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CLIMATE-SMART AGRICULTURE AND THE ECONOMIC IMPLICATIONS FOR SMALLHOLDER FARMERS IN SUB-SAHARAN AFRICA: A REVIEW

Micheal Abimbola Oladosu[1*], Moses Adonduah Abah[2], Oluwapelumi Odugbemi[3], Oke Oluwatosin Isaac[3], Adekoya Daniel Adeyemi[3], Olatunji Emmanuel Kolawole[4], Oluwafemi Jeremiah Oluwasanmi[5], Olaide Ayokunmi Oladosu[6], Helen Moses Akpan[7] and Angel Ojimaojo Ekele[2]

[1]Department of Chemical Sciences, Faculty of Science, Anchor University, Ipaja-Ayobo, Lagos, Nigeria.

[2]Department of Biochemistry, Faculty of Pure and Applied Sciences, Federal University of Wukari, Wukari, Taraba State, Nigeria.

[3]Department of Agricultural Economics and Extension, Faculty of Agriculture, Federal University Oye-Ekiti, Ekiti State, Nigeria.

[4]Department of Horticulture, College of Plant Science, Federal University of Agriculture Abeokuta, Abeokuta, Ogun State, Nigeria.

[5]Department of Mechanical Engineering, School of Engineering and Engineering Technology, Federal University of Technology Akure, Akure, Ondo State, Nigeria.

[6]Department of Computer Science, Faculty of Science and Technology, Babcock University, Ilishan-Remo, Ogun State, Nigeria,

[7]Department of Agricultural Extension and Rural Sociology, University of Calabar, Calabar. Cross River State, Nigeria.

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ABSTRACT

Background: Climate-Smart Agriculture (CSA) is a paradigm shift to solve the multiple challenges that are faced by smallholder farmers in Sub-Saharan Africa (SSA) in the context of climate change and food insecurity, and rural poverty.

Methods: This narrative review brings together empirical studies on CSA adoption trends, productivity gains, economic gains, and challenges published in peer-reviewed journals from 2020 to 2025 to analyse the status of CSA adoption in the region, as well as its productivity, economic, and implementation implications.

Results: Although CSA Practices, such as conservation agriculture, drought-tolerant varieties, agroforestry, and index-based insurance, have been shown to yield productivity gains between 30 and 80% in select contexts, many farmers are still hesitant to adopt them due to financial constraints, insecure land tenure, lack of extension services, and gender-based resource inequalities; the regional climate financing gap is estimated at $365 billion through 2035, with $71 billion per year needed to assist 65 million smallholders.

Conclusions: Scaling CSA requires integrated policy frameworks that combine innovative financing, gender-responsive approaches, digital extension, and market linkages. If there is no conscious structural investment, the economic potential of CSA will not be realised for most of the SSA smallholder farmers.

Keywords:

Vol. 11, No. 06; 2026

ISSN: 2456-8643

1. INTRODUCTION

Smallholder farmers make up the majority of the population in agriculture, with SSA boasting around 77 million of them farming land less than 2 hectares per farmer, which is equivalent to almost 80% of the total agricultural population in the region [1]. The contribution of agriculture to the gross domestic product (GDP) is 15% and between 65–70% of the active labour force is employed in the sector in SSA [2]. However, the sector is highly vulnerable to climate variability notwithstanding its critical role in economic activities. Climate models show a clear consensus that SSA will warm faster than the global mean, which will lead to increased frequency and intensity of droughts, floods and extreme weather events [3]. With no major adaptation efforts, agricultural productivity could see a 30% decline by 2050 across the region, having a significant impact on rural livelihoods, food security and national economies [3].

The Food and Agriculture Organisation (FAO) coined the term climate-smart agriculture (CSA) in 2010 as a multi-faceted strategy for implementing sustainable agriculture that incorporates threefold climate-smart goals: sustainably raise agricultural productivity and incomes; enhance resilience and adaptive capacity to climate variability and shocks; reduce or remove greenhouse gas (GHG) emissions where possible [4]. CSA is a 'triple-win' approach that includes a range of practices depending on the agroecological and socio-economic contexts of the farmers, such as use of drought-tolerant seed varieties, conservation tillage, agroforestry systems, better irrigation, digital climate information services, and others [5].

CSA adoption has significant economic impacts for smallholder farmers rather than just economic dimensions. On the other hand, research conducted throughout SSA shows that adopting households experienced positive outcomes in terms of food security metrics, household incomes, and crop yields [6,7]. However, high implementation costs, credit limitations and institutional barriers have limited the uptake of CSA, and equity issues persist, since only certain beneficiaries can benefit from CSA investments [8]. There is also a rising number of publications that underline the gendered aspects of CSA adoption, as women farmers and up to 60-80% of food producers in certain countries in SSA are more likely to be constrained in accessing the technologies and financing necessary to CSA adoption [9].

In this context, this review seeks to integrate recent empirical work (2020-2025) on the economic implications of CSA for smallholder farmers in SSA in terms of productivity impacts, income implications, financing opportunities, adoption constraints, and policy implications. This paper offers additional evidence to support the development of effective and equitable regional CSA scaling strategies, based on peer-reviewed research from throughout the region.

2. INTRODUCTION TO CSA PRACTICES IN SSA.

2.1 Conservation Agriculture and Soil Management

Conservation agriculture (CA), defined by minimum soil disturbance, permanent soil cover, and crop rotation, has been one of the most extensively promoted CSA practices in SSA [10]. In Zambia, it has been demonstrated that CA can boost the yield of maize by up to 80% in dry years by helping to improve water holding capacity and to minimize the evaporation losses of water [8]. In the same manner, adoption of zero tillage, in combination with the retention of crop residues and intercropping maize-soybean in Ghana resulted in notable increases in both soil organic carbon levels and smallholder economic returns [11]. In Ethiopia, minimum tillage cereal-legume intercropping (CT) has shown to increase soil nitrogen fixation, boost yields by 10-25%, and boost rural households' incomes due to lower input costs [12,13].

Vol. 11, No. 06; 2026

ISSN: 2456-8643

2.2 Drought-Tolerant Varieties and Crop Diversification

A key element of adaptation to drought in rain-fed farming systems is the development and dissemination of drought-tolerant varieties (DTVs). Under moisture stress, DTVs even out yield, and minimize economic losses due to crop failure [10]. In West Africa, there is emerging evidence on the effectiveness of the use of drought-tolerant maize varieties with agroforestry in closing food gaps during the season for smallholder households [1]. Moreover, climate-resilient crops from the local community, e.g. millet and cowpea in South Africa, have also shown good performance in providing food for water-constrained areas while at the same time protecting the environment [14].

2.3 Agroforestry

In the SSA region, agroforestry, especially using nitrogen fixing tree species like Faidherbia albida, has proven to be productive and income-generating. In Ethiopia and Malawi, land management practices integrating agroforestry also benefitted soil fertility and increased cereal production by 15-20% and diversified the income of households [9]. The combination of drought-tolerant maize and conservation tillage plus solar home cold storage in Kenya's Machakos County cut postharvest losses by 25% and raised the income of smallholders by 18% [14]. These results confirm the importance of multi-practice, integrated CSA strategies which aim at production and post-harvest economic losses.

2.4 Digital Tools and Climate Information Services

The advent of Digital Agriculture technology opens new avenues for improving the implementation and effects of CSA. Mobile-based advisory platforms, early warning systems and weather-index insurance products have improved the access of smallholder farmers to climate information and financial risk management tools [15]. Long-term planning and engagement with carbon markets has also been facilitated by smart irrigation systems that are connected with alerts of flooding and pest invasion [15]. But the use of digital CSA tools is still severely limited in SSA, with less than 5% of arable land being equipped with irrigation infrastructure, with 95% of smallholder farmers depending on rainfall alone, and rural internet connectivity and digital literacy still being low [15]. Table 1 gives the Summary of Key CSA Practices and Their Documented Economic Outcomes in Sub-Saharan Africa.

Table 1. Summary of Key CSA Practices and Their Documented Economic Outcomes in Sub-Saharan Africa

CSA Practice	Country/Region	Productivity Outcome	Economic Benefit	Reference
Conservation Agriculture (zero tillage)	Zambia	Maize yield ↑ up to 80% in dry years	Reduced input costs; improved food security	Akinyi et al., 2022 [8]
Drought-Tolerant Varieties (DTVs)	West Africa	Yield stabilisation under moisture stress	Reduced crop failure losses ~30%	Issahaku et al., 2022 [12]

Vol. 11, No. 06; 2026

ISSN: 2456-8643

CSA Practice	Country/Region	Productivity Outcome	Economic Benefit	Reference
Agroforestry (Faidherbia albida)	Ethiopia, Malawi	Soil fertility restoration; cereal yield ↑ 15-20%	Diversified income; reduced fertiliser costs	Adimassu et al., 2024 [9]
Solar-Powered Irrigation	Kenya (Machakos)	Postharvest losses ↓ 25%; year-round production	Smallholder income ↑ 18%	Ongoma et al., 2025 [14]
Cereal-Legume Intercropping	Ethiopia	Soil N fixation; maize yield ↑ 10–25%	Input cost savings; poverty reduction	Tesfaye et al., 2021 [13]
Weather Index Insurance	Ghana, Kenya	Risk mitigation; increased input investment	Consumption smoothing; credit access	Barnett & Mahul, 2022 [16]

3. ECONOMIC IMPLICATIONS FOR SMALLHOLDER FARMERS.

3.1 Productivity and Income Gains

Evidence from all over SSA clearly suggests that CSA has been associated with positive impacts of agricultural production and household income. A 2025 scoping review, which summarised 54 peer-reviewed studies, found that in a few contexts, productivity improvements of 30-60% have been reported due to CSA, alongside improvements in household food security and household resilience. The adoption rates of smallholder maize farmers were found in a systematic review of the situation in Eastern Africa (56.7%), Southern Africa (43.2%) and Western Africa (38.9%) which were partly influenced by institutional capacity and policy environment [3]

The household level, evidence from Ethiopia shows that adoption of CSA has a significant effect on the food security score, with positive results, and on per capita household income, especially when multiple CSA practices (improved seeds, conservation tillage, and climate information services) are adopted by farmers. A study in Benin showed that the adoption of CSA resulted in a significant increase in income and dietary diversity for the adopting households compared to non-adopters [17]. Such income effects accumulate over time because when soil health improves, fewer, and less expensive external inputs are needed.

3.2 Food Security Outcomes

CSA practices have been shown to have a positive impact on household food security in SSA through various pathways, such as yield stabilisation, income generation, and dietary diversification [6]. Ethiopia was among the countries where there was a significant positive relationship between CSA adoption measures (including minimum tillage, soil restoration, and cereal-legume intercropping) and poverty indicators in a systematic review of CSA and food security in SSA [13]. In southern Africa, CSA interventions have been able to partially compensate for the food insecurity resulting from the multistressor environment of smallholder

Vol. 11, No. 06; 2026

ISSN: 2456-8643

agriculture in the subregion, which comprises climate shocks, lack of infrastructure, and poor market access [6]. The effects of low adoption of CSA is graphically illustrated for the 2023/2024 El Niño season in Zimbabwe, including a high level of livestock depletion and a shortage of grain among non-adopting households.

3.3 Cost-Benefit Dynamics

The economics of CSA for the small farmer will be heavily influenced by the cost of adoption and the long-term benefits. A major consistently-documented barrier to adoption is financial constraints; Amadu et al. (2020) report that farmers with access to credit have 45% higher adoption rates of CSA [18]. For most subsistence level smallholders, high initial investment for better seeds, irrigation and soil amendments, and training is still out of reach [9,19]. Once successful, many CSA practices can yield positive economic benefits, such as less reliance on input costs, better yields and access to premium markets such as new opportunities in carbon credit programmes where a supplementary income of around $30–$50 per hectare per year is available. The Comparative economic returns from CSA versus conventional farming systems for smallholder farmers (Figure 1) across sub-Saharan Africa shows that the return on investment for CSA is higher than that of conventional farming systems.



Figure 1. Comparative economic returns from CSA versus conventional farming systems for smallholder farmers across sub-Saharan Africa, 2020–2025.

Sources: Adapted from references [1,3,7,8,12,17].

4. BARRIERS TO THE ADOPTION OF CSA AND ECONOMIC EXCLUSION

Although CSA has been proven to deliver benefits, its adoption by SSA smallholders is not yet uniform and faced with a complex set of financial, institutional, informational and socio-cultural challenges [5,10]. These barriers are not standalone; they work synergistically to cumulatively disadvantage the most vulnerable farming homes.

Vol. 11, No. 06; 2026

ISSN: 2456-8643

4.1 Financial and Credit Constraints

The single most common factor identified in the literature for not adopting CSA is access to finance [8,18]. Smallholders in SSA are less likely to have access to credit provided by financial institutions, due to lack of collateral, formal credit history, and proximity to financial institutions that are required to invest in improved inputs, equipment, or infrastructure [19]. Farmer cooperatives offer a partial solution by aggregates of resources and elimination of transaction costs; research shows that farmer's members are 14% more likely to use fertilisers because of cooperation and better affordability and logistical coordination [19]. Insurance penetration is low, and lenders' risk perception is reduced by index-based weather insurance schemes, which have proven successful in enhancing access to credit, but Insurance is not cheap [16].

4.2 Institutional and Knowledge Gaps

Low-quality agricultural extension services are a significant structural barrier to CSA diffusion. In Nigeria and Tanzania, for example, weak agricultural advisory capacities have been shown to lower adoption probabilities by up to 40% in some districts of the countries [13]. The region's capacity of extension services is severely limited in funding and staffing, while access to reliable climate information services boosts the probability of adaptation by 23–35% [20]. Digital extension platforms have the potential to address geographic barriers, but they are only as effective as the digital literacy and connectivity infrastructure that is still growing in rural SSA [15].

4.3 Land Tenure Insecurity

The lack of secure land tenure presents a major structural constraint on long-term investments in CSA, especially soil improvement investments that involve multiple cropping seasons. Lack of formal or customary tenure for farmers discourages investments in agroforestry, terracing and restoring soil organic matter, which are expected to be realized over years and decades [6,19].

This restriction is especially severe in many SSA environments, particularly for women farmers, where customary land inheritance and/or ownership practices restrict women's formal access to agricultural land, exacerbating gender-based inequities in access to CSA [9]. Table 2 shows the Key Barriers to CSA Adoption Among Smallholder Farmers in Sub-Saharan Africa. Figure 2 presents a conceptual illustration of the interacting barriers to CSA adoption by smallholder farmers in sub-Saharan Africa and their road to economic exclusion.

Table 2. Key Barriers to CSA Adoption Among Smallholder Farmers in Sub-Saharan Africa

Barrier Category	Specific Constraint	Country Context	Documented Impact on Adoption
Financial	High initial implementation costs	SSA-wide	Farmers with credit access show 45% higher CSA uptake (Amadu et al., 2020 [18])
Institutional	Weak extension service delivery	Nigeria, Tanzania	Poor advisory services reduce adoption by ~40% in some districts
Informational	Limited climate	SSA-wide	Access to climate services

Vol. 11, No. 06; 2026

ISSN: 2456-8643

Barrier Category	Specific Constraint	Country Context	Documented Impact on Adoption
	information access		increases adaptation probability by 23–35% (Jellason et al., 2022 [20])
Land Tenure	Insecure land rights	Southern Africa	Insecure tenure reduces long-term investment in soil conservation (Mutengwa et al., 2023 [6])
Gender	Women's limited resource access	West & East Africa	Female farmers 20–30% less likely to adopt CSA without targeted support (Rurii et al., 2025 [3])
Digital Infrastructure	Poor internet/mobile connectivity	Rural SSA	< 5% of SSA farmland has irrigation; 95% rain-fed (Chepkemoi et al., 2025 [15])

Sources: Data compiled from references [3,5,6,9,10,15,18,19,20]

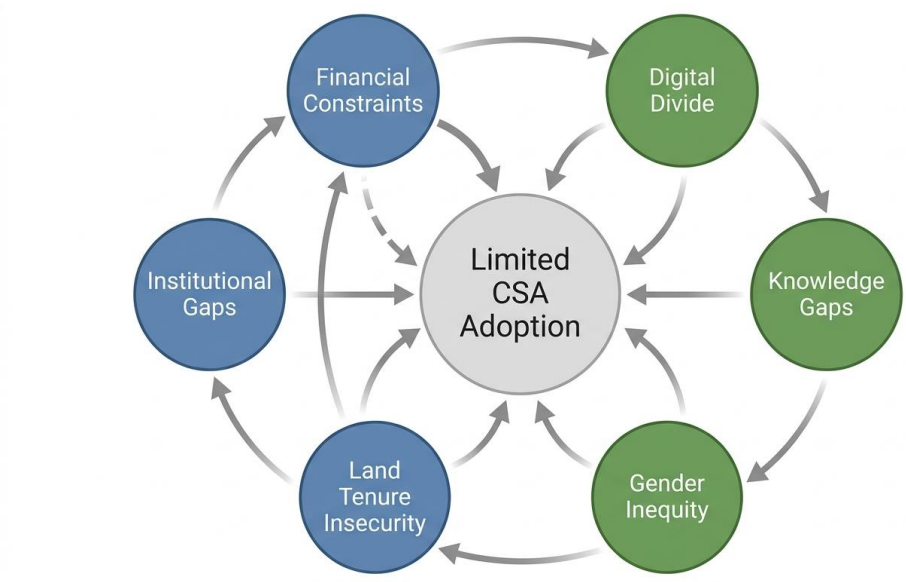


Figure 2. Conceptual diagram illustrating the interacting barriers to CSA adoption among smallholder farmers in sub-Saharan Africa and their pathways to economic exclusion.

Sources: Authors Conceptual diagram from references [5,9,10,18,19,20].

5. FINANCING LANDSCAPE FOR CSA IN SUB-SAHARAN AFRICA

To achieve the goal set by the agency, the gap in adoption of CSA in SSA, there will be a need to have the proper and appropriate financing. The estimated climate adaptation finance gap for the region is about $365 billion up to 2035, of which the analysis puts about $71 billion per year in

Vol. 11, No. 06; 2026

ISSN: 2456-8643

the specific need for supporting 65 million farmers with plots of ten hectares or less [21]. The amount of financing available in the market today under the rubric of 'multilateral financing' is much less: between 2016 and 2018, the World Bank committed to US$3.8 billion for CSA projects across 30 African nations [22].

Political recognition of the importance of CSA is increasing, as evidenced by African countries' Nationally Determined Contributions (NDCs): 45% of African countries (24 nations) have identified the agricultural sector as their topmost priority for adaptation, and 94% of African NDCs mention CSA as an important adaptation measure [22]. But the implementation of these pledges into action on the ground, in terms of financing smallholder farmers, is a key outstanding challenge. The combination of several funding streams, different multilateral climate funds, bilateral donor programs, national government budgets, and private investment without proper coordination leads to a disjointed delivery and suboptimal utilization of resources [5]. Table 3 presents the list of the Climate-Smart Agriculture Financing Mechanisms and the Economic Outcomes in Sub-Saharan Africa.

Table 3. Climate-Smart Agriculture Financing Mechanisms and Their Economic Outcomes in Sub-Saharan Africa

Financing Mechanism	Scale / Amount (USD)	Beneficiary Region	Economic Outcome/Note
World Bank CSA Investment Plans	$2.5 billion (2023)	30+ African countries	Supports agricultural resilience & smallholder productivity (World Bank, 2023 [22])
Climate Adaptation Finance Gap	~$365 billion (2025–2035)	Africa-wide	~$71 billion/year needed for 65M smallholders (Bakhtary, 2025 [21])
Microfinance & Farmer Cooperatives	Varies by programme	SSA-wide	Cooperative members show 14% higher fertiliser use; lowers transaction costs (Otieno et al., 2025 [19])
Weather Index Insurance	Pilot to national scale	Ghana, Kenya, Ethiopia	Increases input investment and consumption smoothing for risk-averse households (Barnett & Mahul, 2022 [16])
National Government Subsidies	Country-specific	Ethiopia, Malawi, Zambia	Input subsidies positively correlated with drought-tolerant seed adoption (Agyekum et al., 2024 [10])
Carbon Markets (AgriCarbon)	Emerging	East/West Africa	CSA practices linked to carbon credits offer supplementary income (~$30–$50/ha/year)

Sources: [10,16,19,21,22]

Vol. 11, No. 06; 2026

ISSN: 2456-8643

6. POLICY AND PROGRAMMATIC RECOMMENDATIONS

It takes conscious policy steps at various levels to implement the evidence on the economic potential of CSA. Based on literature reviewed, the following recommendations are made:

6.1 Integrated National CSA Investment Plans

Governments in SSA should prepare National CSA Investment Plans with costed policies that incorporate agricultural policies, financial sector policies and rural development policies and are consistent with their NDC commitments and include an overall plan for agricultural input supply. Transparent financing mechanisms, such as revolving credit funds, risk sharing facilities and others, need to be set up directly to lower the financial constraints of smallholders to adopt these plans [22]. The experience of mainstreaming CSA in Ethiopia and the promotion of conservation agriculture in Zambia is inspiring for national level programming [8,13].

6.2 Gender-responsive and socially inclusive approaches

All programmes need to include gender disaggregated targeting and monitoring as documented gender disparities in CSA access exist. Adoption rate of female farmers was found to be 20–30% lower compared to their male counterparts and this difference is attributed to unequal access to extension support, credit and land use [9]. Women's farmer groups, female extension workers and gender-inclusive financial tools are essential to ensure gender equitable economic outcomes [3,10].

6.3 Digital Extension and Climate Information Systems.

The transaction costs of delivering CSA information and inputs can be greatly reduced by scaling digital agriculture tools, such as SMS-based advisory service, mobile weather alerts, and e-voucher input subsidy programmes [15]. To achieve these benefits, investments in rural digital infrastructure (connectivity, device access, digital literacy programmes) must be made, and must be coordinated between telecommunications regulators, agricultural ministries, and international development partners [14,15].

6.4 Market Linkages and Value Chain Development

Economic sustainability of CSA adoption is more likely when farmers have access to premium markets for sustainably produced commodities such as carbon credit markets, certified organic supply chains and climate-resilient value chains [5,19]. Enhancing the economic incentive for adopting CSA can be achieved by increasing market linkages and can be supported by farmer groups, digital platforms and public-private partnerships. Figure 3. Scalability plan for climate smart agriculture for smallholder farmers in sub-Saharan Africa.

Vol. 11, No. 06; 2026

ISSN: 2456-8643

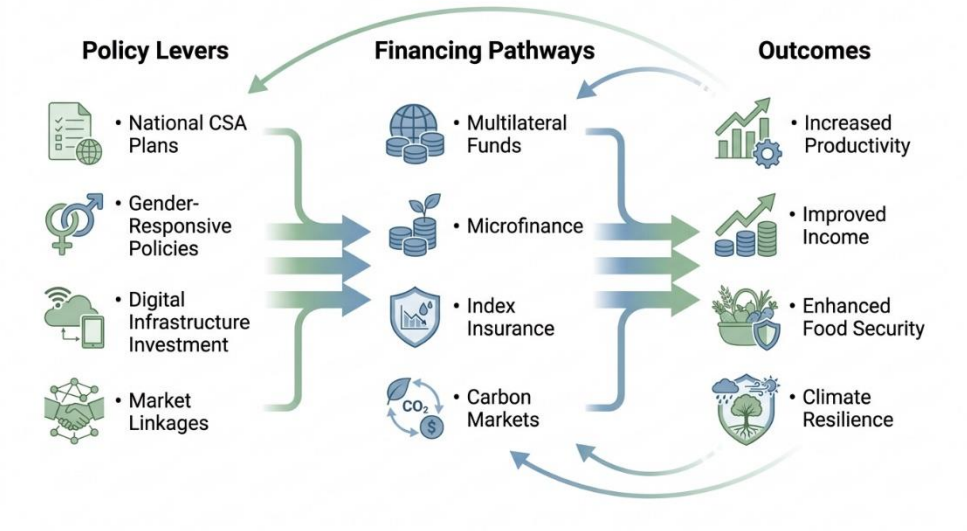


Figure 3. Strategic framework for scaling climate-smart agriculture among smallholder farmers in sub-Saharan Africa, illustrating the policy levers, financing pathways, and outcome domains.

Sources: Adapted from references [3,5,10,15,19,21,22].

7. CONCLUSION

This review has compiled existing evidence on the economic consequences of climate-smart agriculture for smallholder farmers in sub-Saharan Africa. Whereas the evidence base remains developing, the evidence is consistently showing that the adoption of CSA is linked to significant improvements in agricultural productivity (30-80% in certain contexts), household income (15-30% better outcomes) and food security outcomes for CSA adopting households. Conservation Agriculture, Drought tolerant varieties, Agroforestry and Digital climate services are the most evidence-based practices, with proven returns in various agroecological and socio-economic settings.

But most of the 77 million smallholder farmers in SSA are yet to realize the economic potential of CSA. The adoption at scale is constrained by a complex web of financial barriers, institutional weaknesses, gender inequities, land tenure insecurity and digital divides. These barriers need to be addressed through integrated, cross-sectoral policy efforts that are both agronomic and financial, as well as gender and governance, and market systems. The estimated climate adaptation finance gap of $365 billion by 2035 highlights the need for consistent and coordinated climate adaptation investments from multilateral, national and private climate adaptation finance providers.

Further studies should focus on long-term impact assessments reflecting the cumulative economic impacts of CSA over several seasons, gender-segregated economic outcomes studies, and strong studies of innovative financing options across a range of SSA contexts. Filling these knowledge gaps is critical to shaping policies that can achieve the transformative economic benefits of climate-smart agriculture for SSA's smallholder farmers.

Vol. 11, No. 06; 2026

ISSN: 2456-8643

Declarations

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Conflict of Interest Statement

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Author's Contribution:

- **Micheal Abimbola Oladosu (Corresponding Author)**: Conceptualization, methodology, data analysis, writing - original draft
- **Moses Adondua Abah**: Data collection, field supervision, writing - review and editing
- **Oluwapelumi Odugbemi**: Statistical analysis, econometric modelling, writing - review and editing
- **Chukwudi Anyaogu Chinedu**: Literature review, policy analysis, writing - review and editing
- **Samuel Olusiku:** Data Collection, policy analysis, writing - review and editing
- **Paschaline E Agbams**: Data validation, results interpretation, writing - review and editing
- **Helen Moses Akpan:** Data collection, results interpretation and Literature review.

All authors have read and approved the final manuscript and agreed to be accountable for all aspects of the work

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Vol. 11, No. 06; 2026

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