The Contribution of Climate-Smart Agriculture to Reducing Climate-Related Risks to Rain-Fed Maize Production: Insights from Tanzania's Semi-Arid and Sub-Humid Regions

Barnabas Msongaleli[1*]

Abstract

Adaptation responses of rain-fed smallholder farming systems to climate change and variability have become more unpredictable. Semi-arid and sub-humid regions are most affected by knowledge gaps on climate change adaptation strategies. Climate-smart agriculture (CSA) practices are crucial because they ensure predictable and effective adaptation responses that reduce crop failures. To determine potential new strategies for farm-level climate change adaptation, this study examined the implications of three CSA practices on rain-fed maize production: crop diversification, intercropping, and planting date adjustment. Plot-level data were obtained from the Tanzania National Panel Survey (TNPS) throughout waves 1 (2008/2009) and 2 (2010/2011). The consistency of the adaptation responses was evaluated using test-retest reliability. The findings showed that intercropping and splitting plots to plant crops other than maize was an analogue for crop diversification and reduced variability of maize grain yields. The panel linear regression model revealed that the yields of maize grains were positively correlated with intercropping and crop diversification (plot division). Moreover, the results of the meta-analysis showed that intercropping, crop diversification, and planting date adjustments could greatly increase smallholder rain-fed maize farmers' resistance to the effects of climate variability and change. The government and non-governmental organizations should be encouraged to provide funding for agricultural extension education, which is a major factor in the implementation of CSA techniques.

Keywords: Emergent adaptation responses, panel data, agro-climatic zones, plot management level, climate change

[1]Department of Geography and Environmental Studies, The University of Dodoma, Dodoma, Tanzania

*Corresponding author's email: barnabas.msongaleli@udom.ac.tz

Received on November 3rd, 2023/Accepted on December 27th, 2023

Ghana Journal of Geography Vol. 16 (1), 2024 pages 28-58

Doi: https://dx.doi.org/10.4314/gjg.v16i1.2

Introduction

Due to their low adaptation capacity and the exceptional current rise in climate-related pressures such as drought, floods, and rainfall unpredictability, many African countries are extremely vulnerable to the effects of climate change (Guillaumont & Simonet, 2011). Furthermore, according to the sixth IPCC assessment report, regions that are semi-arid or sub-humid will see the greatest increases in temperature on the hottest days, which will coincide with a trend towards more frequent ecological and agricultural drought as well as dwindling groundwater supplies (IPCC, 2022). Therefore, adaptation strategies are required to combat the anticipated impacts of climate change. According to the IPCC (2022) (p. 5), adaptation to climate change is the "process of adjustment to the actual or expected climate and its effects." There is ample scientific evidence that research on adapting to climate change is expanding quickly, although it is not dispersed equally among vulnerable nations (Sietsma et al., 2021).

Furthermore, the adaptation strategies used by smallholder farmers have adhered to a long-standing worldview that views conventional adaptation strategies as unwavering, meaning that their execution does not require the complementarity of emergent and classic strategies. Given the added difficulties brought about by the COVID-19 pandemic and an increase in climatic extremes, this scenario has made it necessary to rethink a portfolio approach to adaptation (Birkmann et al., 2022; Magesa et al., 2023). Accordingly, research on climate change adaptation is crucial to comprehending how smallholder farmers manage risks associated with climate change while taking sustainable development into account (Ayanlade et al., 2022; Birkmann et al., 2022).

The definition of "adaptation response" in the context of this work, according to Eriksen et al. (2021), is a response that comprises one or more adaptation actions to address the underlying vulnerability(s) and implementation alternatives with details on partners and processes for carrying out the actions. The primary motivator of creative proactive adaptation strategies, according to a recent analysis that distinguished between the applicability of proactive and reactive adaptation measures, is the increasing risks associated with climate change (Darjee et al., 2023). According to their findings, even though most households implemented both proactive and reactive adaptation strategies, the proactive ones provided more protection against climate-related hazards. They emphasise how important it is to comprehend local people' viewpoints while planning and implementing adaptations. A paradigm change to naturally self-initiated climate-smart agriculture (CSA) practices has been fuelled by reactive or conventional adaptation strategies. Thierfelder et al. (2017) provide a more comprehensive explanation, defining "climate-smart" as any approach that includes reducing greenhouse gas emissions, adapting to climate change, and boosting agricultural output and incomes in a sustainable manner. Reactive or conventional adaptation strategies include crop and agronomic management practices such as the adoption of improved maize varieties (e.g., long maturity and drought tolerant cultivars) along with continued use of local varieties, modification in planting dates and plant density, increased fertilizer input (Westengen, 2014; Xiong and Tarnavsky, 2020). This change has given rise to the possibility of reconsidering locally specific and contextually appropriate adaptation measures to mitigate climate hazards across different agro-climatic zones. Smallholders' vulnerability manifests itself in who is at risk, highlighting a possible leverage point that might lead to changes in and/or reconsiderations of adaptation strategies planning and/or policy reforms (Eriksen et al., 2021; Olabanji et al., 2021; Kissinger et al., 2013).

Previous studies have evaluated the risk associated with climate change by emphasising the detrimental effects on smallholder farmers' livelihoods and rural economies, especially in semi-arid and sub-humid parts of sub-Saharan Africa (SSA) (Calzadilla et al., 2013; Hansen et al., 2019; Lamanna et al., 2016). Since maize (*Zea mays L*.) is Tanzania's principal staple crop, we have focused on it in this study (Baijukya et al., 2020). But the crop faces increasing threats from rising seasonal temperatures and altered rainfall patterns brought on by climate change (Adhikari et al., 2015). In Tanzania, maize production is also affected differently in different agro-ecological zones, with semi-arid areas experiencing the most impact (Mkonda and He, 2018; Volk et al., 2021). Since the nation is one of those most severely impacted by climate change, creative approaches to mitigating its effects are essential, particularly in drylands where, according to recent estimates, vulnerabilities, hazards, and impacts are greatest (IPCC, 2022; Mdemu, 2021). Examples of the unprecedented increase in smallholder farmers' vulnerability include irregular planting dates and variations in the sizes of planted and harvested plots (Ayanlade et al., 2022; Myeya, 2021).

For the purpose of the productivity of crops, climate-related risk has been defined in this work as the risk resulting from occurrences such as excessive rain, droughts, crop pest outbreaks, and disease outbreaks. Rainfall-related extremes, such as drought, are one of the main risks associated with rain-fed maize that have been identified in Tanzania (Mkonda and He, 2018; Xiong and Tarnavsky, 2020). These risks are closely related to the current adaptation strategies and how the smallholder farmers have been affected. As a result of a changing environment, smallholder farmers have had to face the harsh reality of having to modify their farm management techniques and choices in order to maintain or boost cereal crop yields (Kalungu & Harris, 2013; Nyang'au et al., 2021; Tofu & Mengistu, 2023). Smallholder farmers have been forced to make trial-and-error adjustments because of the growing uncertainty in climate variables that impact cropping patterns and systems, such as the unpredictable nature of rain onset as an analogue for planting dates (Clay & King, 2019; Krell et al., 2021). For instance, in central Tanzania, the planting of normal season crops—which would normally occur in November and December—has gradually moved to the first dekad of January (Msongaleli, 2021; Baijukya et al., 2020). Droughts that recur in December have caused planting delays of approximately one month. Consequently, crop types and varieties have not been chosen and cultivation dates have not coincided with minimising water stress during the growing season (Vermeulen et al., 2012).

While it is undeniable that a dependable crop calendar is essential to the success of crop production in the face of increased rainfall variability, the timing of subsequent operations, such as planting, is rarely met, which increases the uncertainty of smallholder farmers when making decisions (Nyagumbo et al., 2017; Waongo et al., 2015). Thus, a rainfall-based planting date method is at risk due to the shifting and changing duration of the growing seasons, an increase in the frequency of seasonal dry spells, and dryness in semi-arid and dry sub-humid locations (Bell et al., 2015; Nathan et al., 2020). Therefore, smallholder farmers in the developing nations have few options other than to use CSA practices, which include, among other things, altering or adjusting planting dates (Aryal et al., 2021; Issahaku & Abdulai, 2020; Quarshie et al., 2023; Weerasooriya & Karthigayini, 2023), crop diversification (Lakhran et al., 2017; Kalinga et al., 2022) and intercropping (Yusuph et al., 2023).

Accelerated adoption of CSA has been identified by Tanzania's Agricultural Climate Resilience Plan (ACRP) 2014-2019 (United Republic of Tanzania, 2014) as one of the adaptation strategies worth pursuing for reducing the effects of climate-related shocks. It has been demonstrated that smallholder rain-fed cereal farmers can better respond to climate change by implementing CSA strategies. Several studies have demonstrated the effectiveness of such policy interventions in mitigating the negative impacts of climate variability on smallholder farmers who depend on rain for their livelihood (Gebre et al., 2023; Gwambene et al., 2019; Kihupi et al., 2015 and Komba & Muchapondwa, 2018). This has been noted in other places about the various roles that non-governmental organizations, families, and governments play in assisting smallholder rural communities in adapting (Aniah et al., 2019; Brown et al., 2019).

In order to make well-informed judgments on adaptation responses in the most vulnerable places, evidence that can facilitate comprehension of the roles and timing is needed. However, little is known about how the characteristics of shifting rainfall, in particular, affect the timing of crop planting, the area planted, and the area harvested afterward, thereby speeding up the current and on-going unpredictability in output. This paper aims to examine the role of three CSA-practices: crop diversification, intercropping, and planting date adjustment as adaptation strategies on rain-fed maize production with evidence from semi-arid and sub-humid areas. It draws on the two waves of plot-level data from the Tanzania National Panel Survey (TNPS) and a meta-analysis.

Methodology

Study area description

The study area encompassed the regions surrounding Dodoma, Tabora, and Morogoro, which correspond to Tanzania's semi-arid, dry sub-humid, and sub-humid agro-climatic zones (ACZs), respectively (Fig. 1). Crop production, animal farming, and off-farm activities define the farming system of the studied area. This study focuses on two crop enterprises found in the study area: intercropped maize and maize only.

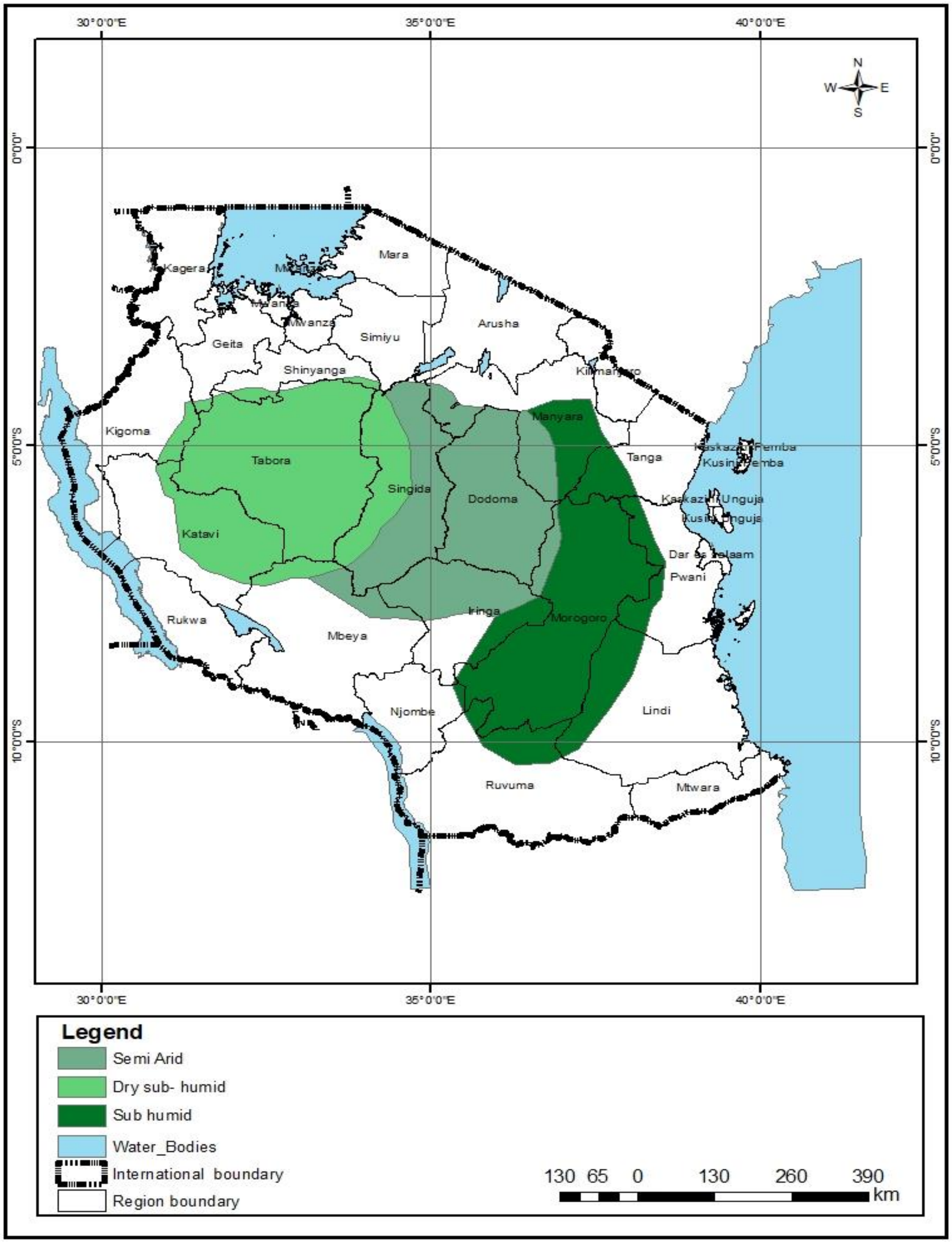

Figure 1: The study area (Source: Author)

Table 1 lists the attributes of the ACZ, including its location, altitude, yearly rainfall, primary crops, and livestock.

Table 1: Agro-climatic characteristics of the study areas

Region	(Morogoro)	(Dodoma)	(Tabora)
Coordinates (latitude, longitude)	-6.63187, 38.05664	-6.10232, 35.35675	-5.62145, 32.71728
Agro climate	Sub humid	Semi-arid	Dry sub-humid
Annual rainfall (mm)	700-900	500-600	600-700
Topography	Alluvial plains	Central plateau	Plateaux
Main crops and livestock (by order of importance)	Maize, sorghum, millet, paddy, cattle, goats, sheep	Sorghum, millet, maize, groundnut, cattle, goats, donkey	Maize, sorghum, groundnut, cattle, goats, donkey

Source. Author’s construction from literature

Description of data sources

In this work, two types of data were employed. Firstly, the TNPS provides a comprehensive dataset on agricultural practices and socioeconomic conditions. The World Bank's Living Standards Measurement Study - Integrated Surveys on Agriculture (LSMS - ISA) and Tanzania's National Bureau of Statistics collaborated to undertake the nationally representative survey known as the TNPS. The TNPS consists of a plot questionnaire that provides comprehensive information on agronomic management, fertiliser application, labour costs, household size, area planted, and the causes of irregularities in the amount of land harvested and planted in the farmer's plots.

The two waves of TNPS provided information on modifications to cropping systems and patterns (NBS, 2012). It covered the following: if plot was intercropped; whether the main plot was divided; and the justifications for not planting maize on the complete area of the main plots during the planting season and for not harvesting from the planted plots. Plot division was viewed as a stand-in for crop diversification in the context of this study, which was defined as the addition or development of new crops to the current farming system (Makate et al., 2016). Furthermore, a study by Mukherji & Kumar (2021) provide support for the choice of cropping system and pattern modifications as the main focus of the adaptation responses, claiming that they account for 45% of the sector's adaptation responses. Another rationale stems from the results of a recent study conducted in Tanzania's semi-arid regions, which ranked intercropping as the most effective CSA method (Yusuph et al., 2023).

Within the scope of this article, intercropping is defined as a farming technique in which farmers grow multiple crop species concurrently in the same field during a single growing season, namely a combination of cereal and legume. In Tanzania, yields from wave 1 of 2008/2009 and wave 2 of 2010-2011 were extracted for the corresponding major plots of maize across the three agro-climatic zones: semi-arid (Singida and Dodoma regions), dry sub-humid (mostly Tabora region), and sub-humid (primarily Morogoro area) (NBS, 2012). The extent to which smallholder farmers in Tanzania's three agro-climatic zones are using agronomic management methods as adaptation strategies to control rainfall variability and promote resilience was examined using the data.

Once household IDs that were kept in both surveys were filtered and matched, the observed maize grain yields from TNPS for the 2008–09 and 2010–11 seasons were acquired. Consequently, out of 225 plots with overlapping information regarding additions or omissions, a dataset involving 125 households' ID plots was kept for study. The study's dataset would consist of 125 x 2 = 250 observations for the two seasons. However, because there were some maize grain yields that were out of the considered range (outliers) of not exceeding the average of 1400 kg/ha, the study's dataset was changed to 206. The following queries were addressed in the light of the corresponding agronomic management data in the study area: why didn't smallholder farmers grow the crop on the complete plot? Did you harvest a smaller area than you planted? Why did the harvested area fall short of the planted area?

The second step involved searching Mendeley and Google Scholar for peer-reviewed studies for a meta-analysis about the information that helped or supported adaptation to climate change. Data were taken from sources and summarised for the following subjects: (a) How the rain-fed cereal cropping system used by smallholder farmers is affected by climate change; (b) CSA techniques that include crop diversification, intercropping, and improved/optimised planting dates are identified.

Data analysis

The majority of the adaptation techniques employed by smallholder farmers during both TNPS waves were determined using frequencies. The consistency of the adopted adaptation tactics during both cropping seasons was subsequently determined using test-retest reliability and the Intraclass Correlation Coefficient (ICC). This characteristic of reliability can be quantitatively estimated using the ICC. In most cases, the ICC is determined as a ratio. ICC is calculated as follows: variance of interest / total variance = variance of interest / (unwanted variance + variance of interest). The capacity of a measure to yield the same rating when administered twice to the same respondents is known as reliability. The main plot division, intercropping, and whether or not the farmer's plots planted and harvested areas differed were the variables that were used. The Shapiro-Wilk test was used to assess if the distribution of the data deviated from a normal distribution before beginning the correlation analysis. Because the distribution in one of the seasons departed from a normal distribution, the nonparametric Spearman's rank correlation coefficient was utilised.

To unfold the potential but less documented strategies that are location (agro-climatic zone) specific, the panel linear regression model including both zone and season fixed effects between two predictors (was the crop planted on the entire area of plot; was a plot intercropped) is employed as a predictive approach. The panel linear regression model (plm) package (Croissant & Millo, 2008) in R is commonly used for panel data analysis. Overall, panel regression is a powerful tool for analyzing panel data and can provide insights into the relationships between independent and dependent variables over time. The panel linear regression obeys the following equation:

$$y_{it} = \beta_0 + \beta_1 x_{it} + \delta_i + T_t \ldots\ldots\ldots\ldots. + \varepsilon_{it}$$

Equation 1

where

i=1,2,3…;

t=1,2,3…..T

The δ_i are zone-specific intercepts that capture heterogeneities across zones

yi: dependent variable (maize grain yield in kg/ha);

xit: independent variables (was the crop planted on the entire area of plot; was a plot intercropped)

βi: parameter.

εit : is the error between the observed yi and what the model predicts

The panel linear regression analysis aimed at ascertaining the impact of each independent variable on the dependent variable (the grain yield in kg/ha of maize produced by farming households) over seasons and time-invariant agro-climatic zone. Regression variables for the computation of the coefficients are as listed in Table 2.

Table 2: Regression variables

Variable description and measurement	Units of measure	Expected sign
Grain yield	Kg/ha	+/-
Was the crop planted in the entire area of the plot?	1 = Yes, 0 = No	+
Was a plot intercropped?	1 = Yes, 0 = No	+
Plot's existence in one of the agro-climatic zones (semi-arid, sub-humid, dry sub-humid)	1 = Yes, 0 = No	+
Season (2008/2009 or 2010/2011)	1 = Yes, 0 =No	+

Source. Tanzania National Panel Survey waves 1 (2008/2009) and 2 (2010/2011)

Results and discussion

Variability in maize grain yields within seasons

Maize grain yield data across Tanzania's semi-arid and sub-humid regions reveal variability that calls for the re-evaluation of adaptation measures to lessen the risk that climate change poses to rain-fed maize production. This means that agronomic management techniques, which are ingrained in the great diversity in agro-ecologies, may mask a sizable amount of the yield variability. This is a challenge that needs to be overcome in order to decrease yield variability. The three Tanzanian agro-climatic zones' average grain yield variability in the seasons 2008/2009 and 2010/2011 as influenced by intercropping and crop diversification is depicted in Figures 2 and 3, respectively. The box plots show that a lesser variability in maize grain yield was obtained when the entire plots were not divided, i.e., when the entire plot was not planted with maize, as an analogue for crop diversification. On the other hand, the box plots show that cereal-grain legume intercropping reduced yield variability of maize during the 2010–2011 growing season prominently in semi-arid compared with other agro-climatic zones. The situation was different during the 2008–2009 growing season where a lesser variability in maize grain yield was obtained in the dry sub-humid and sub-humid zones. The box plot depictions align with the findings of a meta-analysis conducted by Raseduzzaman and Jensen (2017), which demonstrated that intercropping cereal-grain legumes considerably reduced yield variability when compared to monocrops. In order to reduce the variability in maize grain yield, it is imperative that smallholder farmers gain more understanding about developing and implementing alternative CSA practices. This is consistent with the recommendations made by Gwambene et al. (2019), who suggest that using suitable policies, strategies, investment plans, and group actions can result in an increase in smallholder farmers' resilience to the effects of climate change.

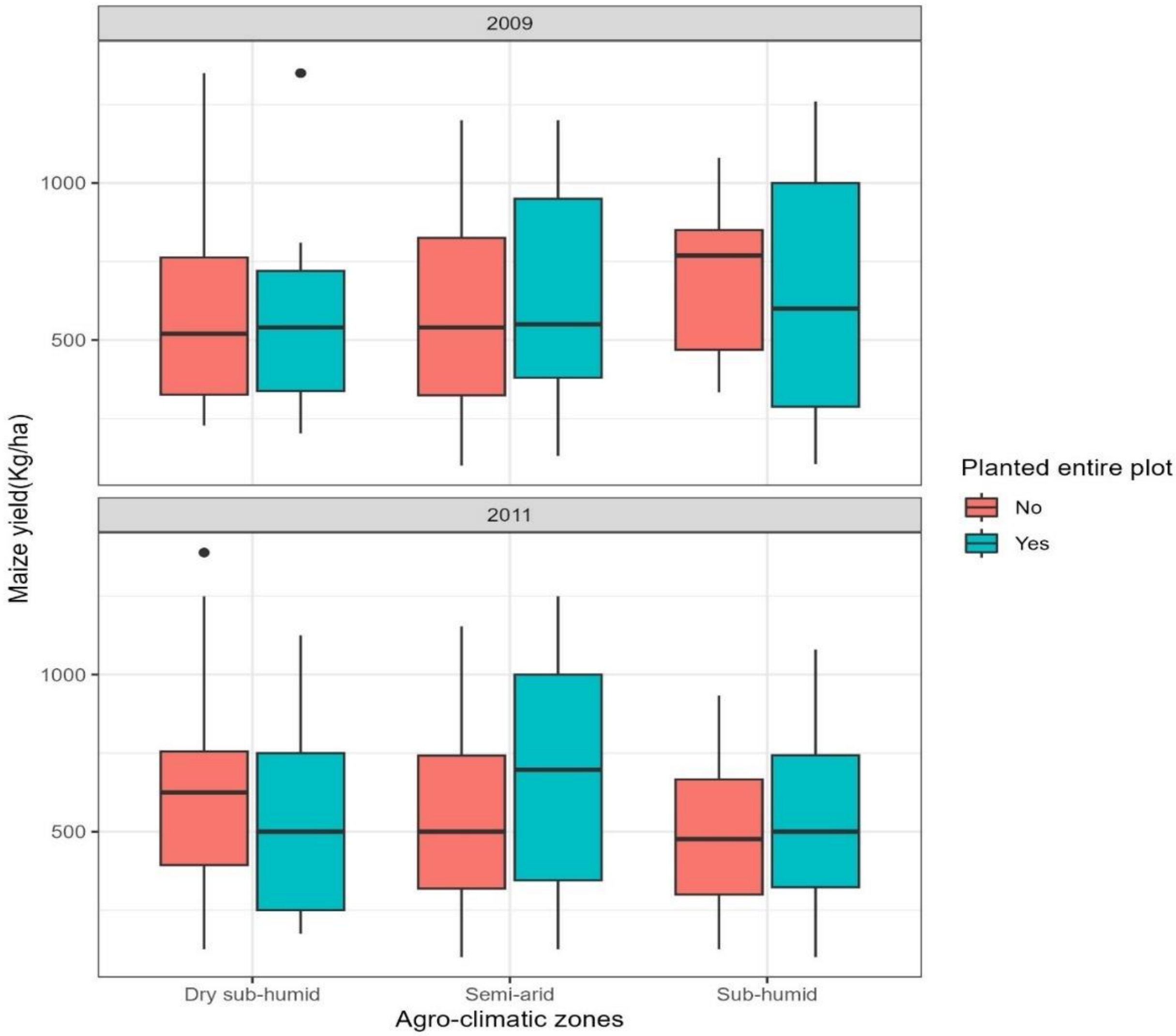

Figure 2: Maize grain yields (kg/ha) across three agro-climatic zones in Tanzania in the seasons 2008/2009 and 2010/2011 where the entire (major) plot was planted or not with maize. Box plot with median (bold line), quartiles (boxes) and variability outside the upper and lower quartiles (whiskers) (Source. Tanzania National Panel Survey waves 1 (2008/2009) and 2 (2010/2011)

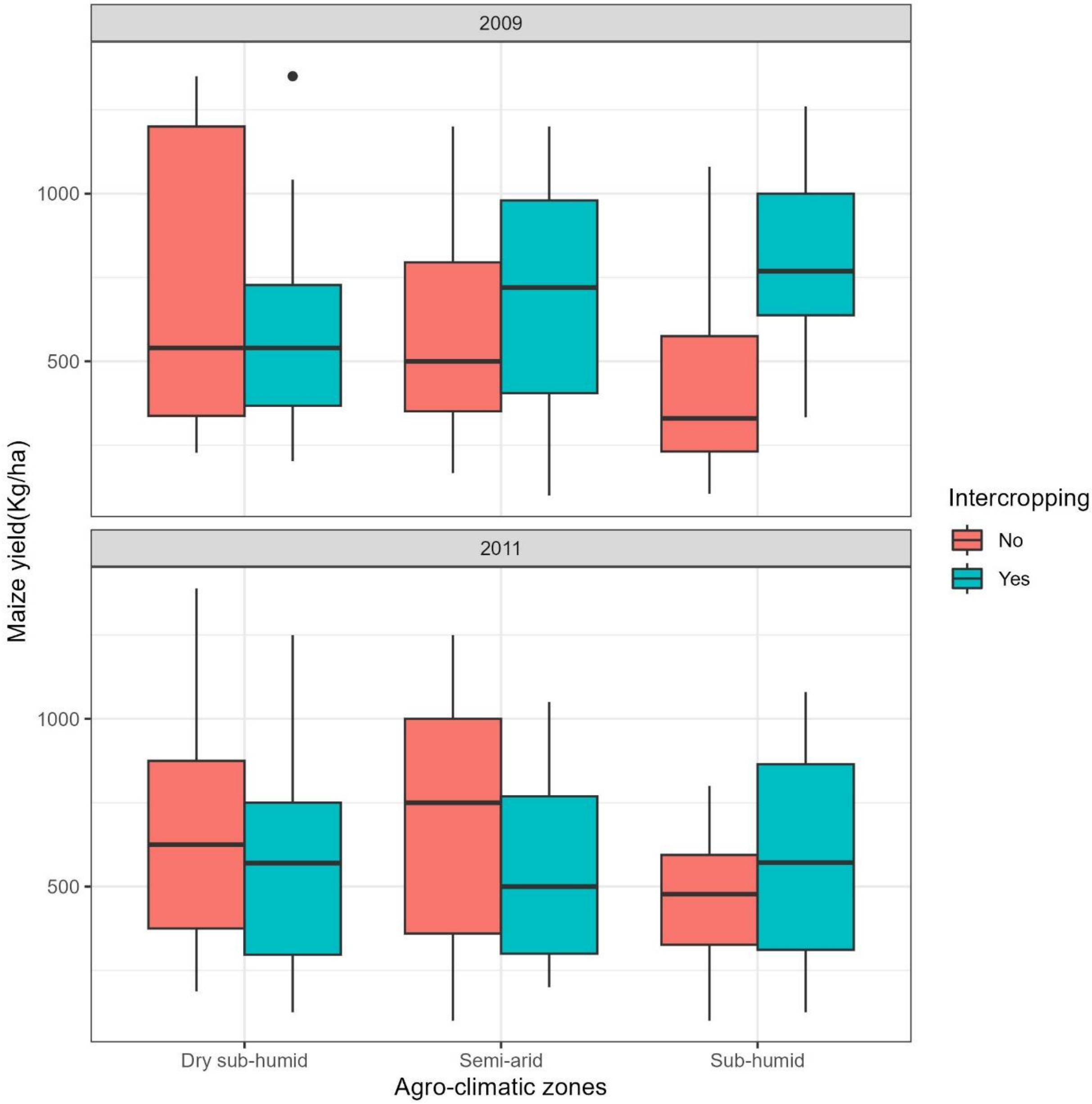

Figure 3: Maize grain yields (kg/ha) across three agro-climatic zones in Tanzania in the seasons 2008/2009 and 2010/2011 with maize plot intercropped (cereal-legume) or not. Box plot with median (bold line), quartiles (boxes) and variability outside the upper and lower quartiles (whiskers) (Source. Tanzania National Panel Survey waves 1 (2008/2009) and 2 (2010/2011)

Results of regression analysis

The panel linear regression model results obtained through fitting using intercropping and planting the entire plot as major predictors of maize grain yield are shown in Table 3. The regression results indicate that maize grain yield; even though not statistically significant, increased by 4.61 kg/ha for planting the entire plots with maize over the season and across agro-climatic. Meanwhile, maize grain yield, also not statistically significant, but increased by 10.92 kg/ha for the intercropped plots. The findings show that smallholder farmers' choice to divide large plots—that is, not to plant the entire plot—as an analogue for crop diversification protects them against the impacts of climate change and variability that could lead to crop failure. This is in line with Kalinga et al. (2022) and Lakhran et al. (2017) who found crop diversification to be one of the main 'climate-smart' practices for adapting maize production systems to climate change and variability in Tanzania and beyond. Moreover, the regression results indicate that there is the potential of intercropping as an effective climate change adaptation strategy, in line with Renwick et al., (2020) and Yusuph et al. (2023) who recommend intercropping as an important 'climate-smart' practice across different agro-climatic zones.

Table 3: Panel linear regression model results

Variable	Dependent variable: Maize grain yield
Was entire area of the plot planted? (Yes = 1)	4.609
Was a crop intercropped? (Yes = 1)	10.919
Observations	206
R^2	0.0003
Adjusted R^2	-0.02467
F-statistic	0.0316858^{ns} (df = 2; 200)

Note: ns = not statistically significant at 95 %. Source: Tanzania National Panel Survey waves 1 (2008/2009) and 2 (2010/2011

Test-retest reliability analysis results

Prior to conducting a test-retest reliability analysis, we ranked all of the chosen cropping systems and patterns implemented by smallholder farmers based on frequency, with the exception of cereal-legume intercropping. All 125 home IDs were included in the analysis for the cereal-legume intercropping (using the question "if the maize plot was intercropped"). As a result, the primary plot division, cereal-legume intercropping, and whether or not the area of the planted and harvested plots differed, were the three characteristics employed in the test-retest reliability study. The ranking indicated that the majority (on average, 62%) of smallholder farmers did not grow maize on their complete main plots throughout both cropping seasons. Figure 4 illustrates the reasons for not planting maize on a particular main plot. Cleverly, smallholder farmers split their major plots, as an analogue for crop diversification, to protect themselves from the harsh effects of unpredictable rains. These findings align with the research conducted by Kalinga et al. (2022), Kihupi et al. (2015) in Tanzania, and Makate et al. (2016) in Zimbabwe. These studies highlight the potential benefits of crop diversification as emerging CSA practice worth adopting as it could help farmers combat the impacts of climate change and variability.

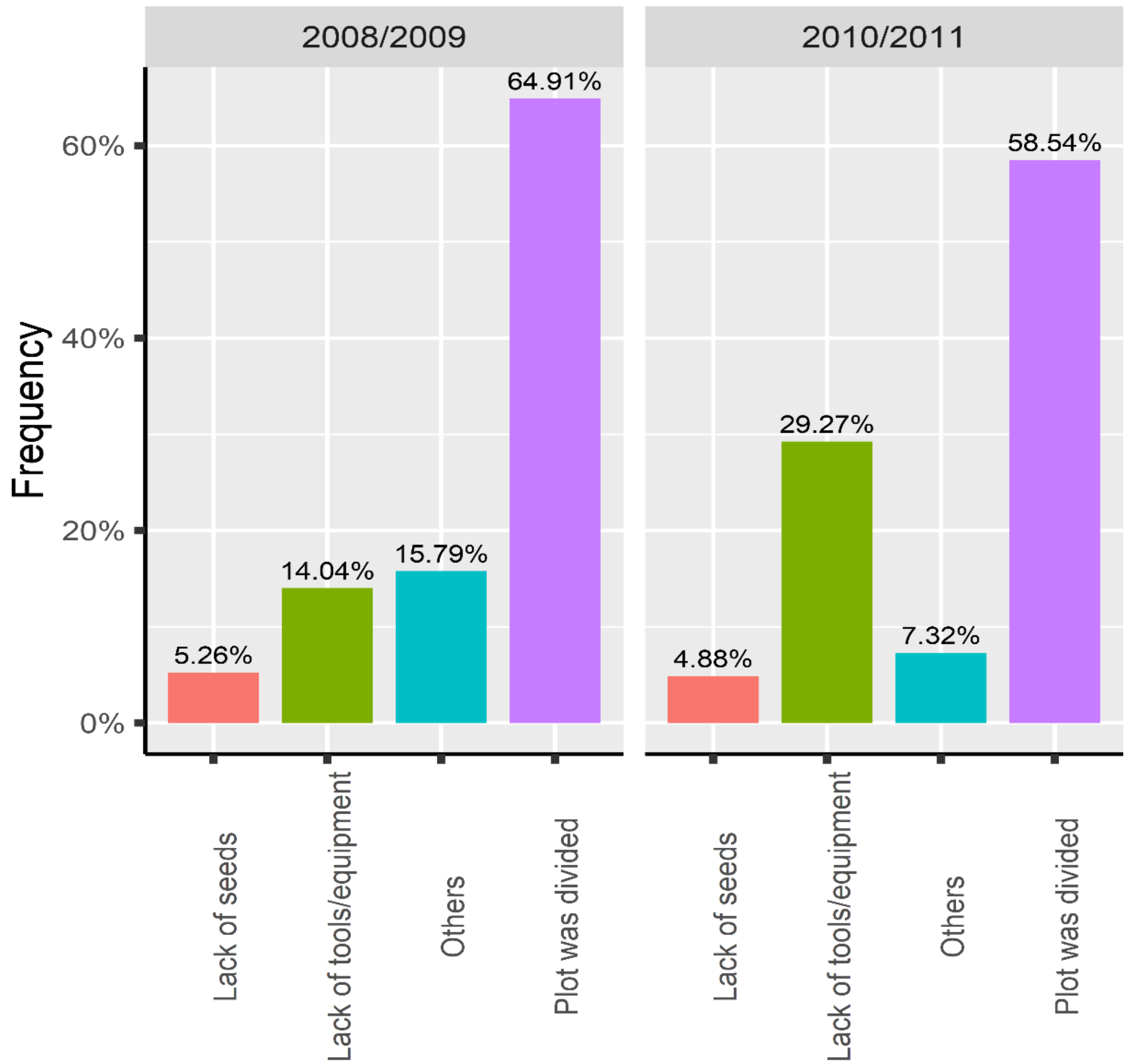

Figure 4: Reasons for not planting maize on the entire plots.

Regarding smallholder farmers who are harvesting from a lesser area than they had previously planted, the ranking showed that, on average, 65% of the reasons for this are related to drought in both cropping seasons. Crop disease infestations, sickness during harvest season, and a shortage of casual labourers rank second in magnitude. These findings are consistent with those of Tumbo et al. (2020), who linked higher rainfall variability to a predicted 5.3%–40.7% decline in maize grain production during the growing season in the Wami River sub-basin.

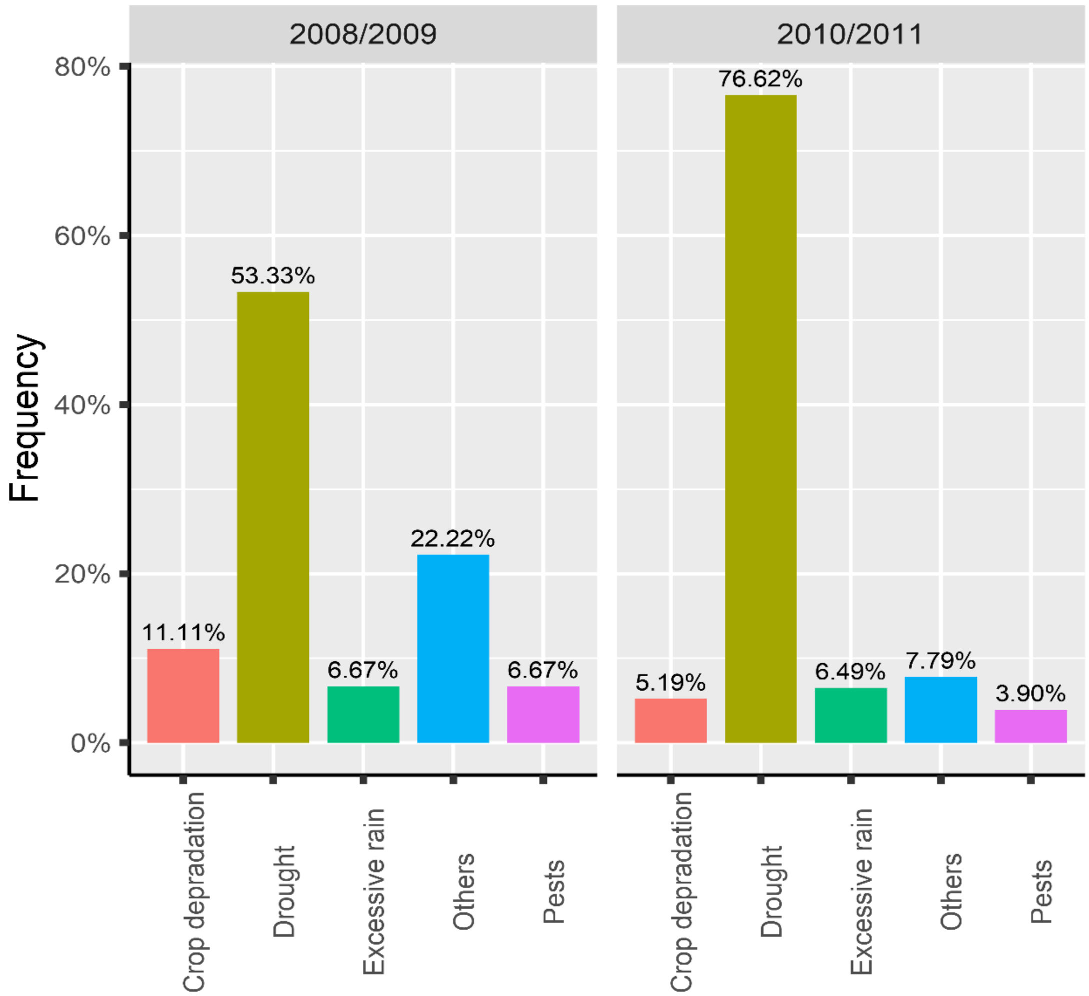

Figure 5: Reasons for harvesting a less area of the plot than area of the plot planted

Regarding the coherence of implemented adaptation tactics throughout cropping seasons, results in Table 5 show that, even with a low ICC, which denotes inadequate reliability, there was a good absolute agreement between cropping seasons on the main plot division (which serves as a stand-in for crop diversification), when employing two-way random effect models (p-value = 0.021).

Table 5: Description of the consistency of adopted adaptation strategies

Parameter (coding)	Intraclass Correlation Coefficient (ICC)	P value	95% CI
Intercropping (Yes =1; No = 2)	-0.0579	0.741	-0.23 < ICC < 0.118
Main plot divided (Yes =1; No = 2)	0.176	0.021	0.006 < ICC < 0.337
Area of plot harvested less than area planted (Yes = 1; No = 2)	-0.0326	0.659	-0.182 < ICC < 0.125

Realigning crop management practices and cropping systems as adaptation responses

A total of 20 articles were selected based on the selection criteria employed for the meta-analysis of CSA practices (Figure 6). The meta-analysis results, as summarized in Table 6, reveal that smallholder farmers have been modifying their crop management strategies and cereal cropping systems in order to reduce crop failures and yield decreases as a result of climate change. The results of the meta-analysis have helped illustrate the extent to which crop management strategies and cropping system modifications, such as intercropping, crop diversification, and planting date adjustments, have benefited smallholder farmers. In a similar vein, Bowles et al. (2020) discovered that farmers employ these responses as a risk-management strategy in unfavourable growing conditions, which frequently leads to increased yields, a decrease in maize failures, and an increase in income.

Comprehending these adaptation responses aids in placing their possible yield gains for rain-fed maize cultivation in the corresponding agro-climatic zones in perspective. Kurgat et al. (2020) have reported comparable results, emphasising the need to prioritise adaptation strategies in order to strengthen household resilience and pave the road for better adoption of CSA technology. Moreover, the results of the meta-analysis have shown that cropping systems and crop management improvements can help farmers better adapt to climate change; as a result, policy designs and reforms are needed to encourage the use of CSA methods. From a similar angle, Yusuph et al. (2023) suggest that governments and non-governmental organisations prioritise training programs as a means of encouraging the adoption of agroecological CSA techniques.

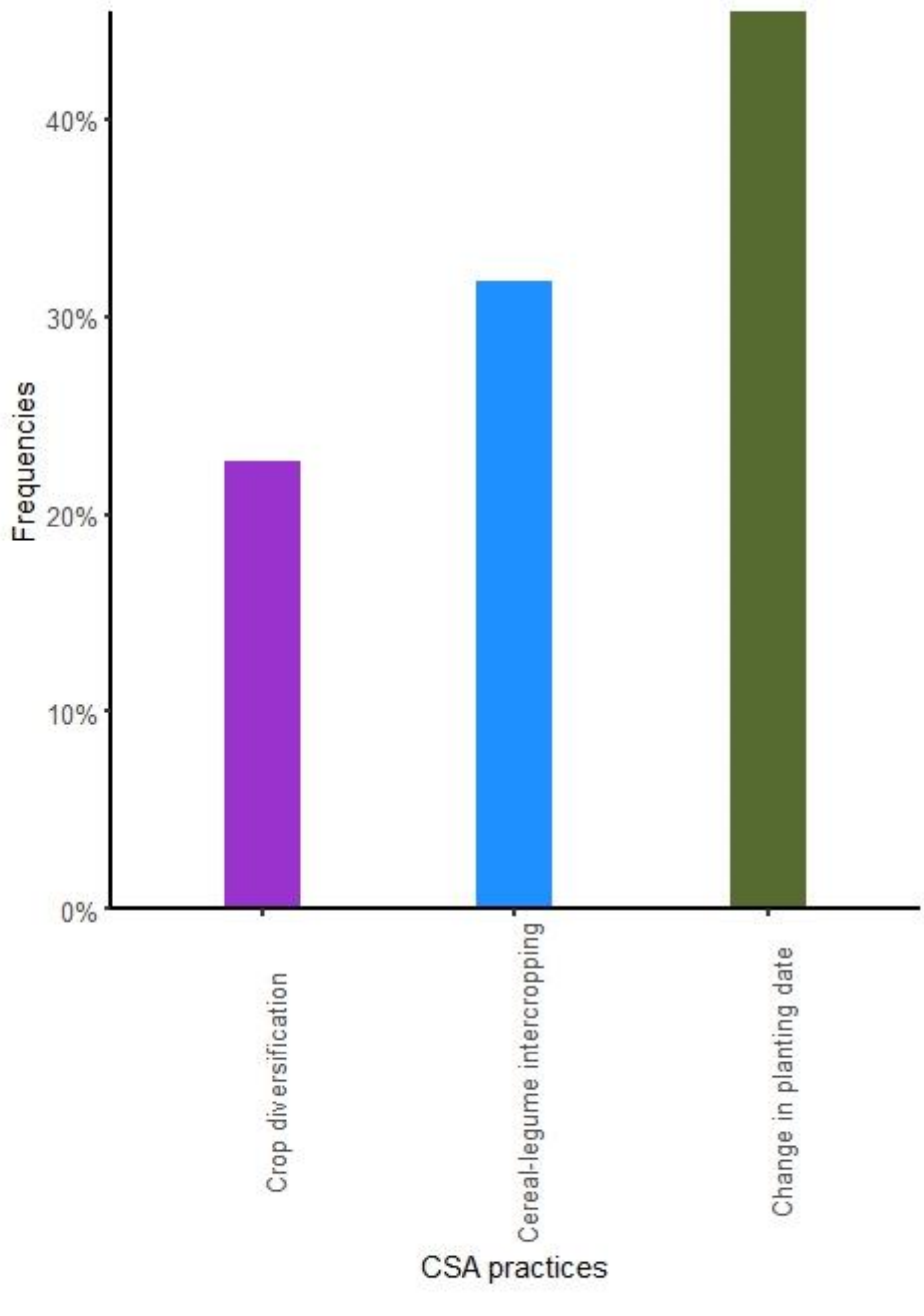

Figure 6. A meta-analysis of the climate-smart agriculture practices used in the study

Table 6: Description of the meta-analysis on CSA practices on rain-fed cereal cropping systems

Climate-smart agriculture practice(s)	Adaptation outcome or Impacts/Benefits
Cereal-legume intercropping	Improves productivity, improves yield stability, increases yields of both (cereal & legume) crops compared to sole crop; and enhances possibility of planting additional crops during the growing season; enhanced food security
Change in planting date	Increases flexibility in the choice of best suitable cereal crop varieties, and increases yields of cereal crops in water-limited environments
Crop diversification	Improves yield stability in the low-input systems and drought conditions; enhances crop resilience, enhances markets for unpopular crops; reduces total crop failure risk, ensures improved food security, and increases climate resilience

Conclusion

This study examined the association between CSA practices and rain-fed maize production in order to help smallholder farmers become more adaptable. Crop diversification, intercropping, and planting date adjustments are increasingly surfacing as crucial CSA practices to mitigate the uncertainties associated with the predicted rise in temperature and the increase in extreme weather events. The objective was to investigate the effects of modifying and adapting crop management techniques in rain-fed cereal production systems under rising rainfall variability. It is clear from our discussion that smallholder farmers in Tanzania's semi-arid, dry sub-humid, and sub-humid agro-climatic zones used a variety of crop management techniques, such as purposefully dividing the main plots to plant crops other than maize and intercropping, to better manage the effects of climate change and variability.

With the help of CSA practices, smallholder farmers may be able to increase profits as a result of improved rain-fed maize yields. Gaining an understanding of the applicability and adaptability of these CSA practices is crucial for enhancing food security as well as for guiding policy reforms for mitigating the impacts of climate change.

This study recommends that smallholder farmers be equipped with information and training regarding promising CSA practices. Moreover, concerted efforts by both public and commercial sectors should be made to support the provision of agricultural extension education, which is currently missing, but plays a crucial role in the adoption of CSA techniques.

References

Adhikari, U., Nejadhashemi, P., & Woznicki, S. A. (2015). Climate change and eastern Africa: a review of impact on major crops. *Food and Energy Security,* 4,110–132.

Aniah, P., Kaunza-Nu-Dem, M. K., & Ayembilla, J. A. (2019). Smallholder farmers' livelihood adaptation to climate variability and ecological changes in the savanna agro ecological zone of Ghana. *Heliyon*, *5*(4), e01492.

Aryal, J. P., Sapkota, T. B., Rahut, D. B., Marenya, P., & Stirling, C. M. (2021). Climate risks and adaptation strategies of farmers in East Africa and South Asia. *Scientific reports*, *11*(1), 10489.

Ayanlade, A., Oluwaranti, A., Ayanlade, O. S., Borderon, M., Sterly, H., Sakdapolrak, P., Jegede, M. O., Weldemariam, L. F., & Ayinde, A. F. (2022). Extreme climate events in sub-Saharan Africa: A call for improving agricultural technology transfer to enhance adaptive capacity. *Climate Services*, *27*, 100311.

Baijukya, F. P., Sabula, L., Mruma, S., Mzee, F., Mtoka, E., Masigo, J., Ndunguru, A., & Swai, E. (2020). Maize production manual for smallholder farmers in Tanzania. Ibadan, Nigeria: IITA. 25pp.

Bell, P., Kimaro, D., & Lal, R. (2015). Agricultural drought analysis for sustainable smallholder maize production in semi-arid areas: A case study of the lower Moshi irrigation scheme, Tanzania. *Tanzania Journal of Agricultural Sciences, 14*(1),34-42.

Birkmann, J., Liwenga, E., Pandey, R., Boyd, E., Djalante, R., Gemenne, F., Leal Filho, W., Pinho, P., Stringer, L., & Wrathall, D. (2022). Poverty, livelihoods and sustainable development. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1171–1274.

Bowles, T. M., Mooshammer, M., Socolar, Y., Calderón, F., Cavigelli, M. A., Culman, S. W., Deen, W., Drury, C. F., Garcia y Garcia, A., Gaudin, A. C. M., Harkcom, W. S., Lehman, R. M., Osborne, S. L., Robertson, G. P., Salerno, J., Schmer, M. R., Strock, J., & Grandy, A. S. (2020). Long-Term Evidence Shows that Crop-Rotation Diversification Increases Agricultural Resilience to Adverse Growing Conditions in North America. *One Earth*, 2(3), 284–293.

Brown, P. R., Afroz, S., Chialue, L., Chiranjeevi, T., El, S., Grünbühel, C. M., Khan, I., Pitkin, C., Reddy, V. R., & Roth, C. H. (2019). Constraints to the capacity of smallholder farming households to adapt to climate change in South and Southeast Asia. *Climate and Development*, *11*(5), 383-400.

Calzadilla, A., Zhu, T., Rehdanz, K., Tol, R. S., & Ringler, C. (2013). Economywide impacts of climate change on agriculture in Sub-Saharan Africa. *Ecological Economics*, *93*, 150-165.

Clay, N., & King, B. (2019). Smallholders' uneven capacities to adapt to climate change amid Africa's 'green revolution': Case study of Rwanda's crop intensification program. *World Development*, *116*, 1-14.

Croissant, Y., & Millo, G. (2008). "Panel Data Econometrics in R: The plm Package," *Journal of Statistical Software*, 27(2),1-43.

Darjee, K. B., Neupane, P. R., & Köhl, M. (2023). Proactive Adaptation Responses by Vulnerable Communities to Climate Change Impacts. *Sustainability*, 15(14), 10952.

Eriksen, S., Schipper, E. L. F., Scoville-Simonds, M., Vincent, K., Adam, H. N., Brooks, N., Harding, B., Lenaerts, L., Liverman, D., & Mills-Novoa, M. (2021). Adaptation interventions and their effect on vulnerability in developing countries: Help, hindrance or irrelevance? *World Development*, 141, 105383.

Gebre, G. G., Amekawa, Y., Fikadu, A. A., & Rahut, D. B. (2023). Do climate change adaptation strategies improve farmers' food security in Tanzania? *Food Security*, *15*(3), 629-647.

Guillaumont, P., & Simonet, C. (2011). *To what extent are African countries vulnerable to climate change? Lessons from a new Indicator of Physical Vulnerability to Climate Change*. Working Papers 108, FERDI.

Gwambene, B., Liwenga, E. T., & Mung'ong'o, C. G. (2019). Agricultural Food Crop Production and Management Challenges Under Variable Climatic Conditions in Rungwe District, Tanzania. *Agriculture and Ecosystem Resilience in Sub Saharan Africa: Livelihood Pathways Under Changing Climate*, 3-28.

Hansen, J., Hellin, J., Rosenstock, T., Fisher, E., Cairns, J., Stirling, C., Lamanna, C., van Etten, J., Rose, A., & Campbell, B. (2019). Climate risk management and rural poverty reduction. *Agricultural Systems*, *172*, 28-46.

IPCC, 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp.

Issahaku, G., & Abdulai, A. (2020). Adoption of climate-smart practices and its impact on farm performance and risk exposure among smallholder farmers in Ghana. *Australian Journal of Agricultural and Resource Economics*, *64*(2), 396-420.

Kalinga, A. S., Kangalawe, R. Y., & Lyimo, J. G. (2022). The Significance of the Diversification of Food Crops in Abating Impacts of Climate Variability: The Case of Rungwe District, Tanzania. *Journal of the Geographical Association of Tanzania*, *41*(2), 1-21.

Kalungu, J. W., & Harris, D. (2013). Smallholder farmers' perception of the impacts of climate change and variability on rain-fed agricultural practices in semi-arid and sub-humid regions of Kenya. *Journal of Environment and Earth Science*, 3(7), 129-140.

Kihupi, M. L., Mahonge, C., & Chingonikaya, E. E. (2015). Smallholder farmers' adaptation strategies to impact of climate change in semi-arid areas of Iringa District Tanzania. *Journal of Biology, Agriculture and Healthcare*, 5(2), 123-131.

Kissinger, G., Lee, D., Narasimhan, P., King'uyu, S., Sova, C., & Orindi, V. (2013). Planning climate adaptation in agriculture. CCAFS Report

Komba, C., & Muchapondwa, E. (2018). Adaptation to climate change by smallholder farmers in Tanzania. *Agricultural adaptation to climate change in Africa*, *129*(168), 129-168.

Krell, N., Morgan, B., Gower, D., & Caylor, K. (2021). Consequences of dryland maize planting decisions under increased seasonal rainfall variability. *Water Resources Research*, *57*(9), e2020WR029362.

Kurgat, B. K., Lamanna, C., Kimaro, A., Namoi, N., Manda, L., & Rosenstock, T. S. (2020). Adoption of climate-smart agriculture technologies in Tanzania. *Frontiers in Sustainable Food Systems,* 4(55), 1-9.

Lakhran, H., Kumar, S., & Bajiya, R. (2017). Crop diversification: an option for climate change resilience. *Trends Biosci*, 10(2), 516-518.

Lamanna, C., Namoi, N., Kimaro, A. A., Mpanda, M., Egeru, A., Okia, C., Ramírez Villegas, J., Mwongera, C., Ampaire, E. L., & van Asten, P. J. (2016). Evidence-based opportunities for out-scaling climate-smart agriculture in East Africa. *CCAFS* Working Paper. No. 172, 61 pp.

Magesa, B.A., Mohan, G., Melts, I., Matsuda, H., Pu, J., & Fukushi, K. (2023). Interactions between Farmers' Adaptation Strategies to Climate Change and Sustainable Development Goals in Tanzania, East Africa. *Sustainability*, 15, 4911.

Makate, C., Wang, R., Makate, M., & Mango, N. (2016). Crop diversification and livelihoods of smallholder farmers in Zimbabwe: adaptive management for environmental change. *SpringerPlus*, *5*, 1-18.

Mdemu, V. M. (2021). Community's vulnerability to drought-driven water scarcity and food insecurity in central and northern semi-arid areas of Tanzania. *Frontiers in Climate*, 3,737655.

Mkonda, M. Y., & He, X. (2018). Climate variability and crop yields synergies in Tanzania's semiarid agroecological zone. *Ecosystem Health and Sustainability*, 4:3, 59-72.

Msongaleli, B. M. (2021). Reducing Vulnerability of Rain-fed Cereal Production through Crop Simulation Modelling. In *Handbook of Climate Change Management* (pp. 1113–1131). Springer.

Mukherji, A., & Kumar, M. (2021). Effectiveness of Water adaptation responses in reducing climate-related risks: A meta-review. ACIAR Report.

Myeya, H. E. (2021). Vulnerability and responses of smallholder farmers to climate change effects in semiarid areas of Bahi and Kongwa districts, Tanzania. *Tanzania Journal of Science*, *47*(4), 1424-1435.

Nathan, O. O., Felix, N. K., Milka, K. N., Anne, M., Noah, A., & Daniel, M. N. (2020). Suitability of different data sources in rainfall pattern characterization in the tropical central highlands of Kenya. *Heliyon*, *6*(10), e05375.

NBS (2012). Tanzania National Panel Survey Report Wave 2, 2010 -2011, Living Standards Measurements Survey, National Bureau of Statistics, Dar-esSalaam, Tanzania. 273pp.

Nyagumbo, I., Mkuhlani, S., Mupangwa, W., & Rodriguez, D. (2017). Planting date and yield benefits from conservation agriculture practices across Southern Africa. *Agricultural Systems*, *150*, 21-33.

Nyang'au, J. O., Mohamed, J. H., Mango, N., Makate, C., & Wangeci, A. N. (2021). Smallholder farmers' perception of climate change and adoption of climate smart agriculture practices in Masaba South Sub-county, Kisii, Kenya. *Heliyon*, 7(4), e06789.

Olabanji, M. F., Davis, N., Ndarana, T., Kuhudzai, A. G., & Mahlobo, D. (2021). Assessment of smallholder farmers' perception and adaptation response to climate change in the Olifants catchment, South Africa. *Journal of Water and Climate Change*, *12*(7), 3388-3403.

Quarshie, P. T., Abdulai, S., & Fraser, E. D. (2023). (Re) assessing Climate-Smart Agriculture practices for sustainable food systems outcomes in sub-Saharan Africa: The case of Bono East Region, Ghana. *Geography and Sustainability*, *4*(2), 112-126.

Raseduzzaman, M. D., & Jensen, E. S. (2017). Does intercropping enhance yield stability in arable crop production? A meta-analysis. *European Journal of Agronomy*, 91, 25-33

Renwick, L. L., Kimaro, A. A., Hafner, J. M., Rosenstock, T. S., & Gaudin, A. C. (2020). Maize-pigeonpea intercropping outperforms monocultures under drought. *Frontiers in Sustainable Food Systems*, 4, 562663.

Sietsma, A. J., Ford, J. D., Callaghan, M. W., & Minx, J. C. (2021). Progress in climate change adaptation research. *Environmental Research Letters*, 16(5), 054038.

Thierfelder, C., Chivenge, P., Mupangwa, W., Rosenstock, T. S., Lamanna, C., & Eyre, J. X. (2017). How climate-smart is conservation agriculture (CA)?–its potential to deliver on adaptation, mitigation and productivity on smallholder farms in southern Africa. *Food Security*, *9*, 537-560.

Tofu, D. A., & Mengistu, M. (2023). Observed time series trend analysis of climate variability and smallholder adoption of new agricultural technologies in west Shewa, Ethiopia. *Scientific African*, *19*, e01448.

Tumbo, S. D., Mutabazi, K. D., Mourice, S. K., Msongaleli, B. M., Wambura, F. J., Mzirai, O. B., Kadigi, I. L., Kahimba, F. C., Mlonganile, P., & Ngongolo, H. K. (2020). Integrated assessment of climate change impacts and adaptation in agriculture: the case study of the Wami river sub-basin, Tanzania. *Climate Variability and Change in Africa: Perspectives, Experiences and Sustainability*, 115-136.

United Republic of Tanzania (2014). Agriculture Climate Resilience Plan 2014-2019. 88pp.

Vermeulen, S. J., Aggarwal, P. K., Ainslie, A., Angelone, C., Campbell, B. M., Challinor, A. J., Hansen, J. W., Ingram, J. S., Jarvis, A., & Kristjanson, P. (2012). Options for support to agriculture and food security under climate change. *Environmental Science & Policy*, *15*(1), 136-144.

Volk, J., Gornott, C., Sieber, S., & Lana, M.A. (2021). Can Tanzania's adaptation measures prevent future maize yield decline? A simulation study from Singida region. *Regional Environmental Change*, 21: 1-13.

Waongo, M., Laux, P., & Kunstmann, H. (2015). Adaptation to climate change: The impacts of optimised planting dates on attainable maize yields under rainfed conditions in Burkina Faso. *Agricultural and Forest Meteorology, 205,* 23-39.

Weerasooriya, G., & Karthigayini, S. (2023). Adoption of Climate Smart Agriculture (CSA) Technologies in Sri Lanka: Scope, Present Status, Problems, Prospects, Policy Issues, and Strategies. In *Smart Agriculture for Developing Nations: Status, Perspectives and Challenges* (pp. 119-133). Springer.

Westengen, O. T. and Brysting, A. K. (2014). Crop adaptation to climate change in the semi-arid zone in Tanzania: the role of genetic resources and seed systems. *Agriculture & Food Security* 3(3): 1-12.

Xiong, W., & Tarnavsky, E. (2020). Better Agronomic Management Increases Climate Resilience of Maize to Drought in Tanzania. *Atmosphere* 2020, 11(9), 982.

Yusuph, A. S., Nzunda, E. F., Mourice, S. K. & Dalgaard, T. (2023). Usage of Agroecological Climate-Smart Agriculture Practices among Sorghum and Maize Smallholder Farmers in Semi-Arid Areas in Tanzania. *East African Journal of Agriculture and Biotechnology*, 6(1), 378-405.

Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this paper.