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Adoption of Climate-Smart Agriculture in Small-Scale farming in Africa: Are the pillars for CSA accounted for?

Mbwambo, J. S[1].

[1]*Sokoine University of Agriculture, Department of Development and Strategic Studies. Email: jonathan.stephen@sua.ac.tz*

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Abstract: *Studies have shown that climate change has a significant effect on the rural landscape and the equilibrium of the agrarian and forest ecosystems resulting in instability disintegration of agricultural-dependent livelihood systems in rural and peri-urban areas. To address these and related challenges, many countries have attempted Climate Smart Agriculture (CSA). CSA has been proven to address the intertwined challenge of increasing agricultural productivity while at the same time maintaining sustainable levels of carbon emissions from agriculture. Despite its proven benefits, the adoption of CSA in Africa varies across the continent. In some countries the adoption of certain practices is as low as 10% and in others above 60%. Using scoping, narrative and descriptive approaches in the analysis of literature, this study has demonstrated that Climate-Smart Agriculture technologies have proved to be effective in delivering food security, climate change mitigation, and adaptation. However, while researchers working in these areas have attempted to work on the biophysical aspects of Climate-Smart Agriculture, there are gaps in the understanding of how the adoption of Climate-Smart Technologies has contributed to climate change mitigation and adaptation. The study further revealed that various factors such as household characteristics, land ownership and gender were considered in the introduction and adoption of CSA technology. The study recommends that more work is needed to enhance knowledge on mitigation and adaptation aspects of CSA technologies. The study recommends further that considerations be made on resources endowment during the recruitment of farmers to adopt CSA technologies.*

Keywords: *Climate-smart agriculture, adoption, climate change, agriculture*

1. Background Information

Climate change, as argued by Filipe et al., (2020) is associated with global warming caused by the increase in the accumulation of greenhouse gas in the lower atmosphere. Morgado *et al.,* (2022) demonstrated that the global temperature is increasing by 0.20C per decade and this increase has contributed significantly to the overall change in the climate affecting various sectors including agriculture. Studies published by IPCC (1990), Adams *et al.,* (1998), and Maria de Salvo (2013) presented proof that climate change significantly affects both the cropping and livestock systems. Other authors, including Walker and Steffen (1997), Bruijnzeel (2004) and Siwar *et al.,* (2013) have shown that climate change has a significant effect on the rural landscape and the equilibrium of the agrarian and forest ecosystems. The resulting effect of the impact on agriculture includes the instability in crop production and the disintegration of agricultural-dependent livelihood systems in rural and peri-urban areas. The far-reaching consequences of the impact of climate change on agriculture as put forward by Siwar *et al.,* (2013) include induced changes in the markets and food prices as well as the destruction of the supply chain infrastructure related to agriculture. Thus, agriculture is both a victim and a perpetrator of the climate change scourge.

Current agricultural management practices and the associated land use changes account for one-third of total Green House Gas emissions in Africa (IPCC, 2014). While there is a significant political will to increase agricultural productivity for both livelihood and economic prosperity in Africa, efforts are being undertaken to ensure that agricultural practices are climate-friendly and thus contribute to the reduction of Green House Gases or increasing resilient productivity and reducing emissions from agriculture (Richards *et al.,* 2016) and Wollenberg *et al.,* 2016).

Addressing the intertwined challenge of increasing agricultural productivity while at the same time maintaining sustainable levels of carbon emissions from agriculture may be resolved through the adoption of climate-smart agriculture. Climate-Smart Agriculture, according to FAO (2013) and Kurgat *et al.,* (2020) targets three objectives: (i) sustainably increasing agricultural productivity to support equitable increases in farm incomes, food security, and development; (ii) adapting and building the resilience of food systems to climate change; and (iii), where possible, reducing greenhouse (GHG) emissions from agriculture. In this case, any farm technology that delivers its impact on the above-mentioned outcomes and agricultural interventions that meet these goals are considered "Climate-Smart" (FAO, 2013). Some of the recently introduced Climate-Smart practices as reported by Kurgat *et al.,* (2020) include Maize-legume rotation in the United Republic of Tanzania, minimum tillage in the Republic of Malawi, and ridges and soil bunds for soil and water conservation in both the United Republic of Tanzania and the Republic of Malawi.

Most of these CSA best practices have been tested and promoted in various countries in Africa. These include the use of an integrated soil fertility management framework to increase maize yields in Uganda, Nigeria, and Kenya (see for example Gram *et al.*, (2020), Rware *et al.*, (2020), Hamed *et al.*, (2020), Birthe *et al.*, (2020), and Oladimeji *et al.*, (2020). Studies by Oladimeji *et al.*, (2020), Ighodaro *et al.*, (2020), Makate *et al.*, (2019) have reported successful stories on the use of soil conservation and multiple stress crop practices in various countries including Nigeria, South Africa, Ethiopia, Mozambique, and Zimbabwe. Despite the benefits described earlier, the adoption of Climate-Smart Agriculture varies from one place to another. Tesfaye *et al.*, (2017) reported that the adoption of maize-legume rotation in Tanzania, minimum tillage in Malawi, and soil water conservation in both Kenya and Tanzania are below 10%. Mungai *et al.*, (2017) reported 62% adoption of improved varieties of maize in Kenya and nearly 95% adoption of improved crop varieties in Lushoto Tanzania as reported by Nyasimi *et al.*, (2017).

This paper argues that the indifferent adoption of CSA technologies is attributed to limited consideration of small-holder farmers' resources endowment and how they impart on the decision-making in the process of adoption of CSA practices. This paper will therefore look at the status of research in CSA in Africa pointing out areas that may require research consideration including resource allocation dynamics as a prerequisite for the adoption of CSA technologies.

The rest of the paper is organized as follows, following this section, the paper presents the methodology used in the review of the literature. The theoretical context of CSA adoption is presented in section three. Section four of this paper is dedicated to the presentation of the status of research on CSA in Africa to unveil areas that have not received adequate attention. The paper is concluded with a discussion on the importance of resource endowment and allocation and how they impart the adoption of CSA practices in Africa.

2.0 Methodology

2.1 Methodological Synthesis: Exploring Climate-Smart Agriculture Literature through a Multifaceted Approach

Based on the work by Arksey and O'Malley 2005, Levac *et al.*, (2010) and Daudt *et al.*, (2013) this work adopted a scooping method to review and decide on relevant literature for this study. The approach helped the author to examine, at the beginning of the study, the extent, range and nature of the research activities on Climate-Smart Agriculture and determine the scope of the literature required for this work.

Thereafter a narrative approach was used. A narrative approach as argued by Sylvester *et al.*, (2013) is used for the qualitative interpretation of knowledge presented in the literature, and in most cases, the approach is used to summarize or synthesize what has been written on a particular topic. However, the approach is limited in its rigor and according to Davies (2000) and Green *et al.*, (2006), the approach does not help in the generalization of gathered information from the literature.

To complement the narrative approach, the author combined the narrative approach with a descriptive or mapping approach. The primary goal of the descriptive approach as put forward by King and He, (2005) and Paré *et al.*, (2015) helps in determining the extent to which a body of knowledge in a particular area of study presents interpretable trends or patterns based on the author's experience and pre-existing theoretical background. In adopting the descriptive approach, the author followed a systematic style where the surveyed literature was screened and classified to accommodate the orientation of the various sources of literature on Climate-Smart Agriculture as a subject and a challenge requiring both policy and program support.

With a descriptive approach, the author was able to extract from the literature certain presentations of interest including the year of publication, methods used for data collection, the significance of the paper on the issue under the study as well as the popularity of the authors. Thus, each paper reviewed in this work was treated as a unit of data collection and analysis.

2.2 Modelling adoption of CSA in Africa

Lipper *et al.*, (2014) defined Climate-Smart Agriculture (CSA) as an approach to agricultural development that aims to address the intertwined challenges of food security and climate change. In this context, Climate-Smart Agriculture as put forward by Kurgat *et al.*, (2020) is adopted for increasing agricultural productivity, building the resilience of food systems to climate change, and reducing greenhouse (GHG) emissions from agriculture. Therefore, farmers adopting CSA are always trying to integrate these objectives which as observed by Wekesa *et al.*, (2018) focus on enhancing agricultural productivity, food security, and the overarching objective of reducing emissions.

Given that CSA practices vary and benefit farmers differently, farmers' choices and the adoption of a given practice, among others, may be explained by the utility model described by Terdoo and Adekola (2014). Terdoo and Adekola (2014) argue that farmers as individuals always rank their choices based on both preferences and the anticipated benefits. In this case, farmers adopt one or more than one set of practices if the anticipated benefits are higher than not adopting the same.

Thus, farmer i may decide to adopt CSA practice j if the utility from j is perceived to be more than that from other options, say k. The utility model may therefore be described as:-

$$Uij = (ß\ j\ Xi + Ɛj) > Uik\ (ß\ Xi + Ɛk),\ k \neq j$$

Where:

- Uij and Uik denote the perceived utility by farmer i from CSA practice options j and k, respectively;
- Xi is a vector of regressors that influence the CSA practice option the farmer chooses;
- ßj and ßk are parameters of the independent variables; and
- Ɛj and Ɛk are the error terms.

However, while farmers tend to adopt a given practice based on the utility model described above, it is important to acknowledge that smallholder farmers are faced with complex decisions to make beyond utility parameters. The adoption of certain practices, as Musafiri et al., (2021) observed, could be influenced by other factors including the location, demographics, biophysical factors as well as the nature of the practices and resources needed for their adoption. In most cases, farmers adopt a bundle of practices to maximize utility.

Other than factors described by Musafiri et al., (2021, Gebremedhin and Swinton, (2003), Marenya and Barrett, (2007), identified the endowment of both physical and human factors as some of the determinants of the adoption of technologies involving small-scale farmers. Others including Gebremedhin and Swinton, (2003) identified food insecurity as the main driver while Holden *et al.*, (2004) and Paudel and Thapa (2004) pointed out that the adoption may also be influenced by access to external opportunities including off-farm employment and access to extension services. It seems from this section that resource allocation and/or constraints were not considered in explaining variation in the adoption of CSA. The next section presents the status of research on CSA in Africa in an attempt to single out areas that have not received attention including the allocation of resources for the adoption of CSA.

2.3 Status of research in CSA in Africa

The growing attention to CSA research in Africa gained momentum in 2014 when the percentage growth in publications in this area reached 22.5% (Barasa et al., (2021). The interest in the CSA was partly driven by the growing impact of climate change in Africa affecting, to a large extent, livelihoods and small-scale farming systems. A review of the literature shows that in dealing with CSA and the desire to support the heavily impacted agriculture, researchers worked and published mainly in the following thematic areas:-

- Soil conservation, fertility improvement and climate change; and
- Adoption of Climate-Smart Agricultural Practices.

Beginning with soil conservation and fertility management, this section presents a summary of findings and recommendations from the literature with the view of identifying areas that may need further attention.

2.4 Soil conservation and fertility improvement and climate change

Working on soil fertility in Kenya, Musafiri (2020) provided evidence that smallholder farming is vital in pinpointing greenhouse gas emission hotspots and thus recommended that policies and intervention measures for CSA be made based on both farm-level soil fertility management technologies and socio-economic characteristics that affect their adoption. Investigating the correlation between soil conservation practices and other factors in Nigeria, Oladimeji (2020), observed a positive correlation between soil conservation practices and contract farming, crop–livestock integration, and off-farm income diversification. Similar studies by Ighodaro *et al.*, (2020) and Abegunde *et al.*, (2020) in South Africa showed that the adoption of soil conservation practices by smallholder farmers substantially influences farmers' revenue. On the utilization of fertilizers, Kurgat *et al.*, (2020) found that major determinants of the adoption of fertilizer use included female control of farm resources, farm location, and household resources. In this case, Kurgat *et al.*, (2020) recommended that the adoption of fertilizers may be enhanced through the implementation of strategies that enhance the building of household resources. This view is supported by Kiwia *et al.*, (2019). Kiwia *et al.*, (2019) showed that intercropping combined with the application of small amounts of inorganic fertilizers is superior to unfertilized intercrops. The authors recommended that the strategic application of small amounts of inorganic fertilizers is essential for the productivity and economic sustainability of cereal–pigeon pea intercropping under smallholder farming. Furthermore, Kpadonou *et al.*, (2019) showed that the use of organic fertilizer may provide an additional benefit as it can serve as an enabling factor for greater adoption of modern seeds, especially in less favourable climate areas.

Working on crop productivity in Sierra Leone Kamara *et al.*, (2019) revealed that smallholder agriculture would be a driver of economic growth and development in Africa if adequate investment is focused on eliminating the challenges faced by smallholder farmers. On the same subject, Baudron *et al.,* (2019) showed that wheat productivity could be increased through increased seeding rate, increased Nitrogen application combined with frequent weeding, and labour-saving technologies. Such technologies tend to be accepted and utilized by farmers. Supporting this view, Abegunde *et al.,* (2020) while working on the perception of farmers towards yield-increasing technologies revealed that the use of organic manure was highly accepted, followed by rotational cropping, mulching, and cultivation of cover crops Analysing the suitability and applicability of Conservation Agriculture (CA), Thierfelder *et al.,* (2016) recommended that blanket recommendations of one CA system across many agro-ecologies must be discouraged as this may lead to underperformance of CA in some areas and rejection by smallholder farmers if yield benefits are not achieved.

Studying agricultural intensification scenarios on household food availability and greenhouse gas emissions in Rwanda, Paul *et al.,* (2018) reported that livestock intensification is essential to the CSA portfolio providing synergies between productivity, generation of household income as well as climate change mitigation. These findings point to the reality that CSA works better when more than one technology or practice is deployed. Supporting this assertion, Setimela *et al.,* (2018) confirmed that a combination of climate-smart agriculture technologies is required especially when the negative effects of extreme events such as El Nino and the increase in the resilience of low-input farming systems are to be mitigated. In this case, Paul *et al.,* (2020) recommended that an expansion of the knowledge base around the concept of climate-smart agriculture towards effectively incorporating sustainability aspects in climate change adaptation discourse be enhanced.

2.4 Adoption of Climate-Smart Agricultural Practices

Publishing on the influence of agricultural insurance on the adoption of Climate-Smart Agricultural Practices (CSAPS) Zougmor *et al.,* (2019) provided evidence that the adoption intensity of CSAPS was significantly influenced by agricultural insurance. Working on the adoption of irrigation as one of the CSAPS, Mango *et al.,* (2018) revealed that employment, access to irrigation equipment, access to reliable water sources, and awareness of water conservation practices, such as rainwater harvesting, significantly influence the adoption of small-scale irrigation farming. The author further revealed that farmers' age, distance travelled to the nearest market, and nature of employment negatively influenced the adoption of small-scale irrigation farming decisions. Furthermore, the study revealed that the adoption of small-scale irrigation farming as a climate-smart agriculture practice has a significant positive influence on agricultural income.

Examining the adoption rates of CSA in Zimbabwe Makate (2018) showed that farm typology identification is an important step toward promoting climate-smart agriculture practices in smallholder agriculture. The author noted that multivariate analysis provides useful tools suitable for identifying the important socio-economic characteristics of households influential in determining the adoption of climate-smart agriculture practices. Observing the interaction between household characteristics and farm strategies, Hammond *et al.,* (2017) revealed that the Climate-Smartness of different farm strategies is determined by an interaction between the farm household characteristics and the farm strategy. From these observations, the author recommended that small farms' off-farm income needs to be in place before interventions can be promoted successfully.

Studying the implementation of the Farm of the Future (FOTF) program in Tanzania, Nyasimi (2017) observed that Farmers are adopting various CSA technologies, practices, and institutional innovations after participating in the farms of the future (FOTF) approach using improved crop varieties, agroforestry, and scientific weather forecast information cited as the main practices. The author further observed that to minimize their risks and reduce vulnerabilities, farmers are diversifying and integrating 5 to 10 CSA practices in one season. Working on training and capacity building for CSA Ghana, Zakaria (2020) argued that Participation in capacity-building training, family labour, and agricultural insurance influence farmers' CSA practices adoption intensity. The study recommended that the adoption of CSA practices can be enhanced through training and capacity-building interventions. Other factors as documented by Maindi *et al.,* (2020) include Capital, gender, water availability, market access, and infrastructure and social Networks. These factors as emphasized by Maindi *et al.,* (2020) are the most important determinants of the adoption of CSA-related decision-making and the adoption and intensification of CSA strategies to enhance climate-smart dairy production systems.

Exploring the role of extension and credits on the adoption of CSA in Ethiopia, Makate (2019) noted that, there is an enhanced collective impact of simultaneous access to credit and extension on CSA technology adoption. The study found joint impacts of credit and extension on adoption were less pronounced in youthful and women farmer groups than their old and male farmer group counterparts. Along with the influence of extension and credits is the establishment of relevant institutions and policies to support farmers' capacity to adopt climate-smart practices. In this, Makate *et al.,* (2019) suggested rolling out effective institutional and policy efforts to reduce resource constraints that inhibit farmers' capacity to adopt complementary climate-smart agriculture packages such as conservation agriculture, drought-tolerant maize, and improved legume varieties.

Other important findings documented under this theme include the study by Sanou *et al.*, (2019) in Burkina Faso, Makate (2019) in Ethiopia, Hamed (2019) in Nigeria, and Bashagaluke *et al.*, (2019) in Ghana. These researchers provided evidence that the adoption of agroforestry may be more successful if local biosphere and socio-economic conditions are considered. They further recommended that the introduction of CSA be considerate of gender and the context in which smallholder farmers operate.

It is evident from this review that, except for Makate *et al.*, 2019 whose work recommended for establishment of effective institutional and policy efforts to reduce resource constraints that inhibit farmers' capacity to adopt complementary climate-smart agriculture packages, the role of resources allocation and constraints at farm level was not considered by researchers working on the adoption of CSA. This, as shown in section 3 and the discussion in the next section may explain why the adoption of CSA, despite its proven benefits is not fully adopted in Africa.

3.0 Discussion

As presented in this paper, Climate Smart Agriculture (CSA) has been proposed as an integrative approach to mitigate ongoing climate change and adapt to its consequences without compromising food security. As indicated in the introduction, climate-smart agriculture consists of three pillars: (i) sustainably increasing agricultural productivity and incomes (food security); (ii) adapting and building resilience to climate change (adaptation); and (iii) reducing and/or removing greenhouse gas emissions (mitigation), where possible. While there have been efforts to understand the biophysical dynamics of Climate-Change technologies in Africa, there is still limited understanding of the mitigation and environmental sustainability of the system. Future work involving sustainability assessments with a focus on land management footprints is needed for the CSA analysis to cover all three pillars. Moreover, work on biophysical assessment covering pathways from crop management and productivity to food security and nutrition will add value to CSA practice in Africa.

On the adoption of CSA in Africa, section 4.2 indicated that the adoption of CSA technologies depends upon a myriad of factors including household and farm characteristics. Unfortunately, the analysis did not specifically account for the combined pillars of CSA, namely food security, climate change mitigation and adaptation. Since CSA is an integrated approach to managing landscapes and the interlinked challenges of food security and climate change, its adoption is relatively complex compared to the ordinary farming system.

As observed from section 4.2, most of the previous studies have examined the adoption of individual CSA technologies. The reviewed studies did not adequately address the bundled objectives of the CSA. In many cases, some of these technologies are interrelated and/or yield better results when bundled together as observed by Ogada and Nyangena (2019). Without treating them together, the results may be underestimated or overestimated and thus misjudging the adoption of CSA technologies. Bundling factors together come out of the reality for CSA to achieve its intended functions, more than one technology must be introduced. Under normal circumstances, a rational household will choose a combination of technologies and practices which maximizes its expected utility. This is the basis of the argument that packaged (bundled) adoption may be more productive and beneficial to the farmers than independent adoption of individual technologies Ogada et al., (2021).

This recommendation emanates from the fact that farmers are guided to maximize utility as described described in section three. In many cases, this utility is captured by agricultural productivity which increases with multiple technologies and practices. To maximize utility, farmers choose among various options. A rational household will choose a combination of technologies and practices which maximizes its expected utility. This is the basis of the argument that package (bundled) adoption may be more productive and beneficial to the farmers than independent adoption of individual technologies and practices. Besides choosing technologies and practices, farmers are forced to account for factors beyond technologies. These factors include the nature of land holdings, financial constraints, and access to markets for both inputs and m products.

Therefore, before we look into the adoption of CSA practices, it is important to examine the nature and dynamics of land ownership in Africa. One of the biggest constraints affecting small-scale farmers is the uncertainties regarding land tenure and inadequate access to land. In other places and especially in mountainous areas, the land is exceedingly segmented into small and uneconomic units, resulting generally in disjointed production arrangements associated with low throughput per unit area. Thus, the insecurity of land tenure, unequal access to land, and lack of a mechanism to transfer rights of ownership may explain why farmers in rural areas fail to adopt land-intensive and often permanent CSA practices. However, the extent to which this occurs need to be fully analysed and relevant policy recommendations made.

The second constraint is the lack of financial capital for investing in Climate-Smart initiatives. In most cases, smallholder farmers in Africa depend on savings from their low-income portfolio. Low income and low savings limit the capacity of smallholder farmers to expand and invest in CSA. Compounding this challenge is the lack of financial institutions supporting smallholder farmers in Africa. In all cases, the share of commercial banks' loans to agriculture in general and smallholder farming, in particular, is very low compared to manufacturing, trade, and other services sectors, hampering expansion and technology adoption. While more recently micro-finance institutions have taken financial amenities to largely un-bankable clients, they have reached poorer rural areas and/or smallholder agricultural producers whose livelihoods are characterized by highly seasonal investments and low returns on investments.

The third constraint is the limited capacity to pay or access both input and output markets. While the adoption of CSA practices is proven to be good, farmers are still grappling with the marketing of both agricultural inputs and outputs. Moreover, the available markets are not adequately equipped to serve the needs of the poor including the provision of storage and facilities for value addition.

4.0 Conclusions and Recommendations

The findings of this study underscore the effectiveness of Climate-Smart Agriculture (CSA) technologies in addressing critical challenges such as food security, climate change mitigation, and adaptation. Evidently, CSA holds immense promise in contributing to sustainable agricultural practices and resilience in the face of climatic uncertainties. However, the extent of CSA technology adoption exhibits considerable variability across different countries, indicating the influence of diverse contextual factors.

While substantial research efforts have been directed towards unraveling the biophysical dimensions of CSA, a discernible gap persists in comprehending the nuanced interplay between technology adoption and its potential contributions to both climate change mitigation and adaptation strategies. This critical insight highlights an area ripe for further exploration and scholarly investigation. In light of this, our study advocates for a concerted research endeavor aimed at delving deeper into the intricate mechanisms through which the uptake of CSA technologies can tangibly advance climate mitigation and adaptation objectives.

In order to bridge this knowledge gap, we propose a multi-faceted research agenda that emphasizes not only the assessment of technological efficacy but also the socio-economic, institutional, and behavioral drivers that underpin successful CSA adoption. A holistic understanding of these drivers will empower stakeholders, policy makers, and practitioners with targeted insights to devise more effective strategies for fostering widespread CSA adoption.

Furthermore, this study sheds light on the importance of considering the varying resource endowments of small-scale farmers during the process of recruiting them to embrace CSA technologies. The diversity in resource availability, coupled with the contextual factors mentioned earlier, underscores the need for a customized and flexible approach to technology dissemination. It is imperative that any initiatives aimed at promoting CSA adoption take into account the local agro-ecological conditions, socio-economic contexts, and existing farming practices. By tailoring interventions to align with the specific circumstances of each region, the likelihood of successful and sustainable CSA adoption can be greatly enhanced.

This study therefore, emphasizes the pivotal role of CSA technologies in addressing the multifaceted challenges posed by climate change. By advocating for further research into the climate change mitigation and adaptation aspects of CSA and by highlighting the significance of context-sensitive adoption strategies, our findings contribute to a more comprehensive and informed approach to fostering sustainable agricultural practices in the face of a changing climate.

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