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Synergies and Trade-Offs of Climate-Smart Agriculture Practices and Mediating Factors in Enhancing Maize Yields among Smallholder Farmers in Tanzania's Semi-Arid Regions

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Authors' contributions

This work was carried out in collaboration among all authors. Author ASY designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Authors EFN, SKM, and TD provided guidance throughout the research process, including refining the study design. They also reviewed and provided substantial feedback and revisions to improve the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The impact of climate change on agriculture in sub-Saharan Africa has been significant in recent years, particularly affecting smallholder farmers in semi-arid regions in Tanzania. Although research on climate-smart agriculture (CSA) practices has grown, the synergies and potential trade-offs from such practices among smallholder farmers in Tanzania's semi-arid regions have received little attention. To address this, 299 households were interviewed and path analysis was used to analyze the data collected. Correlations between CSA practices used in maize farming in semi-arid areas of Tanzania were analysed as well as direct and indirect effects of access to credit, non-governmental organizations (NGOs) assistance, Membership in organisations, distance to market and CSA training on increasing maize yields. The results showed that access to credit, assistance from NGOs, membership in an organization, distance to market, and CSA training act as mediating factors between CSA practices and an increase in maize yield. The study found that improved varieties were positively correlated with changes in planting date, use of animal manure, minimum tillage, intercropping, mixed cropping, and livestock diversification ($P<0.05$).

The study emphasizes the importance of implementing these practices together to generate a positive impact and increase smallholder farmers' crop yields and resilience to climate change in semi-arid regions. The study recommends that in order to increase synergies and minimize trade-offs between climate-smart agriculture (CSA) practices the government and non-governmental organizations strengthen the extension system, promote access to CSA training, and make affordable credit available through financial organizations.

Keywords: Climate-smart agriculture; path analysis; direct effect; indirect effects; synergy; intercropping; improved seed varieties; crop rotation; maize yield; mediation.

1. INTRODUCTION

Agriculture plays an important role in both employment and Gross Domestic Product (GDP) in sub-Saharan Africa, contributing to over 60% of employment and 14% of GDP (Eta et al., 2023). Despite its importance, the agricultural sector in this region faces substantial challenges due to the effects of climate change and variability (Affoh et al., 2022; Gupta et al., 2021).

Among the key challenges in the agricultural sector in sub-Saharan Africa is the increased frequency and intensity of droughts, which has been attributed to an increase in global temperature by 0.8°C over the past century and is expected to increase by 1.5°C to 4.8°C over the next 100 years (Tilahun et al., 2023). Since 1982, crop yields have been reduced by up to 70% due to climate change (IPCC, 2014). This has affected and will continue to affect food prices, crop quality and yield, and the nutritional value of food (Malhi et al., 2021). However, these impacts of climate change and variability vary significantly by region and crop type (IPCC, 2014).

The effects of climate change and variability in Tanzania have resulted in significant negative impacts on the lives of both its people and the country's economic sectors. The country has experienced recurring severe droughts, leading to decreased crop production and water scarcity in various regions (Gwambene et al., 2023). The negative effects of climate change on agricultural productivity include reduced crop yields due to drought and flooding, limited water availability, and altered temperature and rainfall patterns (Mafie, 2022; Volk et al., 2021). Furthermore, climate change has been shown to negatively affect maize, sorghum, and rice production in Tanzania (Volk et al., 2021; Volkov et al., 2022). Maize yield has been reported to decrease by up to 10%, particularly in semiarid agroecosystems (Farooq et al., 2023; Khechba et al., 2021). In Tanzania's semiarid regions, smallholder farmers are taking steps to mitigate the negative effects of climate change by adopting climate-smart agriculture (CSA). These practices include using improved seed varieties, such as short- and drought-tolerant sorghum and maize, retaining crop residue, practising crop rotation, practising mixed cropping, using organic fertilisers, implementing irrigation through excavated ponds and contour terraces, adjusting planting dates, diversifying livestock, and implementing agroforestry practices (Kurgat et al., 2020; Yusuph et al., 2023). These measures help farmers adapt to the changing climate and sustainably improve their yield.

The implementation of these practices creates synergy but also involves trade-offs (Lipper et al., 2014). Synergies between CSA practices are important in Tanzania's semi-arid region, where agriculture is a major source of income and livelihood. Synergy is defined as a positive outcome between different practices or interventions which complement each other to enhance overall sustainability (Baniassadi & Sailor, 2018; FAO, 2021). Synergy occurs when the combined effect of two or more adaptation strategies is greater than the sum of each if they are implemented separately (Pedercini et al., 2019; Torquebiau, 2017). This results in increased productivity, resilience, yield stability, sustainability, and farmer income and reduces the negative environmental impacts of agriculture (Akinyi, et al., 2021; Lipper et al., 2015). For instance, different crop types in rotations provide mitigation benefits such as improving carbon sequestration, nutrient cycling, and reducing soil degradation (Debaeke et al., 2017). Intercropping cereals and leguminous crops can improve resource use efficiency (Nassary et al., 2019). Similarly, diversifying cropping practices in Tanzania and Zimbabwe significantly improved seed productivity, crop income, and food security (Kimaro et al., 2016; Makate et al., 2016).

Though climate-smart agriculture (CSA) aims to achieve synergies in various aspects, it is important to acknowledge that there are often trade-offs when using different CSA practices in combination (Andrieu et al., 2017). Trade-offs are defined as a negative outcome which occurs when implementing certain practices may hinder others leading to challenges in achieving desirable sustainable goals (FAO, 2021). This means that in order to achieve one or two specific goals, compromises may need to be made in other areas. For example, keeping livestock and retaining crop residue, may suggest that farmers must choose between feeding livestock with crop residue or utilizing them as mulch (Antwi-Agyei et al., 2023; Wainaina et al., 2016). Additionally, practices like irrigation can improve crop yield and increase farmers' incomes, but they can also lead to an increase in greenhouse gas emissions if reliant on fossil energy (Feyisa, 2022; Swart, 2009). Mixed cropping, is another common practice, which can enhance adaptability by diversifying income sources (Maguza-Tembo et al*.,* 2017; Nyang’au et al., 2020). However, it can also compromise productivity by degrading the land due to crop overcrowding and insufficient soil nutrient replenishment (Antwi-Agyei et al., 2023). The recognition of trade-offs is therefore crucial when planning and implementing CSA practices.

Despite the growing interest in climate-smart agriculture, research on the synergies and trade-offs between different practices and the studies on factors influencing synergies is insufficient. Most studies on climate-smart agriculture synergies have concentrated on the synergies between the three CSA pillars: productivity, adaptation, and mitigation (Antwi-Agyei et al., 2023; Ogola & Ouko, 2021; Tilahun et al., 2023). Limited research has been conducted on the factors that contribute to the synergies between different CSA practices and help decrease trade-offs. This study advances the literature on climate-smart agriculture synergies by analysing the synergies between CSA practices as well as the factors that increase synergies between CSA practices. It is important to study how smallholders' diverse CSA practices interact and create synergies given that they do not operate in isolation and must manage agricultural risks. Understanding the synergies of CSA practices on the farm level is critical, especially when resources are constrained. This information is crucial to ensure sustainable, socially equitable, and environmentally sound agricultural practices. The objectives of this study were to assess the perception of smallholder farmers on the synergies and trade-offs of climate-smart agriculture practices, analyse the direct and indirect effects of mediating factors on increasing maize yield, and analyse the synergies and trade-offs among the most commonly used CSA practices by smallholder farmers.

2. METHODOLOGY

2.1 Description of the Study Area

The study was conducted in two regions: Tabora and Dodoma. These areas represent Tanzania's semi-arid regions, which are distinguished by erratic and low mean annual rainfall, drought, insufficient soil moisture, soil infertility, higher daytime temperatures, and evaporation rates that exceed precipitation rates (Synnevåg et al., 2015). In Tabora, the study focused on the Igunga district, where temperatures ranged from 20°C to 33°C, and annual rainfall varied between 500 mm and 700 mm (Matata et al., 2018). Similarly, the Dodoma region was represented by the Chamwino district, receiving an annual rainfall of 500 to 800 mm. The average high and low temperatures in this area were 31°C and 18°C, respectively (Mgoba & Kabote, 2020). The selection of semi-arid regions for the study was based on their agricultural potential to support diverse crops and livestock, as well as their proximity to areas most susceptible to the impacts of climate change.

2.2 Sampling Procedure

A multistage random sampling procedure was used to select households within the study area. Initially, specific districts, divisions, wards, and villages actively practising CSA in the semi-arid regions of Dodoma and Tabora were selected (Yusuph et al., 2023). In the second stage, districts were chosen based on their active participation in various climate change adaptation projects implemented by the government and non-governmental organizations (NGOs). Subsequently, two wards were systematically selected from each chosen district. The chosen wards included Idifu and Iringa mvumi wards in Chamwino district and Mbutu and Kining'inila wards in Igunga district (Fig. 1). After that four villages were purposefully chosen from each ward with the assistance of extension officers and ward authorities. The sampling frame for this study consisted of a population comprising all farmers cultivating maize crops as well as the implementation of other CSA practices. The total population size was 1200 farmers and the number of sample households was determined to be 299 using a simplified formula (Yamane, 1967; Adam, 2020; Chaokromthong et al., 2021).

The head of household was selected using a simple random sampling method.

$$n = \frac{N}{1 + N(e)^2} \tag{1}$$

Where: *N* is the size of the population of farmers who practice CSA, *n* is the size of the sample and *e* is the level of precision (5%).

2.3 Data Collection Methods

Data were collected from selected households using a questionnaire. Household interviews were conducted to gather information on CSA practices used by farmers and their perceptions of the synergies between these practices. Face-to-face structured questionnaires were administered to collect the data. Additionally, a review of the relevant literature was conducted to enhance our understanding of synergies and trade-offs among CSA practices that are commonly used in semi-arid areas in Tanzania.

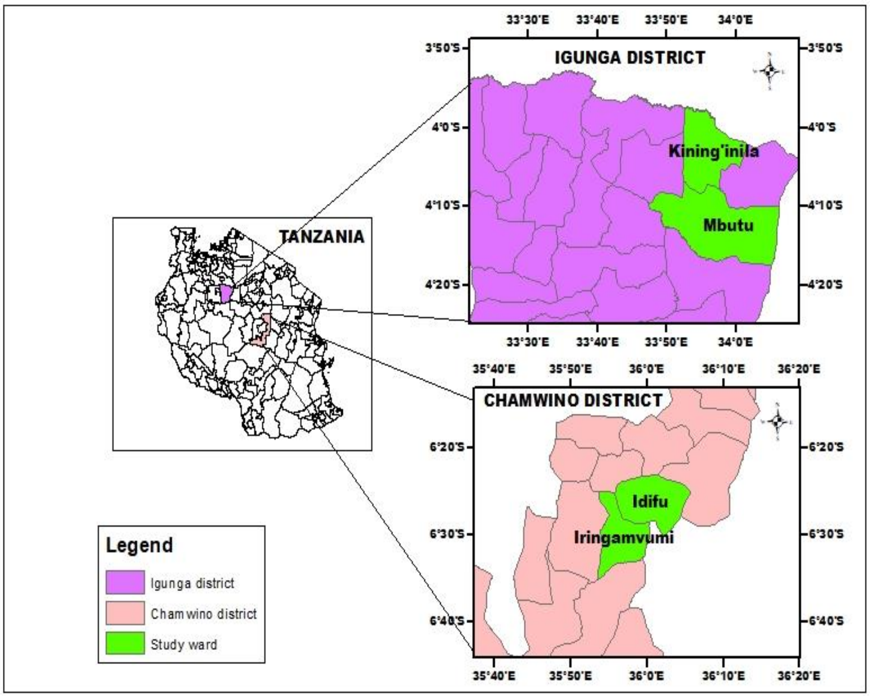


Fig. 1. Map of the study area

2.4 Specification of the Model

The synergy between different climate-smart agriculture (CSA) practices can play a significant role in farmers' adoption. A combination of multiple practices can increase the overall effectiveness and efficiency of farming systems, making them more resilient to the impacts of a changing climate. In turn, this can influence the experience of farming, access to extension services, and NGO support, all of which are important factors that can impact the usage of CSA practices. In this study, structural equation modelling (SEM) was used as a powerful statistical technique to examine the relationships between CSA practices used in maize farming in semi-arid areas of Tanzania and the direct and indirect effects of different factors on increasing maize yields. SEM is a multidimensional technique that combines the elements of multiple regressions and can estimate the number of concurrent interdependent associations (Byrne, 2016; Hair et al., 2017). SEM is the best multivariate method for evaluating construct validity and the theoretical connections between a set of concepts represented by several measured variables (Thakkar, 2020).

Path analysis is a type of structural equation modelling (SEM) that is used to explain the causal relationships between variables (Collier, 2020). It involves creating path diagrams to illustrate the proposed causal relationships and conducting regression analyses to assess them (Collier, 2020). Path analysis makes use of bivariate and multiple linear regression techniques to examine the causal relationship between variables (Sydow et al., 2012). It focuses on the structure of interactions rather than just predicting the dependent variable using independent factors. Path analysis breaks down correlation coefficients into direct and indirect effects, providing information about the relationships between variables (Yammine & Rammal, 2021).

In this study path diagrams were created using a single-headed arrow showing the causal relationship between two variables, with the head pointing to the effect and the tail pointing to the cause. A curving double arrow represents a relationship between two climate-smart agricultural techniques, indicating synergies and trade-offs. The following model (Fig. 2), was created to test the direct relationship between access to credit, membership in an organization, NGO assistance and CSA practice training. The mediating effects of the variables on maize yield increase were viewed using the same model.

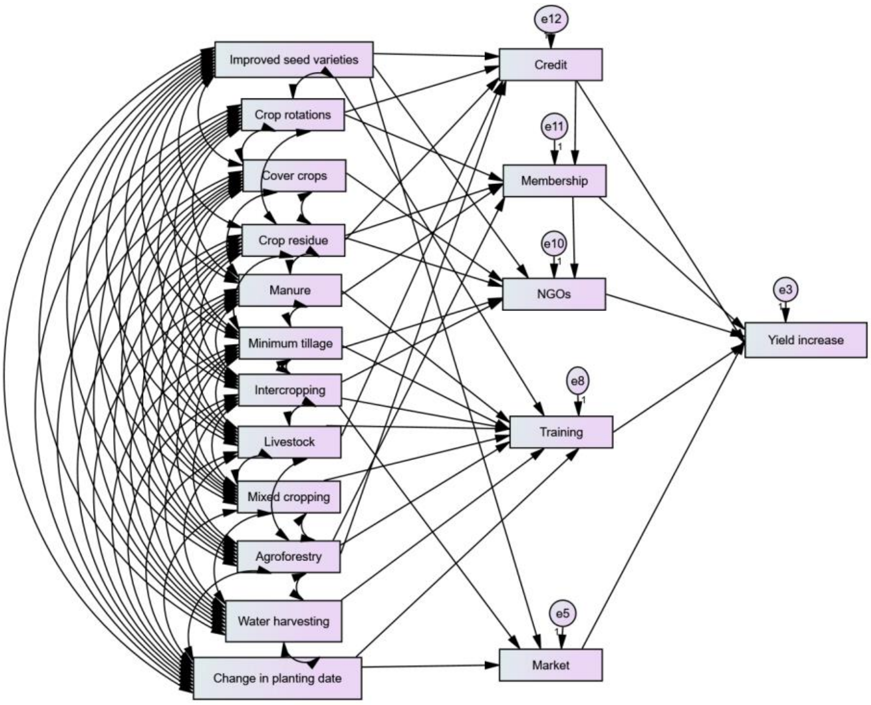


Fig. 2. Conceptual model showing the potential relationships between climate-smart agriculture practices and other factors

2.5 Hypothesis

Access to credit, support from NGOs, membership in organizations, and training in climate-smart agriculture (CSA) practices contribute to synergies among CSA practices, leading to increase maize yields.

2.6 Measurement Model Fit

The model fit measurement was used to assess the model's overall goodness of fit. The root means square error of approximation (RMSEA) recorded a value of 0.069, below the recommended standard of 0.08 (Hair et al., 2006). Additionally, the values of the normed fit index (NFI), the incremental fit index (IFI), the Tucker-Lewis index (TLI) and the comparative fit index (CFI) were within their respective common acceptance levels (Hair et al., 2006) (Table 1). The chi-square value generated by the model was 136.987 with 61 degrees of freedom ($p<0.001$). The normed chi-square value was 2.406, lower than the critical value of 5.0 (Hair et al., 2006). These results indicate that the hypothesized path analysis model exhibited a satisfactory fit with the sample data, suggesting a good overall model fit.

2.7 Sensitivity Analysis

A sensitivity analysis was conducted to evaluate the robustness of the model. This involved examining how modifications to specific paths and variables affected model fit indices, standardised path coefficients, and the variance explained (R^2) in the dependent variable, Yield increase. The model demonstrated a good overall fit, with significant direct effects from training, NGOs, and credit on Yield increase.

Key paths were systematically removed to test their influence on the model. Removing the path between NGOs and Yield increase resulted in a decrease in R^2 for Yield increase from 0.09 to 0.06, removing training from the model decreased R^2 for yield increase from 0.09 to 0.07, highlighting the critical role of NGO assistance and training in increasing synergies between CSA practices. Adjusting the coefficient for Training → Yield increase from 0.21 to 0.10 slightly diminished the overall model fit. The sensitivity analysis revealed that Training and NGOs were the most influential predictors, as changes to these paths significantly impacted R^2 and model fit indices. The model proved robust against minor adjustments in other variables.

2.8 Data Analysis

2.8.1 Analysis of the perception of CSA synergies by smallholder farmers

Smallholder farmers were asked to provide scores to reflect their degree of agreement or disagreement with certain assertions about the synergies between climate-smart agriculture practices as part of the analysis of Likert-scale data. The Likert scale was a five-point system that ranged from "strongly agree" to "strongly disagree." Great insights were gained into the perceived synergies and trade-offs of certain practices by adopting this organised approach. This allowed for a quantitative assessment of the extent to which particular practices contributed to the overall synergistic effects or trade-offs offering a better understanding of how diverse climate-smart agriculture practices interact and affect agricultural outputs.

2.8.2 Analysis of synergies between CSA practices and mediating factors

The data were analyzed using path analysis with AMOS (Analysis of Moment Structures) software which is a specialized software program integrated with IBM SPSS for conducting Structural Equation Modeling (SEM) to assess both direct and indirect effects. The indirect effect of climate-smart agriculture practices on yield was evaluated using a bootstrap technique with

Table 1. Goodness-fit-of indices of the measurement model

Fit indices	Recommended values	Observed value
CMIN/df	3-5	2.167
GFI	>=0.9	0.960
CFI	>=0.9	0.905
TLI	>=0.9	0.798
SRMR	<=0.05	0.05
RMSEA.	<=0.08	0.063

5000 samples, and confidence intervals (CI) were computed (95% bias-corrected) (Collier, 2020). The path analysis model included seven independent variables (CSA practices) and five mediating variables. Bootstrapping was used to obtain 95% bias-corrected confidence intervals and standard error estimates of direct and indirect effects.

3. RESULTS

3.1 Farmer's Perception of Climate-Smart Agriculture Practice Synergies and Trade-offs

Farmers associated synergies in different CSA practices with increased income, yield and improvement in soil fertility as well as food security (Fig. 3). Most farmers (79%) agree that livestock diversification, mixed cropping, cereal legume intercropping, water harvesting pits, terraces, crop rotation, agroforestry can increase crop yields. Moreover, some farmers (59%) indicated that crop rotation increases soil fertility. Furthermore, 46% of farmers indicated a strong positive relationship between tree planting and land restoration. However, uncertainty arises on the effectiveness of agroforestry practices in enhancing carbon sequestration as 68% of farmers did not implement this practice.

About 59% of household heads reported an increase in income due to CSA practices, such as intercropping and mixed crops, indicating a positive correlation between the implementation of CSA practices and income growth. In contrast, 84% of household heads indicated an increase in labour requirements, suggesting a trade-off associated with certain CSA practices, including terraces, intercropping, and agroforestry. Furthermore, only a limited number of household heads recognized the contribution of CSA practices to increased soil fertility. Although food security appears to have improved with the implementation of these practices, reducing production costs remains a challenge for most farmers.

Furthermore, approximately 55% of household heads expressed neutrality regarding the impact of water-harvesting pits on yield, indicating a lack of consensus on the benefits of this practice. Given that this practice requires initial investment and labour, few farmers are able to implement it. There are varying perceptions regarding how these practices influence production costs; some households believe that implementing CSA practices can reduce expenses, whereas others feel that costs may increase.

3.2 Synergies and Trade-Offs. from Existing Literature

Various CSA practices (Table 2), include descriptions and potential synergies and trade-offs, drawn from existing literature. Different practices exhibit different themes like diversification, resilience, resource use efficiency and mitigation of greenhouse gases. These patterns contribute to overall climate change adaptation and mitigation.

3.3 Synergies and Trade-offs of Climate-Smart Agriculture Practices

The correlation between various climate-smart agriculture practices indicates both synergies and trade-offs among CSA practices used by smallholder farmers. Positive correlations indicate synergistic relationships in which the usage of one practice can enhance the effectiveness of another. Conversely, negative correlations point to trade-offs, suggesting that implementing these two practices simultaneously may pose challenges or conflicts.

3.4 Synergies

The results showed that improved varieties were positively correlated with changes in planting date, animal manure, minimum tillage, intercropping, mixed cropping, and Livestock diversification (Fig. 3). This indicates that a positive outcome is realized when improved varieties are used together with these CSA practices. The change in planting date was positively correlated with improved varieties, crop rotation, cover crops, minimum tillage, mixed cropping, and Agroforestry, indicating a complementary relationship between these practices therefore this could mean that adjusting planting schedules can be beneficially integrated with these practices to enhance crop performance. Crop rotation was positively correlated with intercropping and agroforestry. The positive collection indicates that these practices can be combined which can provide diversified benefits, such as improved soil health and resource-use efficiency. Furthermore, cover crops and water harvesting were significantly and positively correlated, implying that these practices may complement each other. Crop residue retention was also positively correlated with intercropping, livestock diversification, and agroforestry indicating that retaining crop residues can support soil health and nutrient cycling. The use of manure was positively correlated with minimum tillage and mixed cropping. Intercropping showed a positive correlation with improved varieties, mixed cropping, and agroforestry, indicating synergies between these combinations. Livestock diversification was positively correlated with mixed cropping and agroforestry while mixed cropping was correlated with agroforestry indicating mutual benefits between these practices.

3.5 Trade-offs

The analysis identifies potential trade-offs, particularly involving minimum tillage, which negatively correlates with changes in planting dates and crop rotation. This suggests challenges in implementing these practices simultaneously. Mixed cropping also exhibits a negative correlation with minimum tillage, indicating possible conflicts in achieving optimal outcomes when these practices are combined.

Table 2. Synergies and trade-offs of climate-smart agriculture practices from existing literature

Climate-smart Agriculture Practices	Synergies	Trade-offs
Improved Seed Varieties	Increased crop yield (Loboguerrero et al., 2019), Increased income (Semalulu et al., 2020), and Improved resilience to climate variability (Debaeke et al., 2017).	Higher costs for seed purchase (Morizet-Davis et al., 2023) a potential increase in the use of agrochemicals (Ward et al., 2016).
Change in Planting Date	Improved crop productivity (Morizet-Davis et al., 2023) and better utilization of seasonal rainfall (Chen et al., 2023).	Limited applicability across different crops (Nassary et al., 2019), Requires timely execution and monitoring (Tadesse & Ahmed, 2023).
Crop Rotation	Improved soil fertility (Loboguerrero et al., 2019), Improved income (Semalulu et al., 2020), Reduced pest and disease pressure (Debaeke et al., 2017).	May increase competition for land and resources (Morizet-Davis et al., 2023) and a potential financial burden for implementing new rotation plans (Nassary et al., 2019).
Cover Crops	Improved soil health (Loboguerrero et al., 2019), Increased water retention (Debaeke et al., 2017), Reduced erosion (Nassary et al., 2019).	Increased management costs (Ward et al., 2016), Competition for nutrients and water with main crops (Morizet-Davis et al., 2023).
Crop Residue Retention	Improved soil fertility (Loboguerrero et al., 2019) and increased carbon sequestration (Asante et al., 2019).	Increase in labour and costs for collection and management (Morizet-Davis et al., 2023), Potential for increased pest presence (Ward et al., 2016).
Manure Use	Improved soil fertility (Loboguerrero et al., 2019), Improved crop yield (Semalulu et al., 2020), and Reduced need for synthetic fertilizers (Chen et al., 2023).	Labor-intensive and costly to transport (Nassary et al., 2019), May contribute to GHG emissions if not properly managed (Fahad et al., 2022).
Minimum Tillage	Reduced soil erosion (Debaeke et al., 2017), Improved water retention (Morizet-Davis et al., 2023), and Increased organic matter in soil (Chen et al., 2023).	Increased weed presence may require herbicides (Ward et al., 2016) and initial costs for machinery (Nassary et al., 2019).
Intercropping	Improved soil fertility (Loboguerrero et al., 2019), Reduced pest pressure (Debaeke et	Potential competition for water and nutrients (Morizet-Davis et

Climate-smart Agriculture Practices	Synergies	Trade-offs
	al., 2017), Increased crop yield (Semalulu et al., 2020), Increased income (Morizet-Davis et al., 2023).	al., 2023), Can increase labor and complexity in crop management (Ward et al., 2016).
Livestock Diversification	Reduced risk from market or climate shocks, Enhanced use of farm resources	Competing demands for feed and water resources
Mixed Cropping	Improved productivity (Loboguerrero et al., 2019), Improved resilience to climate variability, Increased crop diversity	Increased management complexity, Competition for nutrients and space
Agroforestry	Improved soil fertility, Carbon sequestration (Covey & Megonigal, 2019), and Reduced erosion (Akinyi et al., 2021)	Potential damage to crops, Long time to realize benefits
Rainwater Harvesting Pits	Increased water availability for crops (Chen et al., 2023) and improved resilience to dry spells (Fahad et al., 2022)	Reduces land availability for cropping (Morizet-Davis et al., 2023), Requires significant labour for construction and maintenance (Nassary et al., 2019)

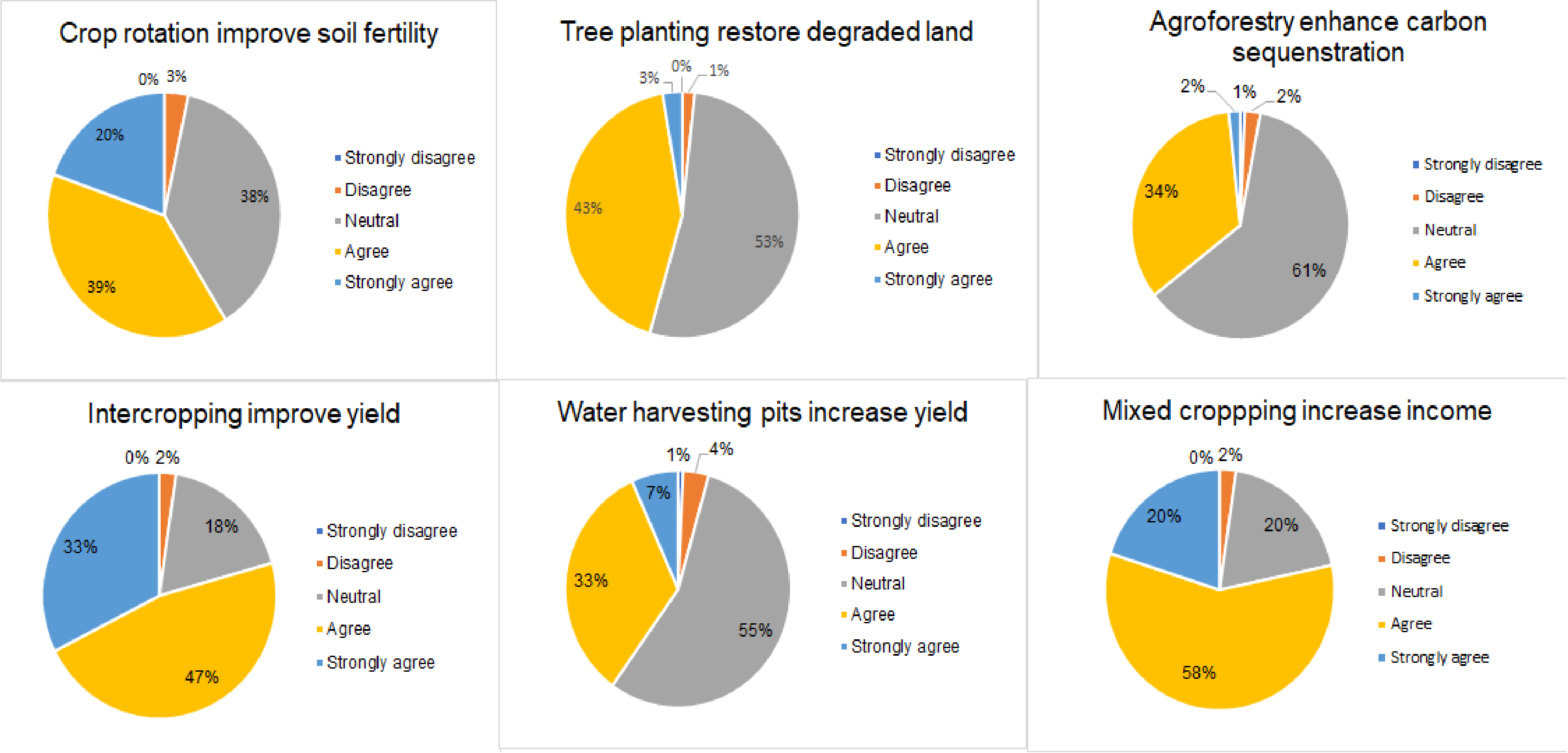
Table 3. Direct effects of different factors on yield

Path				Confidence Interval (95%)		P
			Estimate	**Lower**	**Upper**	
Crop residue	→	Credit	0.205	0.096	0.324	0.000
Agroforestry	→	Credit	0.215	0.095	0.334	0.001
Crop rotations	→	Credit	0.226	0.103	0.349	0.001
Crop rotations	→	Membership	-0.035	-0.118	0.034	0.324
Manure use	→	Membership	0.166	0.099	0.242	0.000
Intercropping	→	Training	-0.064	-0.175	0.041	0.227
Intercropping	→	NGOs	0.061	-0.031	0.161	0.2
Change in planting date.	→	Training	0.066	-0.038	0.172	0.198
Water harvesting	→	Training	-0.033	-0.133	0.058	0.503
Change in planting date.	→	Market	0.248	0.124	0.375	0.000
Intercropping	→	Market	-0.108	-0.23	0.016	0.09
Agroforestry	→	Training	-0.142	-0.253	-0.021	0.022
Membership	→	NGOs	-0.383	-0.484	-0.288	0.000
Minimum tillage	→	NGOs	0.169	0.06	0.282	0.002

*Bootstrapped SE of Beta 95% CI: Bias corrected 95% confidence interval *: statistically significant at P < 0.05*

3.6 Mediating Factors Influencing Synergies among Climate-Smart Agriculture Practices

The study examined how improved seed varieties, intercropping, the use of manure, cover crops, crop residue retention, livestock diversification, mixed cropping, agroforestry, and rainwater harvesting pits affected crop yield. The indirect effects of these factors on yield increases were analyzed through five mediators: access to credit, NGO assistance, membership in an organization, distance to market, and CSA training. A bootstrap sample of 5,000 was analyzed, revealing that improved seed varieties, crop residue retention, and mixed cropping practices had direct effects on maize yield (Table 4). The results show that the relationship between climate-smart agriculture practices and maize yield increases is partially mediated by different mediators. Specifically, the indirect effects of improved seed varieties, intercropping, use of animal manure, and crop rotation through credit access, membership in an organization, NGOs assistance, distance to market and CSA training significantly highlighted the important role played by each of these mediators in promoting the use of climate-smart agriculture practices and hence increasing maize yield.


Crop rotation improve soil fertility
0%
3%
20%
38%
39%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree
Tree planting restore degraded land
3%
0%
1%
43%
53%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree
Agroforestry enhance carbon sequenstration
2%
1%
2%
34%
61%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree
Intercropping improve yield
0%
2%
33%
18%
47%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree
Water harvesting pits increase yield
1%
4%
7%
33%
55%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree
Mixed croppping increase income
0%
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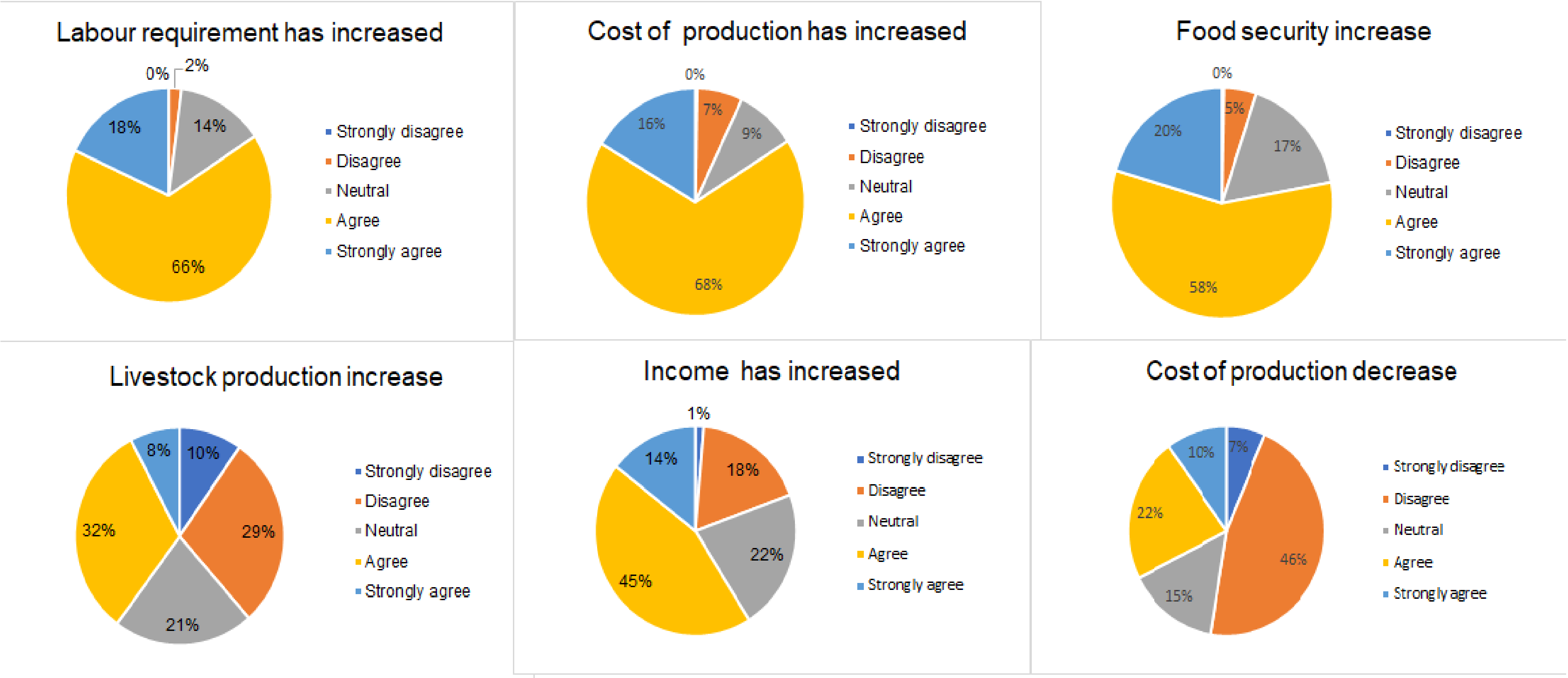

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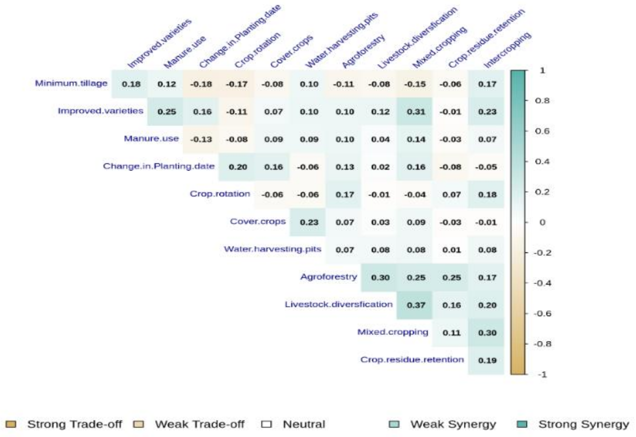
Fig. 3(a & b). Farmer's Perception of climate-smart agriculture synergies and trade-offs.



	Improved.varieties	Manure.use	Change.in.Planting.date	Crop.rotation	Cover.crops	Water.harvesting.pits	Agroforestry	Livestock.diversfication	Mixed.cropping	Crop.residue.retention	Intercropping
Minimum.tillage	0.18	0.12	-0.18	-0.17	-0.08	0.10	-0.11	-0.08	-0.15	-0.06	0.17
Improved.varieties		0.25	0.16	-0.11	0.07	0.10	0.10	0.12	0.31	-0.01	0.23
Manure.use			-0.13	-0.08	0.09	0.09	0.10	0.04	0.14	-0.03	0.07
Change.in.Planting.date				0.20	0.16	-0.06	0.13	0.02	0.16	-0.08	-0.05
Crop.rotation					-0.06	-0.06	0.17	-0.01	-0.04	0.07	0.18
Cover.crops						0.23	0.07	0.03	0.09	-0.03	-0.01
Water.harvesting.pits							0.07	0.08	0.08	0.01	0.08
Agroforestry								0.30	0.25	0.25	0.17
Livestock.diversfication									0.37	0.16	0.20
Mixed.cropping										0.11	0.30
Crop.residue.retention											0.19

Fig. 4. Heatmap of Synergies and trade-offs of climate-smart agriculture practices

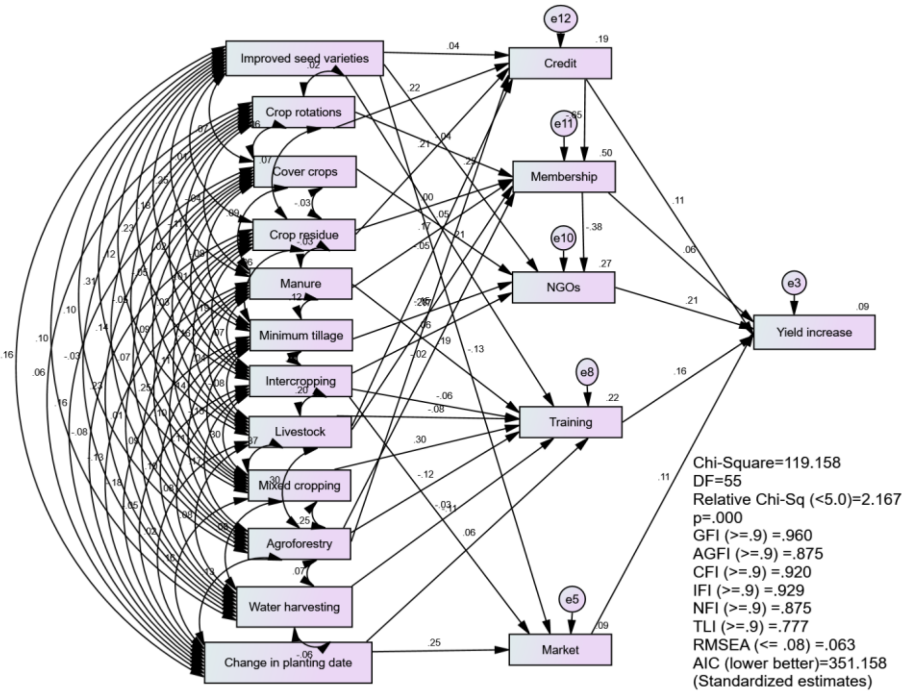


Fig. 5. The path analysis model with standardized estimates

NB: DF= Degree of freedom., RMSEA= Root Means a Square Error of Approximation, NFI=Normed fit index (IFI)= Incremental Fit Index. TLI =Tucker-Lewis Index, GFI= Goodness of Fit Index. AGFI= Adjusted Goodness of Fit Index and the CFI= Comparative Fit Index., AIC= Akaike information criterion index

Improved seed varieties have a positive indirect effect through non-governmental organization assistance and CSA training practices. Crop residue retention has an indirect effect on yield through credit access and non-governmental organizations' assistance. Agroforestry practices have had a positive indirect influence on yield through credits, involvement in NGO assistance, and CSA training. Crop rotation has an indirect positive effect on yields with credit access and NGO assistance. The usage of manure had a positive indirect effect through training in CSA practices. Changes in planting dates had a positive indirect effect on maize yield through distance to market. Minimum tillage has a significant indirect influence on yields through NGO assistance through training.

Table 4. Indirect effects of access to extension officers, farming experience, NGOs, and CSA training on yield

Path	**Estimate**	**Confidence Interval (95%)**		**P**
		Lower	**Upper**	
Improved seed varieties --> Credit --> Yield	0.003	-0.005	0.023	0.321
Improved seed varieties --> NGOs --> Yield	0.045	0.019	0.082	0.000
Improved seed varieties --> Training --> Yield	0.027	0.007	0.062	0.005
Improved varieties --> Market --> Yield	-0.011	-0.033	-0.001	0.037
Crop residue --> Credit --> Membership --> NGOs --> Yield	0.009	0.003	0.019	0.000
Agroforestry --> Credit --> Membership --> NGOs --> Yield	0.019	0.007	0.042	0.000
Crop rotations --> Credit --> Membership --> NGOs --> Yield	0.02	0.008	0.043	0.000
Crop rotations --> Credit --> Yield	0.04	-0.013	0.113	0.120
Crop rotations --> Membership --> NGOs --> Yield	0.005	-0.004	0.018	0.267
Manure use --> Membership --> NGOs --> Yield	-0.015	-0.031	-0.006	0.000
Manure use --> Training --> Yield	0.033	0.011	0.07	0.003
Intercropping --> Training --> Yield	-0.009	-0.032	0.004	0.139
Intercropping --> NGOs --> Yield	0.011	-0.004	0.038	0.162
Intercropping --> Market --> Yield	-0.01	-0.033	0.001	0.067
Change in planting date --> Market --> Yield	0.028	0.002	0.065	0.036
Water harvesting --> Training --> Yield	-0.016	-0.1	0.031	0.380
Minimum tillage --> NGOs --> Yield	0.042	0.013	0.092	0.001
Mixed cropping --> Training --> Yield	0.035	0.011	0.07	0.004

4. DISCUSSION

4.1 Synergies of Climate-Smart Agriculture Practices

The analysis of the structural equation model reveals a strong positive relationship between climate-smart agriculture practices used by farmers in semi-arid areas. This shows the importance of implementing various practices to increase productivity and resilience to climate change impact. Combining different practices can have a synergetic effect, resulting in greater yield and income than using a single practice only. However, the negative correlation between some practices suggests that there are trade-offs and farmers should carefully choose which practices to implement to maximize their benefits. Similar observations by Jabbar et al. (2020), Tetteh et al. (2020); and Wainaina et al. (2016) show the benefits of combining different CSA practices.

The results showed that improved seed varieties were positively correlated with changes in planting date, animal manure, minimum tillage, intercropping, mixed cropping, and livestock diversification. This indicates that a positive outcome is realized when improved varieties are used together with these CSA practices. The positive correlation between improved seed varieties and manure usage suggests that using manure as a nutrient source can enhance the benefits of improved seeds. Studies have shown that organic manure improves soil properties, thereby leading to higher crop productivity and quality. Similarly, Ahmed. (2022) showed that improved seeds have better yield performance and are more adaptable than local seeds. Using new crop varieties in combination with soil management practices, such as mulching or using fertilizers, can serve as a protective measure to effectively address climate change risks (Sanou et al., 2016) and increase crop yields and improve income (Loboguerrero et al., 2019). These practices can also produce high yields withstand rising temperatures and cope with erratic rainfall patterns (Amare et al., 2020; Valarmathi et al., 2019). In contrast, Ficiciyan et al. (2018) contended that the use of improved seed varieties leads to an increased reliance on inorganic fertilizers, herbicides, and agrochemicals which can result in trade-offs instead of synergies.

Change in planting date was positively and significantly correlated with improved seed varieties, crop rotation, cover crops, minimum tillage, mixed cropping, and agroforestry, indicating a complementary relationship between these practices and therefore they could be combined to produce beneficial outcomes. Improved seed varieties, crop rotation, cover crops, minimum tillage, mixed cropping, and agroforestry can have synergistic and complementary effects on agricultural systems. Crop rotation can improve soil quality, increase system production, and promote soil and ecological sustainability (Shah et al., 2021). Cover cropping slows soil erosion, enhances nutrient cycling, and provides environmental benefits (Shekinah & Stute, 2019). Cover crops also increase soil fertility, structure, and biodiversity while decreasing weed and insect populations (Crotty & Stoate, 2019). Minimum tillage practices can influence soil physical characteristics such as soil pore space indices and contribute to changes in soil properties caused by crop management strategies (Panday & Nkongolo, 2021). Agroforestry systems can improve soil health, nitrogen cycling, and structure (Marshall et al., 2022). Similarly, Silberg et al. (2019) indicated that these improve natural nitrogen fixation; prevent erosion and crop failure; and assist in weed, pest, and disease management. When combined, these practices have the potential to build more resilient and sustainable agricultural systems by improving soil health, lowering erosion, improving nutrient cycling, and promoting biodiversity. Farmers who implement these practices benefit from the synergetic effects between enhanced productivity and adaptive capacity due to the variety of crops cultivated.

The positive correlation between improved seeds and mixed cropping can enhance the benefits of improved seeds by increasing biodiversity and reducing the risk of crop failure. The positive correlations between intercropping and improved seeds and crop residues suggest that intercropping can enhance the benefits of these practices. Intercropping can improve soil fertility, reduce pests and diseases, and increase crop yields (Bonke & Musshoff, 2020). Although intercropping can be labour-intensive and costly, its benefits, including reduced inorganic fertilizer use, extra grain revenues, and weed and disease management, outweigh these costs.

While crop rotation holds the potential to enhance soil fertility, mitigate soil erosion, and manage pests and diseases, mixed cropping may compromise these advantages due to resource competition among crops. Many farmers opt for leguminous crops in rotations, as they can effectively utilize organic fertilizers, decrease N2O emissions, and boost nitrogen fixation in the soil (Debaeke et al*.,* 2017). Consequently, this contributes to improved soil fertility (Segnon et al*.,* 2015), elevated soil organic matter levels, enhanced water retention capacity (Asmare et al*.,* 2019), and ultimately leads to enhanced yields (Hansen et al*.,* 2018). Farmers are advised to carefully consider the benefits and drawbacks of each practice and tailor their approaches to their specific needs and objectives.

Livestock diversification and intercropping can complement each other, with livestock providing manure for intercropped crops and helping to control weeds. However, there may be trade-offs with improved seeds because livestock may graze on crops or compete for resources. Factors such as soil type, climate, crop type, and market demand determine whether mixed cropping, crop rotation, or a combination of the two is optimal. Similarly, Rojas-Downing et al. (2017) demonstrated that improved animal husbandry can enable smallholder farmers to adapt to climate change impacts by increasing the amount of Tropical Livestock Unit (TLU) output.

Mixed cropping, intercropping, and livestock diversification are all significant and positively correlated. These practices can increase resource efficiency and production stability while reducing losses due to disease and pest infestations. In a mixed cropping system, planting leguminous crops alongside cereals may offer benefits such as enhanced soil fertility and weed control. However, extra caution is necessary to keep intercropped species in balance. Manure is an important nutrient provider for crop growth, particularly for increasing maize yield when combined with improved seeds and intercropping practices. Similarly, Gong et al. (2021) found that no-tillage, cover crops, and the use of manure are complementary to each other, emphasizing the synergetic effects of these practices.

Mixed cropping and minimum tillage had a negative correlation, indicating that the simultaneous implementation of both practices may result in lower yields. Therefore, farmers should carefully assess the trade-offs between these practices when designing farm management plans. Minimum tillage practices can pose challenges in terms of planting flexibility and crop rotation. The timing of optimal soil conditions and seed establishment under minimum tillage may be more specific, potentially limiting the flexibility of planting dates and crop sequencing (Betiol et al*.,* 2023). This can hinder immediate seedbed preparation and complicate the achievement of the benefits of crop rotation, such as weed and disease suppression (Kudumo et al*.,* 2023).

Furthermore, minimum tillage can conflict with mixed cropping systems, as it necessitates precise management of factors such as seeding rates, planting arrangements, and resource allocation, which can be more challenging under minimum tillage conditions (Betiol et al*.,* 2023; Islam et al*.,* 2024). Additionally, physical disturbance from conventional tillage can alleviate competitive interactions among crops in mixed systems, suggesting potential trade-offs when combining minimum tillage with mixed cropping (Islam et al*.,* 2024). Similarly, Betiol et al. (2023) indicated that minimum tillage and no-tillage increased pod yield for peanuts when rotated with sugarcane, although soil penetration resistance was observed in no-tillage treatments.

4.2 Mediating Factors Influencing Synergies among CSA Practices

Based on the findings, the link between CSA practices and maize yield is entirely influenced by five mediators namely: access to credit, distance to market, assistance from NGOs, membership in an organization, and training in CSA practices. Each mediator was revealed to partially mediate the relationship, suggesting that all five factors contributed to the impact of climate-smart agriculture practices on maize yield. The study suggests that efforts to promote the use of climate-smart agriculture practices should focus on all five mediators, with targeted interventions designed to enhance access to credit, NGO assistance, membership in an organisation, distance to market and CSA training. Similarly, Anuga et al. (2019) indicated that access to credit, training on CSAs, membership in farmer-based groups, and support from non-governmental organizations have been shown to influence the adoption of CSA practices.

NGOs can assist farmers with extension services by offering specialized training, and technical aid, creating and distributing information materials, organizing farmer groups, market information and serving as a platform for collective action (Abiddin et al., 2022; Anuga et al., 2019; Waaswa et al., 2022). Similarly, Njogu, (2011) reported that providing extensive technical assistance and free inputs to farmers resulted in a 23% increase in maize yields compared to limited assistance in Benin. Informal training provided by NGOs resulted in a considerable increase in the yields of maize when farmers followed the excellent agricultural techniques taught to them (Houndolo et al., 2020).

Access to credit plays a crucial role in enabling farmers to implement CSA practices. Farmers with access to credit are equipped with the essential financial resources to engage in diverse climate-smart agriculture practices (Yusuph et al*.,* 2023). This includes acquiring drought-tolerant crop varieties and irrigation equipment, which are essential for mitigating the impacts of climate change on agricultural productivity (Waaswa et al., 2022). Moreover, access to credit enables farmers to implement practices like crop diversification and integrated soil fertility management (ISFM), which are integral components of climate-smart agriculture (Sisay et al., 2023).

Training farmers in CSA practices like soil-water management, minimum tillage, and crop diversification influence the adoption of these technologies by farmers.(Waaswa et al., 2022; Zizinga et al., 2022). Access to training significantly and impacts the usage of various CSA practices, including crop diversification, agroforestry, ISFM, small-scale irrigation, integrated pest management, and conservation agriculture. This in turn helps farmers to increase yield as they apply knowledge gained from such training. Furthermore, the adoption of improved agricultural practices through training programs has been shown to significantly increase maize yield, with farmers experiencing a substantial increase in average yield after adopting good agricultural practices taught to them (Osei et al., 2014).

Distance to the market is an important factor when making farming decisions. It can affect farmers' transaction costs and the likelihood of adopting climate-smart agriculture (CSA) practices (Liang et al., 2021). Distance to the market affects maize yields significantly among smallholder farmers. As distance to the market increases, the adoption rate of improved maize varieties slows down, negatively impacting the overall adoption rate (Abate et al., 2022). Additionally, distance to the market enables farmers to access essential resources, such as improved seed varieties and technologies, which can positively impact maize yield by facilitating better agricultural practices (Adeagbo et al., 2021). Moreover, Tafesse et al. (2023) reported that for every additional kilometer between a farmer's home and the market, his or her likelihood of selling maize decreases by 1.68%, negatively affecting market participation and yield.

Membership in an organization can have a positive impact on maize yield. Access to agricultural inputs, extension services, and market information, which are often provided through membership in an organization, can enhance maize production (Gedil & Menkir, 2019; Sattar et al., 2023). Furthermore, membership in such organizations provides farmers with crucial information regarding production methods and market trends, empowering them to make informed decisions that can optimize their maize production (Zhou et al., 2023). Additionally, many farmer organizations offer credit and other services, enabling farmers to secure loans for agricultural production and other livelihood-enhancing activities (Yusuph et al., 2023).

5. CONCLUSION

The findings of this study highlight the importance of climate-smart agriculture (CSA) practices in enhancing maize yields among smallholder farmers in Tanzania's semi-arid regions. Effective practices identified included improved varieties, crop residue retention, mixed farming, intercropping, adjusted planting dates, minimum tillage, agroforestry, crop rotation, cover crops, and use of manure. Positive correlations were observed between various CSA practices, indicating potential synergies. For instance, improved seed varieties have shown positive associations with changes in planting dates, manure use, minimum tillage, intercropping, mixed cropping, and livestock diversification. Similarly, intercropping exhibited synergy with improved varieties, mixed cropping, and agroforestry systems. On the other hand, trade-offs were noted, such as the negative correlation between minimum tillage and practices like changes in planting dates and crop rotation.

Moreover, employing multiple CSA practices concurrently yielded more significant increases in maize yields than individual practices. This indicated the need for farmers to use multiple CSA practices to maximize yield. The study also identified access to credit, NGO assistance, membership in an organization, and CSA training as mediators in the relationship between practices and maize yield, emphasizing their crucial role in promoting CSA. Key factors, such as access to credit, NGO support, membership in an organization, distance to market, and CSA training play partial mediating roles in the relationship between CSA practices and maize yield. These are the most important factors that contribute to synergies between climate-smart agriculture practices used by the majority of farmers.

The development of a comprehensive and adaptable strategy for promoting CSA practices among smallholder farmers in semi-arid regions is essential for enhancing crop yields, increasing income, and improving climate resilience. This strategy should involve close engagement with farmers to understand their specific needs and requirements and facilitate capacity building through targeted training and extension services. Providing access to vital information, such as weather forecasts and market data, is crucial for informed decision making. Additionally, offering incentives that align agricultural practices with farmers' objectives and resources can encourage the adoption of sustainable methods. To minimize trade-offs a context-specific, CSA practices that optimize the combination of CSA practices should be developed. Careful selection of crop species and crop varieties can maximize complementarity among CSA practices to suit local agroecological conditions and farmer’s needs.

While it is true that the provision of training and credit has some cost implications, this can be mitigated through public-private partnerships, whereby the government can collaborate with private sector entities. For example, microfinance institutions have been instrumental in providing tailored financial products to smallholder farmers, facilitating access to credit. Moreover, utilising digital platforms for training can reduce costs associated with physical materials and travel expenses. For instance, online training modules can reach a broader audience at a lower cost. Additionally, implementing farmer-to-farmer extension models can be cost-effective, improving practices and profits for smallholder farmers. Lastly, government subsidies or grants can offset the costs of credit and training programmes, making them more affordable for farmers.

While this study offers valuable insights into the synergies and trade-offs of CSA practices, it is essential to acknowledge its limitations. The findings are based on Likert-scale data and self-reported data from farmers, which may introduce response bias. Household heads may overestimate or underestimate their engagement in CSA practices due to factors such as social desirability, memory recall errors, or personal interpretations of the survey questions. Despite these limitations, the study's results provides insights on how the implementation of CSA practices can yield both synergies and trade-offs, a crucial consideration for agricultural investment planning and decision-making, particularly in resource-constrained areas. Future research should explore triangulation or incorporate additional field experiments and observations.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology.

Details of the AI usage are given below:

1. Grammary
2. Quilbot

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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