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Evaluating the Adoption Levels of Climate-Smart Agricultural Practices: A Case Study of Mpongwe District, Copperbelt Zambia

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Abstract

This study evaluated the adoption levels of climate smart agricultural (CSA) practices among smallholder farmers in Mpongwe District, Copperbelt Province, Zambia. The objectives were to: i) establish how extensively CSA practices are adopted by smallholder farmers in Mpongwe; and ii) assess the impact of CSA practices on agricultural productivity in the region. A total of 100 respondents were sampled using the Central Limit Theorem. Stratified random sampling ensured proper representation of different subgroups within the population. The research employed a convergent mixed methods design, including pretested questionnaires, focus group discussions, and key informant interviews. Quantitative data were analyzed with Stata 14, while qualitative data were examined thematically. Findings indicated a weak positive correlation (r = 0.023) between farmers' education levels and CSA adoption. This challenges common assumptions about the influence of education on adopting new technologies, suggesting benefits may take longer to manifest or require additional interventions. The results highlight the importance of context specific, long-term strategies to promote CSA such as farmer training, adaptive management, and supplementary livelihood strategies to achieve meaningful improvements in productivity among smallholder farmers.

Keywords: Smallholder Farmers, Climate Smart Agriculture, Mpongwe, Adopting, Impact

Introduction

Zambia's agricultural sector is heavily reliant on rain-fed farming systems, making it particularly vulnerable to the impacts of climate change. Over the past few decades, Zambia has witnessed increasingly erratic rainfall patterns, higher temperatures, and more frequent droughts, leading to reduced agricultural productivity (Mendelsohn, 2013). These changes have significantly affected food security, particularly for smallholder farmers who depend on consistent weather patterns for crop production (Mujinja & Mumba, 2019). According to the Zambia Meteorological Department, average temperatures have increased by 1°C over the past 30 years, and rainfall patterns have become more unpredictable (ZMD, 2020). In response to these challenges, Climate-Smart Agriculture (CSA) has emerged as a set of practices aimed at improving agricultural productivity, increasing resilience to climate change and reducing greenhouse gas emissions (FAO, 2013) [14]. CSA practices include conservation tillage, crop diversification, agroforestry, integrated pest management, and water-efficient irrigation systems, all of which can enhance both environmental sustainability and food security however, despite the promising benefits of CSA, the adoption rate in sub-Saharan Africa, including Zambia, remains relatively low (Giller, 2009). The barriers to CSA adoption are multifaceted and include factors such as lack of knowledge, financial constraints, limited access to inputs, inadequate extension services, and a lack of policy support (Chikodzi., 2020). For example, in Zambia, the majority of farmers have limited access to CSA technologies, and many rely on traditional farming practices that are unsustainable and less resilient to climate change (Giller, 2017).

Climate-Smart Agriculture in Mpongwe District

Mpongwe District, located in Zambia's Copperbelt Province, has a population that relies primarily on smallholder farming for livelihood. The district faces significant climate-related challenges, including unreliable rainfall patterns, high temperatures, and recurrent droughts. Despite these challenges, Mpongwe is a region with a high potential for CSA adoption, due to its proximity to agricultural extension services and the availability of local farmer groups (Chikodzi & Togo, 2020) [9]. However, the adoption of CSA practices in Mpongwe has been slow, with farmers continuing to use conventional farming methods that are less resilient to climate variability (Mujinja & Mumba, 2019).

Given the importance of Mpongwe in Zambia's agricultural sector, understanding the factors influencing CSA adoption in the district is crucial. This study aimed to fill a gap in existing literature by focusing specifically on Mpongwe, investigating the socio-economic, institutional, and environmental factors that influence CSA adoption, and assessing the impact of these practices on agricultural productivity and climate resilience.

Agriculture in Zambia plays a critical role in the national economy, contributing significantly to employment and GDP, particularly in rural areas like Mpongwe District (World Bank, 2017). However, climate change poses a significant threat to agricultural productivity, food security, and the livelihoods of smallholder farmers (Mendelsohn 2013). This challenge has led to the increasing importance of Climate-Smart Agriculture (CSA), which aims to improve agricultural productivity, increase resilience to climate change, and reduce carbon emissions (FAO, 2013) [14]. CSA practices, such as conservation tillage, agroforestry, crop diversification, and integrated pest management, have the potential to address climate-induced agricultural challenges in Zambia.

Despite the potential benefits of CSA practices, adoption rates in Zambia remain low, with several barriers preventing widespread uptake, including limited access to financial resources, lack of awareness, inadequate extension services, and insufficient policy support (Chikodzi, 2020). In Mpongwe, smallholder farmers continue to rely on traditional farming practices, which often exacerbate climate change impacts and lead to lower agricultural productivity (Giller, 2009).

This research aimed to evaluate the adoption of CSA practices in Mpongwe District, Zambia, identify the barriers to adoption, and assess the impact of CSA on agricultural productivity and climate resilience. The findings of this study intended to inform policymakers, development organizations, and local stakeholders on strategies to promote CSA practices in Mpongwe and similar regions in Zambia.

Problem Statement

Climate change has led to increased vulnerability in Zambia's agriculture, particularly in Mpongwe District, where smallholder farmers are highly dependent on rain-fed agriculture. Despite the potential of Climate-Smart Agriculture (CSA) to address these challenges, adoption remains low. This is partly due to barriers such as lack of access to financial resources, limited knowledge about CSA practices, inadequate support services, and socio-cultural constraints (Chikodzi, 2020). The problem is exacerbated by the fact that of the 119000 registered farmers in Mpongwe (sourced MOA Mpongwe 2023-2024 unpblished) the majority continue to use traditional agricultural methods that are not resilient to climate variability (Mujinja & Mumba, 2019). Without understanding the underlying factors influencing CSA adoption, it will be difficult to develop effective strategies to increase adoption rates and enhance the resilience of agriculture to climate change.

Main and Specific Objectives

Main Objective

To evaluate the adoption of Climate-Smart Agricultural (CSA) practices and assess their impact on agricultural productivity District, Copperbelt.

Specific Objectives

1. To determine the extent of CSA practice adoption among smallholder farmers in Mpongwe District.
2. To assess the impact of CSA practices on agricultural productivity.
3. To evaluate the resilience of farmers who have adopted CSA practices compared to those who have not.

Hypotheses

Null (H_0): Farmers' education level predicts the adoption of CSA practices.

Alternative (H_1): Farmers' education level does not predict the intensity of CSA practice adoption of CSA practices.

Null Hypothesis (H_0): There is no significant difference in agricultural productivity (crop yield) between farmers who adopt CSA practices and those who do not.

Alternative Hypothesis (H_1): There is a significant difference in agricultural productivity (crop yield) between farmers who adopt CSA practices and those who do not.

Null Hypothesis (H_0): Farmers who adopt CSA practices exhibit higher resilience (income stability) compared to non-adopters in Mpongwe District.

Alternative Hypothesis (H_1): $_0$): Farmers who adopt CSA practices do not exhibit higher resilience (income stability) compared to non-adopters in Mpongwe District.

Agriculture Extention Education

Agriculture extension education in Zambia plays a critical role in bridging the gap between research institutions and smallholder farmers, who constitute the backbone of the country's agricultural sector. The system aims to disseminate improved farming techniques, modern technologies, and best practices to enhance productivity and food security. Despite its importance, extension services face numerous challenges, including limited funding, inadequate staffing, and poor infrastructure, (Ministry of Agriculture, 2023). Many farmers in remote areas have little to no access to extension officers, leaving them reliant on traditional farming methods that often yield poor results. The government, through the Ministry of Agriculture, has implemented various programs to strengthen extension services, but their reach remains inconsistent across the country. The history of agricultural extension in Zambia dates back to the colonial era, but it gained more structure after independence in 1964. Initially, the focus was on large-scale commercial farming, but over time, the emphasis shifted to supporting smallholder farmers, Food and Agriculture Organization [FAO], (2022). Today, the extension system operates through a network of government-employed officers, non-governmental organizations, and private sector players. These agents work to educate farmers on crop diversification, soil conservation, pest management, and post-harvest handling. However, the ratio of extension officers to farmers is alarmingly high, with one officer often serving thousands of farmers, making individualized attention nearly impossible.

(Zambia National Farmers' Union, 2021), explains that one of the key components of agricultural extension in Zambia is the use of demonstration plots, where farmers can observe the benefits of new technologies firsthand. These plots showcase improved seed varieties, irrigation techniques, and fertilizer application methods. While effective in theory, the practical implementation often falls short due to logistical constraints. Many farmers, especially women and youth, report difficulties in accessing these demonstrations due to distance or lack of information.

Additionally, the success of these plots depends heavily on consistent follow-up, which is frequently lacking due to resource limitations. The integration of digital tools into extension services has shown promise in overcoming some of these barriers. Mobile platforms and radio programs are increasingly used to deliver timely agricultural advice to farmers. For instance, platforms like the Zambia National Farmers Union's SMS-based system provide weather forecasts, market prices, and pest alerts. However, the digital divide remains a significant hurdle, as many smallholder farmers lack smartphones or reliable internet access. Efforts to expand digital literacy and infrastructure in rural areas are essential to maximize the potential of these innovations World Bank, (2021).

Gender disparities further complicate the effectiveness of extension education in Zambia. Women, who constitute a large proportion of the agricultural workforce, often have less access to extension services compared to men. Cultural norms and household responsibilities limit their participation in training sessions and field demonstrations, International Fund for Agricultural Development [IFAD], 2020) [25]. Programs specifically targeting women farmers have been introduced, but their impact is yet to be fully realized. Empowering female farmers with knowledge and resources could significantly boost household food security and economic stability. Youth engagement in agriculture is another area where extension education could make a substantial difference. Many young people view farming as an unattractive career due to its labor-intensive nature and perceived low returns. Extension programs that highlight agribusiness opportunities, such as value addition and niche markets, could help change this perception. Vocational training centers and youth-focused initiatives are beginning to emerge, but they require more support and scaling to make a lasting impact. United Nations Development Programme [UNDP], (2022).

Climate change poses additional challenges for extension services in Zambia. Erratic weather patterns, prolonged droughts, and unpredictable rainfall demand adaptive farming practices. Extension officers are now tasked with educating farmers on climate-smart agriculture, including conservation farming, drought-resistant crops, and water harvesting techniques, United Nations Development Programme [UNDP], (2022). However, the urgency of climate adaptation often outstrips the pace at which these practices are adopted, leaving many farmers vulnerable to environmental shocks. Public-private partnerships have emerged as a viable solution to some of the systemic issues plaguing extension services. Companies in the agro-input sector, for example, often provide training and resources to farmers as part of their corporate social responsibility, International Fund for Agricultural Development [IFAD], (2020) [25]. These collaborations can fill gaps left by government programs, but they also raise concerns about conflicts of interest, such as the promotion of specific products over others. Balancing commercial interests with unbiased agricultural advice is crucial for maintaining trust in extension services.

Adoption of Agriculture Innovations

The adoption of agricultural innovations in Zambia remains a complex process influenced by multiple socioeconomic, institutional, and environmental factors. Smallholder farmers, who constitute the majority of agricultural producers, often face significant barriers in accessing and implementing new technologies despite their potential to improve productivity and resilience, (Arslan 2020). Government programs like the Farmer Input Support Programme (FISP) have attempted to bridge this gap by subsidizing improved seeds and fertilizers, yet adoption rates vary considerably across regions and farmer categories. Many farmers continue to rely on traditional practices passed down through generations, demonstrating the strong influence of cultural factors in technology uptake, (Chikoye, D, & Muleba, M. 2021) [10].

The compatibility of innovations with existing farming systems significantly affects their adoption among Zambian smallholders. Technologies that require minimal changes to current practices, such as improved seed varieties that fit traditional planting methods, tend to see faster uptake than those demanding complete system overhauls, (FAO. 2022). Conservation agriculture techniques, for instance, have shown mixed results as they challenge conventional tillage practices deeply embedded in local farming culture. Farmers often modify introduced technologies to suit their specific contexts, creating hybrid systems that blend modern and traditional elements in ways researchers might not anticipate.

Access to reliable information emerges as a critical determinant of innovation adoption, with many farmers lacking exposure to appropriate technologies or understanding their benefits, (Kuntashula, E., & Chabala, L. M. 2022) [28]. While agricultural extension services represent the primary channel for disseminating innovations, the ratio of extension officers to farmers remains alarmingly high at approximately 1:1,500, (Haggblade, S., & Nyembe, M. 2021) [20]. This severe understaffing limits personalized guidance and follow-up, resulting in partial or improper implementation of new practices. Digital platforms and radio programs have begun supplementing traditional extension methods, but their reach remains constrained by limited internet access and digital literacy in rural areas.

Financial constraints pose another major barrier to technology adoption, as many smallholders lack the capital to invest in improved inputs or equipment. Even when innovations promise long- term benefits, the high upfront costs deter cash-strapped farmers from taking risks. Credit facilities remain largely inaccessible due to stringent collateral requirements and high interest rates, while government subsidy programs often fail to reach the most vulnerable farmers, (Lunduka, R., Mateva, K. I., Magorokosho, C., & Manjeru, P. 2020). This financial exclusion perpetuates a cycle of low productivity and poverty, as farmers cannot afford the very technologies that could help them break free from subsistence farming.

The risk perception associated with new technologies significantly influences adoption decisions in Zambia's unpredictable agricultural environment, (Manda, J, *et al*

2021). Farmers facing climate variability and market instability often prefer familiar practices with known outcomes over innovations that might fail under local conditions. This risk aversion explains why drought-tolerant crop varieties have gained relatively good acceptance, while more complex innovations like precision farming techniques struggle to gain traction. Successful demonstration plots and testimonials from peer farmers have proven effective in reducing perceived risks, but these require substantial investment to scale up across diverse agro-ecological zones.

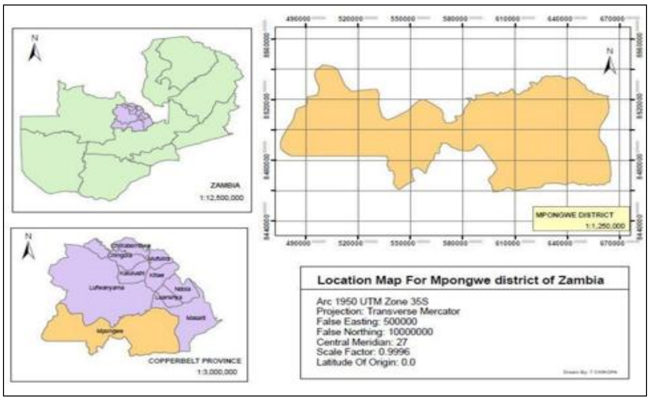
Significance of the Study

This study will contribute to the growing body of knowledge on the adoption of Climate-Smart Agriculture (CSA) in Zambia, specifically in Mpongwe District. The findings will provide a better understanding of the factors that influence CSA adoption, including socio-economic, institutional, and environmental factors. By identifying barriers to adoption and assessing the impact of CSA practices on agricultural productivity and resilience, this research will offer recommendations for policymakers and development agencies on how to increase CSA uptake in Zambia.

The study will also provide valuable insights for smallholder farmers, extension officers, and community-based organizations on the benefits and challenges of CSA, helping them make informed decisions about the adoption of CSA practices. Ultimately, this research will contribute to enhancing food security, improving agricultural sustainability, and increasing the climate resilience of smallholder farmers in Zambia.

Methodology

Study Area Description



Source of map image (Mpongwe town council planning 2023)

Fig 2: Location Map for Mpongwe

Mpongwe District is located in the Copperbelt Province of Zambia, approximately 60 km from the provincial capital, Ndola. The district is in Agro-Ecological zone III characterized by a predominantly rural setting where agriculture forms the backbone of the local economy. Smallholder farmers in Mpongwe engage in the cultivation of crops such as maize, soya beans, cassava, groundnuts, and vegetables, all of which are significantly affected by climate variability.

Study Design

A descriptive study design was chosen to systematically capture the current status of CSA adoption among farmers in Mpongwe District. This approach focuses on detailing the characteristics of a phenomenon without manipulating variables and thus addresses fundamental questions of "what," "where," "when," and "how's It permits identification of prevailing farming practices, challenges, and socio-economic or environmental influences on adoption, providing a comprehensive snapshot of the situation.

Target Population

The target population for this study includes smallholder farmers who are either adopting or not adopting CSA practices in Mpongwe District. Additionally, agricultural extension officers who work closely with these farmers, local policymakers, and representatives from community-based organizations (CBOs) involved in agricultural development will also be part of the study. By targeting these groups, the study aims to gather comprehensive insights into the factors driving or hindering CSA practices from multiple perspectives within the district.

Sample Size and Sample Size Determination

The sample size for this study was determined using the Central Limit Theorem (CLT), which ensures that the sample mean follows a normal distribution even if the population distribution is not normal (sample size >30 is appropriate). A sample size of approximately 100 respondents will be sufficient for reliable results. To determine this sample size, the study applied a formula for sample size determination considering a 95% confidence level, a 5% margin of error. This sample will be distributed proportionally across different categories, such as farmers practicing CSA and those not practicing CSA, as well as extension officers and other stakeholders.

Sampling Technique

A stratified random sampling technique was used to ensure that the different sub-groups within the population are adequately represented. The stratification was based on factors such as the type of farming practices (CSA adopters vs. non-adopters) and the roles of the individuals (e.g., farmers, extension officers, CBO representatives). Random sampling was then employed within each stratum to select participants, ensuring that each individual has an equal chance of being included. This approach anabled for a more accurate representation of the various factors that influence CSA adoption across different groups within Mpongwe District.

Data Collection

Data for this study will be collected using a convergent research design of mixed method approach, including pre tested questionnaires, focus group discussions and key informant interviews. Surveys will be used to gather quantitative data from smallholder farmers, extension officers, and other stakeholders on socio-economic factors, environmental conditions, and institutional support affecting CSA adoption. Semi-structured interviews will provide deeper insights into the perspectives of key informants, such as policymakers, and agricultural extension, regarding the role of policies and support structures in promoting CSA. Focus group discussions will be conducted with smallholder farmers to capture shared experiences and challenges regarding the adoption of CSA, while field observations will provide first-hand information on the agricultural practices being used in the district.

Data Analysis

Data analysis involved both quantitative and qualitative approaches. Quantitative data was analyzed using statistical software Stata, employing descriptive statistics like frequency distributions and percentages to summarize the data. Inferential statistics of correlation and T- Tests, were used to explore relationships between socio-economic, institutional, and environmental factors and CSA adoption. Qualitative data from interviews and focus groups were analyzed using thematic analysis to identify recurring patterns, themes, and insights that reflect the barriers and opportunities related to CSA adoption.

Results

Table 1: Raw Data of Demographic Information

Gender	Age	Household size	Primary occupation	Farm Size (Acre/hectares)	Years of farming experience
Female	32	5	crop farming	1 hector	4
Male	23	4	crop farming	1.5 hectors	5
Male	43	8	livestock farming	1 hector	7
Female	68	6	crop farming	3.5 acres	10
Male	69	6	livestock farming	2 hectors	15
Female	49	8	other	2 acres	10
Female	26	5	crop farming	1 acre	3
Female	68	5	crop farming	one lima	5
Female	33	7	crop farming	1 lima	8
Male	39	4	livestock farming	1 hector	35
Male	28	5	crop farming	3 hectors	12
Female	26	11	crop farming	2 hectors	3
Female	27	6	crop farming	2 hectors	7
Female	31	6	livestock farming	4 hectors	4
Female	27	6	livestock farming	3 hectors	9
Male	29	8	livestock farming	1 hector	10
Female	22	8	livestock farming	1 hector	15
Male	25	5	crop farming	1 hector	2
Male	32	3	other	2 hectors	13
Female	56	10	other	2 acres	20
Male	32	5	other	1 hector	23
Female	51	4	crop farming	89 acres	16
Male	52	7	crop farming	5 hectors	17
Female	60	8	livestock farming	2 acres	8
Male	32	4	crop farming	1 acre	15
Female	47	5	crop farming	2.5 hectors	3

Table 2: Raw Data of Challengees and Barriers to Adoption

What challenges hinder your adoption of CSA practices?	What support do you need to adopt CSA?
Lack of knowledge/training	Training/workshop
Limited Access to inputs	Better access to inputs
Lack of knowledge/training	Training/workshop
Limited Access to inputs	Better access to inputs
Lack of knowledge/training	Training/workshop
Lack of knowledge/training	Financial assistance
High initial costs	Training/workshop
Lack of knowledge/training	Other
Limited Access to inputs	Training/workshop
High initial costs	Training/workshop
Climate uncertainty	Training/workshop
Lack of knowledge/training	Other
Climate uncertainty	Financial assistance
Limited Access to inputs	Training/workshop
High initial costs	Better access to inputs
Lack of knowledge/training	Better access to inputs
Lack of knowledge/training	Training/workshop
Limited Access to inputs	Financial assistance
High initial costs	Training/workshop
Lack of knowledge/training	Financial assistance
Climate uncertainty	Better access to inputs
Lack of knowledge/training	Training/workshop
Limited Access to inputs	Training/workshop
Lack of knowledge/training	Training/workshop
Lack of knowledge/training	Financial assistance
Lack of knowledge/training	Other

Table 3: Summary of Occupation

Primary occupation	Freq.	Percentage	Cum.
crop farming	49	49.00	49.00
livestock farming	31	31.00	80.00
Other	20	20.00	100.00
Total	100	100.00	

Table 4: Summary of Adoption of CSA Practices

Are you currently using any CSA practices on your farm?	Freq.	Percent	Cum.
Yes	88	88.00	88.00
No	12	12.00	100.00
Total	100	100.00	

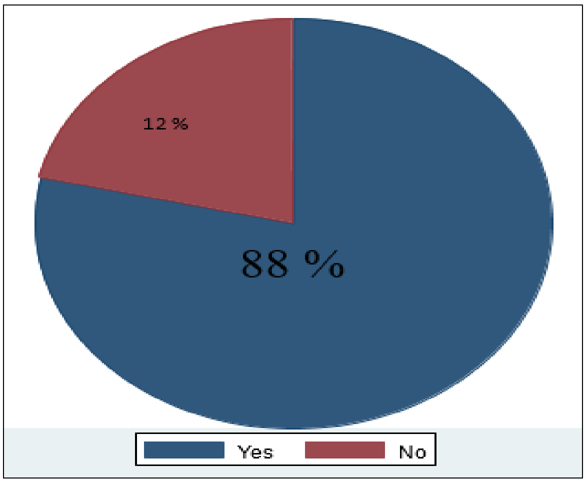


Fig 1: CSA Adoption

The figure above shows a pie chart of the percentage of adoption of Climate smart agriculture practices which answers objective one of the extent of CSA practice adoption among smallholder farmers in Mpongwe District.

Table 5: Correlation test between education level and level of adoption

```
. correlate whatisyourhighestlevelofeducatio ratetheeffectivenessofadoptingcs,
> means covariance
(obs=100)

    Variable |      Mean    Std. Dev.        Min        Max
-------------+----------------------------------------------
whatisyour~o |      2.21     .795124           1          4
ratetheeff~s |       1.7    .6741999           1          3

             | whatis~o ratetheff~s
-------------+--------------------
whatisyour~o |  .632222
ratetheeff~s |  .023232  .454545
```

The correlation results show a weak positive relationship in which higher education levels correlate with lower adoption of Climate smart agriculture practices. Therefore we reject the alternative hypothesis in favor of the null hypothesis that there is a statistically significant level to conclude that the increase in one variable will result in the increase of the other.

Table 6: Correlation of Crop Yield

```
. ttest cropyield1 == cropyield2, unpaired unequal

Two-sample t test with unequal variances
```

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
cropyi~1	88	1.525	.0810274	.7601043	1.363949	1.686051
cropyi~2	12	1.525	.2437476	.8443664	.9885152	2.061485
combined	100	1.525	.0766123	.766123	1.372985	1.677015
diff		4.80e-10	.2568624		-.5526583	.5526583

```
diff = mean(cropyield1) - mean(cropyield2)          t = 0.0000
Ho: diff = 0          Satterthwaite's degrees of freedom = 13.5445

Ha: diff < 0            Ha: diff != 0            Ha: diff > 0
Pr(T < t) = 0.5000   Pr(|T| > |t|) = 1.0000   Pr(T > t) = 0.5000
```

The table above shows the analyzed results of a t-test done on the yield in tonnes per hector for farmers who had adopted Climate smart agriculture practices vs those who did not. At 95% confidence level, the results show that the P-value is 1 which means there is no statistical evidence to support the relationship between the two variables. Therefore we fail to reject the null hypothesis or the alternative hypothesis that there is no significant difference in the yield between adopters and those who do not adopt Climate smart agriculture practices in Mpongwe district.

Table 7: t-Test of Farmer Income

Variable	Obs	Mean	Std. Err.	Std. Dev.	95% Conf.	Interval
i~1max~e	88	6744.186	247.0043	1619.715	6245.711	7242.661
i~2max~e	12	6285.714	285.7143	755.9289	5586.597	6984.832
combined	100	6680	216.5405	1531.173	6244.846	7115.154
diff		458.4718	377.6821		-338.4885	1255.432

diff = mean(income1maxvalue) – mean(income2maxvalue)
t = 1.2139
Ho: diff = 0
Satterthwaite's degrees of freedom = 16.9663
Ha: diff < 0 Pr(T < t) = 0.8793
Ha: diff ≠ 0 Pr(|T| > |t|) = 0.2414
Ha: diff > 0 Pr(T > t) = 0.1207

The table above shows the results from the analysis of resilience in terms of income stability between adopters of Climate smart agriculture practices and those that do not adopt the practices. A test was done in which the results show that the P- value is greater than 0.05 at 95% confidence level. Therefore we reject the null hypothesis in favor of the alternative hypothesis that there is no statistical difference in resilience of income stability between the two groups.

Discussion and Recommendation

The study's finding that 88% of farmers in Mpongwe District had adopted at least one Climate-Smart Agriculture (CSA) practice is noteworthy and suggests a commendable level of awareness and engagement with climate-resilient agricultural strategies. Compared to national and regional averages in Sub-Saharan Africa—where CSA adoption typically ranges between 40–70% (Zulu., 2023; FAO, 2022)—Mpongwe exhibits above-average participation. This can be attributed to strong extension presence, NGO-led interventions, and social learning among farmers. However, as (Mwungu 2022) cautioned, adoption rates measured by "at least one practice" risk overestimating actual implementation intensity. Many farmers adopt simple, low-cost practices such as crop rotation or mulching but not integrated or capital-intensive options like irrigation scheduling, improved seed varieties, or agroforestry. Therefore, the high rate in Mpongwe likely reflects broad awareness rather than deep, intensive adoption, which has implications for the scale of impact on productivity and resilience.

A particularly striking finding was the inverse relationship between education level and CSA adoption, a result that contrasts with conventional diffusion models (Rogers, 2003) and much of the empirical literature that identifies education as a positive predictor of technology uptake (Tambo & Mockshell, 2023; Asfaw, 2019). This counterintuitive trend suggests that in Mpongwe, contextual socio-economic dynamics override education effects. Farmers with higher formal education may diversify their income sources, engaging more in non-farm employment, thereby lowering their dependence on and investment in agriculture. In contrast, less-educated farmers whose livelihoods are more land-dependent might be more responsive to interventions promising improved productivity or stability. This mirrors findings from (Shikuku 2023), who observed that social capital, peer learning, and access to farmer field demonstrations can sometimes substitute for formal education in influencing CSA adoption decisions. Hence, in rural contexts where experiential learning and local trust networks dominate, education alone is not a sufficient determinant of innovation adoption.

The absence of a statistically significant yield difference between CSA adopters and non-adopters provides a critical insight into the temporal and contextual nature of CSA benefits. While CSA is promoted for improving productivity and resilience under climate stress, its outcomes are not instantaneous. Similar to findings by (Komarek, 2021) and (Arslan 2022), yield benefits from conservation agriculture and related practices often manifest after several cropping seasons as soil organic matter improves and ecosystem functions stabilize. The study period in Mpongwe may not have experienced extreme climatic stress, meaning that the buffering advantages of CSA—such as moisture retention and soil fertility restoration were not fully expressed. This supports the argument that CSA's benefits are more pronounced under climate variability conditions, rather than during normal rainfall years.

Moreover, yield outcomes depend on the complementarity of practices rather than the presence of any single technique. As noted by (Totin, 2022), fragmented adoption such as using mulching without improved seed or irrigation—rarely produces measurable yield gains. The findings from Mpongwe therefore underscore that CSA's transformative potential requires bundled and sustained practice adoption, integrated with supportive input and market systems.

Similarly, the non-significant effect of CSA adoption on household income stability suggests that, in the short term, CSA may enhance survival and reduce vulnerability without immediately translating into higher profits. This echoes findings by (Chesterman, 2021) and (Ngoma 2023), who found that while CSA adopters experience fewer total crop losses during droughts, income gains depend heavily on market access, price stability, and off-farm diversification. In Mpongwe, these structural constraints—limited access to reliable markets, fluctuating commodity prices, and weak value chains—may have masked the economic benefits of CSA. In other words, CSA adoption may improve production resilience but not necessarily financial resilience unless complemented by institutional and market support mechanisms.

Synthesizing across these findings, this study contributes to the growing evidence that CSA adoption alone does not guarantee yield or income improvements; rather, outcomes depend on adoption intensity, local agro-ecological context, time horizon, and enabling environments. The Mpongwe case aligns with (World Bank 2023) observations that the success of CSA in Africa depends less on individual practice adoption and more on integrated systems combining agronomic, economic, and institutional support. Thus, the lack of significant productivity or income differences in this study should not be interpreted as CSA ineffectiveness but as evidence that CSA transitions are gradual and context-dependent.

Recommendations

1. Promote Bundled and Context-Specific CSA Adoption
   Future extension and policy programs should prioritize bundled adoption strategies, where farmers are encouraged to implement combinations of practices that are complementary and site-specific.
2. Reinforce Informal Learning and Peer-to-Peer Knowledge Transfer
   The inverse relationship found between education level and CSA adoption in this study indicates that formal education is not necessarily the most effective pathway for promoting CSA knowledge.
3. Enhance Institutional and Structural Support for Sustained Adoption
   Long-term CSA adoption requires an enabling institutional environment. Many farmers in Mpongwe cited challenges such as limited access to inputs, insecure land tenure, and inadequate extension follow-up. To overcome these barriers, it is recommended that policy frameworks provide targeted input subsidies and microcredit schemes specifically for CSA-related investments such as drought-tolerant seed varieties, small-scale irrigation kits, or organic fertilizer inputs. Additionally, strengthening land tenure systems will encourage farmers to make longer-term soil and water management investments.
4. Develop CSA Performance Tracking Systems
   To complement these efforts, it is essential to develop a CSA adoption intensity index that measures not only whether a farmer adopts a practice but also the extent, frequency, and consistency of implementation. Such monitoring tools can help extension agencies and policymakers differentiate between superficial adoption and genuine behavioral change, ensuring that resources are directed toward the most impactful interventions. By focusing on these strategies, adoption in Mpongwe can evolve from broad but shallow engagement to deep, sustained, and effective practice integration, thereby strengthening the district's long-term resilience to climate change.

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