<u>Original Research Article</u>

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

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). 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 climate-smart agriculture 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 of climate-smart agriculture practices, analyse the direct and indirect effects of mediating factors on increasing maize yield, and analyse the synergies 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.

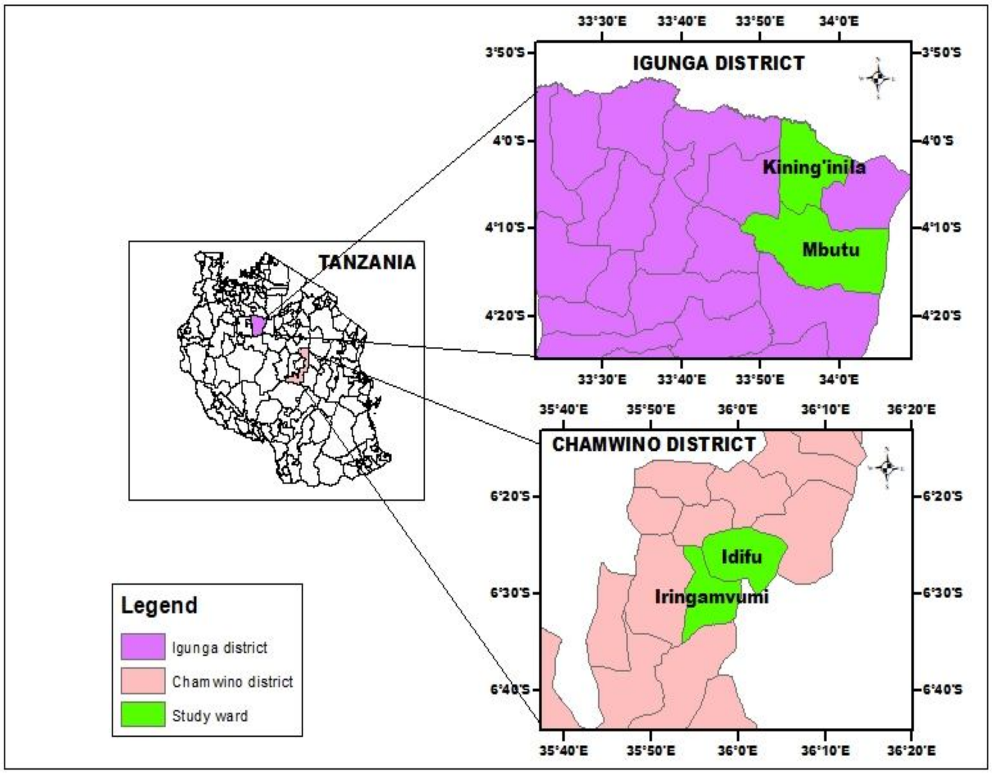

Figure 1: Map of the study area

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 climate-smart agriculture (CSA) in the semi-arid regions of Dodoma and Tabora were selected. 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 and villages were purposefully chosen from each ward. The chosen wards included Idifu and Iringa mvumi wards in Chamwino district and Mbutu and Kining'inila wards in Igunga district. The selection criteria for the villages were based on the cultivation of maize crops as well as the implementation of other CSA practices. This sampling procedure ensured representation from diverse geographic locations, and targeted communities actively engaged in CSA practices. The number of sample households was determined to be 299 using a simplified formula (Yamane, 1967).

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

$$\boldsymbol{n} = \frac{\boldsymbol{N}}{\boldsymbol{1 + N(e)^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

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 questionnaires. 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.

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.

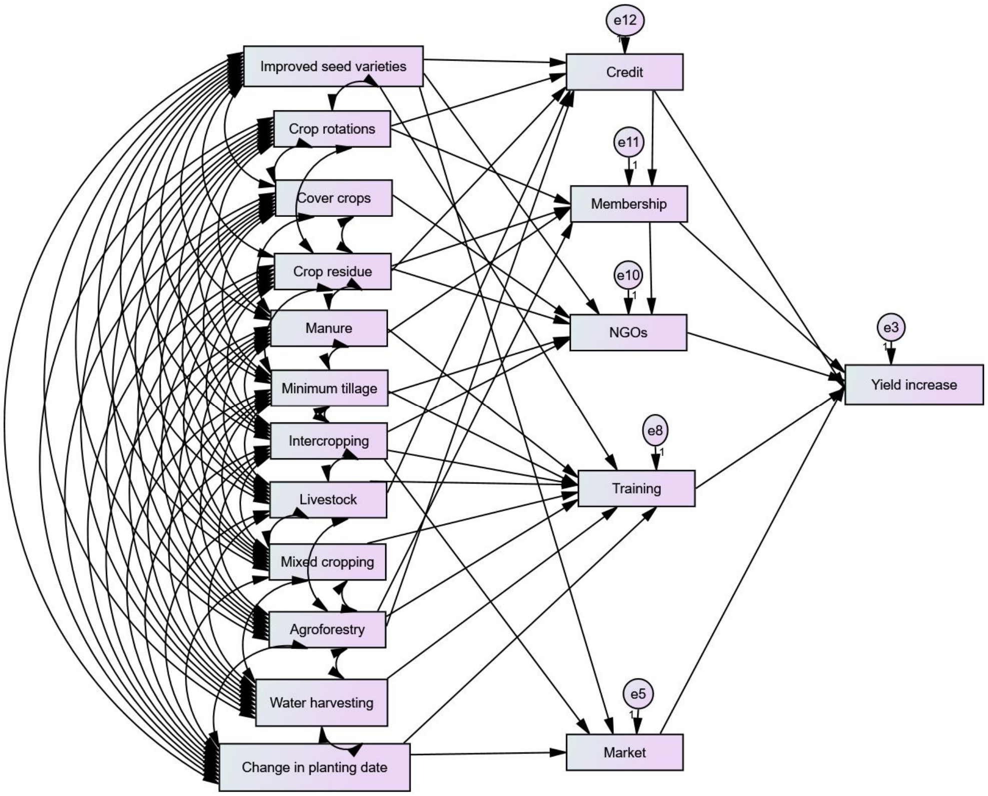

Figure 2: Conceptual model showing the potential relationships between climate-smart agriculture practices and other factors

2.5 Hypothesis

It was hypothesized that credit access, NGO assistance, membership in an organisation and training in CSA practices influence synergies between CSA practices which in turn contribute to increased yield.

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 5.3). 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.

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

Fit indices	Recommended values	Observed value
CMIN/df	3-5	2.406
GFI	>=0.9	0.956
CFI	>=0.9	0.905
TLI	>=0.9	0.798
SRMR	<=0.05	0.05
RMSEA.	<=0.08	0.069

2.7 Data analysis

2.7.1 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.

2.7.2 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 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 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 (Figure 3). Most farmers (79.26%) agree that livestock diversification, mixed cropping, cereal legume intercropping, water harvesting pits, terraces, crop rotation, agroforestry, and maize/safflower planting can increase crop yields. Moreover, some farmers (58.20%) indicated that crop rotation increases soil fertility. Furthermore, 95.65% 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 68.32% of farmers did not implement this practice.

About 58.19% 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, 84.28% 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 55.52% 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.

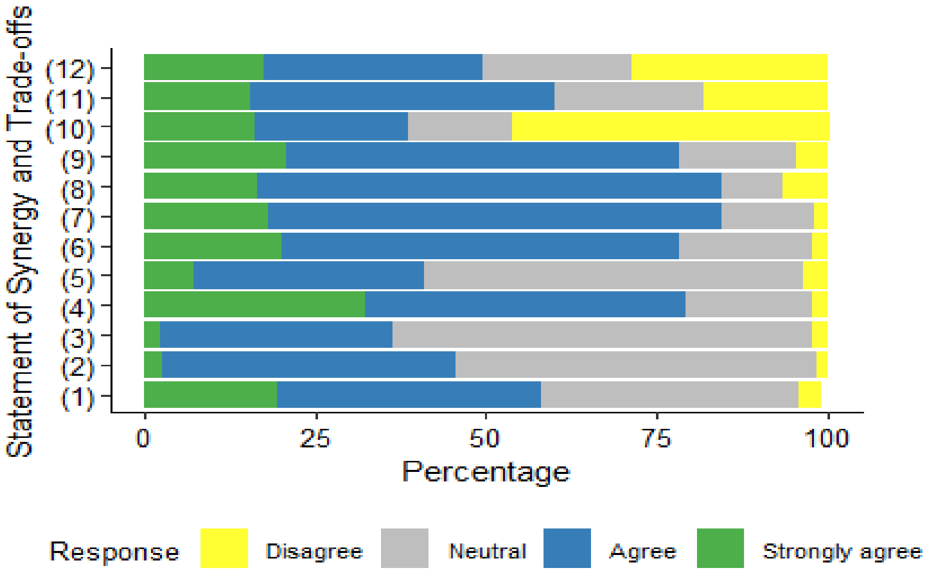

Figure 3: Farmer's Perception of climate-smart agriculture synergies and trade-offs. Key: 1.Crop rotation improves soil fertility, 2. Tree planting restores degraded land, 3. Agroforestry enhances carbon sequestration, 4. Intercropping improve yield, 5. Water harvesting pits increase yield, 6. Mixed cropping increases income, 7. Labour requirement has increased, 8. The cost of production has increased, 9. Food security increase, 10. Cost of production decrease, 11. Total annual house hold income has increased, 12. Livestock production increase

3.2 Synergies of climate-smart agriculture practices from existing literature

Various Climate Smart Agriculture (CSA) practices (Table 1), 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.

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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).	This 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).

Climate smart Agriculture Practices	**Synergies**	**Trade-offs**
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 al.,* 2017), Increased crop yield (Semalulu*et al.,* 2020), Increased income (Morizet-Davis *et al.,* 2023).	Potential competition for water and nutrients (Morizet-Davis *et 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)

3.3 Synergies and Trade-offs of climate-smart agriculture practices

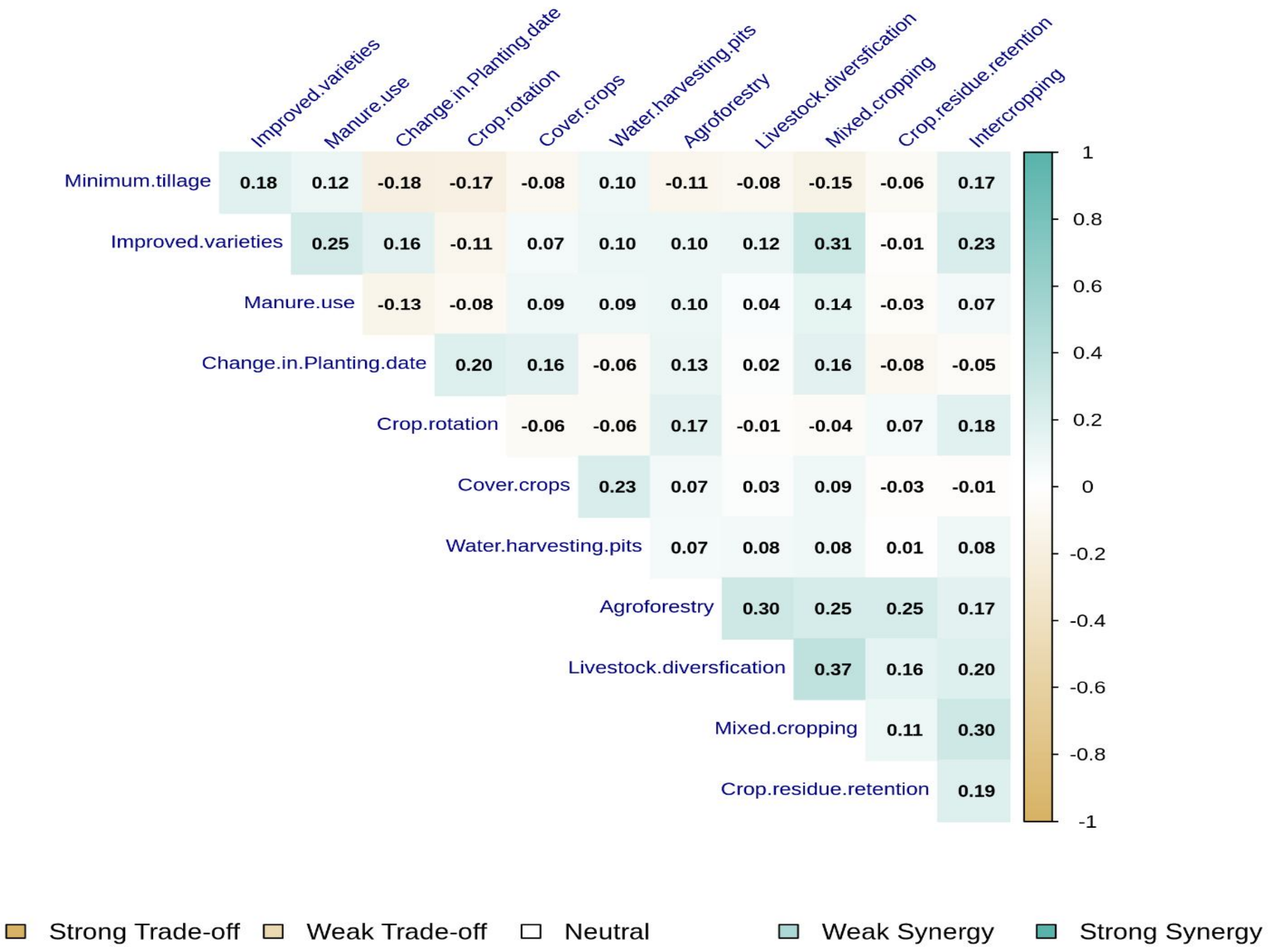
The correlation between various climate-smart agriculture practices indicates both synergies and trade-offs among CSA practices used by smallholder farmers. Positive correlations indicate synergistic relationships in which the usage of one practice can enhance the effectiveness of another. Conversely, 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 (Figure 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.



	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

Figure 4: Heatmap of Synergies and trade-offs of climate-smart agriculture practices

4.5 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.

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.

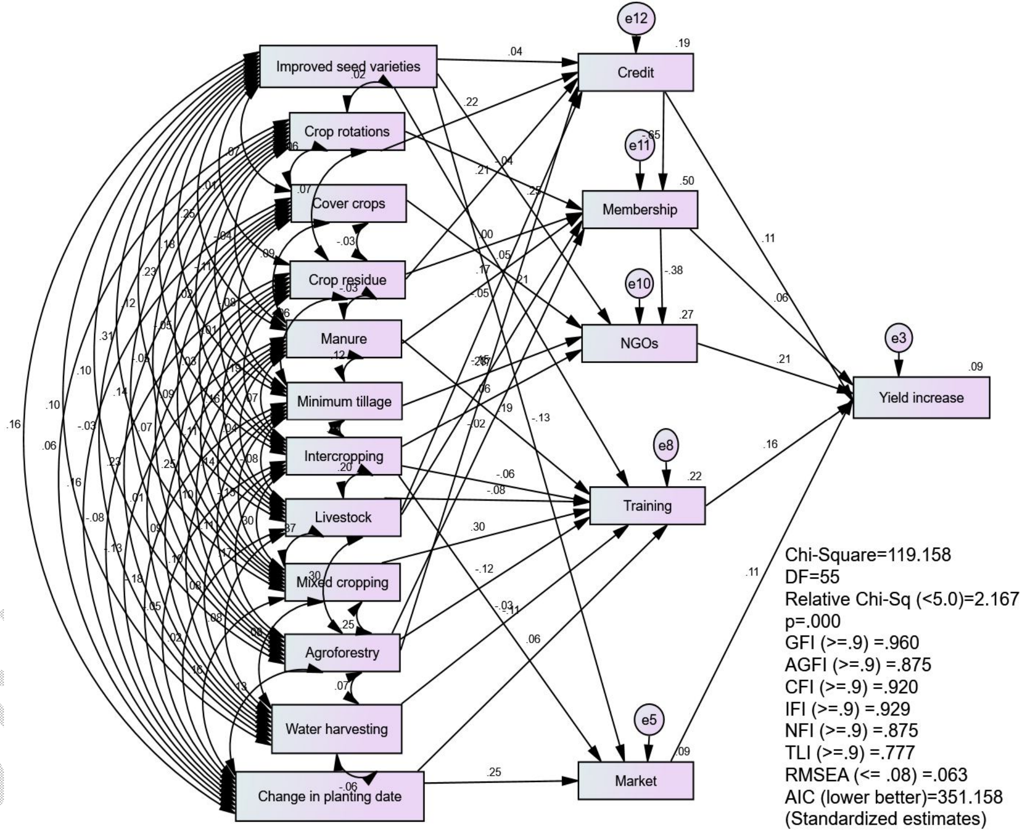


Figure 5: The path analysis model with standardized estimates

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 Indexand the CFI= Comparative Fit Index.. AIC= Akaike information criterion index

Table 3: Direct effects of different factors on yield

Path			Estimate	Confidence Interval (95%)		P
				Lower	Upper	
	→	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 $P < 0.05$

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 have been shown to have a negative correlation, which implies that implementing both practices at the same time may result in lower yields or other undesirable outcomes. Therefore, farmers should carefully assess the trade-offs between these practices when designing their farm management plans.

4.2 Mediating factors influencing synergies among CSA practices

Based on the findings, the link between climate-smart agriculture practices and maize yield is entirely influenced by five mediators namely: access to credit, assistance from non-governmental organizations (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.

Non-governmental organizations (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 Climate-Smart Agriculture (CSA) practices. Farmers with access to credit are equipped with the essential financial resources to engage in diverse climate-smart agriculture practices. This includes acquiring drought-tolerant 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 Climate-Smart Agriculture (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 kilometre 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 climate-smart agriculture 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 pivotal 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.

A comprehensive and adaptable strategy for CSA promotion is important. This strategy should include close engagement with farmers to understand their needs and requirements, capacity building through training and extension services, and access to information such as weather changes and market information. Additionally, incentives should be provided for aligning practices with their objectives and resources. This strategy is important for increasing crop yields, and income and improving climate resilience among smallholder farmers in semi-arid regions.

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