IJCCSM
17,1

656

Received 17 September 2024
Revised 8 February 2025
Accepted 16 April 2025

Unveiling the challenges and opportunities of climate change mitigation through climate-smart agriculture in East Africa, systematic review

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Abstract

Purpose – The purpose of this paper is to delve deeply into the challenges and opportunities of adopting climate-smart agriculture (CSA) as a way of dealing with the problems of climate change in the Eastern Africa region.

Design/methodology/approach – This review was qualitative in nature and relied on systematic literature review techniques such as searching, data extraction and analysis for determination of the emerging themes regarding challenges, opportunities and best practices in CSA.

Findings – This review identifies not only socio-economic disparities, institutional barriers and policy as primary impediments to adopting CSA but also best practices and innovative approaches that prove CSA works. Some of the important ways of dealing with such situations are involvement of all stakeholder, partnerships and knowledge dissemination. In addition, this paper provides a number of relevant suggestions on how best to incorporate CSA at a country and regional level to ensure that the financial and investment strategies are improved. The urgency of accelerating the shifting to climate-resilient agriculture needs to happen much faster, emphasizing the need for proactive measures to ensure food security, livelihoods and environmental integrity. By prioritizing CSA, fostering collaboration and enacting supportive policies, East

International Journal of Climate Change Strategies and Management
Vol. 17 No. 1, 2025
pp. 656-677
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-09-2024-0159

Africa can navigate the impacts of climate change and build a sustainable agricultural future. Everyone has a role to play in turning these challenges to opportunities and achieving sustainable agricultural development.

Originality/value – This review primarily focuses on the most commonly practiced CSA strategies, as examined by various scholars.

Keywords Climate change, Climate mitigation, Climate variability, Climate-smart agriculture

Paper type Literature review

1. Introduction

Food security, livelihoods and the environment are under enormous threat because of climate change (Lee *et al.*, 2023). The East African region relies heavily on agriculture as an economic activity and the impacts are dire. With rampant poverty, rain-fed farming and limited infrastructure, the region is rendered highly vulnerable. Unpredictable rainfall patterns, rising temperatures and extreme weather events like floods and droughts disrupt the farming cycle, thus leading to food scarcity (Kirina *et al.*, 2022). The situation is worsened by rapid population growth that further burdens agricultural resources. This is particularly dire for the smallholder farmers that account for most of the workforce (Yengoh and Ardö, 2020).

East Africa's agricultural sector, which plays a vital role in its economic stability, faces numerous challenges from climate change. Irregular rainfall, increased temperatures and extreme weather threaten the yield of maize and wheat crops at risk (Tadesse *et al.*, 2022).

The World Meteorological Organization expresses concern regarding the severity of droughts across the globe and the increased risk of flooding because of heavier precipitation events (Lee *et al.*, 2023; Polya, 2023). Furthermore, increased temperatures along with change in precipitation also lower soil quality and fast track desertification, which on its own poses a serious threat to developing regions and food security (Bristol-Alagbariya, 2023).

Biodiversity loss is another adverse problem of climate change. Changing temperature and rainfall patterns disrupt ecosystems, leading to species migration, decline or extinction (Iucn, 2006). In East Africa, water scarcity is intensified by changing rainfall patterns and melting glaciers, putting at risk both rural and urban water supplies and hydropower (Kattel, 2019). Warmer temperatures also contribute to the spread of vector-borne diseases like malaria and dengue fever, posing significant health risks to vulnerable populations (Organization, 2021). The rich biodiversity region is also under threat because of habitat loss and extreme weather conditions, highlighting the need for conservation efforts (Li *et al.*, 2013).

Climate change's socio-economic impacts are particularly harsh on vulnerable communities in East Africa, worsening poverty and displacement (Omotoso *et al.*, 2023). Climate-induced displacement is growing, leading to migration and conflicts over scarce resources (Freeman, 2017). Flooding, intensified by climate change, leads to severe damage to infrastructure such as roads, buildings or bridges. Cities such as Nairobi and Dar es Salaam are impacted by flooding that causes transportation and housing issues. With each occurrence, the economic losses grow further (Long'or Lokidor *et al.*, 2024). As a solution, planning for infrastructure must include climate resilience features which ensures long-term sustainability (Chirisa *et al.*, 2016). Climate change has devastated East Africa, and as a response to climate-smart agriculture (CSA), this systematic review seeks to answer how effective CSA can be for climate mitigation in this region.

2. Objective of the review

The objective of this review is to fully assess the barriers and opportunities of applying CSA as an adaptive strategy to climate change in the Eastern African region. The review attempts to assess the key hindering factors of CSA adoption practices including, but not limited to, social and economic factors, institutional and policy issues, while also seeking to document the successes and scope of CSA implementation. Furthermore, the review aims to provide practical suggestions and recommendations for overcoming these barriers and providing strategies to transition toward CSA adoption in East Africa, emphasizing stakeholder engagement, partnership building, policy integration and financing mechanisms to mainstream CSA into national and regional development agendas.

3. Climate change mitigation and climate-smart agriculture approach

CSA is an approach of tackling challenges of climate change in agriculture through increasing agricultural productivity, resilience and decreasing greenhouse gas emissions (Faurès *et al.*, 2013). It incorporates sustainable practices like agroforestry, better crop varieties and conservation tillage for sustainable smallholder farming systems for climate change mitigation by increasing carbon sequestration (Lipper *et al.*, 2014). The implementation of CSA varies by region, requiring tailored solutions based on local socio-economic and environmental conditions. In sub-Saharan Africa where agriculture is heavily dependent on rainfall, CSA adapts to the erratic rainfall by incorporating water management practices like rainwater harvesting and conserving soil moisture (Huyer and Partey, 2020).

3.1 Enhancing resilience through climate-smart agriculture practices

CSA involves a range of practices and technologies suited to different agro-ecological contexts, including agroforestry, conservation agriculture, improved crop varieties, water management techniques and advanced livestock production and management practices. These practices aim to build resilience in agricultural systems to climate variability and changes. For example, agroforestry systems that integrate trees with crops provide multiple benefits, soil fertility, moisture retention and diversified income sources, so farmers are more resilient to drought and floods (Lin, 2011). Conservation agriculture techniques such as minimum tillage and cover cropping promote soil health and moisture conservation and reduce the impact of erratic rainfall and soil erosion (Powlson *et al.*, 2014). Moreover, according to Lipper *et al.* (2014), practices such as agroforestry, crop diversification and conservation tillage have shown great potential to improve resilience of agricultural systems. Agroforestry which is integrating trees into agricultural landscapes can enhance biodiversity, improve soil health and provide additional income sources, so farmers can withstand climatic shocks.

3.2 Mitigating greenhouse gas emissions

CSA resilience will not only increase resilience but also bring emissions by agriculture mitigation, as an important contribution to global emissions. Distinct measures of sustainable land management such as agroforestry along with better nutrient management would sequester carbon in vegetation and soils, offset emissions, decrease albedo and take part in climate change mitigation as per Smith *et al.* (2007). Moreover, the adoption of climate-resilient crop varieties and livestock breeds with lower methane emissions potential can further reduce the carbon footprint of agricultural production systems (Rosenzweig *et al.*, 2014). Through the promotion practices that increase carbon sequestration and reduce emissions intensity, CSA offers the way toward more climate-resilient and environmentally sustainable agriculture.

3.3 Empowering smallholder farmers

One of the key strengths of CSA lies in its capacity to empower smallholder farmers, who are the most affected by climate change impacts (Lipper *et al.*, 2014). Access to climate-smart technologies, knowledge and finance through CSA enables farmers to adapt to changing climatic conditions and improve their livelihoods. Farmer-centered approaches, such as participatory extension services and farmer field schools, further promote such innovation and knowledge sharing among farming communities, hence increasing farmers' adaptive capacity and resilience (Bommarco *et al.*, 2018). Moreover, by diversifying income sources and reducing production risks, CSA contributes to poverty reduction and food security, particularly in vulnerable rural areas (Thornton *et al.*, 2006).

4. Methods

The assessment relies on the qualitative techniques of systematic review and analysis from the literature to find recurring themes on challenges, opportunities and best practices for CSA. Authors used systematic search strategies, particularly through such databases as Google Scholar, Web of Science and AGORA, as well as institutional repositories to identify peer-reviewed articles, reports and gray studies.

4.1 Literature search technique and data extraction

The literature search was systematically conducted using Google Scholar, Web of Science and AGORA. The timeframe for search was for studies published from 2001 and 2024 in credible journals. This was further limited to studies regarding East Africa. Some of the keywords that triggered relevant searches included impact of climate change in East Africa, challenges to CSA implementation and adopting as well as best practices and initiatives of CSA in East Africa.

Figure 1 shows the PRISMA flowchart, used by different authors (Gebrekidan and Gebremedhin, 2024; Gebrekidan, 2024; Gebrekidan *et al.*, 2025, 2024a, 2024b) which indicates the process of selecting the literature for systematic review. Stage 1 involved identifying a total of 1,142 online materials through database searches using several keywords and titles. In Stage 2, 446 duplicates were removed, leaving 696 records. Stage 3 consisted of 235 records, while 461 were excluded mostly because of broader study areas and scopes outside East Africa. In Stage 4, after title, abstract and keyword reviews, 147 records passed inclusion criteria, while 60 were excluded. Finally, full-text review was done on 87 records.

Data extraction and compilation into matrix-wise classification into various sections was done after the studies were basically reviewed. These sections comprised: author(s) year of publication, title, study area, objectives, analysis, findings and conclusions regarding CSA practices.

5. Result and discussion

5.1 Climate change projections and trends in East Africa

East Africa is experiencing variations in extreme weather events such as prolonged droughts followed by heavy rainfall, which significantly affect food and water security. These extremes pose risks to agricultural productivity and livelihoods, which threatens socio-economic stability. A 5°C temperature rise by the 2090s could lead to a 20% reduction in crop yields, affecting food availability, nutrition and health (Salah *et al.*, 2023; Adhikari *et al.*, 2015). Droughts will reduce crop yields and less feed for livestock, thus worsening food security in the region.

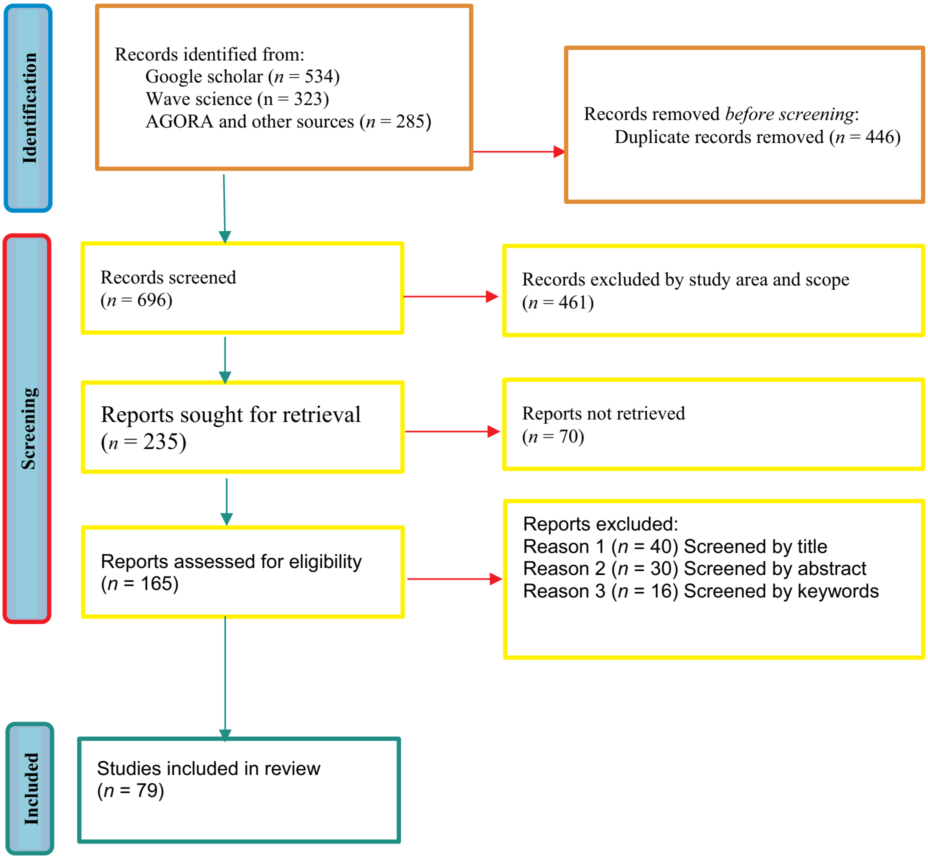

Figure 1. Graphic presentation of the literature screening
Source: Authors' own work (2024)

Increased temperature in East Africa has been associated with poor agricultural production as well as increased incidence rates of vector-borne diseases. According to a study, Ethiopia's mean annual temperature has risen by 1.3°C since 1960, with projections showing further increases by the 2060s and 2090s. Increased temperatures further lead to evaporation and moisture loss in soils, which negatively affect crop yields (Kizza *et al.*, 2009). Moreover, shifts in rainfall patterns might create alternating series of heavy rains and long dry spells, making water resource management and agricultural planning more challenging (Obwocha *et al.*, 2022).

According to predictions, these trends will deepen to create more conditions for food insecurity, water scarcity and health risks. High temperatures create environments for the breakout of diseases such as malaria and dengue, significantly affecting vulnerable populations (Kizza *et al.*, 2009). In addition, the impact of climate change further worsens social inequalities in East Africa, disproportionately affecting women, children and marginalized populations (McCarthy, 2001).

5.2 Environmental, social and economic impacts of climate change in the region

Climate change is creating significant environmental, social and economic challenges in East Africa, severely impacting ecosystems and livelihoods. Alteration of precipitation patterns has made droughts and floods frequent and millennial, adversely affecting agriculture, water resources and biodiversity. Prolonged droughts in the region have resulted in crop failures, food insecurity and livestock losses (Erezi *et al.*, 2023). Rising temperatures also contribute to the melting of glaciers on Mount Kilimanjaro and the Rwenzori Mountains, threatening water supply for millions who depend on these rivers (Vuille, 2013).

Climate change socially disproportionately impacts vulnerable populations, such as women, children and indigenous communities. In fact, it is mostly obvious for rural women in East Africa who participate in agriculture and water management and are, therefore, exposed to the impacts of climate change (Eriksen *et al.*, 2008; Leal Filho *et al.*, 2022). Because of limited resources that the communities can use for adaptation, climate change exacerbates existing inequalities and marginalization.

Sectors such as agriculture, tourism and infrastructure are all economically threatened. Changed weather patterns influence crop yields and livestock productivity, resulting in income losses for farmers. In addition, the effects on wildlife habitats and natural attractions threaten the tourism industry in countries such as Kenya and Tanzania (Kirina *et al.*, 2022). Floods, which are some of the climate-related disasters, destroy infrastructure, causing further strain on national budgets to divert resources from serious development efforts (McCarthy, 2001).

Addressing these impacts requires coordinated efforts at all levels. CSA, improved water infrastructure and disaster risk reduction strategies are essential for building resilience (Kirina *et al.*, 2022). Gender-responsive adaptation strategies are also crucial to ensure the inclusion of women and vulnerable groups in climate action, empowering them through access to resources and decision-making processes (Awiti, 2022).

5.3 Conceptual framework of climate change and climate-smart agriculture

CSA is a method planned to transform agricultural systems to improve food security in the face of climate crisis (Ouda and Zohry, 2022). It consists of three key pillars: agricultural productivity, building adaptation to climate change and reducing greenhouse gas emissions wherever possible [Food and Agriculture Organization of the United Nations (FAO), 2010]. CSA acknowledges that agriculture simultaneously contributes to and is affected by climate change, attempting to balance adaptation and mitigation in practices (Lipper *et al.*, 2014).

The main pillar of the strategy is to sustainably increase productivity by promoting the use simplified asset application such as agroforestry, precision farming and conservation farming, while minimizing environmental damage (Thornton *et al.*, 2006). The next pillar stresses the need to fight climate-smart technologies, such as drought-resistant crops, diversified cropping systems and improved water management techniques to withstand changing climate patterns (Rosenzweig *et al.*, 2014).

The third pillar's objective is to reduce emissions from agriculture through sustainable practices, that is improved livestock management, soil carbon sequestration and renewable energy use (Smith *et al.*, 2014). CSA encourages integrating climate change crisis factors into agricultural planning, such as promotion of solar pumps and drought-resistant crops. Overall, CSA's interconnected principles of sustainability, resilience and mitigation offer a comprehensive solution to climate change's challenges in agriculture, supporting sustainable food production for the future (Lipper *et al.*, 2014). Generally, the conceptual framework of climate change and CSA is summarized in Figure 2.

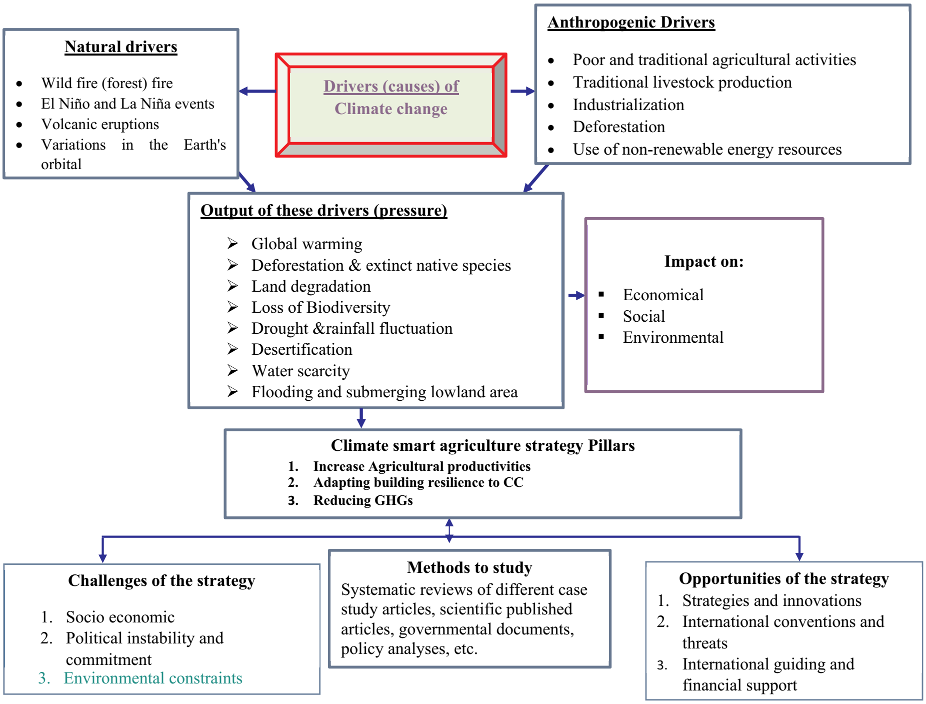

Figure 2. Conceptual framework of climate change and climate-smart agriculture
Source: Authors' own work (2024)

5.4 Role of climate-smart agriculture on climate adaptation, mitigation and resilience

To address with the issues posed by climate change, CSA integrates climate adaptation, mitigation and resilience, which are necessary components (Palombi and Sessa, 2013). For instance, Lipper *et al.* (2014) emphasize that CSA assists farmers in adopting climate-resilient crops and livestock by enhancing agricultural systems' capacity to cope with climate impacts. Further, these measures increase resilience and promote sustainable agricultural practices like quality-based livestock production [Food and Agriculture Organization of the United Nations (FAO), 2010].

As suggested by Smith *et al.* (2014), CSA assists in achieving both climate mitigation and adaptation goals, such as agroforestry, which enhances soil fertility, water retention and sequesters carbon. Rosenzweig *et al.* (2014) state that conservation agriculture practices like minimal soil disturbance reduce greenhouse gas emissions and enhance soil health, making a positive contribution to both mitigation and adaptation. Additionally, Taylor (2018) notes that efficient water use and biodiversity protection as components of CSA support long-term goals.

For CSA to succeed, policy and institutional support is necessary. Providing access to finance, technology and knowledge empowers farmers to adopt climate-smart practices [Food and Agriculture Organization of the United Nations (FAO), 2010]. Integrating climate considerations into agricultural policies ensures that adaptation and mitigation become part of broader development agendas, enhancing the resilience of agricultural systems to climate change (Lipper *et al.*, 2014). Overall, CSA offers a sustainable pathway to climate-resilient agriculture (Faurès *et al.*, 2013).

5.5 Challenges to climate-smart agriculture implementation

In East Africa, the adoption of CSA faces numerous socio-economic challenges, particularly for smallholder farmers lacking in resources and access to finance (Raj and Garlapati, 2020). Without this support, farmers cannot access drought-resistant seeds and irrigation systems (Taylor, 2018). Moreover, limited access to markets and extension services further constrains CSA adoption, with many farmers having little or no information or market access for climate-resilient crops (Greenhalgh *et al.*, 2017).

Political barriers also hinder CSA implementation, including poor governance, political instability and a lack of coherent policies (Brisebois *et al.*, 2022). Inadequate policy support, land tenure issues and corruption discourage farmers from adopting sustainable practices (Commission, 2020). Additionally, conflicts and instability in the region impede agricultural productivity, thus limiting efforts to promote CSA (Furlow *et al.*, 2011).

Environmental constraints like water scarcity, soil degradation and deforestation also challenge CSA adoption (Neufeldt *et al.*, 2021). Climate change exacerbates these constraints with more frequent droughts and floods; thereupon, farmers invest in short-rather than long-term CSA strategies (Watkiss *et al.*, 2023). Addressing these challenges requires an integrated approach, including improving access to finance, policy coordination and sustainable land management practices like agroforestry and soil conservation (Neufeldt *et al.*, 2021; Garcia and WSG, 2023).

5.6 Institutional barriers and policy gaps impacting the scalability and sustainability of climate-smart agricultural initiatives in East Africa

In East Africa, institutional barriers accompanied by policy gaps have severely impacted the scalability and sustainability of CSA. This happens because of poor coordination among government agencies, research institutions and other stakeholders, leading to inefficient use of resources and storage of efforts (Thottadi and Singh, 2024). Additionally, fragmented institutional capacity at both national and local levels limits the development and implementation of coherent CSA policies (Branca *et al.*, 2021). This fragmentation restricts the effectiveness of CSA initiatives across the region (Commission, 2020).

Policy gaps further complicate CSA adoption. While some countries have developed climate strategies, the absence of specific CSA-focused policies, incentives and regulatory frameworks creates uncertainty for farmers and investors (Hussain *et al.*, 2022). Inconsistent land tenure, water management policies and inadequate carbon market regulations also hinder CSA scaling (Neufeldt *et al.*, 2018). Additionally, limited financial resources and investment mechanisms, particularly for smallholder farmers, reduce CSA's impact. High transaction costs and perceived risks deter private sector investment, further limiting the expansion of CSA initiatives (Neufeldt *et al.*, 2018, 2021).

The above-mentioned challenges require coordinated efforts by the governments, civil society and the private sector. Efforts should be put into strengthening institutional coordination and developing a sound policy framework that facilitates CSA, including land tenure reforms and climate-resilient insurance schemes (Branca *et al.*, 2021). Further, innovative financing mechanisms like climate-smart credit and public–private partnerships could help to mobilize resources and promote private sector investment in CSA (Watkiss *et al.*, 2023).

5.7 Opportunities and innovations

East Africa has seen emerging CSA strategies and developments. One of the big strategies is the progress on climate resilience crops varieties and livestock breed compatibility with the local conditions. Genetically modified crops, such as drought-resistant maize and heat-resistant beans, have improved the resilience of smallholder farmers (Ocimati *et al.*, 2021). Moreover, heat- and disease-tolerant indigenous livestock breed introduction can enhance resiliency and livestock production (Branca *et al.*, 2021).

As shown on Tables 1, 2, 3, 4 and 5, the agroecological approaches are critical for promoting CSA through the application of ecological principles to agricultural systems. Strategies such as crop diversification, agroforestry and organic farming increase biodiversity, soil health and resilience (Altieri *et al.*, 2015). These practices decrease reliance on external inputs and contribute to smallholder farmers' ability to adjust to changing climate conditions (Erezi *et al.*, 2023).

Table 1. Review of case study, pilot projects and initiatives on climate-smart agriculture project in Kenya

Country	Case study, pilot project and initiatives	Review of case study, pilot project and initiatives	Sources
Kenya	Climate-smart agriculture project	The Climate-smart agriculture project focuses on promoting sustainable land management, improving water harvesting techniques and introducing drought-resistant crop varieties. By using conservation agriculture techniques such as minimum tillage and mulching, farmers have experienced increased yields and resilience to climate variability	Kirina *et al.* (2022)
		Moreover, the project is structured around five key components: scaling up climate-smart agricultural practices, strengthening research and seed systems, providing agro-weather and market advisory services, ensuring effective project coordination and establishing contingency emergency responses	Ngigi and Muange (2022) and Waaswa *et al.* (2022)
		It also promotes community-driven rangeland management and better access to livestock services in arid and semi-arid lands (ASALs). These efforts are designed to adapt agricultural practices to the evolving climate conditions, thus ensuring sustainable agricultural productivity and the livelihoods of farmers	Ngauri (2023) and Ngigi and Muange (2022)
		The project's holistic approach underscores its significance in contributing to the sustainable development goals (SDGs) and securing Kenya's agricultural future against the backdrop of climate change	Ngigi and Muange (2022) and Waaswa *et al.* (2022)

Source(s): Authors' own work (2024)

Table 2. Review of case study, pilot projects and initiatives in one cow per poor family program in Rwanda

Country	Case study, pilot project and initiatives	Review of case study, pilot project and initiatives on one cow per poor family program	Sources
Rwanda	One cow per poor family program	Rwanda's one cow per poor family program boosts food security and climate resilience by providing dairy cows to families in need. This boosts nutrition, income and sustainable land management through cow dung as used as organic fertilizer. The approach enhances soil fertility and agricultural productivity	Ngamije (2022) and Pezo *et al.* (2024)
		Beneficiaries are expected to pass on the first female calf to another poor family, creating a chain of support and fostering community solidarity	Pezo *et al.* (2024)
		This integration of livestock into farming systems has helped reduce soil erosion and improve crop yields, which is particularly important in a country like Rwanda, where agriculture supports 80% of the population	Smith (2017)

Source(s): Authors' own work (2024)

To scale up CSA in East Africa, innovative financing mechanisms are needed. Climate-smart credit facilities, microfinance and climate risk insurance support farmers in making investments to practice climate-resilient plant and livestock production (Neufeldt *et al.*, 2021). Furthermore, investment in CSA projects is reinforced by public–private partnerships and value chain financing models leveraging private sector expertise and resources to support smallholder farmers (Doyle *et al.*, 2018). Strengthening institutional capacities and using digital technologies, such as mobile apps and GIS, also enhance decision-making and promote knowledge exchange among farmers (Herforth *et al.*, 2020; Garcia and WSG, 2023).

5.8 Review of successful case studies, pilot projects and initiatives in East Africa that demonstrate effective climate-smart agricultural practices in each respective country

5.9 Existing partnerships and collaborations aimed at supporting climate-smart agriculture initiatives

In East Africa, collaboration between the government and non-governmental organization (NGO) plays crucial role in promoting CSA. For example, collaborations between the Kenyan Government and organizations like World Vision and CARE International have facilitated sustainable land management and crop diversification initiatives (Makokha and Waswa, 2022). These partnerships combine government resources and NGO expertise to strengthen agricultural resilience in vulnerable communities.

International organizations and national governments are super important in scaling CSA interventions. The Food and Agriculture Organization (FAO) has worked with Ethiopia, Uganda and Tanzania to develop national CSA strategies and action plans, providing

Table 3. Review of case study on sustainable land management program in Ethiopia

Country	Case study, pilot project and initiatives	Review of case study sustainable land management program	Sources
Ethiopia	Sustainable land management program	Ethiopia's sustainable land management program (SLMP) addresses land degradation and climate change through community-based interventions like terracing, agroforestry and reforestation. The program has rehabilitated landscapes, restored ecosystem services and increased agricultural productivity by promoting beekeeping, dairy production and more at small-scale levels. Its participatory approach and use of indigenous knowledge have been key to its success and scalability	Bristol-Alagbariya (2023) and Schmidt and Tadesse (2019)
		The SLMP has also been associated to the broader Ethiopia Climate Action through Landscape Management Program, which aims to bring 2.5 million hectares of degraded land under sustainable management by 2030. This initiative emphasizes climate resilience, land productivity and carbon storage. By focusing on integrated landscape management, these programs work to mitigate the impacts of climate change while promoting sustainable economic growth in rural areas	Scherr *et al.* (2012)

Source(s): Authors' own work (2024)

technical support and capacity building to enhance agricultural resilience (Kim *et al.*, 2023). Similarly, research institutions like the International Livestock Research Institute have partnered with farmer organizations to promote climate-resilient livestock management and pasture rehabilitation (Kirina *et al.*, 2022).

Collaborations between private sector and NGOs help smallholder farmers adopt CSA innovations. In Tanzania, Syngenta and TechnoServe have introduced drought-tolerant maize varieties and agronomic training to farmers, improving their resilience to climate change (Ilakut *et al.*, 2022). Multi-stakeholder platforms such as the Climate-Smart Agriculture Alliance further enhance CSA efforts by fostering dialogue and collaboration among governments, NGOs, farmers and the private sector (Osumba and Recha, 2022).

Donor–recipient partnerships, such as those between the Green Climate Fund and Kenya and Rwanda, mobilize resources for CSA projects, including soil conservation and water harvesting (Fund, 2020). Additionally, South–South cooperation, like the Ethiopia–Brazil partnership, promotes agroecology and small-scale irrigation through knowledge exchange and peer learning (Waisbich, 2022). These diverse partnerships ensure CSA initiatives are well-supported and sustainable across the region.

Table 4. Review of case study and pilot projects on climate-smart villages initiatives in Tanzania

Country	Case study, pilot project and initiatives	Review of case study, pilot project and initiatives	Sources
Tanzania	Climate-smart villages	Tanzania's climate-smart villages (CSVs) initiative, driven by CCAFS, helps rural communities adapt to climate change while enhancing food security and livelihoods. By promoting practices like conservation agriculture and agroforestry, CSVs have boosted yields and diversified incomes. The use of climate information services aids farmers in managing risks and reducing greenhouse gas emissions	Ogada *et al.* (2020)
		Agriculture and food security (CCAFS), the initiative, focuses on testing and promoting climate-smart agriculture (CSA) practices. These villages are strategically located in high-risk areas prone to climate change impacts, such as Lushoto in Tanzania, where the approach integrates local knowledge with scientific research to develop resilient farming systems	Njogu *et al.* (2024)
		The CSVs project uses a participatory approach, engaging community members in the decision-making process to identify and implement suitable climate-smart options. This inclusive process ensures that the interventions are well-suited to the local context and address the specific needs of the communities, including vulnerable groups like women and smallholder farmers	Kirina *et al.* (2022)
		A significant achievement of the CSVs in Tanzania is the enhancement of soil carbon sequestration, which plays a critical role in mitigating climate change. Studies have shown that CSVs in Tanzania have significantly increased soil carbon stocks, with an average increase ranging between 70% and 86% compared to control areas without CSA practices. This increase in soil carbon helps in reducing carbon dioxide emissions and improving soil health, thus supporting sustainable agricultural productivity	Ambaw *et al.* (2020)

Source(s): Authors' own work (2024)

5.10 Capacity building and knowledge transfer

Education and training programs are essential for raising awareness about CSA practices in East Africa. By teaching farmers about conservation agriculture, agroforestry and water harvesting, these programs help them adapt to climate change and improve agricultural productivity (Tesfaye *et al.*, 2023). Training also emphasizes soil conservation, crop diversification and water management, which are crucial for mitigating climate risks.

Table 5. Review of case study, on farmer field schools program in Uganda

Country	Case study, pilot project and initiatives	Review of case study, on farmer field schools program	Sources
Uganda	Farmer field schools	Farmer field schools (FFS) program is an experiential learning approach that empowers smallholder farmers with climate-smart agricultural techniques. By providing farmers with hands-on training in sustainable farming practices such as organic agriculture, crop rotation and integrated pest management, FFS has enhanced resilience to climate change and reduced reliance on external inputs. The program's emphasis on farmer-to-farmer knowledge sharing has fostered peer learning and adoption of innovative practices	Commission (2020)
		Uganda's farmer field schools (FFS) have successfully promoted climate resilience in the Kiboga district, where droughts and erratic rainfall are common. By introducing drought-tolerant crops, effective irrigation and agroforestry, FFS has helped farmers manage water resources and maintain productivity. A study found that FFS participants were more skilled in adaptive agriculture, enhancing resilience and food security	Mfitumukiza *et al.* (2017)
		The impact of FFS extends beyond just agricultural practices to encompass economic and social benefits. For instance, in the Terego district, farmers who participated in FFS reported improved financial habits and entrepreneurial skills. Many farmers have started small businesses, such as milling and transportation services, using profits from increased agricultural productivity. This has not only boosted individual incomes but also created employment opportunities within communities. The ripple effect of knowledge sharing and skill transfer among farmers has fostered a culture of self-reliance and community support, essential for long-term sustainable development	Strong *et al.* (2023)

Source(s): Authors' own work (2024)

Capacity-building initiatives, like farmer field schools, provide hands-on training, equipping farmers with practical skills in sustainable farming (Shekmohammed *et al.*, 2023). These programs foster innovation by encouraging farmers to experiment with new techniques and share knowledge with peers, promoting practices such as intercropping and organic farming (Kirina *et al.*, 2022). This empowers farmers to make informed decisions and adopt adaptive strategies, enhancing their resilience to climate change (Solomon *et al.*, 2018).

Strengthening agricultural extension services through education and training enhances the reach and effectiveness of technical support to farmers. Extension workers facilitate field demonstrations and provide advisory support on climate-smart practices (Zerssa *et al.*, 2021). Additionally, digital tools like mobile apps and radio broadcasts provide farmers with timely information on weather, pest alerts and market prices, improving transparency and efficiency (Ngigi and Muange, 2022).

Education programs also promote gender equality by ensuring women farmers have equal access to resources, knowledge and decision-making processes (Eastin and Dupuy, 2021). Community-based training fosters collaboration among diverse groups, building resilient communities capable of addressing climate-related challenges. This knowledge dissemination supports policy development and contributes to sustainable development goals by enhancing food security and environmental sustainability (Kirina *et al.*, 2022).

5.11 Mechanisms for enhancing technical capacity and empowering local communities to adopt climate-smart agriculture solutions

Training programs and extension services are crucial for building technical capacity and empowering local communities to adopt CSA in East Africa. Organizations like the FAO and IFAD work with governments to deliver farmer field schools, workshops and demonstration plots, equipping farmers with skills in soil conservation, water management and agroforestry (Tesfaye *et al.*, 2023). These programs enhance farmers' practical knowledge of sustainable agriculture.

Peer learning and knowledge exchange further support CSA adoption by promoting collaboration among farmers and stakeholders. Farmer-to-farmer networks and platforms like the East African Farmers Federation facilitate the sharing of experiences, lessons learned and innovative climate-resilient solutions (Solomon *et al.*, 2018). Such initiatives encourage collaborative problem-solving and adaptation.

Digital technologies play an increasingly vital role in CSA by providing farmers with real-time access to weather forecasts, market information and agronomic advice. Mobile apps, radio broadcasts and Web platforms help farmers make informed decisions about their farming practices. Organizations like the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) use ICT tools to improve decision-making and knowledge dissemination (Kirina *et al.*, 2022).

Participatory research and innovation engage farmers in co-developing CSA solutions tailored to local conditions. Farmer-led experiments, breeding programs and on-farm trials help identify climate-resilient practices. By involving farmers in research and valuing indigenous knowledge, organizations like CIAT foster ownership and sustainability in CSA projects (Osumba and Recha, 2022).

Access to climate information services is essential for empowering communities to make informed decisions about CSA. Accurate weather forecasts, early warning systems and climate risk assessments help farmers mitigate impacts and adapt to changing conditions. Programs like the Climate Services for Agriculture initiative provide farmers with tailored advisory services to support their CSA efforts (Ngigi and Muange, 2022).

5.11.1 Linking conceptual framework and theory of change to empower local communities in adopting climate-smart agriculture. To empower local communities to adopt CSA solutions, a theory of change framework (Figure 3) commences with building their capacity through training and extension services, together with peer learning and knowledge sharing. These interventions aim to build a foundation of knowledge and skills, enabling farmers to

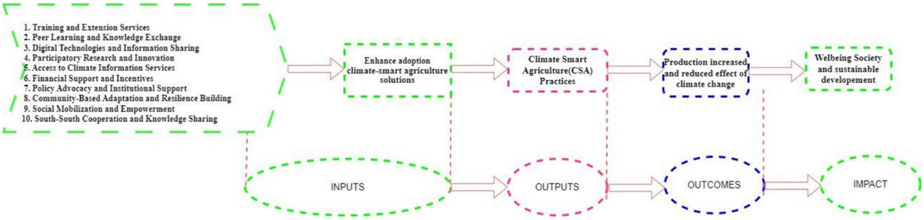

Figure 3. Linkage conceptual framework and theory of change to empower local communities in adopting climate-smart agriculture
Source: Authors' own work (2024)

understand and implement sustainable agricultural practices. Leveraging digital technologies and information exchange, communities can access real-time data and climate-smart practices, and participatory research and innovation ensures local challenges and opportunities are addressed through co-created solutions. These efforts, reinforced by access to climate information services, allow farmers to anticipate climate risks and adjust their practices, improving both productivity and resilience.

Further transformation is achieved by integrating financial support and incentives, making CSA adoption economically viable. At the same time, policy advocacy and institutional support ensure a conducive policy environment that fosters CSA practices at the grassroots level. Through community-based adaptation and resilience-building, local groups are empowered to create context-specific solutions to climate challenges. Social mobilization and empowerment strengthen collective action, while South–South cooperation and knowledge sharing facilitate the exchange of successful CSA models across regions, fostering sustainable agricultural practices on a broader scale. Ultimately, these interconnected interventions lead to sustainable, climate-resilient communities.

5.12 General policy recommendations from the review

Governments in East Africa should prioritize the development and implementation of comprehensive strategies. Clearly outlining goals and actions across sectors like crop production, livestock management and natural resource conservation (Tesfaye *et al.*, 2023). By embedding CSA in national policies, governments can create a framework for promoting climate resilience in agriculture.

Policymakers must ensure coherence between CSA policies and other areas like climate adaptation, food security and rural development. Integrated policies help maximize synergies, minimize trade-offs and allocate resources more effectively for sustainable agriculture (Solomon *et al.*, 2018). This holistic approach promotes cross-cutting solutions to climate challenges.

To enhance CSA implementation, governments need to strengthen institutional capacities and coordination. Creating dedicated units within ministries like agriculture, environment and finance, alongside fostering collaboration with civil society and the private sector, ensures effective policy execution and governance (Thottadi and Singh, 2024). This will improve inter-ministerial coordination and stakeholder involvement.

Investing in research and innovation is crucial for advancing CSA technologies and practices. Research institutions and universities should be supported in generating knowledge and testing climate-resilient solutions (Kirina *et al.*, 2022). By prioritizing research, governments can promote the adoption of climate-smart technologies and sustainable agricultural practices.

Policymakers should also focus on financial incentives to encourage CSA adoption. Providing grants, subsidies and credit facilities tailored to smallholder farmers' needs will enable them to invest in climate-resilient technologies and infrastructure (Mungai *et al.*, 2021). Access to finance is vital for boosting farmers' capacity to adapt to climate change impacts.

5.13 Strategies for enhancing financing mechanisms and investment opportunities for climate-smart agriculture projects in East Africa

The review highlights that governments and development finance institutions should establish CSA Investment Funds to mobilize CSA project financing in East Africa. These funds can pool resources from public, private and philanthropic sources to support sustainable land management, climate-resilient crop production and agroforestry (Mungai *et al.*, 2021). By offering concessional finance, risk-sharing mechanisms and technical assistance, these funds can attract private sector investment and expand CSA initiatives across the region.

Public–private partnerships have been found to be essential for unlocking financing for CSA projects in East Africa. Governments collaboration with agribusinesses, financial institutions and technology providers to co-finance CSA initiatives, share risks and create value-added products (Mungai *et al.*, 2021). Public–private partnerships offer a platform for blending public and private resources, addressing market failures and advancing sustainable agricultural development in East Africa.

According to Acharyya (2022), by incentivizing private investments in CSA, governments can introduce fiscal measures (like tax-credits) for investments in renewable-energy, water-efficient irrigation and climate-resilient crops. These incentives are reported to align fiscal policies with climate objectives, encouraging private sector engagement and innovation.

Green finance instruments by financial institutions (such as "green-bonds, climate insurance products and weather derivatives") are also found to be supporting CSA projects (Kiremu, 2020). These instruments provide tailored financial products that meet the specific CSA needs offering long-term financing and protection against climate risks (Mungai *et al.*, 2021).

Governments and development partners should strengthen rural financial markets to improve access to finance for smallholder farmers and rural enterprises engaged in CSA. Expanding microfinance, cooperatives and mobile banking services, alongside promoting financial literacy, will enhance financial inclusion and resilience in rural areas (Mungai *et al.*, 2021). By boosting rural finance, governments can unlock investment potential and promote sustainable agricultural development.

6. Conclusion and recommendation

The review highlights successful case studies and innovative approaches demonstrating the effectiveness of CSA practices in East Africa, emphasizing the role of stakeholder engagement, partnerships, and knowledge dissemination in deriving CSA. It sheds light on crucial insights and findings imperative for steering East Africa toward climate-resilient and sustainable agriculture.

Key findings underscore the significance of climate change impacts in East Africa, manifested through rising extreme weather events, declining agricultural productivity and socio-economic vulnerabilities. In this instance, it becomes paramount to address challenges and leverage opportunities presented by CSA to ensure food security, livelihoods and environmental sustainability. The review projects CSA as a promising pathway, integrating adaptation, mitigation and resilience strategies to mitigate climate change impacts enhancing agricultural sustainability. This is particularly important considering the diversity within and between countries of the climate change vulnerable region. Moreover, the review identifies socio-economic disparities, prolonged conflicts, institutional barriers and policy gaps, as the major constraints hindering CSA adoption and applicability.

Consequently, the review brings forth the urgent need for targeted interventions. Actionable policy recommendations are also proposed to mainstream CSA into national and regional development agendas, alongside strategies for enhancing financing mechanisms and investment opportunities for CSA projects.

Emphasizing the importance of CSA addressing challenges and opportunities, the review highlights the urgency of accelerating the transition toward climate-resilient and sustainable agriculture in the region. By prioritizing CSA adoption, fostering collaborations and enacting supportive policies, the region can build a resilient agricultural sector capable of withstanding climate impacts while ensuring food security, livelihoods and environmental integrity for present and future generations. Finally, it is acknowledged that it is high time for concerted efforts to transform climate change challenges into opportunities; steering East Africa toward sustainable agricultural and subsequently toward realizing the region's SDGs.

References

Acharyya, A. (2022), "Climate-Smart agriculture in developing economies: an analysis of strategies and policies", *Environmental Economics in Developing Countries*, Routledge, pp. 231-257.

Adhikari, U., Nejadhashemi, A.P. and Herman, M.R. (2015), "A review of climate change impacts on water resources in East Africa", *Transactions of the ASABE*, Vol. 58 No. 6, pp. 1493-1507.

Altieri, M.A., Nicholls, C.I., Henao, A. and Lana, M.A. (2015), "Agroecology and the design of climate change-resilient farming systems", *Agronomy for Sustainable Development*, Vol. 35 No. 3, pp. 869-890.

Ambaw, G., Recha, J.W., Nigussie, A., Solomon, D. and Radeny, M. (2020), "Soil carbon sequestration potential of climate-smart villages in East African countries", *Climate*, Vol. 8 No. 11, p. 124.

Awiti, A.O. (2022), "Climate change and gender in Africa: a review of impact and gender-responsive solutions", *Frontiers in Climate*, Vol. 4, p. 895950.

Bommarco, R., Vico, G. and Hallin, S. (2018), "Exploiting ecosystem services in agriculture for increased food security", *Global Food Security*, Vol. 17, pp. 57-63.

Branca, G., Braimoh, A., Zhao, Y., Ratii, M. and Likoetla, P. (2021), "Are there opportunities for climate-smart agriculture? Assessing costs and benefits of sustainability investments and planning policies in Southern Africa", *Journal of Cleaner Production*, Vol. 278, p. 123847.

Brisebois, A., Eriksen, S.H. and Crane, T.A. (2022), "The politics of governing resilience: gendered dimensions of climate-smart agriculture in Kenya", *Frontiers in Climate*, Vol. 4, p. 864292.

Bristol-Alagbariya, E.T. (2023), "UN convention to combat desertification as an international environmental regulatory framework for protecting and restoring the world's land towards a safer, more just and sustainable future", *International Journal of Energy and Environmental Research*, Vol. 11 No. 1, pp. 1-32.

Chirisa, I., Bandauko, E., Mazhindu, E., Kwangwama, N.A. and Chikowore, G. (2016), "Building resilient infrastructure in the face of climate change in African cities: scope, potentiality and challenges", *Development Southern Africa*, Vol. 33 No. 1, pp. 113-127.

Commission, A.U. (2020), *Africa–Regional Overview of Food Security and Nutrition 2019: Containing the Damage of Economic Slowdowns and Downturns to Food Security in Africa (Vol. 1)*, Food and Agriculture Org.

Doyle, L., Oliver, L. and Whitworth, C. (2018), "Design of a climate smart farming system in East Africa", *Paper presented at the 2018 IEEE Global Humanitarian Technology Conference (GHTC)*.

Eastin, J. and Dupuy, K. (2021), *Gender, Climate Change and Livelihoods: vulnerabilities and Adaptations*, CABI.

Erezi, E., Ehi, O.E. and Ayodeji, O.T. (2023), "Promoting sustainable agriculture and climate resilience in African nations", *International Journal of Agriculture and Earth Science*, Vol. 9 No. 5, pp. 27-45.

Eriksen, S., O'Brien, K. and Rosentrater, L. (2008), *Climate Change in Eastern and Southern Africa Impacts, Vulnerability and Adaptation, Global Environmental Change and Human Security, University of Oslo*, Blindern.

Faurès, J., Bartley, D., Bazza, M., Burke, J., Hoogeveen, J., Soto, D. and Steduto, P. (2013), "Climate smart agriculture sourcebook", *FAO, Rome*, *557*.

Food and Agriculture Organization of the United Nations (FAO) (2010), '*Climate-Smart' Agriculture: Policies, Practices and Financing for Food Security, Adaption and Mitigation*, Food and Agriculture Organization of the United Nations.

Freeman, L. (2017), "Environmental change, migration, and conflict in Africa: a critical examination of the interconnections", *The Journal of Environment and Development*, Vol. 26 No. 4, pp. 351-374.

Fund, G.C. (2020), "Building a resilient Churia region in Nepal", *Retrieved from Green Climate Fund Projects and Programs*.

Furlow, J., Smith, J.B., Anderson, G., Breed, W. and Padgham, J. (2011), "Building resilience to climate change through development assistance: USAID's climate adaptation program", *Climatic Change*, Vol. 108 No. 3, pp. 411-421.

Garcia, M.G. and Wsg, S.W. (2023), "Climate resilient development framework and the creation of common agendas to tackle climate change".

Gebrekidan, T.K. (2024), "Environmental education in Ethiopia: history, mainstreaming in curriculum, governmental structure, and its effectiveness: a systematic review", *Heliyon*, Vol. 10 No. 9.

Gebrekidan, T. and Gebremedhin, G. (2024), "Integration and effectiveness of formal environmental education in Africa and India: review", *European Journal of Sustainable Development Research*, Vol. 8 No. 2.

Gebrekidan, T.K., Gebremariam, M.G., Teferi, M.K. and Yebyo, S.G. (2025), "Chronological development of environmental protection and sustainable development in Ethiopia: systematic review", *Watershed Ecology and the Environment*, Vol. 7.

Gebrekidan, T.K., Gebremedhin, G.G., Weldemariam, A.K. and Teferi, M.K. (2024a), "Municipal solid waste management in Ethiopia–physical and chemical compositions and generation rate: systematic review", *Journal of the Air and Waste Management Association*, Vol. 74 No. 12, pp. 861-883.

Gebrekidan, T.K., Weldemariam, N.G., Hidru, H.D., Gebremedhin, G.G. and Weldemariam, A.K. (2024b), "Impact of improper municipal solid waste management on fostering one health approach in Ethiopia—challenges and opportunities: a systematic review", *Science in One Health*, Vol. 3, p. 100081.

Greenhalgh, T., Wherton, J., Papoutsi, C., Lynch, J., Hughes, G., Hinder, S., … Shaw, S. (2017), "Beyond adoption: a new framework for theorizing and evaluating nonadoption, abandonment, and challenges to the scale-up, spread, and sustainability of health and care technologies", *Journal of Medical Internet Research*, Vol. 19 No. 11, p. e8775.

Herforth, A., Bai, Y., Venkat, A., Mahrt, K., Ebel, A. and Masters, W.A. (2020), "Cost and affordability of healthy diets across and within countries: Background paper for the state of food security and nutrition in the world 2020", *FAO Agricultural Development Economics Technical Study No. 9*, Food and Agriculture Org, Vol. 9.

Hussain, S., Amin, A., Mubeen, M., Khaliq, T., Shahid, M., Hammad, H.M., … Amjad, M. (2022), "Climate smart agriculture (CSA) technologies", *Building Climate Resilience in Agriculture: Theory, Practice and Future Perspective*, pp. 319-338.

Huyer, S. and Partey, S. (2020), "Weathering the storm or storming the norms? Moving gender equality forward in climate-resilient agriculture: introduction to the special issue on gender equality in climate-smart agriculture: approaches and opportunities", *Climatic Change*, Vol. 158 No. 1, pp. 1-12.

Ilakut, B., Barungi, J., Okonya, J., Odeke, M. and Recha, J. (2022), "Dialogue on commercialization of climate-smart agricultural technologies", *Innovations and Management Practices in Eastern & Central Africa*, AICCRA, Nyando, Kenya.

Iucn (2006), *2006 IUCN Red List of Threatened Species, International Union for Conservation of Nature and Natural Resources*, Gland, Switzerland.

Kattel, G.R. (2019), "State of future water regimes in the world's river basins: balancing the water between society and nature", *Critical Reviews in Environmental Science and Technology*, Vol. 49 No. 12, pp. 1107-1133.

Kim, K.-H., Hewitt, C.D., Kanamaru, H., Alvar-Beltrán, J., Heureux, A., Park, S.-Y., … Stefanski, R. (2023), "Prospects for enhancing climate services in agriculture", *Bulletin of the American Meteorological Society*, Vol. 104 No. 2, pp. E352-E358.

Kiremu, M.K.G. (2020), *Climate Finance Instruments and Kenyan Agriculture*, The University of Waikato.

Kirina, T., Groot, A., Shilomboleni, H., Ludwig, F. and Demissie, T. (2022), "Scaling climate smart agriculture in East Africa: experiences and lessons", *Agronomy*, Vol. 12 No. 4, p. 820.

Kizza, M., Rodhe, A., Xu, C.-Y., Ntale, H.K. and Halldin, S. (2009), "Temporal rainfall variability in the Lake Victoria basin in East Africa during the twentieth century", *Theoretical and Applied Climatology*, Vol. 98 Nos 1/2, pp. 119-135.

Leal Filho, W., Barbir, J., Gwenzi, J., Ayal, D., Simpson, N.P., Adeleke, L., … Nzengya, D.M. (2022), "The role of indigenous knowledge in climate change adaptation in Africa", *Environmental Science and Policy*, Vol. 136, pp. 250-260.

Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., … Barrett, K. (2023), "Climate change 2023: synthesis report", *Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, The Australian National University.

Li, J., Lin, X., Chen, A., Peterson, T., Ma, K., Bertzky, M., … Poulter, B. (2013), "Global priority conservation areas in the face of 21st century climate change", *PLoS ONE*, Vol. 8 No. 1, p. e54839.

Lin, B.B. (2011), "Resilience in agriculture through crop diversification: adaptive management for environmental change", *BioScience*, Vol. 61 No. 3, pp. 183-193.

Lipper, L., Thornton, P., Campbell, B.M., Baedeker, T., Braimoh, A., Bwalya, M., … Henry, K. (2014), "Climate-smart agriculture for food security", *Nature Climate Change*, Vol. 4 No. 12, pp. 1068-1072.

Long'or Lokidor, P., Taka, M., Lashford, C. and Charlesworth, S. (2024), "Nature-based solutions for sustainable flood management in East Africa", *Journal of Flood Risk Management*, Vol. 17 No. 1, p. e12954.

McCarthy, J.J. (2001), *Climate Change 2001: impacts, Adaptation, and Vulnerability: contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Vol. 2, Cambridge university press.

Makokha, J. and Waswa, C. (2022), "Climate smart agriculture multistakeholder platform strategic plan 2022-2026".

Mfitumukiza, D., Barasa, B., Nankya, A.M., Dorothy, N., Owasa, A.H., Siraj, B. and Gerald, K. (2017), "Assessing the farmer field schools diffusion of knowledge and adaptation to climate change by smallholder farmers in Kiboga district", *Uganda. Journal of Agricultural Extension and Rural Development*, Vol. 9 No. 5, pp. 74-83.

Mungai, E.M., Ndiritu, S.W. and Da Silva, I. (2021), "Unlocking climate finance potential for climate adaptation: case of climate smart agricultural financing in Sub Saharan Africa", *African Handbook of Climate Change Adaptation*, Springer, pp. 2063-2083.

Neufeldt, H., Christiansen, L. and Dale, T.W. (2021), Adaptation gap report 2020.

Neufeldt, H., Martinez, G.S., Olhoff, A., Knudsen, C.M.S. and Dorkenoo, K.E. (2018), "The adaptation gap report 2018", *United Nations Environment Programme (UNEP)*, Nairobi, Kenya.

Ngamije, F. (2022), "The livestock system in Rwanda–an overview".

Ngauri, G.A. (2023), *Adoption of Climate-Smart Technologies and Their Effect on Income among Agro-Pastoralists in Marsabit County*, KENYATTA UNIVERSITY, KENYA.

Ngigi, M.W. and Muange, E.N. (2022), "Access to climate information services and climate-smart agriculture in Kenya: a gender-based analysis", *Climatic Change*, Vol. 174 Nos 3/4, p. 21.

Njogu, J.W., Karuku, G., Busienei, J. and Gathiaka, J.K. (2024), "Assessing determinants of scaling up pathways for adopted CSA climate smart agricultural practices: evidence from climate smart villages in Nyando basin, Kenya", *Cogent Food and Agriculture*, Vol. 10 No. 1, p. 2316362.

Obwocha, E.B., Ramisch, J.J., Duguma, L. and Orero, L. (2022), "The relationship between climate change, variability, and food security: understanding the impacts and building resilient food systems in west Pokot county, Kenya", *Sustainability*, Vol. 14 No. 2, p. 765.

Ocimati, W., Groot, J.C., Blomme, G., Timler, C.J., Remans, R., Taulya, G., … Tittonell, P. (2021), "A multi-objective model exploration of banana-canopy management and nutrient input scenarios for optimal banana-legume intercrop performance", *Agronomy*, Vol. 11 No. 2, p. 311.

Ogada, M.J., Radeny, M.A., Recha, J.W. and Solomon, D. (2020), *Adoption of Climate-Smart Agricultural Technologies in Lushoto Climate-Smart Villages in North-Eastern Tanzania*, *CCAFS Working Paper.*

Omotoso, A.B., Letsoalo, S., Olagunju, K.O., Tshwene, C.S. and Omotayo, A.O. (2023), "Climate change and variability in Sub-Saharan Africa: a systematic review of trends and impacts on agriculture", *Journal of Cleaner Production*, Vol. 414, p. 137487.

Organization, W.H. (2021), 2021 WHO health and climate change global survey report 2021 WHO health and climate change global survey report.

Osumba, J. and Recha, J. (2022), "Scaling Climate-Smart agriculture (CSA) through Multi-Stakeholder platform (MSP) engagement", Paper presented at the Workshop on accelerating Impact s of CGIAR Climate Research for Africa.

Ouda, S. and Zohry, A.E.-H. (2022), *Climate-Smart Agriculture*, Springer.

Palombi, L. and Sessa, R. (2013), "Climate-smart agriculture: sourcebook".

Pezo, D., Ávalos, I., Pulido, A., Villanueva, C., Peguero, F., Sepúlveda, C., … Steinfeld, H. (2024), "Key drivers of change that affect livestock systems and their impact on sustainability and resilience. Serie técnica", *Informe Técnico*.

Polya, G. (2023), "WMO warning: 1.5 degree C warming breach very soon and with increasing frequency", *Act Now! Climate Change*.

Powlson, D.S., Stirling, C.M., Jat, M.L., Gerard, B.G., Palm, C.A., Sanchez, P.A. and Cassman, K.G. (2014), “Limited potential of no-till agriculture for climate change mitigation”, *Nature Climate Change*, Vol. 4 No. 8, pp. 678-683.

Raj, S. and Garlapati, S. (2020), *Extension and Advisory Services for Climate-Smart Agriculture Global Climate Change: Resilient and Smart Agriculture*, Springer, pp. 273-299.

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A.C., Müller, C., Arneth, A., … Khabarov, N. (2014), “Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison”, *Proceedings of the National Academy of Sciences*, Vol. 111 No. 9, pp. 3268-3273.

Salah, M., Moursy, F., Soliman, E. and Gamal, G. (2023), “Assessing the potential impacts of climate change on droughts in East Africa using CORDEX-CORE regional climate models’ simulations: a focus on Tanzania”, *Contributions to Geophysics and Geodesy*, Vol. 53 No. 3, pp. 271-300.

Scherr, S.J., Shames, S. and Friedman, R. (2012), “From climate-smart agriculture to climate-smart landscapes”, *Agriculture and Food Security*, Vol. 1 No. 1, pp. 1-15.

Schmidt, E. and Tadesse, F. (2019), “The impact of sustainable land management on household crop production in the Blue Nile basin, Ethiopia”, *Land Degradation and Development*, Vol. 30 No. 7, pp. 777-787.

Shekmohammed, S., Hany, U. and Lemma, S. (2023), “Review of farmers field school approach for facilitation of climate smart agriculture”, *International Journal of Agriculture and Veterinary Sciences*, Vol. 5, pp. 9-17.

Smith, G. (2017), “‘One cow’ programme can cut poverty and pave the way for lower ‘hoofprints' too”, *Appropriate Technology*, Vol. 44 No. 3, pp. 50-51.

Smith, P., Martino, Z. and Cai, D. (2007), “Agriculture”, in *Climate Change 2007: mitigation*.

Smith, P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E.A., … Jafari, M. (2014), “Agriculture, forestry and other land use (AFOLU) climate change 2014: mitigation of climate change”, *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, pp. 811-922.

Solomon, D., Radeny, M.A., Mungai, C., Recha, J.W., Schuetz, T. and Gadeberg, M. (2018), “CCAFS East Africa 2019–2021: strategy for supporting agricultural transformation, food and nutrition security under climate change”.

Strong, R., Baker, M., Dooley, K. and Ray, N. (2023), “The Often-Forgotten innovation to improve sustainability: assessing food and agricultural sciences curricula as interventions in Uganda”, *Sustainability*, Vol. 15 No. 21, p. 15461.

Tadesse, W., Zegeye, H., Debele, T., Kassa, D., Shiferaw, W., Solomon, T., … Assefa, S. (2022), “Wheat production and breeding in Ethiopia: retrospect and prospects”, *Crop Breeding, Genetics and Genomics*, Vol. 4 No. 3.

Taylor, M. (2018), “Climate-smart agriculture: what is it good for?”, *The Journal of Peasant Studies*, Vol. 45 No. 1, pp. 89-107.

Tesfaye, A., Radeny, M., Ogada, M.J., Recha, J.W., Ambaw, G., Chanana, N., … Solomon, D. (2023), “Gender empowerment and parity in East Africa: evidence from climate-smart agriculture in Ethiopia and Kenya”, *Climate and Development*, Vol. 15 No. 9, pp. 768-778.

Thornton, P.K., Jones, P.G., Owiyo, T., Kruska, R.L., Herrero, M., Kristjanson, P., … Omolo, A. (2006), “Mapping climate vulnerability and poverty in Africa”.

Thottadi, B.P. and Singh, S. (2024), “Climate-smart agriculture (CSA) adaptation, adaptation determinants and extension services synergies: a systematic review”, *Mitigation and Adaptation Strategies for Global Change*, Vol. 29 No. 3, p. 22.

Vuille, M. (2013), “Climate change and water resources in the tropical Andes”.

Waaswa, A., Oywaya Nkurumwa, A., Mwangi Kibe, A. and Ngeno Kipkemoi, J. (2022), "Climate-Smart agriculture and potato production in Kenya: review of the determinants of practice", *Climate and Development*, Vol. 14 No. 1, pp. 75-90.

Waisbich, L.T. (2022), "Policy circulation and South–South cooperation in Brazil–Africa relations: Rise, fall and change", *Brazil and China in Knowledge and Policy Transfer: Agents, Objects, Time, Structures and Power*, Springer, pp. 153-183.

Watkiss, P., Chapagain, D. and Savvidou, G. (2023), "The adaptation finance gap adaptation gap report 2023: Underfinanced", *Underprepared. Inadequate Investment and Planning on Climate Adaptation Leaves World Exposed. The Adaptation Finance Gap Update 2023*, United Nations Environment Programme, pp. 58-64.

Yengoh, G.T. and Ardö, J. (2020), "Climate change and the future heat stress challenges among smallholder farmers in East Africa", *Atmosphere*, Vol. 11 No. 7, p. 753.

Zerssa, G., Feyssa, D., Kim, D.-G. and Eichler-Löbermann, B. (2021), "Challenges of smallholder farming in Ethiopia and opportunities by adopting climate-smart agriculture", *Agriculture*, Vol. 11 No. 3, p. 192.

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