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REVIEW PAPER
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Climate smart agriculture in Sub-Saharan Africa: Review of the potentials for maize and common beans smallholder farmers in semi-arid areas

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Abstract

Climate-smart agriculture (CSA) is an alternative approach to tackle food insecurity under climate change conditions. Its credibility is gaining wide acceptance to double food production to feed the growing population in semi-arid areas of Sub-Saharan Africa (SSA). Various CSA technologies have been identified and reported with successful outcomes, but characterization of CSA technologies by smallholder farmers remains low despite its proven potential. The present study provides detailed overview of CSA technologies for drought tolerant or escape, soil fertility and water management for maize and common beans productivity of smallholder farmers in semi-arid of SSA. This review: (i) synthesized available information on the potential of CSA technologies ii) identified CSA management practices and their contribution to soil fertility and water management iii) identified and discussed the adaptive strategies to climate change, the influences, and limitations of smallholder farmers adoption to CSA technologies. To achieve this study, secondary data from peer-reviewed papers, universities thesis, Science Direct, and the Web of Science database were collected and reviewed using SSA as a case study. About 544 published data between 2002 and 2024 were evaluated and discussed for maize and common beans production potentials. The improved drought-tolerant maize and early-maturity common beans as well as the intercropping, tied ridges, and farm-yard manure were identified as potential CSA technologies widely promoted in SSA. The review elucidated that, CSA technologies can build synergies and increase resource use efficiency to strengthen food sovereignty and climate change adaptation in semi-arid areas of SSA.

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Introduction

Climate change refers to the increase in greenhouse gas emissions (GHGs) in the atmosphere causing irregularity (Abegunde *et al*., 2020; Akrofi-Atitianti *et al*., 2018; Mizik, 2021; Republic, 2016; Thierfelder *et al*., 2017), variability and unpredictability weather patterns and conditions which results into biotic (pest and diseases) and abiotic (floods and drought) stresses (Bukhari *et al*., 2019; Kapoor *et al*., 2020; Zandalinas *et al*., 2018). These effects likely to be "severe, pervasive, and irreversible" in sub- Saharan Africa (SSA), agriculture productivity in SSA has already been negatively impacted to varied degrees (Kapoor *et al*., 2020). The IPCC provided a warning that a rise in climatic variables, such as temperature and rainfall variability, results in intensification of natural hazards (IPCC, 2021). The climate change having effects on crop productivity in the SSA, it is clearly increasing the risk of food crisis for smallholder farmer with low-incomes (Adimassu *et al*., 2021; Volk *et al*., 2021). Various studies have shown the vulnerability of SSA countries to climate change in crop production particularly maize and common beans (Volk *et al*., 2021). The challenge of SSA farming is primarily based on smallholder farming systems where farmers produce for subsistence, with limited or no access to improved climate resilient seed genotypes, improper land use and soil infertility (Imoro *et al*., 2021).

The role of climate-smart- agriculture (CSA) technologies in climate change adaptation of maize and common beans production in semi-arid areas is not fully understood (Mittal, 2016; Nkumulwa and Pauline, 2021; Ogunyiola *et al*., 2022, 2022; Umar, 2021; Zougmoré *et al*., 2021). There is limited information on specific CSA technologies with greatest suitability and potential to contribute to maize and common beans production of smallholder farmers in semi-arid areas in SSA (Dougill *et al*., 2021). However, the smallholder farmers have been employing various doable tactics to build intrinsic resilience of their farming systems (Dougill *et al*., 2021; Zougmoré *et al*., 2021). The CSA as shown resilience and adaptive to ash environment, it has the capacity to absorb climate shocks and eventually adapt to changing environment (Kokwe, 2022).

The CSA technologies focused on reducing risks through enhanced agricultural ecosystem's ability for adaptation, enabling farmers to meet present and future food needs while coping with uncertainty (Kokwe, 2022). The highly dynamic farming systems of using CSA help smallholder farmers to best respond to climate change and contribute to producing sufficient food (Musafiri *et al*., 2022).

The CSA has been identified as an important tool that can be used to overcome the climate change challenges to agricultural systems (Hussein, 2024; Kirina *et al*., 2022). The CSA assist smallholder farmers in mitigating climate change and increasing resilience (Hussein, 2024; Ogunyiola *et al*., 2022) by means of adaptation and effectively respond to long-term climate change risks (Agarwal *et al*., 2022; Mizik, 2021; Zougmoré *et al*., 2021). According to the FAO (Akrofi-Atitianti *et al*., 2018; Republic, 2016), defined CSA as agricultural practices that improves resilience, increases productivity in a sustainable way, reduces or removes greenhouse gases and boosts food security (Bhattacharyya *et al*., 2021; CIMMYT, 2005). The CSA technologies with a variety of integrated options include agro-ecological approaches, sustainable natural resource management and ecosystem management that are central to climate change adaptation (van Zonneveld *et al*., 2020). The CSA strategies could contribute significantly to social equity and local economies, especially, in SSA countries (Azadi *et al*., 2021; van Zonneveld *et al*., 2020). A lot of interest has been shown in CSA in recent years and a number of actors such as local non-government and international government organizations, farmers, the private sector and the research community have initiated different interventions in CSA (Dougill *et al*., 2021; van Zonneveld *et al*., 2020).

In this review paper, the assumption made that climate-smart agriculture technologies have been used in sub-Saharan African countries (Dougill *et* *al*., 2021; Kurgat *et al*., 2020; Zerssa *et al*., 2021). However, the current status of the prioritization of climate change in the government agenda varies from one country to another, that their impact has been noted by smallholder farmers in various degrees, for example, in Tanzania, the climate smart agriculture (Dougill *et al*., 2021; Kirina *et al*., 2022; Nyasimi *et al*., 2017). In some Africa countries, climate change are not prioritized as the main agenda such countries in Eastern Mediterranean like Algeria and Lesotho (Lange, 2019). In Tanzania, climate change presents a significant challenge; hence the country has prioritized adaptation actions into development planning (Rasmussen, 2020).

However, the implementation of CSA practices in Tanzania like most of SSA countries has been hindered by several factors, including a lack of awareness and information among farmers, limited access to finance, and weak extension services (Dougill *et al*., 2021). In addition, the adoption of CSA practices is often slowed by the lack of reliable and consistent support from the government and other stakeholders (Kirina *et al*., 2022; Kurgat *et al*., 2020; Nkumulwa and Pauline, 2021; Umar, 2021). Despite these challenges, there is potential for CSA to contribute to sustainable agricultural development and food security in SSA countries (Zougmoré *et al*., 2021). The present study aimed to (i) synthesize available information on potential of CSA, (ii) assessed CSA management practices contributing to soil fertility and water management on smallholder farms in semi-arid of SSA, (iii) identify and discuss the bottlenecks on CSA adoption and adaptative strategies to climate change effects by smallholder farmers in semi-arid areas.

Review scope

This manuscript critically reviews the literature to identify Climate-Smart Agriculture (CSA) technologies widely promoted for evaluation among smallholder farmers of maize and common beans in semi-arid regions of Sub-Saharan Africa (SSA). Given the diverse environmental settings and intensive anthropogenic activities across SSA, smallholder farmers are experiencing accelerated rates of change, posing significant challenges to agricultural sustainability. The review further explores the potential of various CSA technologies, such as improved crop varieties to climate change adaptation and field management including field soil conservation and water management practices. The study explored the CSA such as conservation agriculture, improved crop varieties, agroforestry, and integrated soil fertility management. It examines their impacts on soil health, water use efficiency, yield stability, and resilience to climate variability.

By synthesizing findings from different studies, the review seeks to highlight the best practices and key challenges in implementing CSA technologies, providing a comprehensive understanding of their efficacy and scalability in the context of SSA's semi-arid regions. The review goal offer insights that can guide policy and practice towards enhancing the productivity and resilience of smallholder farming systems.

Literature search and selection of studies

This review was completed through a thorough search of available literature, including peer-reviewed publications and reports of ongoing studies on CSA technologies, soil nutrient and water management practices, adaptative strategies of smallholder farmers to climate change for sustainable production of maize and common beans in SSA from the year 2002 to present. The data from Science Direct, Web of Science, and completed the internet sources databases from Google Scholar). The search was gathered using specific keywords such as “climate-smart agriculture”, “maize-common beans intercrops”, “adaptative strategies”, and “semi-arid”. The search yields various networks of studies and key terms as shown in Fig. 1. The search yields 544 peer reviewed publication, which were assessed the relevance of publications retrieved by reviewing the title, abstract and finally fully-text appraisals.

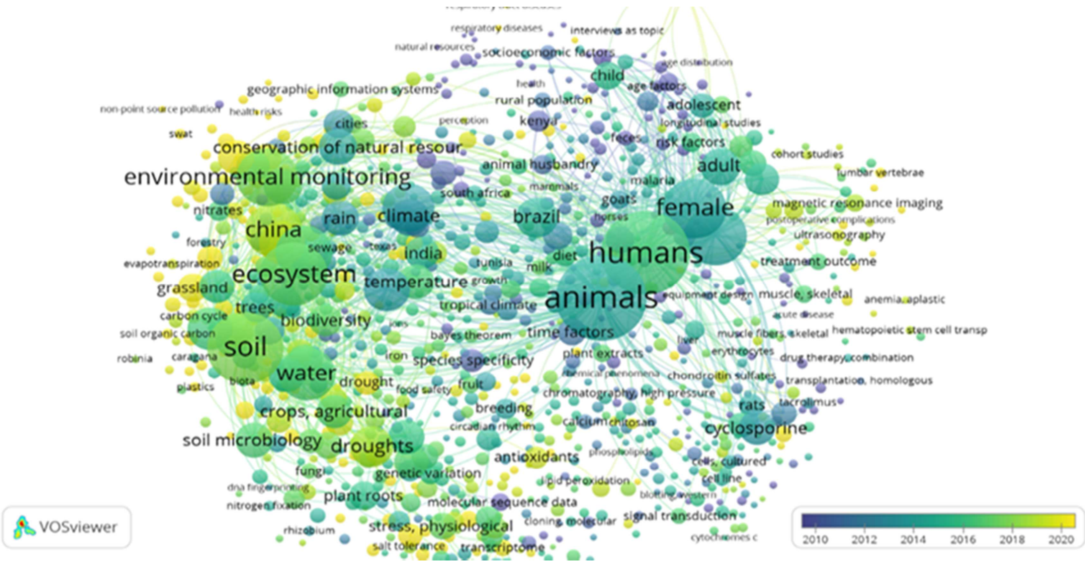

Fig. 1. The network of keywords observed among the peer reviewed research papers on climate

Evaluation of climate-smart agriculture on maize-beans intercrops

Climate smart agriculture

Climate smart agriculture (CSA) includes ways to grow more food, commercial crops, and income in challenging environments, such as dry regions, with efficient use of natural resources, restoration and conservation of ecosystems, and resilience to climatic extremes (Zerssa *et al.*, 2021). The focus of CSA is to achieve transformation in the agriculture sector through promoting the mechanisms and incentives for adoption, investment to shift to sustainable production and resilience to climate vulnerabilities, as a part of the broader agricultural strategies and investment programs (Azadi *et al.*, 2021; Chavula and Turyasingura, 2022; Mizik, 2021). The CSA interventions improve the income and food security of small-scale farmers, particularly women, young farmers, and marginalized groups (Hussein, 2024; Pamuk *et al.*, 2021). Smallholder farmers are increasingly recognized as operating on a spectrum from highly vulnerable to climate extremes and potentially contributing to the mitigation of the causes of climate change through adaptation and sustained ecosystem services provided that they have improved access to sustainable land use and restoration practices as well as to markets and financial services (Ariom *et al.*, 2022). Crucial to the concept of CSA is that detrimental trade-offs are avoided in order to create symbiotic relations between ecosystem services and agricultural production, adapted to the location-specific changes in climate (Abegunde and Obi, 2022).

To provide an effective CSA approach directly to the smallholders, institutional capacity development with knowledge and skill, education, and governance for reducing barriers and access to poor farmers play key roles in accelerating sustainable agricultural transformation (Azadi *et al.*, 2021; Makate, 2019; Ogunyiola *et al.*, 2022; Zerssa *et al.*, 2021). The CSA demonstration on site-specific cases using site-specific and participatory technology development and validation through use of innovation platforms create greater value and longer-lasting commitment from stakeholders (Dougill *et al.*, 2021). To scale out orchard value chain improvements, CSA can draw on successful CSAs in some areas, replicating them elsewhere.

Successful scaling may be achieved by linking these improvements to major structural reforms in crop breeding or conservation services (Tovihoudji *et al.*, 2022) as they have proven to have positive impact in the agro-ecosystem productivity (Table 1). Due to the declining yield effects of traditional varieties, the potential for traditional varieties to contribute to climate resilience may be compromised (Zerssa *et al.*, 2021).

Table 1. Summary of studies on climate-smart agriculture in sub-Saharan Africa for maize and beans farming

Study	Location	Crops	Key findings	Conclusion reached	Notes
Zerssa *et al*., 2021)	Ethiopia	Maize, Beans	CSA practices increased maize and bean yields, improved soil fertility, and enhanced water use efficiency.	CSA practices significantly improve agricultural productivity and resilience to climate variability.	Emphasizes the need for context-specific CSA practices tailored to local conditions.
Azadi *et al*., 2021	Kenya	Maize, Beans	Adoption of drought-tolerant varieties led to higher yields and greater income for smallholder farmers.	Investing in CSA can lead to sustainable production and increased resilience to climate change.	Highlights the importance of financial support and incentives for farmers.
(Chavula and Turyasingura, 2022)	Uganda	Maize, Beans	Improved crop management practices reduced pest incidence and increased crop resilience.	CSA practices contribute to both yield stability and environmental sustainability.	Stresses the role of training and extension services in promoting CSA adoption.
Mizik, 2021)	Malawi	Maize, Beans	Agroforestry practices improved soil structure and provided additional income from tree products.	Agroforestry is a viable CSA practice for enhancing both productivity and environmental health.	Points out the multifunctional benefits of integrating trees into farming systems.
Hussein, 2024)	Tanzania	Maize, Beans	CSA interventions improved food security and income, especially for women and marginalized groups.	CSA practices can lead to socio-economic benefits and gender equity in farming communities.	Underlines the importance of inclusive approaches in CSA implementation.
Pamuk *et al*., 2021	Nigeria	Maize, Beans	Conservation agriculture increased soil moisture retention and reduced erosion, boosting crop yields.	Conservation agriculture is effective for improving soil health and crop productivity.	Advocates for widespread promotion of conservation agriculture techniques.
Ariom *et al*., 2022	Zambia	Maize, Beans	Improved access to markets and financial services enhanced the adoption of CSA practices.	Market access and financial services are crucial for the success of CSA initiatives.	Recommends policy reforms to facilitate better market integration for farmers.
Abegunde and Obi, 2022	Ghana	Maize, Beans	Adoption of CSA practices led to increased resilience to climate extremes and improved ecosystem services.	CSA practices are essential for sustainable agricultural development in the face of climate change.	Emphasizes the need for continuous research and adaptation of CSA practices.
Dougill *et al*., 2021	Senegal	Maize, Beans	Participatory technology development and validation increased stakeholder engagement and commitment.	Stakeholder involvement is key to the successful implementation of CSA practices.	Highlights the benefits of collaborative approaches in CSA projects.
Tovihoudji *et al*., 2022	Benin	Maize, Beans	Structural reforms in crop breeding linked to CSA practices improved crop resilience and productivity.	Linking CSA practices with structural reforms can amplify their impact on agricultural systems.	Suggests integrating CSA into national agricultural policies and programs.

Climate smart agriculture technologies

The intensification aspect of CSA on smallholder farming is heavily dependent on technological innovation, both new and efficient use of the existing ones (Zeleke *et al.*, 2024; Senyolo, 2020; Ogada *et al.*, 2021; Kalimba and Culas, 2020; Waaswa *et al.*, 2022; Ifeanyi-Obi *et al.*, 2022; Mulwa, 2020). This includes both production technologies like seed, cultivation techniques, as well as animal and soil health technologies (Shahane and Shivay, 2021). The mitigation of greenhouse gases (GHGs) associated with farming, including what to produce, from where, with what resource use, and for whom, will need to combine attention to improving the productivity and resilience of agricultural systems. "Win-win technologies" are those which offer the possibility of increasing productivity and adaptation and reducing emissions all at the same time, for example, increased food production, reduced energy inputs, and resilience to a range of production risks (Selya *et al.*, 2023). These are essential (a prerequisite) for agricultural intensification rather than the increasing risk, which has been responsible for considerable expansion of the cultivated area in the past to ensure domestic food production which can simultaneously mitigate negative effects of agricultural emissions on climate change (Golla, 2021; Rusere *et al.*, 2020; Kuyah *et al.*, 2021).

Maize and common bean production technologies which encompass benefits in productivity, sustainability, and resilience building, considering the importance of such technologies to be developed and implemented globally given the trend of decreasing agricultural production and increasing food insecurity (Semalulu *et al.*, 2022; Ng'ang'a *et al.*, 2020; Tadesse *et al.*, 2021). The important role that these crops play in food security, nutrition, and income generation, particularly for the rural poor in SSA, cannot be overemphasized (Popoola *et al*., 2022; Jarzebski *et al*., 2020; Hlophe-Ginindza and Mpandeli, 2021). Climate change, Climate smart agriculture and internet of things are key components in climate smart agricultural technologies which have been evolving over time, most of the technologies has been on improving soil-water management and nutrition improvement where smallholder farmers has been a centre of the technologies, in sub–Saharan Africa where farming is dominated by smallholder farmers adoption of climate smart agricultural technologies will be very useful (Fig. 2). These were found as key components in smart agricultural technologies which have been evolving over time, most of the technologies have been on improving soil-water management and nutrition improvement where smallholder farmers have been a center of the technologies, in sub–Saharan Africa where farming is dominated by smallholder farmers.

Maize and common beans production in semi-arid regions

Maize and common beans are basic food staples in SSA, often cultivated by smallholder farmers who grow it under rain-fed conditions (CIMMYT, 2005; Meseka *et al*., 2018). Under rain-fed agriculture, the conditions for maize and common beans production are variable due to changing weather: erratic rainfall, high temperatures, low humidity, soil degradation, poor local varieties, and weak and erratic market systems (Casali *et al*., 2022; Mthethwa *et al*., 2022). These factors restrict food production, food consumption, and agricultural income (Rurinda *et al*., 2014). Especially in the semi-arid regions of SSA, these unreliable weather and climatic conditions have led to food insecurity and poorer people living in semi-arid areas (Agarwal *et al*., 2022; Harrison *et al*., 2019). The grain yield obtained by small scale farmers for maize is low 1.5 – 3.5 t/ha compared to the potential yield of 8.0 – 10.0 t/ha while common bean grain yield is also very low 0.8 – 1.0 t/ha compared to the potential yield of 1.5 – 3.5 t/ha (CIMMYT, 2022a; Nkhata *et al*., 2021). The weather conditions are changing with seasonal rainfall variations results into severe climate shocks, the Intergovernmental Panel on Climate Change (IPCC), by 2050s predicts, a rise in temperature of roughly 2.5°C to 2.8°C in SSA (IPCC, 2021). It expected yield reduction of both maize and common beans by 13% and 50-70%, respectively (Harrison *et al*., 2019; Myeya, 2021).

In SSA, most smallholder farmers grow crops under monoculture, the practice which have caused soil nutrient depletion (CIMMYT, 2022a). The soil fertility deterioration is considered the biophysical root cause of the low crop yields (Nassary *et al*., 2020). Cattle manure, the traditional source of fertilizers, is now limited to a few households that still own cattle and their use is constrained by limited knowledge among farmers (Umar, 2021). Therefore, improving agricultural development through "closing yield gaps," "improvements in related support services, notably the availability of key inputs including improved crop varieties," and "improvement in water management will be agro-ecosystem changer in SSA regions and communities (Andrews *et al*., 2021; Thompson *et al*., 2015). The CSA offers significant opportunities for compensating for these constraints and pressures (Abegunde *et al*., 2020; Akrofi-Atitianti *et al*., 2018). The Semi-arid areas of SSA have various opportunities for improvement for smallholder farmers who are dependent on rain-fed agriculture (Magombeyi *et al*., 2018). Extensive investments in the right CSA input portfolios, institutions, and policies are crucial to ensure that smallholder farmer's benefits with available CSA options (Mason *et al*., 2022; Pamuk *et al*., 2021; Teklewold *et al*., 2020).

The semi-arid regions generally have poor soils and varying crop yields with increasing aridity (Partey *et al*., 2018). Improving climate resilience through CSA options that can increase water content and reduce moisture stress through better soil fertility, cultivar choice, moisture and nutrient retention increases both maize and common bean yields in semi-arid areas (Tabe-Ojong *et al*., 2023). Therefore, CSA combined with an alignment and design of specific areas would help to close the maize yield gap in the semi-arid areas of SSA through the types of options selected (Ariom *et al*., 2022; Teklewold *et al*., 2020).

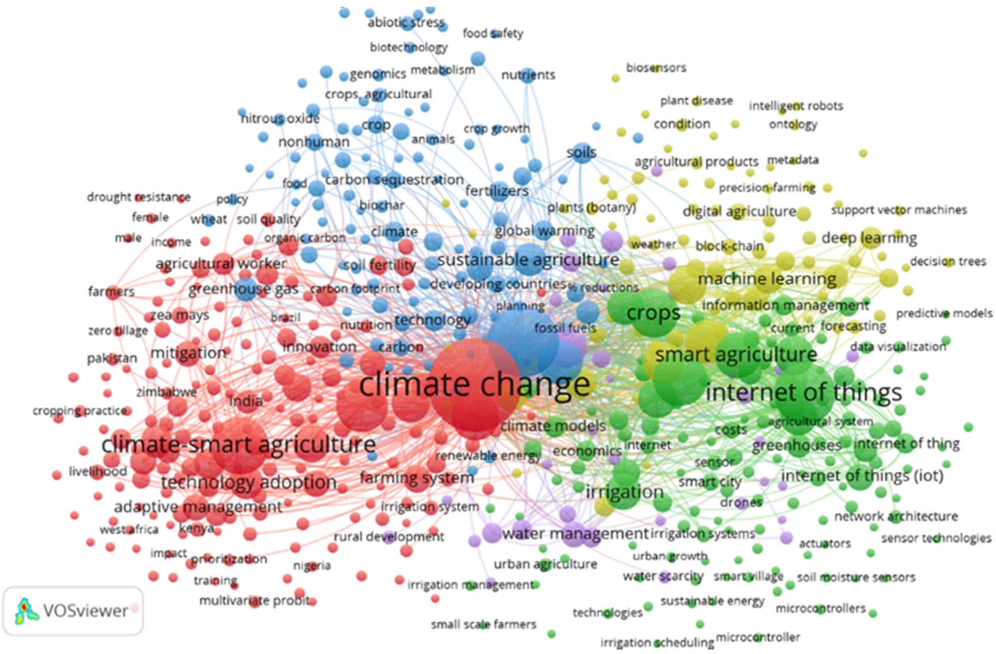

Fig. 2. Climate change, climate smart agriculture and internet of things

Key review findings and lesson learned

Contribution of climate smart agriculture to smallholder farmers in sub-Saharan Africa

Climate Smart Agriculture (CSA) is an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate (Weniga Anuga *et al.*, 2019). For smallholder farmers in sub-Saharan Africa, CSA can provide significant contributions that increase resilience to climate change (Kurgat *et al.*, 2020; Mizik, 2021; Ogunyiola *et al.*, 2022; Tabe-Ojong *et al.*, 2023), it also contributes to diversification of crops such as introducing of drought-resistant and heat-tolerant crop varieties helps smallholder farmers cope with extreme weather conditions (Weniga Anuga *et al.*, 2019). It improved water management techniques such as rainwater harvesting and efficient irrigation systems reduce the dependency on erratic rainfall (Ariom *et al.*, 2022; Dougill *et al.*, 2021; Hussein, 2024). Thus, enhanced productivity and income (Mthethwa *et al.*, 2022), sustainable intensification practices such as agroforestry, intercropping (Table 2), and crop rotation can enhance soil fertility and increase yields (Kurgat *et al.*, 2020). Access to markets by improve the quality and quantity of produce (Zougmoré *et al.*, 2021), enabling farmers to access better markets and increase their income (Agbenyo *et al.*, 2022; Mthethwa *et al.*, 2022; van Zonneveld *et al.*, 2020).

Reduction in greenhouse gas emissions through soil management techniques like conservation tillage and the use of organic fertilizers can enhance soil carbon sequestration (Dougill *et al.*, 2021; Kim *et al.*, 2021). Another technique is the use of agroforestry through integrating trees into agricultural landscapes helps in capturing carbon dioxide from the atmosphere (Nkumulwa and Pauline, 2021; Oppong *et al.*, 2021; Zerssa *et al.*, 2021).

Increasing the resilience of crops and livestock to climate variability, CSA practices ensure a more stable food supply (Ariom *et al.*, 2022; Hussein, 2024). It also diversifying crops can lead to a more varied and nutritious diet for farming families (Ariom *et al.*, 2022). It engaging local communities in CSA practices promotes collective action and knowledge sharing include training programs to equip farmers with knowledge and skills in sustainable farming practices (van Zonneveld *et al.*, 2020).

Table 2. Contribution of climate smart agriculture to smallholder farmers in sub-Saharan Africa

Study	Location	Key Findings	Remarks
Weniga Anuga *et al.*, 2019	Ghana	CSA practices, such as crop diversification, increased resilience to climate variability and improved food security.	CSA practices are essential for enhancing resilience and food security among smallholder farmers.
Kurgat *et al.*, 2020	Kenya	Introduction of drought-resistant crop varieties improved yields and income for smallholder farmers.	Drought-resistant crops are crucial for sustaining agricultural productivity in arid regions.
Mizik, 2021)	Malawi	Agroforestry practices enhanced soil fertility, increased yields, and provided additional income from tree products.	Agroforestry is a viable CSA practice for improving both agricultural productivity and income.
Ogunyiola *et al.*, 2022	Nigeria	Improved water management techniques reduced dependency on erratic rainfall and increased crop productivity.	Effective water management is vital for ensuring stable agricultural production in changing climates.
Tabe-Ojong *et al.*, 2023)	Cameroon	Organic farming practices enhanced soil health, reduced pest pressure, and increased crop resilience.	Organic farming is beneficial for sustainable agriculture and improving resilience to pests.
Ariom *et al.*, 2022)	Zambia	Access to markets and financial services facilitated the adoption of CSA practices, improving income and resilience.	Market access and financial support are crucial for the successful implementation of CSA initiatives.
Dougill *et al.*, 2021	Senegal	Participatory technology development increased stakeholder engagement and long-term commitment to CSA practices.	Stakeholder involvement is key to the successful implementation and sustainability of CSA practices.
Hussein, 2024	Tanzania	CSA practices improved food security and income, particularly for women and marginalized groups.	CSA practices can lead to socio-economic benefits and gender equity in farming communities.
(Mthethwa *et al.,* 2022	Swaziland	Water harvesting techniques increased water availability during dry periods, enhancing crop yields.	Water harvesting is an effective CSA practice for improving water use efficiency and crop productivity.
Zougmoré *et al.*, 2021)	Burkina Faso	CSA practices improved the quality and quantity of produce, enabling better market access and increased income.	Improved market access is vital for the economic viability of CSA practices among smallholder farmers.

The key CSA practices for smallholder farmers in Sub-Saharan Africa identified was conservation agriculture which involve minimal soil disturbance, maintaining a permanent soil cover, and crop rotations such as agroforestry which integrating trees and shrubs into crop and livestock systems (Abegunde *et al.*, 2020; Bongole *et al.*, 2020; Tapsoba *et al.*, 2023). Integrated pest management (IPM) which combining biological, cultural, physical, and chemical tools to manage pests (Negera *et al.*, 2022). The other CSA is water harvesting techniques to capture and store rainwater for use during dry periods (Mthethwa *et al.*, 2022). The organic farming using organic fertilizers and natural pest control methods (Abegunde *et al.*, 2020; Abegunde and Obi, 2022; Tabe-Ojong *et al.*, 2023; Zerssa *et al.*, 2021).

Challenges which face sustainability of maize and common bean production in semi-arid area of sub-Saharan Africa

Smallholder farmers in semi-arid areas of sub-Saharan Africa face several challenges that affect the sustainability of maize and common bean production. These challenges include climatic, economic, social, and technical factors (Nyamasoka-Magonziwa *et al.*, 2020).

Climatic challenges

Drought and Erratic Rainfall: Semi-arid areas experience low and unpredictable rainfall, which can lead to crop failures and reduced yields (Rurinda *et al.*, 2014). Pest and Disease Management: Maize and beans are susceptible to pests and diseases such as maize weevil, stem borers, and bean rust, which can significantly reduce yields (Mthethwa *et al.*, 2022). Extreme Weather Events: Increased frequency of heatwaves and unseasonal storms can damage crops and reduce productivity (Tabe-Ojong *et al.*, 2023). Soil Degradation: Poor rainfall can lead to soil erosion and degradation, further reducing soil fertility and crop yields (Moore *et al.*, 2019; Nyawira *et al.*, 2021; Zerssa *et al.*, 2021).

Economic challenges

Climate change poses a significant challenge to smallholder farmers in sub-Saharan Africa, impacting their ability to access financial services and crucial agricultural inputs. Smallholder farmers in sub-Saharan Africa face significant economic challenges when it comes to adopting climate smart agriculture technologies, which has implications for their livelihoods and food security. Smallholder farmers often have limited access to credit and financial services, making it difficult to invest in quality seeds, fertilizers, and irrigation systems (Mizik, 2021; Ogisi and Begho, 2023; Ogunyiola *et al.*, 2022). Poor infrastructure and limited market access restrict farmers from selling their produce at fair prices, reducing their income and ability to reinvest in their farms (Hussein, 2024). The cost of agricultural inputs such as fertilizers, pesticides, and improved seed varieties can be prohibitive for smallholder farmers (Hussein, 2024). Innovative solutions and best practices have been developed to address the challenges faced by smallholder farmers in accessing financial services and agricultural inputs in Sub-Saharan Africa. These solutions aim to provide sustainable and effective support to improve the livelihoods of farmers in the region. However, Extension services are often under-resourced, limiting the dissemination of knowledge and technologies that could help farmers improve their practices (Hussein, 2024; Mpogole *et al.*, 2023). Farmers may not have access to drought-tolerant, disease-resistant, and high-yielding maize and bean varieties (Atlin *et al.*, 2017). Therefore, addressing the challenges faced by smallholder farmers in accessing financial services and agricultural inputs in sub-Saharan Africa is crucial for the region's agricultural development and food security.

Social challenges

Many smallholder farmers in sub-Saharan Africa are vulnerable to food insecurity due to their dependence on rain-fed agriculture, exposure to economic, social, and biological shocks, and their assets (Phiri *et al.*, 2022). These farmers are considered one of the most vulnerable groups to climate change (Valli, 2019). Technologies, such as climate-smart agriculture (CSA), aim to increase farm productivity, total yields, and reduce greenhouse gas emissions (Ogisi and Begho, 2023). However, adoption rates of these initiatives are low due to numerous challenges. Drawing on current CSA literature, this paper outline the social challenges experienced by smallholder farmers and identified the social enablers (Pamuk *et al.*, 2021). These challenges and enablers warrant attention from international development organizations, particularly since sub-Saharan African smallholder farmers have unique social characteristics.

Smallholder farming is a significant global business system, as 73% of the world's poorest households are connected to these farms, with over 2 billion people relying on these farms for their household incomes (Sasson, 2012). Consequently, decision-makers in the fields of research, development, policy, business, civil society, and donor organizations are investing in initiatives aimed at enhancing the productivity and profitability of smallholders. Nevertheless, the adaptation and adoption rates of these innovations by smallholder farmers are low. Smallholder farmers face numerous challenges that hinder their abilities to adapt to any agricultural technologies. Many smallholder farmers have limited access to agricultural education and training, hindering their ability to adopt improved farming practices and technologies (Partey *et al.*, 2018). Women, who constitute a significant proportion of the agricultural workforce, often have less access to resources, education, and decision-making processes (CIMMYT, 2022b).

Insecure land tenure and lack of property rights can discourage farmers from making long-term investments in their land (Ogunyiola *et al.*, 2022).

Strategies to overcome challenges of maize and common bean production in semi-arid areas

Promote the use of drought-resistant and early-maturing crop varieties (Partey *et al.*, 2018). Implement water conservation techniques such as rainwater harvesting and drip irrigation (Singh *et al.*, 2019). Economic Empowerment through improve access to microfinance and credit facilities tailored to smallholder farmers (Pamuk *et al.*, 2021). Develop infrastructure to improve market access and reduce post-harvest losses (Mpogole *et al.*, 2023; Utonga, 2022; van Zonneveld *et al.*, 2020). Provide subsidies or financial incentives for the adoption of sustainable agricultural practices (Bhattacharyya *et al.*, 2021;

Chabay, 2018). The social Inclusion by offer training programs and workshops to educate farmers on best practices and new technologies and empower women by ensuring equal access to resources, training, and decision-making processes.

Strengthen land tenure systems to provide farmers with secure land rights. Enhance pest and disease management through integrated pest management (IPM) practices. Strengthen agricultural extension services to improve knowledge transfer and support for farmers.

Facilitate access to quality seeds and inputs through farmer cooperatives and public-private partnerships (Akplo *et al.*, 2023; Makate *et al.*, 2018; Oppong *et al.*, 2021). According to the IPCC, droughts in sub-Saharan Africa have increased in frequency and severity over recent decades (IPCC, 2021). Projections suggest a 5-8% increase in drought frequency by the end of the 21st century (IPCC, 2021). The World Bank reported that approximately 40% of the sub-Saharan Africa region is vulnerable to drought risks, with economic losses averaging $520 million annually due to drought-induced agricultural losses (Tovihoudji *et al.*, 2022). Severe droughts have led to maize yield reductions of up to 40% in some areas, for example, the 2015-2016 El Niño-induced drought caused significant crop failures across East and Southern Africa (Thoithi *et al.*, 2021). Common beans, which are highly sensitive to water stress, can experience yield reductions of 50-75% during severe drought conditions (Muhammad *et al.*, 2021).

The Food and Agriculture Organization (FAO) estimates that 65% of Africa's arable land is affected by soil degradation, including nutrient depletion, erosion, and other forms of degradation (Kapoor *et al.*, 2020; Musafiri *et al.*, 2022; Shahane and Shivay, 2021). In semi-arid regions, soil organic carbon content has decreased by 25-50%, significantly affecting soil fertility and crop productivity (Lamanna *et al.*, 2018; Thierfelder *et al.*, 2017; Zerssa *et al.*, 2021). Soil degradation results in annual productivity losses of 0.5-1.5% in sub-Saharan Africa, for maize, soil fertility loss can reduce yields by 20-40% and for beans, by 10-30% (J *et al.*, 2020; Meseka *et al.*, 2018).

The fall armyworm, which attacks maize, has spread across 44 African countries since 2016, leading to annual losses of up to 20 million metric tons of maize (Atwood *et al.*, 2022; Ndayisaba *et al.*, 2023; Negera *et al.*, 2022). Bean diseases such as bean rust and root rot have increased due to changing climate conditions, causing yield losses of 30-50% (Agegnehu *et al.*, 2021). The economic impact of pest infestations like the fall armyworm is substantial, with annual losses estimated at $1-3 billion for maize in sub-Saharan Africa. Crop diseases lead to significant income losses for smallholder farmers, with bean diseases alone causing up to 50% loss of potential income in affected regions. Mitigation measures to enhance sustainable maize and common beans production in semi-arid areas of Sub-Saharan Africa focus on improving productivity and enhancing resilience to climate variability.

Key measures to enhance common beans and maize productivity in SSA

Drought-tolerant and early maturing crop varieties

Developing and promoting the adoption of drought-tolerant maize and common bean varieties that are adapted to semi-arid conditions can reduce yield variability and enhance farmer resilience to drought. For example, the study by (Phiri *et al.*, 2022) emphasizes the importance of selecting and disseminating drought-tolerant crop varieties has it enhance agricultural productivity and adoption of new improved varieties by smallholder farmers in semi-arid regions.

Conservation agriculture practices

Implementing conservation agriculture techniques such as minimum tillage, mulching, and crop residue retention helps improve soil structure, reduce erosion, and enhance water infiltration and moisture retention. The research by (Thierfelder *et al.*, 2017) highlights the benefits of conservation agriculture in semi-arid areas, including improved soil fertility and water efficiency.

Water management strategies

Adopting water management strategies such as rainwater harvesting, small-scale irrigation systems (e.g., drip irrigation), and water-efficient cropping patterns helps mitigate water scarcity and ensures more reliable crop yields. The researches by (Andrews *et al.*, 2021; Nyamasoka-Magonziwa *et al.*, 2020) underscores the importance of water management practices in enhancing agricultural productivity and resilience to climate change in dryland areas.

Agroforestry and integrated farming systems

Integrating trees and shrubs into farming systems through agroforestry can improve soil fertility, provide shade and windbreaks, and diversify farm income through multiple products. The studies such as those by (Thierfelder *et al.*, 2017) discuss the benefits of agroforestry systems in enhancing soil fertility and crop productivity while promoting biodiversity and resilience to climate variability.

Soil fertility management

Implementing sustainable soil fertility management practices through the use of organic fertilizers, cover cropping, and crop rotation helps maintain soil health and nutrient balance, supporting long-term crop productivity. The studies by (Musa *et al.*, 2022; Wortmann and Sones, 2017) explores various soil fertility management strategies suitable for semi-arid environments, emphasizing their role in sustaining crop yields and soil health.

Climate information services and decision support tools

Providing farmers with timely climate information, weather forecasts, and decision support tools helps them make informed decisions on planting dates, crop varieties, and resource allocation. Research by (Mason *et al.*, 2022) discusses the impact of climate information services on agricultural decision-making and adaptation strategies in semi-arid regions. Therefore, these mitigation measures are essential for enhancing the sustainability of maize and common beans production in semi-arid areas of Sub-Saharan Africa, contributing to improved food security, livelihoods, and resilience to climate change impacts.

The smallholder farmers in semi-arid regions have shown varying levels of adoption of drought-tolerant maize varieties and the adoption rates were influenced by availability, accessibility, farmer preferences, and support from extension services. Thus, has been documented by (Mmbando and Baiyegunhi, 2016; Partey *et al.*, 2018), notes that while there has been significant promotion of drought-tolerant maize varieties, adoption rates vary across regions due to socio-economic factors and institutional support. The adoption of early maturing common bean varieties is generally higher compared to maize varieties due to their shorter growth cycle and ability to fit within the shorter rainy seasons typical of semi-arid areas. Research by (Wossen *et al.*, 2017) indicates that smallholder farmers in semi-arid regions of Sub-Saharan Africa have embraced early maturing common bean varieties as they provide a more predictable harvest window and reduce exposure to late-season droughts.

The drought-tolerant maize varieties have demonstrated potential to increase yields and reduce yield variability in water-stressed environments. However, their impact depends on effective adoption and complementary practices like soil and water management, highlight that adoption of drought-tolerant maize varieties has led to yield increases of up to 20% in some regions, contributing to improved food security and farmer livelihoods (Partey *et al.*, 2018; Siminyu *et al.*, 2021).

The Early maturing common bean varieties contribute to improved food security by providing farmers with an earlier and more reliable harvest (Phiri *et al.*, 2022). They help mitigate risks associated with late-season droughts and can be intercropped or rotated with maize to optimize land use (Tonnang *et al.*, 2020). According to (Phiri *et al.*, 2022) adoption of early maturing common bean varieties has led to increased household food availability and income among smallholder farmers in semi-arid areas, contributing to improved resilience.

Conclusion

The adoption of improved maize drought-tolerant and early maturing common bean varieties by smallholder farmers in semi-arid areas of Sub-Saharan Africa shows promise in enhancing food security, resilience to climate variability, and livelihoods. While both types of varieties offer benefits, their adoption rates and impacts vary due to socio-economic factors, institutional support, and specific agro-ecological conditions. Addressing challenges related to seed availability, input costs, extension services, and market access is crucial for scaling up adoption and maximizing the benefits of these improved varieties for smallholder farmers.

Intercropping aligns well with the principles of Climate Smart Agriculture by promoting resilience, resource efficiency, and sustainability in semi-arid areas of sub-Saharan Africa. While it offers significant benefits such as enhanced resource use and risk mitigation, careful management and consideration of local conditions are essential to maximize its potential and overcome potential challenges.

Each country in sub-Saharan Africa has tailored its approach to Climate Smart Agriculture based on local climate conditions, agricultural practices, and socio-economic factors specific data points and detailed statistics, referring to the respective national agricultural reports and strategy documents is recommended.

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