107(26), 12052–12057. [Google Scholar]
2. Food and Agriculture Organization. 2013. *Climate-smart agriculture sourcebook*. Rome: FAO. [Google Scholar]
3. Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M., & Meinke, H. 2007. *Adapting agriculture to climate change. Proceedings of the National Academy of Sciences*, 104(50), 19691–19696. [Google Scholar]
4. Kang, Y., Khan, S., & Ma, X. 2019. *Climate change impacts on crop yield, crop water productivity and food security: A review. Progress in Natural Science: Materials International*, 29(3), 268–276. [Google Scholar]
5. Khatri-Chhetri, A., Aggarwal, P.K., Joshi, P.K., & Vyas, S. 2017. *Farmers' prioritization of climate-smart agriculture practices in three agri-food systems of India. Regional Environmental Change*, 17(7), 1915–1928. [Google Scholar]
6. Li J, Ma W, Zhu H. A systematic literature review of factors influencing the adoption of climate-smart agricultural practices. Mitig Adapt Strateg Glob Chang. 2024;29(1):2. https://doi.org/10.1007/s11027-023-09939-8 [Google Scholar]
7. Lobell, D.B., Hammer, G.L., McLean, G., Messina, C., Roberts, M.J., & Schlenker, W. 2013. *The critical role of extreme heat for maize production in the United States. Nature Climate Change*, 3(5), 497–501. [Google Scholar]
8. Ma, W., & Rahut, D.B. 2024. *Climate-smart agriculture: Adoption, impacts, and implications for sustainable development. Mitigation and Adaptation Strategies for Global Change*, 29(4), 44. [Google Scholar]
9. Porter, J.R., Xie, L., Challinor, A.J., Cochrane, K., Howden, S.M., Iqbal, M.M., Lobell, D.B., & Travasso, M.I. 2014. *Food security and food production systems*. In C.B. Field et al. (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC* (pp. 485–533). Cambridge University Press, Cambridge, UK. [Google Scholar]
10. Rana, R., Singh, G., Tanwar, A.K., Kumar, R. (2017) Effect of weather parameters on the infestation of yellow stem borer, (*Scirpophaga incertulas* Walker) in basmati rice. *Journal of Entomology and Zoology Studies*, 24-27. [Google Scholar]
11. Thornton, P.K., Boone, R.B., & Ramirez-Villegas, J. 2014. *Climate change impacts on livestock. Global Environmental Change*, 27, 147–157. [Google Scholar]
12. United Nations, Department of Economic and Social Affairs, Population Division. 2019. *World Population Prospects 2019: Highlights*. ST/ESA/SER.A/423. New York: United Nations. [Google Scholar]
13. Vermeulen, S.J., Campbell, B.M., & Ingram, J.S.I. 2012. *Climate change and food systems. Annual Review of Environment and Resources*, 37, 195–222. [Google Scholar]