Impacts of Climate Smart Agriculture on livelihoods in sub-Saharan Africa: A Meta-analysis

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Abstract

Sub-Saharan Africa is grappling with surging food demand amid a growing population and challenges of climate change. Climate Smart Agriculture (CSA) emerges as a holistic solution, aiming to counter these complexities and enhance livelihoods. However, the evidence remains thin and mixed. We used a meta-analysis with 18 studies to assess the impacts of climate smart agricultural practices on livelihood indicators in sub-Saharan Africa. We find that adoption of climate smart agriculture is positively correlated with crop and household income and food security in sub-Saharan Africa. We found that the adoption of climate smart agriculture is associated with reduced incidences of poverty on average and improved food security outcomes. These last two findings are, however, only statistically significant at 10%, signifying the need to integrate CSA with other measures to improve food security and to reduce poverty. We can conjecture that the positive effects on incomes are not sufficient to significantly drive-up food security and poverty alleviation.

Keywords: Conservation agriculture; impact assessment; income; poverty

Introduction

Sub-Saharan Africa is at a crossroads, with rapidly rising demand for food driven in part by population growth, increasing average incomes, and changing dietary preferences. The predominant rain-fed smallholder farming systems crucial for enhancing production and productivity are most severely affected by climate change and variability (Anantha et al., 2023; Kassiea et al., 2014). Recent assessments from the Intergovernmental Panel on Climate Change (IPCC) suggest that climate change poses high threats on agricultural yields, food security and income (Birkmann et al., 2022; IPCC, 2022).

A review of the impact of climate change on agriculture shows that climate change has significantly reduced global maize yield by about 4% since 1980 (Campbell et al., 2014) and decline in average maize yield in sub-Saharan Africa is estimated at 5% over the next three decades (IPCC, 2022). This is indicative of increased risks to food security because maize yield is the main staple crop in the region (Ray et al., 2019). As a result, climate smart agriculture (CSA) has gained prominence as one of key approaches championed to address the dual challenges of climate change and the need to increase agricultural productivity (Campbell et al., 2014; Taylor, 2018). Climate smart agriculture aims to increase agricultural productivity and incomes, improve resilience and adaptation to climate change, and to reduce greenhouse gas emissions from agriculture (FAO, 2023; Lipper et al., 2014).
The push for climate smart agriculture in sub-Saharan Africa also helps to close yield gaps, which remain among the highest at 9 t ha\(^{-1}\) and above in some countries (Gassner et al., 2019; Global Yield Gap Atlas, 2023; Jain et al., 2023; Silva et al., 2023). Water stress is among the common factors that result in large yield gaps (Lobell et al., 2009). Silva et al. (2023) found that yield gaps in Zambia due to water limitations follow an increasing regional gradient from Northern Province to Southern Province. This is partly because the northern region is a high region rainfall while the Southern region is characterised by low and erratic rainfall and is projected to be the worst affected by climate change (Ngoma, Lupiya, et al., 2021). Further, increasing incidences of climate change in sub-Saharan Africa may lead to shortening of growing periods, leading to yields penalties (Ofori et al., 2021). With these variations in climatic conditions, farmers need to adapt and change their agricultural practices to those that are resilient and adapted to climate change. These challenges render climate-smart agriculture a viable adaptation option for farmers in response to heightened climatic variations (Teklewold, 2023).

CSA is complex and constitutes a wide range of practices/technologies such as conservation agriculture (CA), fertilizer application, crop rotation, crop residue retention (mulching), intercropping, multiple-stress tolerant varieties, crop diversification, agroforestry among others (Rosenstock et al., 2016). CA is a climate smart agriculture practice based on three principles i.e., minimum/no soil disturbance, residue retention and crop diversification (Giller et al., 2009; Powlson et al., 2016). Intercropping involves the planting of more than one crop in the same lines or alternating lines. An example is maize intercropped with legumes. Crop rotation is the repetitive sequence of crops in the same field in a defined order i.e., when a legume is planted in the current season, a cereal (usually maize) is planted in the same field the next season (Thierfelder et al., 2015). Mulching involves covering at least 30% of the soil surface by organic residue from the previous season (Erenstein, 2002). Agroforestry integrates woody vegetation such as trees and shrubs in agricultural systems to benefit from the ecological interactions (Pantera et al., 2021; Tschora & Cherubini, 2020) leading to increased amounts of carbon in the soil and improved soil quality as a result of increased concentration of nutrients (Ospina, 2017).

In this paper, we define CSA in a broad way, and includes minimum tillage (minimum soil disturbance), cereal and legume intercropping, crop rotation and drought tolerant seed varieties. In terms of adoption, we consider both full and partial conservation agriculture and CSA more generally. Partial climate smart agriculture/conservation agriculture adoption refers to use of minimum tillage and any of the following complementary practices such as crop residue retention (mulching), cereal-legume rotation, intercropping, and improved maize varieties. Full conservation agriculture includes the use of all three main principle of minimum tillage, rotation/intercropping, and mulching.

Various CSAs practices are associated with improved biophysical outcomes such as land productivity, water retention and infiltration and climate resilience (Komarek et al., 2021; Thierfelder et al., 2017; Thierfelder & Wall, 2010). Thierfelder and Wall (2010) found that implementing residue retention with minimum tillage leads to higher infiltration rates and increased moisture retention levels, resulting in increased maize yields compared to
conventional ploughed plots. Additionally, Jain et al. (2023) and Lunduka et al. (2019) found that the cultivation of drought-tolerant maize (DTM) varieties contributes to higher maize yields. Farmers who adopt DTM experience a notable increase in per capita household expenditure, sometimes up to 50%, compared to those using traditional maize varieties (Jain et al., 2023). Furthermore, Manda et al. (2015) found that in Eastern Zambia, farmers who embraced climate-smart agricultural practices achieved higher maize yields and per capita income compared to their non-adopting counterparts. These findings underscore the potential for climate-smart agriculture to not only enhance agricultural productivity but also improve economic outcomes for farmers in the face of a changing climate.

Given its potential benefits, there have been and there are several efforts promoting the use of climate smart agriculture in sub-Saharan Africa (Thierfelder et al., 2015). Some non-governmental organizations (NGOs) and civil society organizations have formed advocacy groups on climate smart agriculture such as the Alliance for Climate-Smart Agriculture in Africa (ACSAA) (Rosenstock et al., 2019) which is a partnership between the New Partnership for Africa’s Development (NEPAD) and international non-governmental organizations such as Oxfam, Catholic Relief Services, CARE, World Vision and Concern (Zougmoré et al., 2021). The promotion of CSA fits in with the need to make agriculture an important element in transforming economies and sustaining livelihoods (Nhemachena et al., 2020) and is key to achieving Sustainable Development Goals (SDGs) 1 and 2 which aims to end poverty in all forms, end hunger, achieve food security and improved nutrition and promote sustainable agriculture (UN, 2023).

As the evidence base is improving on the impacts of climate smart agriculture on land productivity and other livelihood indicators in general, there is need to collate this evidence systematically for SSA where CSA practices has been promoted over the last three decades. This is necessary because there is still a dearth of evidence on the impacts of CSA on livelihoods, and yet this matters for scalability. Where the evidence exists, it is mixed and context specific, at best. Meta-analysis provides a suite of tools to collate such evidence to give more representative results than is possible from single studies. While meta-analyses have been conducted on CSA before, most have focused on adoption (Arslan et al., 2022) and biophysical outcomes such as yield (Corbeels et al., 2020; Corbeels et al., 2014). A few have focused on both biophysical and economic outcomes (Jain et al., 2023; Ngoma, Angelsen, et al., 2021). Arslan et al. (2022) found that diverse factors affect the adoption of technologies and most studies do not include adoption intensity nor adoption of many technologies at a time, while Corbeels et al. (2014) and Corbeels et al. (2020) found that adoption of minimum tillage alone does not give more benefits compared to when it is adopted together with mulching and intercropping/rotation though the practice of mulching and crop rotation face challenges as mulch is used for many other competing needs by farmers and legume cultivation is not attractive due to lack of market for legumes compared to cereals. Jain et al. (2023) and Ngoma, Angelsen, et al. (2021) focused on both biophysical and economic factors and identified labor availability, financial constraints, and economic contexts as pivotal in influencing CA adoption and indicate positive effects on crop yield in the medium to long term, while its impact on household incomes remains uncertain and varies in different studies and contexts.
We complement, extend and build on previous work, especially the meta-analyses in Ngoma, Angelsen, et al. (2021) and Jain et al. (2023) that included both biophysical and economic factors in two main ways. First, we update findings on the impacts of climate smart agriculture on livelihoods in Ngoma, Angelsen, et al. (2021) by expanding the scope, and add crop income in addition to household income. Second, we add to Jain et al. (2023) by expanding by including food security and poverty indicators in our study. In sum, this paper contributes towards a better understanding of the impacts of CSA on livelihoods in SSA by collating emerging evidence using a meta-analysis.

A secondary contribution of this analysis is to propose a consistent definition of CSA. This is because what constitutes CSA differs from author to author. For example, improved maize varieties as used by Bezu et al. (2013) in the study in Malawi comprise both open-pollinated varieties and hybrid maize seed, while Khonje et al. (2015) in Zambia only mentioned hybrid maize seed varieties. On Conservation agriculture, Nkhome et al. (2017) and Zulu-Mbata and Chapoto (2016) use the general definition of conservation agriculture whether CA is used partially (any of the three CA principles) or fully (all three CA principles). According to Mujeyi et al. (2021), CSA adoption is the use of any (at least one) CSA component by a farmer’s household. Makate et al. (2017) considered a household to have adopted sustainable intensification practices (SAPs) if the household adopted any of the following: residue retention (mulching), agroforestry, crop rotation, cereal and legume rotation, organic farmyard manure, inorganic fertilizer, green manure, compost, lime, and land/soil and water conservation measures.

We measure livelihood outcomes using four main indicators: household and crop income, food security and poverty. Food security is measured in various ways to capture access, utilization, and consumption. Household dietary diversity score is often used to assess economic access to food. It is viewed as a reliable proxy that quantifies the number of food groups consumed by any member of a household within a 24-hour period (Kennedy et al., 2011). Another common measure of access to food is months of adequate household food provisioning, which measures how stable a household’s food access is over a 12-month period (Frayne & McCordic, 2015; Sauer et al., 2018). Other measures of food security include breakeven food security, which is defined as a situation where a household has neither a surplus nor shortage of food while occasional food insecurity is defined as a situation whereby a person suffers from periodic shortage (decline) in food consumption (Manda, 2018). The food consumption score is a common measure of food security that shows the quantity and quality of food consumed by a household over a period of seven days (Mango et al. (2017). We measure household income as the sum of crop income, livestock income, non-crop income, remittances, and off-farm income. When considering poverty, it is assessed through various methods by different authors. These include asset-based measurement (Brandolini et al., 2010; Von Maltzahn & Durrheim, 2008), income and Henderson poverty lines (HPLs) (Cutillo et al., 2022; Garner & Short, 2010; Kuypers & Marx, 2018; Von Maltzahn & Durrheim, 2008) and expenditure (De, 2017; Deaton & Kozel, 2005) and it is based on a reference category or threshold. For the studies reviewed, poverty was measured using poverty headcount (Abdoulaye et al., 2018; Abdulai, 2016) and reduced coping strategies index (Setsoafia et al., 2022).
Methods

Data used in this study were collected from scientific literature on the impacts of CSA on livelihood indicators in sub-Saharan Africa published between 2001 and 2023 to capture the most relevant and contemporary literature available through a comprehensive literature search for peer-reviewed publications. The literature search used the following key words and their combinations: “climate smart agriculture”, “conservation agriculture”, “crop rotation”, “intercropping”, “livelihoods”, “nutrition”, “crop income”, “household income”, “dietary diversity”, “improved maize varieties”, “drought tolerant maize varieties”, “hunger, food consumption”, “Africa”, “sub-Saharan Africa”, “Malawi”, “Kenya”, “Zambia”, “Zimbabwe” in Google Scholar. The search returned about 160 articles published between 2001 and 2023. For the studies to be considered for meta-analysis, they had to have discernible and well-defined CSA technologies, coefficients, means, standard errors had to be reported or allow for their calculations from the reported data. After a search, 18 papers published between 2012 and 2022 were selected for the final dataset having met in full the required conditions needed for meta-analysis. Although this study draws evidence from sub-Saharan Africa, the studies reviewed do not represent the entire region but are biased towards southern Africa (Malawi, Mozambique, Zambia, and Zimbabwe). Data was extracted from the economic papers that were selected into an Excel template which was developed in line with the objectives of this study and meta-analysis requirements comprising of study, year, country, coefficient, standard error, factor, and outcome.

In terms of analytical approaches, we used a meta-analysis, which provides a quantitative assessment of the relationship between climate smart agriculture and livelihood indicators (Hansen et al., 2022). We used forest plots to collate results from various studies on the effects of climate smart agriculture on livelihood indicators. The forest plot graphically presents results of a meta-analysis showing the effect-size estimates and their confidence intervals for each study and, the overall effect size from the meta-analysis (Ngoma, Angelsen, et al., 2021; Sedgwick, 2015; Verhagen & Ferreira, 2014).

Results

We first start by giving a summary of results from literature (Table 1). These results show that the effects of CSA on livelihoods remains mixed in southern Africa. Thus, discerning patterns across the different studies would require a meta-analysis as it aids in collating and generalizing results by combining data across diverse studies. Once collated, these results from different studies highlight several nuances as discussed below.

Table 1. Impacts of climate smart agriculture on livelihood indicators

<table>
<thead>
<tr>
<th>Authors</th>
<th>Indicator</th>
<th>Impact (+/-)</th>
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<tbody>
<tr>
<td>Belay et al. (2023); Makate et al. (2017); Manda et al. (2015); Ngoma (2016); Nkhoma et al. (2017); Zulu-Mbata and Chapoto (2016); Tafa et al. (2021); Khonje et al. (2015); Asmare et al. (2019); Kuntashula et al. (2014); (Khonje et al., 2015); Osewe et al. (2021); Sardar et al. (2020)</td>
<td>Crop income (Income realised from crop sales only)</td>
<td>+</td>
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<tr>
<td>Abegunde et al. (2022); Makate et al. (2017); Mango et al. (2017); Mujeyi et al. (2021); Wagstaff (2010); Wekesa et al. (2018); Zulu-Mbata and Chapoto (2016); Manda (2018); (Ngoma, 2016)</td>
<td>Food security</td>
<td>+</td>
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</table>
Household income + 
Poverty -

| Agbenyo et al. (2022); Makate et al. (2019); Mujeyi et al. (2021); Ngoma (2016); Tambo and Mockshell (2018); Zulu-Mbata and Chapoto (2016); Abdoulaye et al. (2018); Agbenyo et al. (2022); Bezu et al. (2013) | Household income |
| Abdoulaye et al. (2018); Abdulai (2016); Setsoafia et al. (2022) | Poverty |

Source: Authors’ compilation from various sources

**Impacts of various CSA practices adoption on household income**

Different CSA practices were used to assess the impacts on household income by different authors. For example crop rotation and residue retention (Ngoma, 2016), conservation agriculture (Zulu-Mbata & Chapoto, 2016), climate smart agriculture (Mujeyi et al., 2021), improved maize varieties (Abdoulaye et al., 2018; Bezu et al., 2013; Khonje et al., 2015), and improved groundnut varieties (Simtowe et al., 2012) are common. We also included per capita food and total expenditure (Khonje et al., 2015; Simtowe et al., 2012) based on the assumption that higher household income increases household expenditure (Durguner et al., 2017; Osberg et al., 2004).

Although research has shown that climate smart agricultural practices increase yields and incomes (Nkhoma et al., 2017; Siziba et al., 2019; Thierfelder et al., 2015), results from the meta-analysis show that the impact of climate smart agricultural practices on household income from various studies is mixed (Figure 1, left panel). In fact, most of the studies report only weakly statistically significant results and fall within the 95% percentile band (Figure 1, right panel). Only Mujeyi et al. (2021) show that adoption of climate smart agriculture is positively and strongly correlated with increased household income. Despite mixed results from various studies under review, the overall results show that adoption of climate smart agricultural practices has a statistically significant ($p = 0.03$) positive effect on household income and this is consistent with results by Tambo and Mockshell (2018) who found that the adoption of conservation agriculture (partial CSA) significantly increases household income.

**Figure 1:** Impact of various CSA practices adoption on household income

Note 1. The horizontal lines in the forest plots are the confidence intervals (CI) and the blue areas are study weights generated in the meta function. CIs that cross the zero line indicate statistical insignificance at 5%, while those on the left (right) show statistically significant negative (positive) effects at 5%.

Notes 2. IMV – improved maize variety, IGV – improved groundnut variety, CA – conservation agriculture, CSA – climate smart agriculture.

**Impacts of CSA adoption on crop income**

Crop income is one of the purported benefits of climate smart agriculture derived from increased crop yields (Agbenyo et al., 2022; Makate et al., 2019; Nkhoma et al., 2017). The impact of climate smart agriculture on crop income has been measured using minimum tillage (Kuntashula et al., 2014), crop residue retention/mulching (Ngoma, 2016), cereal and legume rotation (Kuntashula et al., 2014; Ngoma, 2016), improved maize varieties e.g., drought tolerant maize (Martey et al., 2020; Setsoafia et al., 2022), conservation agriculture (Nkhoma et al., 2017; Zulu-Mbata & Chapoto, 2016), row planting (Martey et al., 2020), crop diversification (Makate et al., 2016) and sustainable agricultural practices (Makate et al., 2017). Productivity is also used in the same category as crop income because it is believed that increased agricultural productivity leads to increased income (Belay et al., 2023; Mutenje et al., 2019). Despite reviewed studies showing inconsistent results, the overall effect of climate smart agricultural practices adoption is positively correlated with increased crop (Figure 2, left panel) and the right panel of Figure 2 shows that most of the studies report statistically significant results and fall within the 95% percentile band.

![Figure 2: Impact of CSA adoption on crop income](image-url)

Source: Author computations from Kuntashula et al. (2014), Makate et al. (2016), Ngoma (2016), Zulu-Mbata and Chapoto (2016), Makate et al. (2017), (Martey et al., 2020) and Setsoafia et al. (2022)

Note 1. The horizontal lines in the forest plots are the confidence intervals (CI) and the blue areas are study weights generated in the meta function. CIs that cross the zero line indicate statistical insignificance at 5%, while those on the left (right) show statistically significant negative (positive) effects at 5%.

Note 2. MT – minimum tillage, CA – conservation agriculture, SAPs – sustainable agricultural practices, DTM – drought tolerant maize, CD – crop diversification, ROW – row planting, ISF - Improved seed, fertilizer, and soil and water conservation, FSWC – fertilizer and soil and water conservation.

**Impacts of CSA adoption on food security**

For the studies reviewed, food security outcomes were measured using household dietary diversity score (HDDS) (Setsoafia et al., 2022; Zulu-Mbata & Chapoto, 2016), adequate food
(Makate et al., 2017), food consumption score (FCS) (Mango et al., 2017), months of adequate household food/grain provisioning (Sauer et al., 2018; Siziba et al., 2019), occasional food insecurity and breakeven food security (Manda, 2018), own consumption per adult equivalent unit (Ahmed, 2022; Martey et al., 2020), and household food security (Khonje et al., 2015; Mujeyi et al., 2021) while poverty was measured using poverty headcount (Abdoulaye et al., 2018; Abdulai, 2016) and reduced coping strategies index (Setsoafia et al., 2022).

Results from Figure 3, left panel show mixed effects of adoption of climate smart agricultural technologies on food security with only two publications in the meta-analysis showing that the adoption of climate smart agricultural practices has a statistically significant positive effect on food security (Mujeyi et al., 2021; Zulu-Mbata & Chapoto, 2016). However, overall results on the effect of climate smart agricultural practices adoption show a statistically significant positive impact on food security at 10% ($p = 0.07$) and Figure 3, right panel indicates a possibility of publication bias.

![Image of Figure 3: Impact of CSA adoption on food security](image)

**Figure 3:** Impact of CSA adoption on food security


Note 1. The horizontal lines in the forest plots are the confidence intervals (CI) and the blue areas are study weights generated in the meta function. CIs that cross the zero line indicate statistical insignificance at 5%, while those on the left (right) show statistically significant negative (positive) effects at 5%.

Note 2. MT – minimum tillage, CA – conservation agriculture, SAPs – sustainable agricultural practices, DTM – drought tolerant maize, CD – crop diversification, ROW – row planting, ISF - Improved seed, fertilizer, and soil and water conservation, FSWC – fertilizer and soil and water conservation.

**Impacts of CSA adoption on poverty**

Unlike other indicators, the results from Figure 4, left panel on poverty are similar for all studies reviewed. The right panel of Figure 4 shows that the studies are not symmetrically distributed, and this means that there is a possibility of publication bias. Adoption of climate smart agricultural practices has a negative effect on poverty i.e., it reduces poverty (Setsoafia et al., 2022). Despite mixed effects of adoption of climate smart agricultural practices on poverty from the reviewed studies, Figure 4, left panel shows that adoption of climate smart agricultural practices has a statistically significant negative overall effect on poverty at 10% ($p = 0.07$). This is further underscored by Hellin and Fisher (2018) that when appropriately...
directed towards the right category of farmers, climate smart agricultural practices offer a viable pathway out of poverty. It is important to note that these results on poverty are based on five studies and might not be representative due to a small sample size.

Figure 4: Impact of CSA adoption on poverty
Source: computed from Abdulai (2016), Abdoulaye et al. (2018) and Setsoafia et al. (2022)
Note 1. The horizontal lines in the forest plots are the confidence intervals (CI) and the grey areas are study weights generated in the meta function. CIs that cross the zero line indicate statistical insignificance at 5%, while those on the left (right) show statistically significant negative (positive) effects at 5%.
Note 2. CA – conservation agriculture, IMV – improved maize varieties, FSWC - fertilizer and soil and water conservation, SAPs – sustainable agricultural practices.

Discussion
Our review suggests that climate smart agriculture has mixed effects on livelihood as the results do not tell one consistent story in all the studies reviewed. It is important to note that some reviewed studies had insignificant results and most of them used partial adoption of climate smart agriculture. In a nutshell, we find the following results on the impact of adopting climate smart agriculture on livelihood.

First, we find a positive correlation between adoption of climate smart agricultural practices and household income. The positive impact of climate smart agriculture on household income is confirmed by Belay et al. (2023), Sardar et al. (2020), Nkhoma et al. (2017), Brown et al. (2018), Agbenyo et al. (2022), and Mutenje et al. (2019). Brown et al. (2018) found that adoption of climate smart agricultural practices leads to increased yields and increased financial benefits because of a corresponding reduction in the use of hired labour, in preferences for herbicides to control weeds. Climate change mitigation in agriculture through climate smart agriculture is further supported by Ogada et al. (2020) who found that adoption of drought tolerant crops increased household income by more than 80% in Nyando, Kenya and Mkwambisi et al. (2016) who found that climate smart agriculture adopters had higher household income than non-adopters. These results underscore the positive role climate adaptation through climate smart agriculture plays in sustaining household income.

Second, the results from the reviewed studies show that adoption of climate smart agricultural practices has a positive overall impact on crop income. Our findings are consistent with findings by Asfaw and Shiferaw (2010), Rosenstock et al. (2019) and Osewe et
al. (2021), Sardar et al. (2020). Asfaw and Shiferaw (2010) found that farmers who adopted climate smart agriculture in Tanzania had more than 70% increase in crop income compared to those that did not adopt. Furthermore, Sardar et al. (2020) found bundled adoption of climate smart agriculture increased crop income by about 45% and 48% for cotton-wheat and rice-wheat crops in Pakistan, respectively. This shows that bundled climate smart agriculture adoption has more benefits than partial adoption (Corbeels et al., 2020; Paul Jr et al., 2023). These findings respond to the one of the main climate smart agriculture concepts of increasing food security in a sustainable manner by increasing farm incomes (McCarthy et al., 2018). Notwithstanding, it is important to note that there are differences between climate smart agriculture adopters and non-adopters and Asfaw and Shiferaw (2010), Rosenstock et al. (2019) found that climate smart agriculture adopters are more educated, have more assets and own more livestock, have more contacts with government extension services and have a good perception of climate smart agriculture. This suggests the need for targeted interventions to ensure climate smart agricultural practices yield their full benefits.

Third, we find that climate smart agriculture has a positive overall impact on household food security, despite inconsistencies in the studies reviewed. We also find insignificant results of the impact of climate smart agriculture on household dietary diversity score (HDDS), breakeven food security, occasional food insecurity, months of adequate household food provisioning (MAHFP), food security score, . This is not surprising as other studies have shown insignificant impacts of climate smart agricultural practices on livelihood, poverty (Mgomezulu et al., 2023). Nevertheless, we find overall significant positive results on the impact of climate smart agricultural practices on food security. This is consistent with the arguments on the importance of climate smart agriculture in improving livelihoods in sub-Saharan Africa through increased yields leading to improved household food security (even surplus food) (Belay et al., 2023; Wagstaff, 2010). Farmers in low and middle income countries are more vulnerable to climate change and climate smart agricultural practices are important in mitigating the effects of climate change which threatens food security (Zougmoré et al., 2021). These results show that climate smart agriculture is an important element in helping improve food security (Lipper et al., 2014) and this is also backed by evidence from Wekesa et al. (2018) and (Jaleta et al., 2018) which shows that farmers who adopted climate smart agriculture are more food secure compared to those that did not.

Fourth, the results from the reviewed studies show that climate smart agricultural practices have a negative and significant impact on poverty. Similar results were found by Obayelu et al. (2019), Mkwambisi et al. (2016) with Mgomezulu et al. (2023) finding contrary results. Mgomezulu et al. (2023) found that the sustained use of climate smart agricultural practices (sustainable agricultural practices used in their study) had no significant impact on poverty in selected districts of Malawi. To the contrary, the majority of results show that adoption of climate smart agriculture reduces poverty and Obayelu et al. (2019) found that adoption of climate smart agriculture (drought tolerant maize varieties) reduced poverty in Northern Nigeria. These results strengthen the assertion by Gordon (2000) that agricultural productivity can be way of improving the availability of food for households as well as increasing household income leading to reduced poverty among smallholder farmers which has worsened due to climate change (Makate, 2019).
Last, the results from the reviewed studies also show that different climate smart agricultural practices can have different effects on different livelihood indicators in sub-Saharan Africa. We therefore conclude that adoption of various climate smart agricultural practices can positively impact livelihoods in the wake of intensified climatic variations in sub-Saharan Africa and there is an urgent need to devise mechanisms to enhance adoption of climate smart agricultural by smallholder farmers who are the major producers of food in sub-Saharan Africa. Climate smart agriculture enhancement mechanisms should integrate the challenge of partial adoption as evidence has shown that the use of partial climate smart agriculture is likely not to give the full benefits of the technology as compared to full adoption or bundled use (Corbeels et al., 2020; Paul Jr et al., 2023) and this could explain why some of the reviewed studies have insignificant results. In sum, the reviewed studies show that climate smart agriculture brings about desired outcomes on all the four livelihood indicators looked at in this paper demonstrating that climate smart agriculture is critical in improving livelihoods of farming households in sub-Saharan Africa. It is worth noting that the positive effects of CSA on food security and poverty are only weakly significant at the 10% significance level. This suggests that while CSA may contribute to yield and income improvements, it cannot be the sole avenue for increasing food security and poverty alleviation.

Conclusion
Sub-Saharan Africa is grappling with surging food demand amid a growing population and challenges of climate change. Climate Smart Agriculture (CSA) emerges as a holistic solution, to counter these complexities and enhance livelihoods. However, the evidence remains thin and mixed. We used a meta-analysis with 18 studies to assess the impacts of climate smart agricultural practices on livelihood indicators in sub-Saharan Africa. We use household and crop income, food security and poverty as livelihood indicators. There are several key results. First, the adoption of CSA practices shows a positive correlation with increased household income, reinforcing the findings of multiple studies suggesting that climate smart agricultural practices lead to improved yields, and reduced labor costs, and higher incomes for farming households. Second, CSA adoption is associated with higher crop income. This finding aligns with studies emphasizing the substantial increase in crop income following the implementation of CSA techniques, emphasizing the importance of bundled adoption rather than partial. Third, while the impact on food security presents mixed results across different studies, the overall result suggests a statistically significant positive effect of CSA adoption on household food security. Despite variations in specific measurements, there’s a consensus that CSA contributes positively to food security, particularly through increased yields and surplus food production. This result is only weakly significant at 10%.

Fourth, the analysis highlights a noteworthy reduction in poverty associated with the adoption of CSA practices. Although a few studies present contrary findings, the majority indicate a significant decrease in poverty levels among smallholder farmers implementing CSA methods, underscoring the potential of CSA in poverty alleviation. This too, is only statistically significant at 10%. The main implication of these findings is a need to devise strategies to enhance the adoption of bundled CSA practices among smallholder farmers in sub-Saharan Africa as partial adoption may not yield the full benefits observed with bundled adoption.
It is worth noting that the positive effects of CSA on food security and poverty are only weakly significant at the 10% significance level. This suggests that while CSA may contribute to yield and income improvements, it cannot be the sole avenue for increasing food security and poverty alleviation. In sum, the findings underscore the importance of CSA in positively influencing livelihood indicators for farming households in sub-Saharan Africa. The nuanced understanding provided by this meta-analysis serves as a valuable guide for policymakers and stakeholders aiming to promote climate smart agricultural practices and to improve the well-being of farming communities in the face of climatic challenges. As the meta-analysis in this paper is based on 18 studies, there is scope to update this analysis with more studies that will be published on the impact of climate smart agriculture in sub-Saharan Africa to increase the validity of the results.

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